HOT MIX ASPHALT LEVEL II

INSTRUCTION MANUAL

2026

TECHNICAL TRAINING AND CERTIFICATION PROGRAM

TECHNICAL TRAINING AND CERTIFICATION PROGRAM
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LEVEL II HMA MIX DESIGN

AASHTO T176

AASHTO T283

AASHTO T304

ASTM D4791

ASTM D5821

I.M. T203

I.M. 319

I.M. 321

I.M. 325G

I.M. 350

I.M. 380

I.M. 500

I.M. 501

I.M. 505

I.M. 510

I.M. 511

Spec 2303

SS- 23005

DS- 23016

DS- 23038

INTRODUCTION

Hot Mix Asphalt

Mix Design

In simplest terms, hot mix asphalt (HMA) is nothing more than a combination of rocks and asphalt. The rock provides the skeleton and the asphalt provides the glue or "muscles" to hold the skeleton together. The skeleton must carry the weight while the muscles must be strong enough to hold the skeleton in place but still be flexible.

Over the last one hundred years, engineers and technicians have observed that certain combinations of rocks and asphalt work well while others do not. Those who purchase HMA have taken those observations and turned them into specifications or requirements that the HMA is expected to meet. Today, the producer of HMA must be able to prove that he will deliver a product that meets the requirements for the job. That proof is often called the "Job Mix Formula" (JMF) or "Mix Design".

The JMF is the proportions of the aggregates to be used and the amount of asphalt to add. These proportions are established by testing various combinations in the laboratory until one is found that meets all the requirements. On the surface, this sounds simple, until one considers how many combinations of various aggregates are possible and how many requirements must be met. Not all jobs have the same requirements and more than one aggregate is usually needed. Over the years the requirements have become more stringent and more numerous, while the number of high quality aggregate sources have dwindled.

Of course, the most important requirement from the HMA producer's point of view is to make money while supplying a product that meets the purchaser's needs. The JMF can have a significant effect on the costs associated with the production of the HMA. The mix designer, therefore, can affect the HMA producer's bottom line. This places the mix designer in a difficult position, where costs must be minimized but a certain level of quality must be maintained.

Add to this the fact that most JMF's require some adjustment during plant production in order to maintain the required quality, and the complexity of the mix designer's job becomes obvious. The purpose of this training course is to help the student sort through these complexities and learn how to balance conflicting expectations while designing a mixture that will produce a durable pavement. Simple!!!

Hot Mix Asphalt (HMA) Mixture Design

Course Objectives

- Identify the major steps in HMA mix design
- Perform the steps hands-on
- State the reasons we do a mix design

Purpose of Mix Design

- What is a HMA mixture?
- What is a mix design?
- Find a starting point
- Prove the selected materials will meet specs.
- Get the most economical blend (maximize profit)
- Build a good road

Purpose of Mix Design

- What is a HMA mixture?
  - A skeleton (aggregate) to provide structure and glue (binder) to provide flexibility and hold the skeleton together.

Purpose of Mix Design

- What is a mix design?

Purpose of Mix Design

- Find a starting point
  - Recipe
    - Proportions of materials

Purpose of Mix Design

- Prove the selected materials will meet the specs.
  - Standard Specifications
  - Supplemental Specifications
  - Other Documents
  - Developmental Specifications

Purpose of Mix Design

- Standard Specification 2303
  - Hot Mix Asphalt Mixtures
    - Description
    - Materials
    - Construction
      - Quality Control Program
    - Method of Measurement
    - Basis of Payment

Purpose of Mix Design

- Standard Specification 4127
  - Aggregate for Hot Mix Asphalt
- Standard Specification 4137
  - Asphalt Binder
- General Supplemental Specifications

Purpose of Mix Design

- Other Documents
  - Addendums
  - Proposal
  - Special Provision
  - Plans
  - IMs

Purpose of Mix Design

- IMs
  - I.M. 500 Terminology
  - I.M. 501 Equations
  - I.M. 510 Mix Design
  - I.M. 511 Quality Control

Purpose of Mix Design

- AASHTO M332
  - Asphalt Binder
- Combined State Binder Group Document
  - Asphalt Binder

Purpose of Mix Design

- Get the most economical blend (maximize profit)
  - Mixture and binder are paid for separately
  - Aggregate costs

Purpose of Mix Design

- Build a good road
  - Durability
  - Low Maintenance
  - Rutting
  - Fatigue
  - Low Temperature Cracking

OVERVIEW

Materials Overview

As stated earlier, HMA is just a combination of rocks (aggregates) and asphalt. It is logical to start with a look at these two types of material before examining the combination of them. Over the years, specifications have been developed for each of these materials that help insure the quality of the combination. Both of these are naturally occurring materials but require some processing before they can be used in HMA. Asphalt binders usually require more processing than aggregate does.

While there are deposits of asphalt binder that require very little processing such as Trinidad Lake asphalt, most asphalt binders are produced from the refining of crude oil. Over the years, various methods have been used to extract gasoline and other volatile components from crude oil. Distillation is one common method. After the lighter (more volatile) compounds are distilled off what is left is the dark, high molecular weight, “tar like” substance called asphalt. Different methods of refining and different sources of crude oil create different asphalt binders.

What is important to understand about asphalt binder is: it must be liquid enough to mix and coat aggregate at a high yet reasonable temperature but solid enough at normal temperatures to act as the glue in the pavement. Prior to 1997, asphalt binders were specified based on penetration or viscosity. Mix designers understood that a stiffer binder (higher viscosity or lower penetration) was needed in hot climates and with heavy axle loads. Very little was known about low temperature properties, however, except that softer binders cracked less in cold weather. This illustrates the first dilemma faced by those who must specify what they want from an HMA pavement. A stiff binder should be used to resist the effects of hot summer temperatures while soft binder should be used to resist cracking in the winter. Can both properties be achieved?

The Performance Grading (PG) system was developed to help address the often conflicting requirements for asphalt binders. Unlike the old penetration or viscosity grading systems, the PG system looks at the asphalt binder’s behavior at high, intermediate and low temperatures. Thus giving the specifier the tools needed to get the desired product. Under the PG system, the high temperature behavior, the low temperature behavior and the traffic level are specified, for example, PG 58-28H. The intermediate temperature is addressed in the testing for the specified grade. So now the specifier can require an asphalt binder that has the needed stiffness at high temperatures as well as the needed flexibility at low temperatures and base these requirements on the local climate and axle loadings.

Aggregates are processed in two basic ways. Some aggregates are simply dug from the earth and sized or processed. These are referred to as “natural” sands and gravels. Sometimes these natural aggregates are crushed to enhance their properties for use in HMA. The other type of rock is produced from quarries where the deposits are massive and must be blasted first before processing. All quarried aggregates are crushed, as this is the only method available to reduce the size of the rocks to a usable range. Crushed aggregates are often refered to as “manufactured” aggregates. For example, sand produced from crushing rock is called “manufactured sand” or “man sand” for short.

Crushing aggregates often generates large quantities of fine dust in the material. While some dust is needed in a good HMA mixture, too much dust can lead to problems. For this reason, some aggregates need to be washed before they can be used. It is important to remember that every additional step added to the processing of the aggregate adds to the cost. That is why natural sand is usually a cheaper material than a crushed limestone and a washed chip is more expensive.

The other factor that impacts costs is transportation. Haul costs are often the controlling factor in the total cost of an aggregate. It is, therefore, desirable to use the locally available aggregates as much as possible. In some areas there are numerous sources of aggregate, in other areas the nearest source may be several counties away. The mix designer often has some latitude in selecting which aggregates to use, but not in all cases. Sometimes the estimator who drew up the bid for the job has based the bid on the use of one or two particular sources for the aggregate. In this situation, the mix designer is faced with the job of “making it work” even if another aggregate source might work better.

There are several specifications that aggregate for HMA must meet. The ones most important to the mix designer are called the “consensus properties”. These four properties are: fine aggregate angularity, coarse aggregate angularity, flat and elongated particles and sand equivalent. Iowa uses three of these properties but substitutes crushed particle content for the coarse aggregate angularity. All of these consensus properties are required to be met by the combination of aggregates. It is beneficial to the mix designer, however, to know what these properties are on the individual stockpiles of aggregate proposed for use. That way, the mix designer can estimate what the properties of the combined aggregate will be and can evaluate several combinations without additional testing.

There are a number of specifications that apply to the source of the aggregate. These include limits on deleterious materials such as clay balls, shale, sticks etc. Chemical, freeze-thaw and abrasion testing is also performed on the source materials. These are often refered to as quality tests. The mix designer needs to be aware of these requirements because the quality of the aggregate is one of the specifications that applies to all mix designs. In Iowa there are two levels of quality; Type A aggregate is the highest quality and is specified for high traffic pavements and Type B aggregate is used in base mixtures, many secondary road and low traffic pavements. The mix designer must use care to be sure the right aggregates are being used. Some projects may require Type B aggregates for the base mix and Type A for the surface. Also, some sources can produce both a Type A and a Type B aggregate depending on which beds they are working. The possibility of confusion is obvious. One thing to remember, a higher quality aggregate can always be substituted for a lower quality aggregate, but the reverse is not true. In other words, when a Type B aggregate is specified a Type A aggregate may be used but when a Type A aggregate is specified a Type B aggregate may not be substituted.

The other aggregate properties that the mix designer finds important are gradation, specific gravity and absorption. The range of allowable gradations of the combined aggregate is specified, however the gradations of the individual stockpiles can be anything as long as it will combine with other stockpiles to produce an acceptable gradation. Control of the stockpile gradations is based on an agreement between the aggregate producer and the contractor as documented on Form 955. The DOT monitors the production of the aggregates to be sure they are the right quality and the gradation conforms to the agreed production limits. The aggregate producer also performs a sieve analysis on a regular basis and can provide to the mix designer the average gradation of the stockpile as it was produced. The mix designer should check with the District Materials Engineer (DME) who monitors the source to confirm that the average gradation agrees with the monitor tests before selecting blends of aggregate for trial mix testing. If the mix designer submits a JMF for approval without confirming the gradations, the DME may reject the design if the monitor tests show the gradation of the stockpile is significantly different from the average provided by the producer. The importance of knowing the actual gradation of the stockpile cannot be overemphasized. All of the laboratory work could be wasted effort if the gradations are not correct.

Specific gravity and absorption are properties the mix designer must measure on each of the individual aggregates to be used. There is a specification limit on water absorption of 6.0%. This value is checked by the Central Laboratory in Ames on the samples taken at the source during production. The reason the mix designer performs this test is to determine the bulk dry specific gravity of the aggregates and to give the computer program SHADES the information it needs to help predict mixture characteristics. Obtaining accurate specific gravities is essential to the mix designer because many of the calculations employ specific gravities to obtain volumes. The specific gravities shown in the General Aggregate Source Information, IM T203, are not correct for use in HMA mix designs they apply only to PC mixtures. At this time, only a few aggregate producers perform this test, so it is up to the mix designer to determine the specific gravity and absorption.

Materials Overview

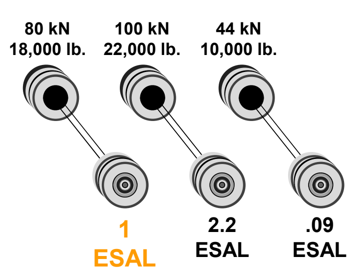
Asphalt Binder
Aggregates

Materials Overview Objective

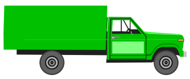
- Name the two major ingredients in Hot Mix Asphalt.
- List the 10 important aggregate properties.

Materials Overview – Binder

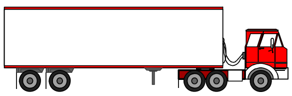
ESAL Comparison



Materials Overview – Binder



67 kN
15,000 lb
0.48 ESAL
+
27 kN
6,000 lb
0.01 ESAL
= 0.49 ESALs

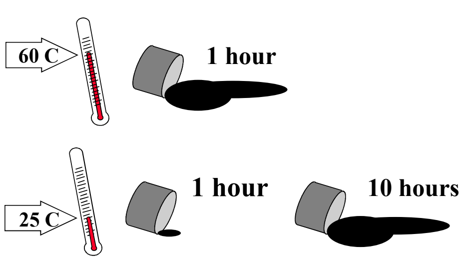


151 kN
34,000 lb
1.10
+
151 kN
34,000 lb
1.10
+
54 kN
12,000 lb
0.19
= 2.39 ESALs

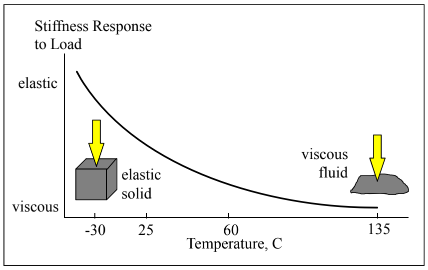
Materials Overview – Binder

- Where does asphalt binder come from?
  - Refining process
- Why does it work in HMA?
  - Provides stiffness and elasticity to pavement

Materials Overview – Binder

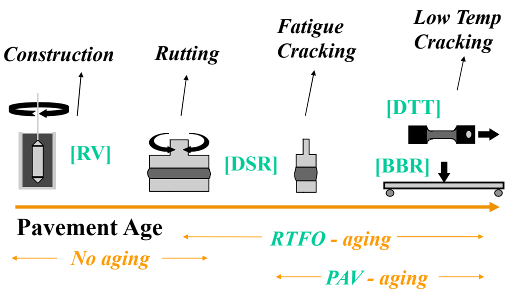


Materials Overview – Binder



Materials Overview – Binder

PG grading system



Materials Overview – Binder

Asphalt Binder Specification

- Grading System Based on Climate

PG 58 -22

- **PG**: Performance Grade
- **58**: Average 7-day max pavement design temp, °C
- **-22**: Min pavement design temp, °C

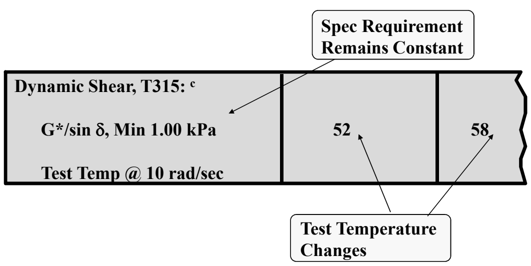
Materials Overview – Binder

Performance Grades

Avg 7-day Max, °C	PG 46	PG 52	PG 58	PG 64	PG 70	PG 76	PG 82
1-day Min, °C	-34 -40 -46	-10 -16 -22 -28 -34 -40 -46	-16 -22 -28 -34 -40	-10 -16 -22 -28 -34 -40	-10 -16 -22 -28 -34 -40	-10 -16 -22 -28 -34	-10 -16 -22 -28 -34
ORIGINAL							
≥ 230 °C	(Flash Point) FP						
≤ 3 Pa·s @ 135 °C	(Rotational Viscosity) RV						
≥ 1.00 kPa	(Dynamic Shear Rheometer) DSR G*/sin δ						
	46	52	58	64	70	76	82
(ROLLING THIN FILM OVEN) RTFO Mass Loss ≤ 1.00 %							
≥ 2.20 kPa	(Dynamic Shear Rheometer) DSR G*/sin δ						
	46	52	58	64	70	76	82
(PRESSURE AGING VESSEL) PAV							
20 Hours, 2.07 MPa	90	90	100	100	100 (110)	100 (110)	110 (110)
≤ 5000 kPa	(Dynamic Shear Rheometer) DSR G* sin δ						
	10 7 4	25 22 19 16 13 10 7	25 22 19 16 13	31 28 25 22 19 16	34 31 28 25 22 19	37 34 31 28 25	40 37 34 31 28
S ≤ 300 MPa m ≥ 0.300	(Bending Beam Rheometer) BBR "S" Stiffness & "m"- value						
	-24 -30 -36	0 -6 -12 -18 -24 -30 -36	-6 -12 -18 -24 -30	0 -6 -12 -18 -24 -30	0 -6 -12 -18 -24 -30	0 -6 -12 -18 -24	0 -6 -12 -18 -24
Report Value	(Bending Beam Rheometer) BBR Physical Hardening						
≥ 1.00 %	(Direct Tension) DT						
	-24 -30 -36	0 -6 -12 -18 -24 -30 -36	-6 -12 -18 -24 -30	0 -6 -12 -18 -24 -30	0 -6 -12 -18 -24 -30	0 -6 -12 -18 -24	0 -6 -12 -18 -24

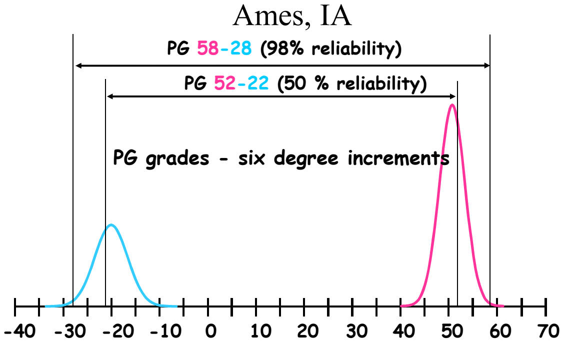
Materials Overview – Binder

- How the Spec Works



PG Binder Grades

Ames, IA

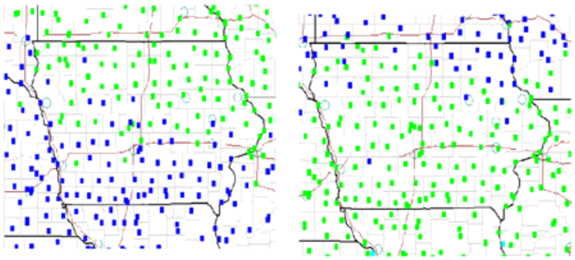


PG 58 -XX

PG 64 -XX

PG XX -34

PG XX -28

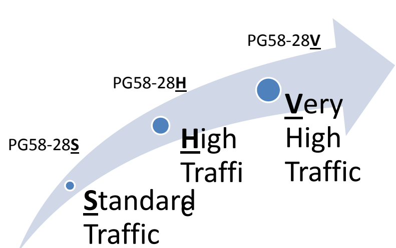


Materials Overview – Binder

Miscellaneous Spec Requirements

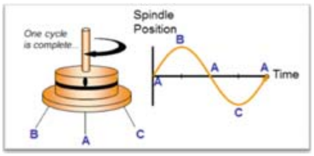
- Pumping and Handling
  - Rotational or capillary viscometer
  - Controlled by unaged binder vis @ 135 C≤ 3 Pa-s
- Safety
  - Flash point by COC
  - Controlled by flash point ≥ 230 C
- Aging During Hot Mixing/Construction
  - RTFO
  - Controlled by mass loss ≤ 1.00%

Binder Example

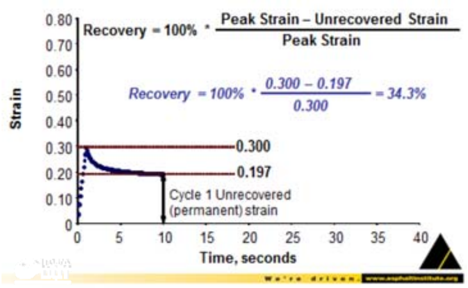


New Test

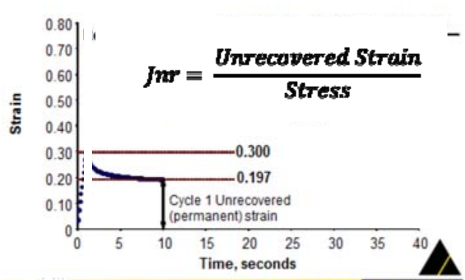
- AASHTO M332 – Multiple Stress Creep Recovery (MSCR)
- Same equipment



MSCR



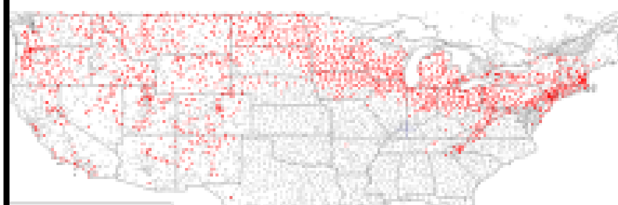
MSCR



New Binder "Bumping" Designations

- S = Standard Traffic
  - < 1M ESALS <u>and</u>
  - >45 mph
- H = High Traffic
  - 1-10M ESALS <u>or</u>
  - 15-45 mph
- V = Very High Traffic
  - >10M ESALS <u>or</u>
  - ≤ 15 mph
- E = Extremely High Traffic
  - >10M ESALS <u>and</u>
  - ≤ 15 mph

58°C (98% Confidence)



There is a 98% Probability the highest 7-day pavement temperature in Iowa will not exceed 59.7°C

PG58-XX Meets the Performance for the Climate

Materials Overview – Binder

- Specific Gravity @ 77°F
  - From supplier
- PG Grade Selection
  - Agency specifies

Materials Overview – Binder

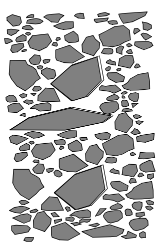
Important Asphalt binder features

- Crude source
- PG Binder Grade
  - Temp/load/aging

For additional information on PG binder testing, see the end of this chapter.

Materials Overview – Aggregate

- Aggregate is the skeleton of the pavement.



Materials Overview – Aggregate
Sources Available

- Underwater Sources
  - Natural Sands and Gravels
    - Rivers and Lakes
    - Barge-mounted dredges, draglines, scoops, conveyors or pumps
    - Relatively clean

Materials Overview – Aggregate
Sources Available

- Land Sources
  - Natural Sands and Gravels
    - Gravel or sand pits
    - Bucket loader
    - As is – no wash

Materials Overview – Aggregate
Sources Available

- Quarried Sources
  - Crushed stone and rock
    - Blasting required
    - Crushing required
    - Blend of formation ledges

Materials Overview – Aggregate
Aggregate Processing

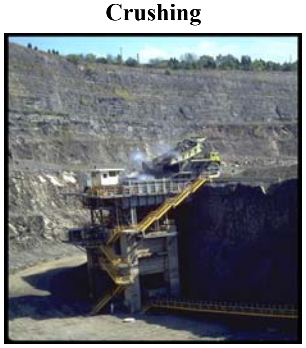
- Excavation
- Crushing
- Sizing
- Washing
- Transportation

Geology and processing/handling can affect aggregate properties

Materials Overview – Aggregate
Excavation

Materials Overview – Aggregate
Excavation

Materials Overview – Aggregate
Crushing



Materials Overview – Aggregate

Crushing

Materials Overview – Aggregate

Sizing

Materials Overview – Aggregate

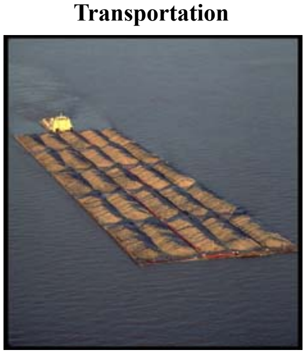
Washing

- Some aggregates require washing to remove excess fines.

Materials Overview – Aggregate
Transportation

Materials Overview – Aggregate
Transportation

Materials Overview – Aggregate
Transportation



Materials Overview – Aggregate
Costs

- All of these factors impact the cost of the aggregate.
  - Excavation
  - Crushing
  - Sizing
  - Washing
  - Transporting

Materials Overview – Aggregate
Important Aggregate Properties

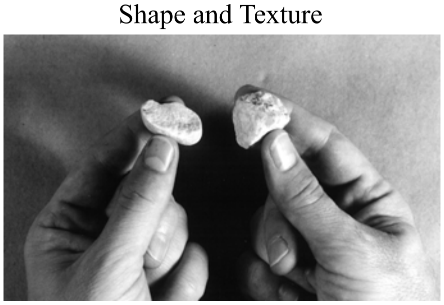
Consensus Properties
- Shape
- Texture
- Cleanliness

Gradation
- Size

Source Properties
- Deleterious Materials
- Toughness
- Soundness
- Specific Gravity
- Absorption
- Friction

Materials Overview – Aggregate
Consensus Aggregate Properties

Shape and Texture



Materials Overview – Aggregate
Consensus Aggregate Properties

Shape and Texture

- Influences
  - Strength/stability
  - Compactibility
- Best interlock from angular, cubical aggregates
- Easier to compact with rounded aggregates. Less stability

strength

workability

Materials Overview – Aggregate
Consensus Aggregate Properties

Shape and Texture

- Rough texture
  - Stronger adhesion and skeleton
  - Harder to lay and compact
- Smooth texture
  - Easier to coat and compact
  - Lower adhesion and strength

Materials Overview – Aggregate
Consensus Aggregate Properties

Shape and Texture

- Coarse Aggregate Angularity
  - Crushed Content
- Fine Aggregate Angularity
  - Gyratory design only
  - Also depends somewhat on surface texture
- Flat and Elongated Particles
  - Gyratory design only

Materials Overview – Aggregate
Consensus Aggregate Properties

Shape and Texture

- Percent Crushed Fragments in Gravels
  - Minimum values depended upon traffic level and layer (lift) of the pavement
  - Quarried materials always 100% crushed
  - Crushed gravel defined as % mass with one or more fractured faces

Materials Overview – Aggregate
Consensus Aggregate Properties

Shape and Texture

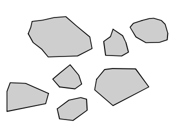
- Percent Crushed Fragments in Gravels

0% Crushed **100% with 2 or More Crushed Faces**

Materials Overview – Aggregate
Consensus Aggregate Properties

Shape and Texture

- Coarse Aggregate Angularity
  - Measured on + No. 4 (4.75 mm) material
  - Based on Fractured Faces
    - Fractured surface larger than 25% of aspect ratio
  - ASTM D 5821
  - Spec Requirements depend on
    - Depth of layer within pavement
    - Traffic level
- Not used in Iowa



Materials Overview – Aggregate
Consensus Aggregate Properties

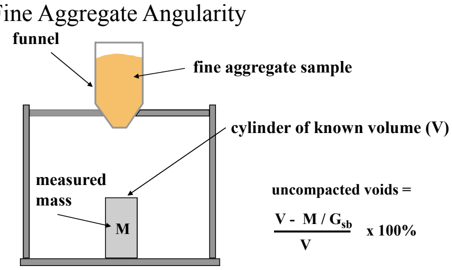
Shape and Texture

- Fine Aggregate Angularity
  - Measured on – No. 8 (2.36 mm) material
  - Based on Air Voids in Loose Sample
  - AASHTO T 304
  - Requirements depend on
    - Depth of layer within pavement
    - Traffic level

Materials Overview – Aggregate
Consensus Aggregate Properties

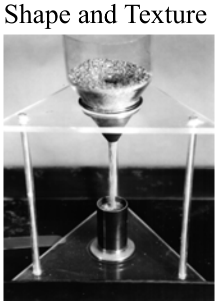
Shape and Texture

- Fine Aggregate Angularity



Materials Overview – Aggregate
Consensus Aggregate Properties

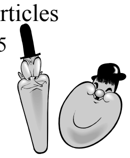
Shape and Texture



Materials Overview – Aggregate
Consensus Aggregate Properties

Shape and Texture

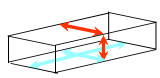
- Flat and Elongated Particles
  - Measured on + No. 4 (4.75 mm) material
  - Based on dimensional ratio of particles
    - Ratio of max to min dimensions < 5
  - ASTM D 4791
  - Requirements depend on
    - Traffic level



Materials Overview – Aggregate
Consensus Aggregate Properties

Shape and Texture

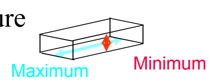
- Flat and Elongated Particles
  - ASTM D 4791
    - Flat or elongated
    - Total flat and elongated
  - Gyratory
    - Flat and Elongated
    - Maximum to minimum dimension (5:1)

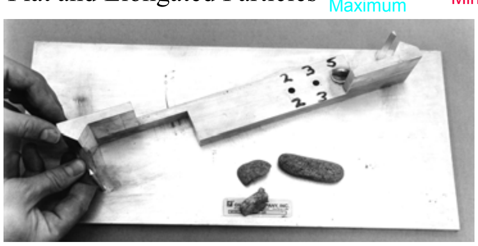


Materials Overview – Aggregate
Consensus Aggregate Properties

Shape and Texture

- Flat and Elongated Particles

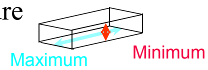


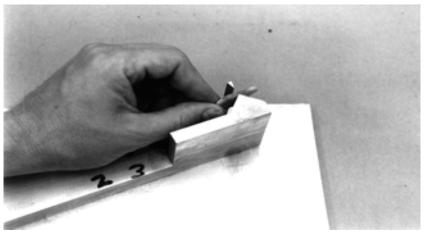


Materials Overview – Aggregate
Consensus Aggregate Properties

Shape and Texture

- Flat and Elongated Particles

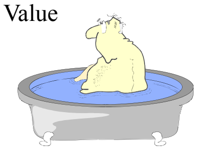




Materials Overview – Aggregate
Consensus Aggregate Properties

Cleanliness

- Clay Content
  - Measured on – No. 4 (4.75 mm) material
  - Based on Sand Equivalent Value
  - AASHTO T176
  - Requirements depend on traffic level
  - How dirty is the sand?



Materials Overview – Aggregate
Consensus Aggregate Properties

Cleanliness

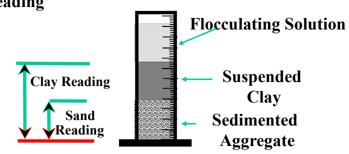
- Clay Content (Sand Equivalent Test)
  - AASHTO T176, ASTM D2419
    - Used to estimate the relative proportions of fine agg. and clay-like or plastic fines and dust.

Materials Overview – Aggregate
Consensus Aggregate Properties

Cleanliness

- Clay Content (Sand Equivalent Test)

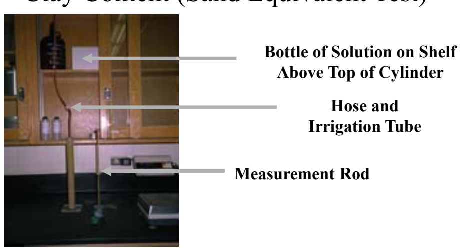
$$SE = \frac{\text{Sand Reading}}{\text{Clay Reading}} \times 100$$



Materials Overview – Aggregate
Consensus Aggregate Properties

Cleanliness

- Clay Content (Sand Equivalent Test)



Materials Overview – Aggregate
Important Aggregate Properties

Consensus Properties
- Shape
- Texture
- Cleanliness

Gradation
- Size

Source Properties
- Deleterious Materials
- Toughness
- Soundness
- Specific Gravity
- Absorption
- Friction

Materials Overview – Aggregate
Source Properties

Deleterious Materials

- Clay Lumps and Friable Particles
  - ASTM C 142
  - Dry a given mass of agg., then soak for 24 hr., and each particle is rubbed. A washed sieve is then performed over several screens, the aggregate dried, and the percent loss is reported as the % clay or friable particles.

Materials Overview – Aggregate
Source Properties

Toughness

- Los Angeles Abrasion
  - AASHTO T96, ASTM C131
  - Resistance of coarse agg. to abrasion and mechanical degradation during handling, construction and use
- Aggregate of standard gradation subjected to damage by rolling with prescribed number of steel balls in large drum for a given number of rotations
- Result expressed as % change in original weight

Materials Overview – Aggregate
Source Properties

Toughness

- LA Abrasion Test

- Approx. 10% loss for extremely hard igneous rocks
- Approx. 60% loss for soft limestones and sandstones

Materials Overview – Aggregate
Source Properties

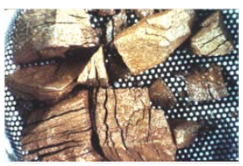
Soundness

- Estimates resistance to weathering by a freeze/thaw process
  - The result is identified by the quality (A or B)

Materials Overview – Aggregate
Source Properties

Soundness

Before



After

Materials Overview – Aggregate
Specific Gravity

- Used as a bridge between mass and volume.
- Will be discussed in detail later.
- I.M. 380

Most Critical Aggregate Test

Materials Overview – Aggregate
Absorption

- Porous aggregate absorbs asphalt
  - Dry, less cohesive mix
  - Expensive
- Difficult to design for highly porous aggregates
- Standard Specification 2303.02D
  - Max binder content

Materials Overview – Aggregate
Friction

- Estimates the ability of an aggregate to resist polishing.
  - Based on grain size and hardness.
- Spec 2303.02
- Type 2, 3, or 4
  - Type specified by traffic volume and speed

Materials Overview – Aggregate
Important Aggregate Properties

Consensus Properties
- Shape
- Texture
- Cleanliness

Gradation
- Size

Source Properties
- Deleterious Materials
- Toughness
- Soundness
- Specific Gravity
- Absorption
- Friction

Materials Overview – Aggregate
Size

- Coarse Aggregate
  - Retained on No. 4 (4.75 mm) ASTM D692
- Fine Aggregate
  - Passing No. 4 (4.75 mm) ASTM D1073
- Mineral Filler
  - At least 70% passing No. 200 (0.075 mm) ASTM D242

Materials Overview – Aggregate
Size

- Size Distribution – sieve analysis or gradation
  - The distribution of particle sizes expressed as a percent of total weight.
  - Determined by sieve analysis

Materials Overview – Aggregate
Gradation

Individual Sieve

Stack of Sieves

Materials Overview – Aggregate
Gradation

Stack in Mechanical Shaker

Materials Overview – Aggregate
Gradation

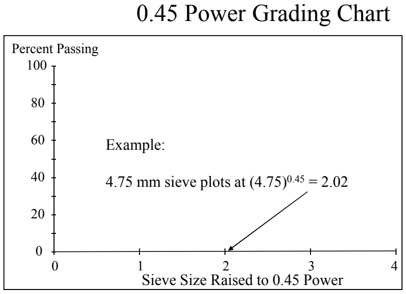
Standard Aggregate Sieves

- 2 in. (50 mm)
- 1 1/2 in. (37.5 mm)
- 1 in. (25 mm)
- 3/4 in. (19 mm)
- 1/2 in . (12.5 mm)
- 3/8 in. (9.5 mm)
- No. 4 (4.75 mm)

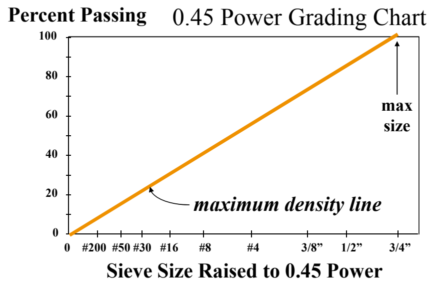
No. 8 (2.36 mm)
No. 16 (1.18 mm)
No. 30 (0.6 mm)
No. 50 (0.3 mm)
No. 100 (0.15 mm)
No. 200 (0.075 mm)

Materials Overview – Aggregate
Gradation

0.45 Power Grading Chart

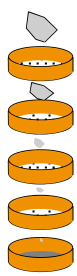


Materials Overview – Aggregate
Gradation



Materials Overview – Aggregate
Gradation

- Use 0.45 Power Gradation Chart
- Blend Size Definitions
  - Maximum size
  - Nominal maximum size
- Gradation limits
  - Control points

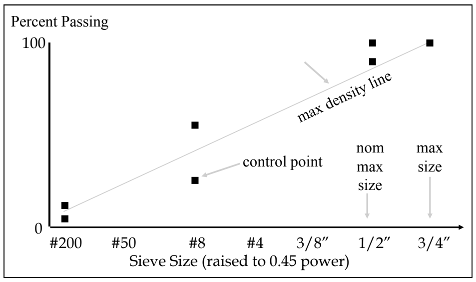


Materials Overview – Aggregate
Gradation

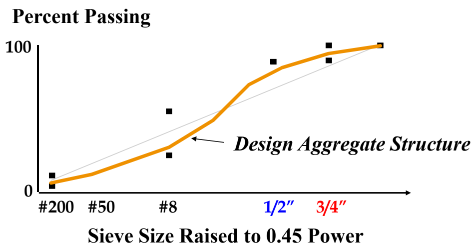
100	100
100	99
90	89
72	72
65	65
48	48
36	36
22	22
15	15
9	9
4	4

- Aggregate Size Definitions
  - *Nominal Maximum* Aggregate Size
    - One size larger than the first sieve to retain more than 10%
  - *Maximum* Aggregate Size
    - One size larger than nominal maximum size

Materials Overview – Aggregate
Gradation



Materials Overview – Aggregate
Gradation



Materials Overview – Aggregate
Gradation

Gyratory Size Designations

Gyratory Designation	Nom Max Size, in.	Max Size, in.
1 1/2”	1 1/2	2
1”	1	1 1/2
3/4”	3/4	1
1/2”	1/2	3/4
3/8”	3/8	1/2

Materials Overview – Aggregate

Important Aggregate Properties

Consensus Properties

- Shape
- Texture
- Cleanliness

Gradation

- Size

Source Properties

- Deleterious Materials
- Toughness
- Soundness
- Specific Gravity
- Absorption
- Friction

Materials Overview Objective

- Name the 2 major ingredients in Hot Mix Asphalt.
- List the 10 important aggregate properties.

Mix Behavior

All pavements have a life cycle. HMA pavements are subject to numerous distresses over their life cycle. Different distresses appear at different times during the pavements life. HMA pavements are subject to rutting, stripping and thermal cracking early in their life. The specifications are intended to prevent these distresses, but the mix designer can help also. It is important to understand that the current specifications do not truly predict the performance of the pavement. It is still possible to design a “bad” mix that will meet all the specifications. With this in mind, what can the mix designer do to help?

Rutting and shoving often occur the first time the pavement is exposed to a week of hot weather. Rutting is plastic behavior where the HMA displaces either sideways or down in the wheel tracks under the tire loads. Shoving is similar but is always sideways movement. Flushing often accompanies this distress. Flushing is the asphalt binder being squeezed out of the mixture and depositing on the surface of the pavement. Rutting is often the most important distress to prevent because it can lead to hydroplaning and becomes a public safety issue. Angularity, crushed content, voids and asphalt binder stiffness all play a role in preventing rutting. The mix designer needs to be sure that the angularity of the combined aggregate meets the requirements for the traffic level expected.

Stripping can also be a catastrophic failure early in a pavements life. Stripping is the loss of adhesion between the asphalt and the rock. When this happens, the action of the traffic when water is present on the road causes the asphalt to come off the aggregate. Since the asphalt is the glue, when it is gone the pavement becomes a granular material with nothing to hold it in place; it literally falls apart. Stripping is usually only a problem with siliceous aggregates like quartzite, granite or steel slag. When dealing with these types of aggregate, the mix designer may need to put additives in the mix to enhance the adhesion of the asphalt to the rock.

Thermal cracking is caused by the shrinking of the pavement in cold weather. Some pavements show none of this distress until they experience an extremely cold winter. Thermal fatigue can also occur due to the repeated expansion and contraction of the pavement with temperature changes. This is primarily related to the asphalt binder properties. The grade of binder to be used is normally specified in the contract, so the mix designer can do little to prevent this type of distress.

There are other distresses HMA pavements experience that don’t appear until several years after construction. Raveling and fatigue cracking normally don’t occur until the pavement is five to ten years old. Raveling is simply the loss of aggregate from the mixture. This could be associated with stripping but is often localized to areas where water can enter the pavement and freeze-thaw action takes place. Often these localized areas of raveling are associated with segregation of the mixture in the pavement. The mix designer can help prevent this problem by designing mixtures with more than the minimum film thickness. Higher film thickness means there is more glue between the rocks so the pavement should be resistant to moisture damage. The mix designer can also help prevent raveling by designing mixtures that are evenly graded and less prone to segregation.

Fatigue cracking is a pavement structural failure caused by repeated flexing or bending of the pavement under heavy loads. This is usually a pavement design problem not a mix design problem. If a pavement is designed too thin or does not have enough subgrade support, it will flex too much and eventually crack. The cracking progresses until the classic alligator pattern develops. At that point the pavement has failed and must be rebuilt or reclaimed. While higher asphalt contents and the use of polymer modified asphalts will help slow the fatigue damage, the mix designer can do little to help.

There is one final problem that all HMA pavements are subject to: aging. From the moment the hot asphalt binder is mixed with the heated aggregate the mixture begins to age. Several processes contribute to aging. During mixing and placement when the mixture is hot there is a loss of volatiles from the asphalt binder. Once in place and cooled off this loss of volatiles slows but never stops entirely. The volatiles are what makes the asphalt soft and sticky. As they leave, the asphalt binder gets stiffer and the pavement becomes more brittle.

Oxidation and other chemical changes also contribute to aging of the HMA. Oxidation makes the asphalt binder stiffer. At some point the aging causes the pavement to become brittle and more subject to cracking, raveling and fatigue damage. Obviously, aging cannot be avoided, however the mix designer can help. Research has shown that film thickness is related to aging. Mixtures with films in excess of nine microns have been shown to age less quickly than those with thinner films. Designing the mixtures with a little more film thickness than the minimum helps minimize the effects of aging.

Mix Behavior

Mix Behavior Objectives

- Describe 6 possible distresses an HMA pavement may be subjected to during its life.
- Recognize which distresses the mix designer can control.

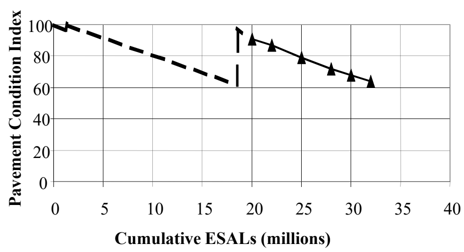
Mix Behavior

What can the mix designer control?

- Possible distress types
  - Permanent Deformation/Rutting (0-3 yrs)
  - Stripping (0-3 yrs)
  - Thermal Cracking (conditions)
  - Raveling (5+ yrs)
  - Fatigue (10+ yrs)
  - Aging (always)

Mix Behavior
Life Cycle

Pavement Performance History



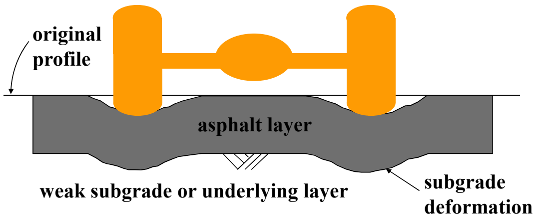
Mix Behavior
Permanent Deformation

Mix Behavior
Permanent Deformation

- Rutting in Subgrade or Base
- Rutting in Asphalt Layers
- Depends (for asphalt layer) on
  - Asphalt binder
  - Aggregates
  - Density (Compaction)

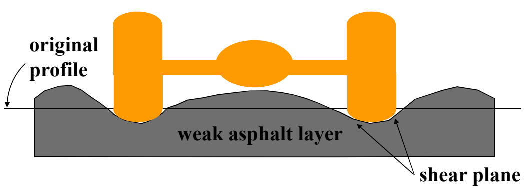
Mix Behavior
Permanent Deformation

Rutting in Subgrade or Base



Mix Behavior
Permanent Deformation

Rutting in Asphalt Layer



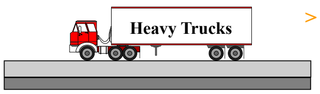
Mix Behavior
Permanent Deformation

Mixture Resistance to Rutting

- Asphalt Binder
  - Stiff and elastic at high temperatures
- Aggregate
  - High inter particle friction
  - *Acts like one large elastic stone*

Mix Behavior
Permanent Deformation

- Addressed by high temp stiffness
  - G*/sin δ on unaged binder ≥ 1.00 kPa
  - G*/sin δ on RTFO aged binder ≥ 2.20 kPa



> *Early part of pavement service life*

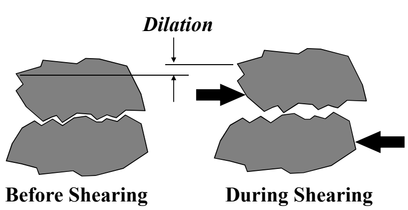
Mix Behavior
Permanent Deformation

Question: Why a minimum G*/sin δ to address rutting?

Answer: We want a *stiff, elastic* binder (to contribute to mix rutting resistance.

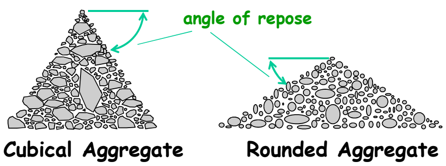
Mix Behavior
Permanent Deformation

Shearing Behavior of Aggregate



Mix Behavior
Permanent Deformation

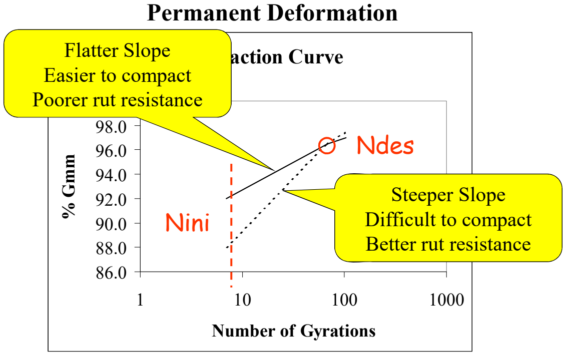
Shearing Behavior of Aggregate



Internal Friction

Mix Behavior
What can the mix designer control?

Mix Behavior
Permanent Deformation



Mix Behavior
Permanent Deformation

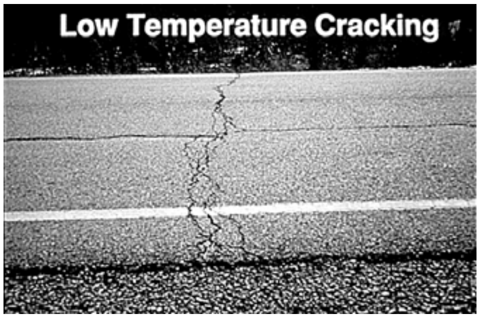
- Mixes with a steeper slope
  - more difficult to compact
  - potential for better rut resistance
- Mixes with flatter slope
  - easier to compact
  - possibility of poorer rut resistance

Mix Behavior
Stripping

- Loss of adhesion
- Hydro-dynamic pressure
- Test for stripping (AASHTO T-283)
- Hamburg Wheel Tracker (IM 319)
- Control stripping by:
  - Aggregate selection
  - Adequate film thickness
  - Treatments (lime, liquids)

Mix Behavior
What can the mix designer control?

Mix Behavior
Thermal Cracking

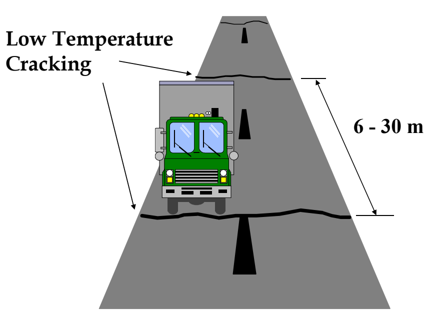


Mix Behavior
Thermal Cracking

Low Temperature Cracking

- Environmental distress
- Stresses/Strains induced by temp change
- Transverse cracks
- One cycle vs. many cycles
- Depends primarily on asphalt binder

Mix Behavior
Thermal Cracking



Mix Behavior
Thermal Cracking

Question: Why a minimum m-value and a maximum S to address low temp cracking?
OR Why a minimum failure strain?

Answer: We want a binder that will *relax* when stressed, AND a *soft elastic* binder OR a stiffer binder that will *stretch without breaking*

Mix Behavior
Thermal Cracking

Cures for Low Temperature Cracking

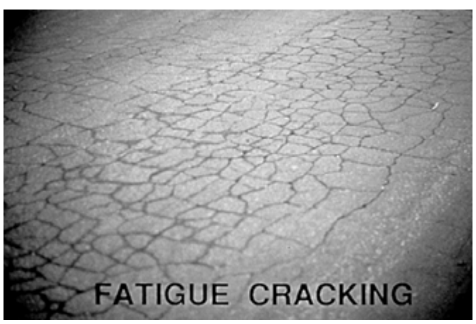
- Use an asphalt binder with appropriate Low Temperature Grade
  - Lower stiffness at low temps
  - Relaxation of stresses
- Use asphalt binder less prone to aging
- Construct HMA with proper air voids

Mix Behavior
What can the mix designer control?

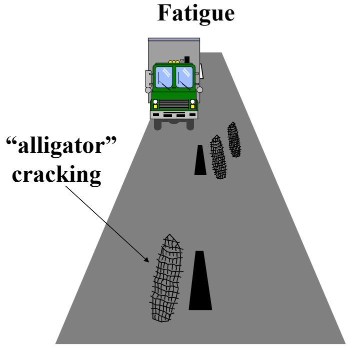
Mix Behavior
Raveling

- Loss of cohesion
- Normally caused by segregation
- Progressive deterioration
- Dry mixes (low film thickness)

Mix Behavior
Fatigue



Mix Behavior
Fatigue



Mix Behavior
Fatigue

- Wheelpath Distress
- Progressive Damage
  - Longitudinal cracking
  - Alligator cracking
  - Potholes
- Depends on
  - Asphalt binder
  - Aggregates
  - Pavement structure

Mix Behavior
Fatigue

- Addressed by intermediate temperature stiffness
  - $G^*\sin\delta$ on RTFO & PAV aged binder $\leq$ 5000 kPa

Later part of pavement service life

Mix Behavior
Fatigue

<u>Question</u>: Why a maximum $G^*\sin\delta$ to address fatigue?

<u>Answer</u>: We want a *soft elastic* binder (to sustain many loads without cracking)

Mix Behavior
Fatigue

Thermal Fatigue

- The repeated expansion and contraction resulting in cracking.

Mix Behavior
Fatigue

Cures for Fatigue Cracking

Account for number of heavy loads during design

Keep subgrade dry (i.e., low deflections)

Use thicker pavements

- Use non-moisture susceptible materials
- Use paving materials that are resilient

Mix Behavior
What can the mix designer control?

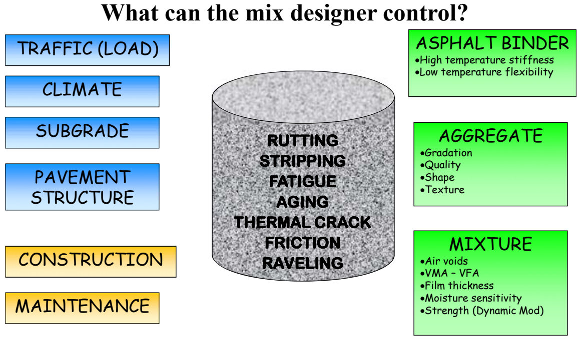
Mix Behavior
Aging

- Asphalt reacts with oxygen
  - “oxidative” or “age” hardening
- During construction – short term
  - Hot mixing
  - Placing/compaction
- Volatilization – short term
- In service – long term
  - Hot climate worse than cool climate
  - Summer worse than winter

Mix Behavior
Fatigue

- Ways to reduce the impact of aging
  - Thicker binder film thickness
  - Proper filler:bitumen ratio
  - Use “softer” binders

Mix Behavior
What can the mix designer control?



Mix Behavior

What can the mix designer control?

Mix Behavior Objective

- Describe 6 possible distresses an HMA pavement may be subjected to during its life.
- Recognize which distresses the mix designer can control.

Mix Behavior

- For additional information see:
  - Asphalt Handbook produced by the Asphalt Institute

Volumetrics Overview

Volumetrics is just a term used to describe those properties of a HMA mixture that must be expressed in terms of volume instead of weight. The best example of this is air voids. Obviously, air voids cannot be measured by weight. So when the specification states the mixture shall have 4.0 percent voids it means 4.0 percent of the volume shall be air. Voids in the Mineral Aggregate (VMA) and Voids Filled with Asphalt (VFA) are also measurements of voids and therefore are expressed as percent of volume.

In the testing of HMA, volumes are usually measured by water displacement. The tests for G_{mb} and G_{mm} both involve the determination of the water displaced by the test specimen. By knowing the weight of the specimen in grams and the volume of displaced water in cubic centimeters, the specific gravity is determined. This is the reason that the laboratory uses the metric system. One gram of water = one cubic centimeter of water = one milliliter of water, so the conversion from weight to volume is direct. It is easy to weigh the amount of water displaced in grams and then use that value as the volume of the specimen in the calculations of specific gravity. For example, when determining G_{mb} the specimen is weighed under water and weighed in air and the difference determined. The difference is the weight of displaced water, which is then used as the volume in the calculations.

Specific gravity is the ratio of the density of an object to the density of water at a set temperature. For example, if a sample weighs ten grams and displaces four grams (4 cc) of water the specific gravity is (10 g / 4 cc)/(1 g / 1 cc) = 2.5. Notice that the units cancel out and, since the bottom of the equation equals one (the density of water), it can be ignored and the simple equation is 10 g / 4 cc = 2.5. Put simply, specific gravity is how much more or less dense an object is compared to water. For example, if a rock has a specific gravity of 2.500 that means it is 2.500 times as dense as water.

Specific gravity is the bridge between weight and volume. If the specific gravity of a material is known and the weight of the material is measured, then the volume of material can be calculated simply by dividing the weight by the specific gravity. Similarly, if the volume of a material is measured and the specific gravity is known, then the weight of material can be determined by multiplying the volume times the specific gravity. This technique is used regularly, for example in the determination of asphalt binder quantities at the plant where a volume is measured in the storage tank then converted to weight for pay purposes.

The mix designer must obtain several specific gravities for use in the analysis of a mix design. Only one of these, the specific gravity of the asphalt binder (G_b), is provided by the supplier. The rest must be determined by testing the materials or the mixture. To make matters more interesting, we determine three different specific gravities just for the aggregate.

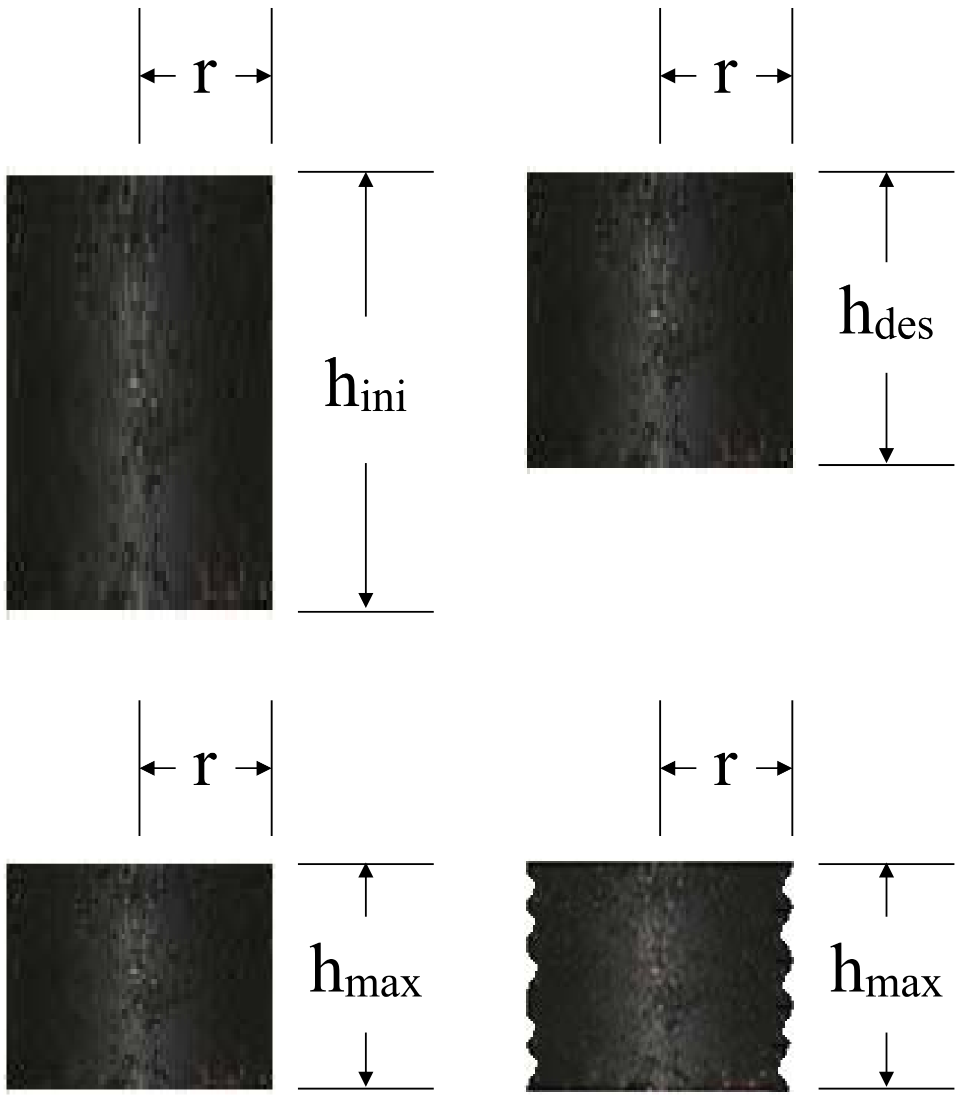
The most difficult and confusing one to measure is the bulk dry specific gravity of the aggregate (G_{sb}). The difficulty with this determination is the fact that aggregates absorb water so a direct measurement of displaced water is not possible with dry aggregate. To get around this problem, the test method in IM 380 specifies that the aggregate be saturated with water first then the displaced water is determined. This still does not yield a bulk DRY specific gravity, but what is called the apparent specific gravity (G_{sa}). Next the test method requires that the aggregate be brought to a saturated surface dry (SSD) condition, weighed and then dried and weighed again to determine how much water was absorbed. Once the percent of water absorption is known then the G_{sb} can be calculated from the G_{sa}. This works because the difference between G_{sa} and G_{sb} is the volume of absorbed water that occupies the pores in the rock.

Why don't we seal the rock with asphalt before we measure the volume of displaced water? We do, but that gives us G_{mm} not G_{sb}. Well then, why don't we just subtract out the volume of the asphalt from the G_{mm} calculation. Once again, we do, but that yields the calculation of the effective specific gravity of the aggregate (G_{se}). The reason this doesn't work is the fact that rock also absorbs some asphalt. Aggregates absorb less asphalt than water because the asphalt is more viscous. It is the asphalt absorption that makes dealing with the volumes difficult because some of the volume of the asphalt binder just disappears inside the rock.

So, G_{sa} will always be the largest value of the three aggregate specific gravities because the measured volume is the smallest: the bulk volume minus the volume of absorbed water. And, G_{se} will always be next largest because the measured volume is the bulk volume minus the volume of absorbed asphalt. G_{sb}, then, will always be the smallest value because it uses the true bulk volume of the aggregate.

The importance of obtaining accurate and representative specific gravities of the aggregates cannot be overemphasized. These values effect many of the calculations of other properties such as: VMA, VFA, Film Thickness and Filler/Bitumen ratio.

Gyratory Bulk Specific Gravity



Volumetric Overview

Mixture Volumetrics
Specific Gravity

Volumetric Overview Objective

- Solve basic volumetric equations.
- Define the relationship between mass and volume.

Volumetric Overview

- I.M. 501 contains many of the equations and much of the terminology used in volumetrics.

Volumetric Overview

Mixture Volumetrics

Volumetric Properties

- Air Void Content (P_a or V_a)
- Voids in the Mineral Aggregate (VMA)
- Voids Filled with Asphalt (VFA)

Volumetric Overview

Mixture Volumetrics

What do we need?

- Asphalt Binder Content (P_b) and Specific Gravity (G_b)
- Bulk Specific Gravity of Compacted HMA (G_{mb})
- Maximum Specific Gravity (G_{mm})
- Effective Specific Gravity of the Aggregate (G_{se})
- Bulk Specific Gravity of the Aggregate (G_{sb})

Volumetric Overview

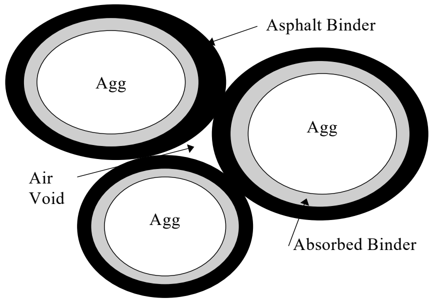
Mixture Volumetrics

Two Ways to Approach

- Component Diagram
  - logic
  - promotes understanding
- Equations
  - memorization
  - easy to program in computer

Volumetric Overview

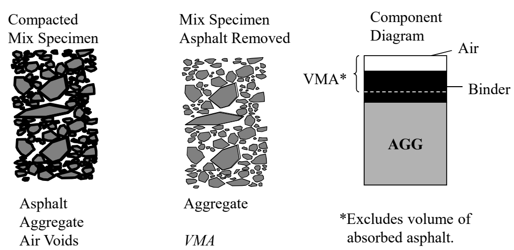
Mixture Volumetrics



Volumetric Overview

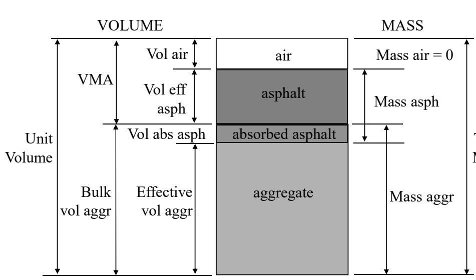
Mixture Volumetrics

Component Diagram Concept



Volumetric Overview

Mixture Volumetrics



Volumetric Overview

Mixture Volumetrics

Asphalt Content

$$P_b = \frac{\text{mass(binder)}}{\text{mass(mix)}} \times 100\%$$

Volumetric Overview

Mixture Volumetrics

Absorbed Asphalt Content

$$P_{ba} = 100 \times \frac{(G_{se} - G_{sb})}{G_{sb} \text{ x } G_{se}} \times G_b$$

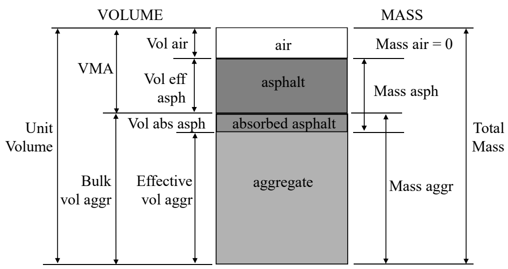
Volumetric Overview

Mixture Volumetrics

Effective Asphalt Content

$$P_{be} = P_b - \frac{P_{ba} \times P_s}{100}$$

Volumetric Overview
Mixture Volumetrics



Volumetric Overview
Mixture Volumetrics

Air Void Content

$$V_a = \frac{G_{mm} - G_{mb}}{G_{mm}} \times 100\%$$

or

$$V_a = \left[1 - \frac{G_{mb}}{G_{mm}}\right] \times 100\%$$

Volumetric Overview
Mixture Volumetrics

Example Calculations

- Air Voids
  - $G_{mb} = 2.222$
  - $G_{mm} = 2.423$

$$V_a = \left[1 - \frac{2.222}{2.423}\right] \times 100 = 8.3\%$$

Volumetric Overview

Mixture Volumetrics

VMA

$$VMA = 100 - \frac{G_{mb} \times P_s}{G_{sb}}$$

Volumetric Overview

Mixture Volumetrics

Example Calculation

Given: $G_{mb} = 2.455$

$P_s = 95\%$

$G_{sb} = 2.703$

$$VMA = 100 - \frac{(2.455)\,(95)}{2.703} = 13.7\%$$

Volumetric Overview

Mixture Volumetrics

VFA

$$VFA = \frac{VMA - V_a}{VMA} \times 100\%$$

Volumetric Overview
Mixture Volumetrics

- Calculate the VFA Using the Results of the Voids and VMA Calculations Performed Earlier.

Volumetric Overview
Specific Gravity

Density

- Definition
  - Mass of a unit volume of material
  - Units of pcf or g/cm^3
- "Bulk Density"
  - Contains several materials

Volumetric Overview
Specific Gravity

- Definition
  - Ratio of mass/volume (density) of object to mass/volume (density) of water at the same temperature
  - Unitless (units cancel)
  - Essentially, how many time heavier or lighter than water is the object
- Used as bridge between mass and volume of objects

Volumetric Overview
Specific Gravity

$$G = \frac{\text{mass(object)}/\text{volume(object)}}{\text{mass(water)}/\text{volume(water)}}$$

Or,

$$G = \frac{\text{density(object)}}{\text{density(water)}}$$

Volumetric Overview
Specific Gravity

Density of Water

- In the metric system, the density of water (at standard temperature of 77°F (25°C) is:
  - 1 g/cm^3 = 1000 kg/m^3
- In English units, the density of water is 62.4 pcf.
- *For ease, use metric.*

Volumetric Overview
Specific Gravity

So, in the metric system,

$$G = \frac{\text{density(object)}}{1.000 g/cm^3}$$

Or,

$$G = \frac{\text{mass}/\text{volume}}{1.000 g/cm^3}$$

Volumetric Overview

Specific Gravity

- Relates Density

$$D = G \times 1.000$$

Density in g/cm^3

specific gravity of object

approx density of water in g/cm^3 at 77°F (25°C)

Volumetric Overview

Specific Gravity

- Relates Volume

$$V = \frac{W}{G \times 1.000}$$

Weight (mass) of object

volume of object

specific gravity of object

density of water at 77°F (25°C) (=1 can be ignored)

Volumetric Overview

Specific Gravity

- Relates Volume (example)

$$\text{Volume} = \frac{75 \text{ kg} \times 1000 \text{ g/kg}}{2.500 \times 1.000 \text{ g/cm}^3} = 30{,}000 \text{ cm}^3$$

Volumetric Overview
Specific Gravity

Types of Specific Gravity

- Specific Gravity of Binder (1.00 to 1.05)
- Specific Gravity of Aggregate (2.40 to 2.80)
- Specific Gravity of Mix (2.20 to 2.60)

Volumetric Overview
Specific Gravity

Convention

- Symbols for Specific Gravity show material and type of specific gravity

G_{mb}

Material
m=mix
s=stone
b=binder

Type of SG
a=apparent
b=bulk
e=effective
m=maximum

Volumetric Overview
Specific Gravity

Three Aggregate Specific Gravities

- Aggregate Apparent (G_{sa}) – measured
  - Dry weight and apparent volume
  - Excludes absorbed water volume
- Aggregate Effective (G_{se}) – calculated
  - Dry weight and effective volume
  - Excludes absorbed asphalt volume
- Aggregate Bulk (G_{sb}) – measured
  - Dry weight and bulk volume

Volumetric Overview

Specific Gravity

$$G_{sa} = \frac{W \times R}{W + W_1 - W_2}$$

- W = mass of dry sample, g
- W_1 = mass of pycnometer filled with water at test temperature, g
- W_2 = mass of pycnometer filled with water and sample, g
- R = correction multiplier from Table 2 to correct for density of water at test temperature

Volumetric Overview

Specific Gravity

$$G_{sb} = \frac{G_{sa}}{1 + (ABS)(G_{sa})}$$

Where:

$$ABS = \%Abs/100$$

Volumetric Overview

Specific Gravity

$$G_{se} = \frac{100 - P_b}{\frac{100}{G_{mm}} - \frac{P_b}{G_b}}$$

Volumetric Overview
Specific Gravity

Example Calculation

Knowns: Mixed with 5% asphalt binder

$G_{mm} = 2.535$

$G_b = 1.030$

Then:
$$G_{se} = \frac{100 - 5.0}{\frac{100}{2.535} - \frac{5.0}{1.030}} = 2.746$$

Volumetric Overview
Specific Gravity

Aggregate Specific Gravity

- G_{sa} – highest value
- G_{se} – middle value
- G_{sb} – lowest value

- **G_{sa} – Will always be the highest value!**

Volumetric Overview
Specific Gravity

Approximation

$$G_{se} \cong G_{sb} + 0.5(G_{sa} - G_{sb})$$

Approximation used in design when G_{mm} is unknown.

Factor 0.5 can vary. 0.3-0.8 range is typical in Iowa. Use your knowledge of your materials

Volumetric Overview
Specific Gravity

Specific Gravity of Combined Aggregate

$$G_{sb} = \frac{P_{s1} + P_{s2} + \ldots}{P_{s1}/G_{sb1} + P_{s2}/G_{sb2} + \ldots}$$

Where:

P_{s1}, P_{s2} are percentages of agg. 1 and 2

G_{sb1}, G_{sb2} are specific gravities of agg. 1 and 2

Volumetric Overview
Specific Gravity

- I.M. 380 for combined or individual (required) aggregate specific gravity and absorption
- AASHTO T84 for fine aggregate specific gravity (not used in Iowa)
- AASHTO T85 for coarse aggregate specific gravity (not used in Iowa)

Volumetric Overview
Specific Gravity

Method of Test for Vacuum Saturated Spec. Grav. and Absorption of Combined or Individual Agg. Sources (I.M. 380)

- Purpose
  - To determine specific gravity and absorption of combined or individual aggregate only for HMA design.

Volumetric Overview
Specific Gravity

Apparatus (I.M. 380)

- Balance
- Pycnometer flask and glass cover plate
- Vacuum pump and manometer
- Thermometers
- Flat weighing pan and funnel
- Scoop, spatula or trowel and bulb syringe
- Elevated water container

Volumetric Overview
Specific Gravity

Pycnometer Calibration (I.M. 380)

- Fill pycnometer with water at 77±0.5°F (25 ±0.2°C), put on glass cover plate, dry outside of pycnometer and determine total mass to nearest 0.1g.
- Calibration must be verified periodically.
- A calibration chart can be made by running the test at several water temperatures.

Volumetric Overview
Specific Gravity

Specific Gravity Determination (I.M. 380)

- Obtain oven-dried test sample of at least 2000g and weigh to nearest 0.1g. (Individual source)
- Transfer to calibrated pycnometer containing water to depth of about 65 mm, add water to cover sample if necessary.

Volumetric Overview
Specific Gravity

Specific Gravity Determination (I.M. 380)

- Apply vacuum to 30mm or less absolute pressure for 30 minutes, agitate continuously (mechanical) or about every 2 minutes (manually).
- Remove vacuum apparatus, fill pycnometer with water and let stand 20 minutes.

Volumetric Overview
Specific Gravity

Specific Gravity Determination (I.M. 380)

- Place the glass cover plate on such that there are no entrapped air bubbles.
- Dry outside of pycnometer and plate, weigh to nearest 0.1g. Immediately after weighing, determine water temperature to nearest 0.5°F (0.2°C).

Volumetric Overview
Specific Gravity

Specific Gravity Calculation (I.M. 380)

- Apparent Specific Gravity = G_{sa}

$$G_{sa} = \frac{W \text{ x } R}{W + W_1 - W_2}$$

Volumetric Overview
Specific Gravity

- G_{sa}
  - W = mass of dry sample, g
  - W_1 = mass of pycnometer filled with water at test temperature, g
  - W_2 = mass of pycnometer filled with water and sample, g
  - R = correction multiplier from Table 2 to correct for density of water at test temperature

Volumetric Overview
Specific Gravity

Absorption Determination (I.M. 380)

- After determining specific gravity, pour water off sample through No. 200 (75μm) sieve.
- Remove sample and wash over No. 200 (75μm) sieve.
- Split sample over No. 8 (2.36 mm) sieve.

Volumetric Overview
Specific Gravity

Absorption Determination (I.M. 380)

- Remove free water from coarse portion (retained on No. 8 (2.36 mm) sieve) by rolling over bath towel.
- Place coarse portion on flat pan or clean hard surface and watch for dull appearance and no streaks of moisture (2-3 minutes), weigh to 0.1g.

Volumetric Overview
Specific Gravity

Absorption Determination (I.M. 380)

- Place fine portion (passing No. 8 (2.36 mm) sieve) in large pan and dry to SSD condition by stirring until free flowing and not adhering to spatula.
- Immediately weigh to nearest 0.1g.
- Dry to constant mass on hot-plate or in oven and weigh to nearest 0.1g.

Volumetric Overview
Specific Gravity

Absorption Calculation (I.M. 380)

$$\%Abs = \frac{(W_a + W_b - W_c)}{W_c} \times 100$$

W_a = SSD mass of coarse portion

W_b = SSD mass of fine portion

W_c = Dry mass of coarse and fine portions combined

Volumetric Overview
Specific Gravity

Bulk Specific Gravity (I.M. 380)

$$G_{sb} = \frac{G_{sa}}{1 + (ABS \times G_{sa})}$$

Where:

$$ABS = \%Abs/100$$

Volumetric Overview
Specific Gravity

Specific Gravity of Mix

- Maximum Theoretical Specific Gravity
  - G_{mm}
  - Loose mix
  - Zero air voids
- Bulk Specific Gravity
  - G_{mb}
  - Compacted mix
  - Includes air voids

Volumetric Overview
Specific Gravity

Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Mixtures (I.M. 321)

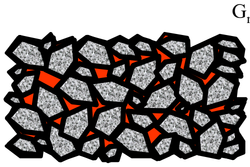
- Purpose
  - Determine G_{mb} and density of compacted specimens
  - Used in volumetric analysis
- Apparatus
  - Balance
  - Sample Basket
  - Water Bath
  - Clean cloth

Volumetric Overview
Specific Gravity

BSG of Compacted HMA

- Binder mixed with agg. and compacted in sample

$$G_{mb} = \frac{\text{Mass (Agg.+Binder)}}{\text{Vol. (Agg.+Binder+Air voids)}}$$



Volumetric Overview
Specific Gravity

Sample Preparation (I.M. 321)

- Compacted specimens (Gyratory) or field cores
  - Field cores must be dried to SSD condition

Volumetric Overview
Specific Gravity

Testing (I.M. 321)

- Mass of dry sample
- Mass under water
- Mass saturated surface dry (SSD)

Volumetric Overview
Specific Gravity

Testing (I.M. 321)

Obtain mass of dry compacted sample

Volumetric Overview
Specific Gravity

Testing (I.M. 321)

Obtain mass of specimen at SSD

Volumetric Overview
Specific Gravity

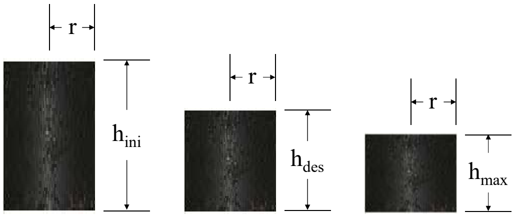
Calculations (I.M. 321)

$$G_{mb} = \frac{W_1}{(W_3 - W_2)}$$

- W_1 = mass of dry sample
- W_2 = mass of sample under water
- W_3 = mass of SSD sample
- Report all gravities to 0.001

Volumetric Overview
Specific Gravity

- G_{mb}



Volumetric Overview
Specific Gravity

- G_{mb} back-calculated to N_{ini} the easy way!
- G_{mb} measured at N_{des} multiplied by the ratio of the height at N_{des} to the height at N_{ini}

$$G_{mb(\text{ini})} = G_{mb(des)} \times \frac{h_{des}}{h_{\text{ini}}}$$

Volumetric Overview
Specific Gravity

Maximum Specific Gravity of HMA Mixtures (Rice) (I.M. 350)

- Purpose
  - Determine G_{mm}
  - Used in volumetric analysis

Volumetric Overview
Specific Gravity

Maximum Specific Gravity of HMA Mixture (Rice) (I.M. 350)

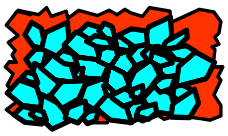
- Apparatus
  - Container (bowl or flask)
  - Vacuum and manometer
  - Water bath
  - Balance
  - Oven

Volumetric Overview
Specific Gravity

Maximum Specific Gravity

- Loose (uncompacted) mixture

$$G_{mm} = \frac{\text{Mass (Agg.+Binder)}}{\text{Vol. (Agg.+Binder)}}$$



Volumetric Overview
Specific Gravity

Rice Gravity (I.M. 350)

- Flask Calibration
  - Determine mass of water required to fill flask at 77±0.5°F (25±0.2°C) and record mass to nearest 0.1g (W_1)

Volumetric Overview
Specific Gravity

Rice Gravity (I.M. 350)

- Sample preparation
  - Obtain appropriate sample size by splitting or quartering if not lab prepared (function of nominal maximum size)
  - Break lumps of fine aggregates to less than ¼" (may require warming)

Volumetric Overview

Specific Gravity

Test Procedure (I.M. 350)

- Cool sample to room temp, place in flask or pycnometer and record net mass to 0.1g (W)
- Apply partial vacuum of 30mm Hg or less absolute pressure for 15±1 minutes
- Agitate while vacuuming – continuously (mechanical) or at 2 minute intervals (manual)
- Fill flask with water at 77°F (25°C) and allow to stand for 10±1 minute, record mass to 0.1g (W_2)

Volumetric Overview

Specific Gravity

Testing (I.M. 350)

Loose Mix at Room Temperature

Volumetric Overview

Specific Gravity

Testing (I.M. 350)

- Flask determination: $G_{mm} = \frac{W}{(W + W_1 - W_2)}$
- Report all gravities to 0.001

Volumetric Overview Objective

- Solve basic volumetric equations.
- Define the relationship between mass and volume.

Volumetric Overview

- For additional information see:
  - SP-2 from the Asphalt Institute

MIX DESIGN

Design Requirements

What's the first thing a mix designer needs before starting the process of trial mixing? INFORMATION! Every job has different requirements. The mix designer needs to take the time to review all the contract documents to be certain that all the requirements have been identified. This is not always an easy task because there are several places the requirements are shown. Specification 1105.04 lists the contract documents in the order of precedence:

- Addendum
- Proposal Form
- Special Provision
- Plans
- Supplemental Specifications
- Standard Specifications
- Materials I.M.

There is also a new type of specification called a "Developmental Specification" that, in order of precedence, would appear right after Special Provision. Developmental Specifications are used to try out new ideas before incorporating them into the other specifications.

Information important to the mix designer may be found in any or all of the above listed documents. The Plans and Proposal Form contain the bid item descriptions, but notes that specify special requirements often appear on Proposals and Plans also. The requirements shown in a Special Provision often conflict with and override those shown in the Standard Specifications. The I.M.'s contain most of the standard mix design criteria but have the lowest precedence and can be overridden by any of the other documents. The possibility of confusion is obvious. Do your home work!

Mix Design

Design Requirements

Mix Design Objective

- Locate and Identify all design criteria relevant to a specific project.
- Input design criteria into SHADES.

Mix Design
Design Requirements

- Where can the design requirements be found?
  - Addendums
  - Proposal
  - Special Provisions
  - Developmental Specifications
  - Plans
  - Supplemental Specifications
  - General Supplemental
  - Standard Specifications
  - IMs

Mix Design Objective

Design Requirements

- Locate and Identify all design criteria relevant to a specific project.
- Input design criteria into SHADES.

Selecting Materials

Once the mix designer has identified the requirements for the project, the process of selecting the materials to be used can begin. Many considerations must be addressed in the selection process. Selecting aggregates is often complicated by the fact that a single project may require two, three or even more different mix designs. A good example of this would be a project that included base widening (a Base Mix), a ¾" Intermediate Mix and a ½" Surface Mix. Each of these mixes has different requirements even though they are for the same project.

Aggregate selection involves identifying the producers in the area and determining if they can provide the required aggregates in the quantity needed. Sometimes special aggregates, such as Type 2 Frictional class, must be transported from a distant source. The estimator who made up the bid for the project often has made arrangements with one or more producers to provide the aggregates, so the mix designer may be limited in the selection process.

Once the sources have been identified, the mix designer must begin to gather the information needed to produce trial blends. Crushed limestone sources normally can provide a variety of different sizes and gradations. These products include crusher run aggregates such as ¾" to dust, coarse aggregates such as 3/8" chips or ¾" clean, and fine aggregates such as manufactured sand. A gravel source, however, may only produce one or two products such as sand and pit run gravel. Some gravel sources can produce crushed gravels in addition to natural sands and gravels. Some crushed gravels can be used as Type 3 Frictional class aggregates. The aggregate producer can provide the gradation of existing stockpiles and can also tell the mix designer what other gradations can be produced when needed.

The mix designer next checks the requirements for such things as friction type, Type A or Type B quality, and percent crushed particles. If RAP is available or is required to be used, it also affects the selection of aggregates. Most unprocessed RAP contains a high percentage of fines, so coarse cleaner aggregates are often required when RAP is used in the mix.

Finally, the mix designer must obtain the costs of the various aggregates available. It is important, however, to recognize that the cheapest mix to produce at the plant may not be the cheapest mix design. Nearly all mixtures require some adjustment during plant production. If the mix designer pays attention only to using the cheapest aggregates, a mix may be designed that cannot be adjusted. If the plant produced mix, then, does not meet the requirements, the project may have to be halted until a new mix design can be established. Such delays can be costly to the contractor.

Adjustment of the mixture must be anticipated by the mix designer. For this reason, most prudent mix designers will include a small amount of a washed chip and/or a man. sand in the design even if the design would be acceptable without it. When designing a mixture for adjustability, the idea is to be able to control the gradation of the fine portion (-200), the middle portion (#8, #4) and the coarse portion (3/8”, ½”) independently of each other. For example, when adjusting a mix it is often necessary to reduce the amount of –200 dust in the mix without affecting the rest of the gradation. This can be accomplished by reducing the amount of the ¾” to dust aggregate which carries most of the -200 and increasing the amount of clean chip and man. sand. By adjusting this way, the percent crushed particles and the angularity are not affected but voids, VMA and film thickness can be improved. If the mixture were designed with only ¾” to dust and a natural sand there would be little if any room for adjustment.

The selection of the asphalt binder is not usually up to the mix designer. The contract normally specifies the grade of binder to be used. The only thing that affects the selection of the binder is whether RAP is to be used in the mix. Because RAP contains aged and stiff asphalt, a softer grade may need to be used to blend with the RAP to achieve the grade specified on the contract. In Iowa up to twenty percent RAP can be incorporated into the mixture without adjusting the grade of asphalt binder. More than twenty percent up to thirty percent RAP requires the grade of binder to be reduced one step. For example: twenty five percent RAP will be used in a mixture and PG 64 –22S binder is required, then the grade of binder to use would be PG 58 –28S. For RAP contents above thirty percent, an analysis would be performed before deciding what grade of binder was needed to achieve a blend that would meet the required grade.

Once the mix designer has identified the materials to be used for trial blends, the next step is to obtain samples. The importance of obtaining **REPRESENTATIVE** samples of the aggregates cannot be overemphasized! It can be difficult to do, particularly when the entire stockpile has not yet been produced. There is a requirement that at least five hundred tons of an aggregate be produced before a sample can be taken for mix designing, but if fifty thousand tons of that aggregate are needed will the first five hundred tons produced represent what the entire stockpile will be? Maybe, maybe not. Mix designers must simply do the best they can to be sure that the aggregate samples they use for trial mixing have the same properties as the average for the stockpile.

The best way to be sure the aggregate samples are representative is to haul the material to the asphalt plant, run it through the bins and sample it from the stream flow of the cold feed belt. This is obviously the closest to the end product that can be achieved. Unfortunately, this method is only practical at permanent plants that use the same aggregate stockpiles for most of their mixtures. Portable plants are seldom set up far enough in advance of the project start-up to afford the mix designer the opportunity to sample there. So the mix designer is usually faced with getting the aggregate samples at the source.

Whenever possible, samples obtained at the source should be taken from the stockpile. For coarse aggregates this requires that the producer use an end loader to dig into the stockpile at three locations, load a bucket from each location into a sampling bin and then the mix designer can obtain stream flow samples as the bin is unloaded. Fine aggregate samples can be taken directly from the stockpile with shovels or probes, but care must still be exercised and several locations around the stockpile should be sampled to be certain of getting truly representative material.

What if the aggregate producer doesn't have a sampling bin on hand for sampling coarse aggregate? Aggregate producers are required to run a gradation test every fifteen hundred tons as they produce a stockpile. Some producers save bags of material from each sample they test. After several tests they know what the average gradation is and can then provide the mix designer with bags they have saved that are closest to the average. Because the producer normally samples from the crusher, this method of obtaining samples does not include the degradation of the aggregate from stockpiling, loading and handling. The mix designer must anticipate that the aggregates delivered to the plant will be somewhat finer than the samples used for the mix design when using this method.

The District Materials Engineer can help assure the mix designer is getting representative samples. It is a requirement that the DME be informed before mix design aggregates are sampled. Often the DME will send an Area Inspector to be present when the aggregate samples are taken. The Area Inspectors are familiar with the producers and have monitored the stockpiles so they know what the aggregate properties should be. They are also familiar with the best sampling procedures available at each source. Communication with both the DME and the aggregate producer is essential at this point to be sure that the right aggregates are being properly sampled.

How much material is required to do a complete mix design? There are a number of factors that affect the amount needed, but the general rule is to obtain about five hundred pounds of aggregate for each design. This gives the mix designer enough aggregate to try several blends and then do several asphalt contents on the selected blend. It also should leave enough for the District Materials Laboratory to do any confirmation testing they deem necessary. It is always better to obtain more than needed because problems can arise that may require additional testing and often the test results do not line up properly when stockpiles must be resampled for additional material. Asphalt binder samples are usually provided by the asphalt supplier, but may be obtained from the line on the plant if the correct grade is in use. Five gallons of binder is normally enough for all the mix design testing.

Mix Design

Selecting Materials
Obtaining Samples

Mix Design

Selecting Materials (Aggregates)

Fixed

- Friction Type
- Quality A or B
- Percent Crushed

Open

- Sources (A#)
- Availability
- Costs
- Adjustability
- Gradation
- Form 955 (SHADES)
- RAP?

Mix Design

Selecting Materials (Aggregates)

- Friction Type
  - Is the design required for use as a surface mix?
    - If yes, a frictional aggregate requirement may need to be met.

Mix Design
Selecting Materials (Aggregates)

- Quality A or B
  - Depending on what the traffic volume is and where the mix is to be placed a different type of aggregate may be needed.
  - In Iowa there are two types of aggregate qualities.
    - A (higher classification)
    - B (lower classification)

Mix Design
Selecting Materials (Aggregates)

- Quality A or B
  - If a job is listed as requiring Type A aggregate, all of the aggregates must meet Type A quality.
  - If a job is listed as requiring Type B aggregate, all of the aggregates must meet at least Type B quality.

Mix Design
Selecting Materials (Aggregates)

- Percent Crushed
  - All state work requires a percentage of crushed aggregate.
    - Depends on traffic volume and where the mix is to be placed.
  - On local agency projects, the Engineer will specify the amount of crushed material needed.

Mix Design
Selecting Materials (Aggregates)

- Sources (I.M. T203)
  - In Iowa, sources are identified by an A#.
    - The A# is also used to identify some sources from surrounding states.
  - The A# only provides a piece of the source information. The other essential piece of information is the beds being used.

Mix Design
Selecting Materials (Aggregates)

- Availability
  - The availability of the aggregate is a key factor in design.
    - How much is available for the project?
    - Is the amount available for the project limited by production?

Mix Design
Selecting Materials (Aggregates)

- Costs
  - What are the costs of the aggregates?
    - Is it cheaper to have a longer haul for materials?

Mix Design
Selecting Materials (Aggregates)

- Adjustability
  - How much variety will different aggregates provide?
    - Will the mix be easy to adjust during plant production?

Mix Design
Selecting Materials (Aggregates)

- Gradation
  - Is the gradation very coarse or very fine?
    - To much fine material will limit the amount to be used. (No. 200 sieve)
    - To much of the upper sieves will also limit the amount to be used.

Mix Design
Selecting Materials (Aggregates)

- Form 820955 (SHADES)
  - Form 955 is the agreement between the contractor and the aggregate producer.
    - Both parties must sign.
    - State <u>must</u> receive signed copy
    - Both parties should have signed copy

Mix Design
Selecting Materials (Binder)

- RAM (**R**ecycled **A**sphalt **M**aterials)
- RAP?
- Specific Gravity
  - Provided by DOT Central Lab tests
- RAS?
- Specific Gravity
  - Assumed in SHADES 2.489

Mix Design
Selecting Materials (Aggregates)

- RAP?
  - Is RAP specified for use on the project?
  - What type of RAP is available?
    - Classified
    - Unclassified
    - Designated (required on contract from a designated source)

Mix Design
Selecting Materials (Binder)

- RAP?
  - Is RAP specified for use on the project?
  - How much RAP is to be used in any mix?
    - If less than 20% binder replacement no binder grade adjustment needed.
    - If between 20% and 30% one grade adjustment required. (If 64-22S is desired a 58-28S needs to be used.)
    - If greater than 30% a special analysis will be performed by the Contracting Authority to determine what grade adjustment is needed.

Mix Design
Selecting Materials (Binder)

- RAS?
  - The specifications now allow only 15% of the total asphalt to come from the RAM when it is a combination of RAP and RAS or just RAS without adjusting the grade of the virgin binder.

Mix Design
Selecting Materials (Binder)

- Specific Gravity
  - The specific gravity of the asphalt binder is provided by the supplier.

Mix Design
Obtaining Samples (Aggregates)

- Why Sampling is Important
  - To evaluate the potential quality of a proposed aggregate source.
    - Does new source meet aggregate specifications?
  - To determine compliance with project specification requirements.
    - Do current aggregates meet specifications?

Mix Design
Obtaining Samples (Aggregates)

- Minimum stockpile
- Contact DME
- Stream flow (preferred)
- Supplier samples
- Fine aggregate from stockpiles
- Quantity (get plenty)

Mix Design
Obtaining Samples (Aggregates)

- Minimum stockpile
  - The minimum stockpile size required prior to sampling is 500 tons (500 Mg), or project amount if less.
  - This will allow for representative samples of the processed material to be taken.

Mix Design
Obtaining Samples (Aggregates)

Stockpiling

- Prevent segregation and contamination
- Good stockpiling = uniform gradations
  - Short drop distances
  - Minimize moving
  - Don't use "single cone" method
  - Separate stockpiles

Mix Design

Obtaining Samples (Aggregates)

Stockpiling

Mix Design

Obtaining Samples (Aggregates)

- Contact DME
  - The DME must be notified prior to sampling of the aggregate stockpiles and RAP.

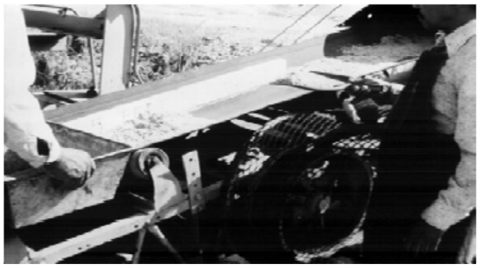
Mix Design

Obtaining Samples (Aggregates)

- Preferred sampling method
  - The stream flow method for obtaining samples is the preferred method. Coarse aggregate should always be stream flow sampled.
  - Sampling from the stockpile is another allowed method for obtaining representative samples of fine aggregate only.

Mix Design
Obtaining Samples (Aggregates)

Sampling from Conveyor



Mix Design
Obtaining Samples (Aggregates)

Sampling from Stockpile

Sampling from the aggregate stockpile is allowed for fine aggregates ONLY!

Mix Design
Obtaining Samples (Aggregates)

- Quantity
  - Be sure to get plenty of material when sampling for design.
  - The amount of material needed will be somewhat determined by the number of designs to be performed.
  - In most cases, 500 lbs. will be sufficient for a mix design.

Mix Design
Obtaining Samples (Binder)

- Grade (got RAP?)
- Quantity
- Normally sample provided by the supplier

Mix Design
Obtaining Samples (Binder)

- Grade (got RAP?)
  - Is RAP to be used in the mix?
  - Obtain the appropriate grade from the binder supplier.

Mix Design
Obtaining Samples (Binder)

- Quantity
  - Be sure to get enough for the design.
  - The amount of binder needed will be somewhat determined by the number of designs to be performed.
  - In most cases, 5 gallons will be more than sufficient for a mix design.

Mix Design
Obtaining Samples (Binder)

- Remember, the binder sample will normally be provided by the supplier.

Mix Design
Selecting Materials/Obtaining Samples

- For additional information see:
  - I.M. 301 for Aggregate Sampling
  - I.M. 323 for Binder Sampling

Mix Design

Sample Preparation

Mix Design
Sample Preparation

- Air drying
- Check gradation
- Splitting on appropriate sieves
- Split or Build-back Sp. Gr. and %Abs samples of individual aggregates
- Split or Build-back samples for individual aggregate consensus properties

Mix Design
Sample Preparation

Air Drying

- Aggregates and RAP <u>must</u> be air dried to a surface dried condition prior to further preparation.

Mix Design
Sample Preparation

Check Gradation

- Review the gradations indicated on Form 820955.
- Are the gradation results within the production tolerances?

Mix Design
Sample Preparation

Splitting

- Follow the procedures in C-6 and C-7 of I.M. 510 for determining the sieve size for splitting aggregates.

Mix Design
Sample Preparation

Specific Gravity and Absorption

- If the gradation results are within production tolerances, a sample shall be obtained from the split portion.
- If the gradation results are outside production tolerances, a sample shall be obtained by building back to the target gradation.

This shall be done for each individual aggregate.

Mix Design

Sample Preparation

Consensus Properties

- If the gradation results are within production tolerances, a sample shall be obtained from the split portion.
- If the gradation results are outside production tolerances, a sample shall be obtained by building back to the target gradation.

This may be done for each individual aggregate.

Mix Design

Testing

Mix Design

Testing

- Individual aggregate specific gravity and absorption
- Individual aggregate consensus properties

Mix Design

Testing

Specific Gravity and Absorption

- The specific gravity and absorption of each individual aggregate shall be determined in accordance with I.M. 380.

Mix Design
Testing

Consensus Properties

- The consensus properties of each individual aggregate may be determined by following the applicable National Standard.

Mix Design
Testing

Consensus Properties

- In Iowa, the Coarse Aggregate Angularity test is not performed.
- The Flat and Elongated Particles requirement is usually not a concern.
- The FAA and Sand Equivalent are the two primary concerns for design.
- The test procedures are provided.

Mix Design

Blending

Mix Design
Blending

Need to combine aggregates

- To create economical mix design
- To meet mixture properties – need different textures and shapes
- To control sizes

Mix Design
Blending

Aggregates

- Combined Gradation
  - Do gradation analysis of each component
  - Note control points
  - Determine proportion of each component you can combine to approach target
    - Often look at No. 200 (0.075 mm) sieve first, then No. 4 (4.75 mm)
  - Calculate combined gradation

Mix Design
Blending

Procedures

- Trial and Error
- Calculation
- Computer programs – allows for multiple blends to be checked very quickly.

Mix Design
Blending

Calculation

- Combined Gradation

$$P = Aa + Bb + Cc + ...$$

  – A, B, C = percentages passing sieve for aggregates A, B, C
  – a, b, c = proportions of aggregates A, B, C used in combination (a+b+c+…=1.00)
  – P = total percent of combined aggregate passing sieve
  – Calculate for each sieve size individually

Mix Design
Blending

Calculations

- Combined gradation
  – The example will show one sieve size.
    - The same procedure is used for all sizes.
  – Consider a mix with 60% of aggregate 1 and 40% of aggregate 2. We will look at the No. 4 (4.75 mm) sieve.

Mix Design
Blending

Calculations

- Combined Gradation

Aggregates	% Passing No. 4		% Blend		% Passing % contribute to total No. 4
Aggregate 1	43	x	(0.60)	=	25.8
Aggregate 2	32	x	(0.40)	=	12.8

- Combined Gradation = 25.8 + 12.8 = 38.6 % Passing No. 4 of total blend
- This same calculation is performed on each sieve size.

Mix Design
Blending

Calculations

- Combined G_{sb}

$$G_{sb} = \frac{100}{\frac{P_{s1}}{G_{sb1}} + \frac{P_{s2}}{G_{sb2}} + \frac{P_{s3}}{G_{sb3}} + \ldots}$$

Mix Design
Blending

Calculations

- Combined G_{sb}
  - Given $G_{sb1} = 2.657$ and $G_{sb2} = 2.642$
  - Given $P_{s1} = 60\%$ and $P_{s2} = 40\%$

$$G_{sb} = \frac{100}{\frac{60}{2.657} + \frac{40}{2.642}} = 2.651$$

Mix Design
Blending

Calculations

- Combined G_{sb}

$$G_{sb} = \frac{100}{\frac{P_{s1}}{G_{sb1}} + \frac{P_{s2}}{G_{sb2}} + \frac{P_{s3}}{G_{sb3}} + \ldots}$$

Mix Design
Blending

Calculations

- Combined G_{sb}
  - Given $G_{sb1} = 2.657$ and $G_{sb2} = 2.642$
  - Given $P_{s1} = 60\%$ and $P_{s2} = 40\%$

$$G_{sb} = \frac{100}{\frac{60}{2.657} + \frac{40}{2.642}} = 2.651$$

Mix Design
Blending

Calculations

- Combined Absorption

$$\%\ Abs = \%\ Abs_1(P_{s1}) + \%\ Abs_2(P_{s2}) + \%\ Abs_3(P_{s3}) + \ldots$$

Mix Design
Blending

Calculations

- Combined Absorption
  - Given % Abs_1 = 1.34 and % Abs_2 = 0.74
    % Abs = (1.34)(0.60) + (0.74)(0.40) = 1.10

Mix Design
Blending

Control Points

- The control points for the combined aggregate gradation are found in I.M. 510 Appendix A.

Mix Design
Blending

Maximum Density Line

- If the combined aggregate gradation is located along the maximum density line, very little room will be available for air voids and asphalt binder.

Mix Design
Blending

SHADES

- The SHADES mix design software will allow the designer to quickly check multiple combinations of aggregates for meeting design requirements without having to batch all possible combinations.

Mix Design
Blending

Aggregate Variable Designs

- One of the many tools available to the mix designer to better define the starting point of a mix is the aggregate variable design tool.
  - Multiple blends of aggregates
  - Allows for greater variety and adjustability

Mix Design
Blending

- Aggregate Criteria
  - The % friction aggregate and crushed content must now be checked for specification compliance.
  - Why check now?

Mix Design
Blending

- Aggregate Criteria
  - % Frictional Aggregate plus No. 4

$$A = \frac{(B \times C)}{D}$$

  - Where:

A = % Frictional Aggregate of total blend of all plus No. 4 (4.75 mm) material
B = % Frictional Aggregate retained on No.4 sieve
C = % Frictional Aggregate of total blend
D = % Retained on No. 4 of total blend

Mix Design
Blending

- Aggregate Criteria when Type 2 is specified
  - % Frictional Aggregate minus No. 4

$$F = \frac{(J \times K)}{P}$$

  - Where:
    - F - % Frictional Aggregate in the total blend passing the No. 4 sieve
    - J - % Passing the No. 4 sieve in the Type 2 Frictional Aggregate
    - K - % of Type 2 aggregate in the total blend
    - P - % Passing the No. 4 sieve in the total blend

Mix Design
Blending

- Aggregate Criteria when Type 2 is specified
  - Fineness modulus of the Type 2 Aggregate must be determined
  - Fineness Modulus must equal or exceed 1.0

Mix Design
Blending

- Aggregate Criteria
  - Crushed Content
    - The total crushed content is the total percent of all crushed material used in the mixture.

Mix Design
Blending

- Aggregate Criteria
  - Crushed Content
    - If a 60-40 percent blend is used and the 60 represents, for instance, a crushed limestone and the 40 represents a natural sand, the crushed content would be 60%.

Mix Design
Blending

- For additional information see:
  - SP-2 from the Asphalt Institute
  - MS-2 from the Asphalt Institute

Mix Design

Initial Binder Content Determination

Mix Design

Initial Binder Content Determination

- What can be used to determine the initial binder content?
  - Surface Area
  - SHADES
  - Experience
- Do estimated values meet specifications?

Mix Design

Initial Binder Content Determination

Surface Area

- The surface area of the combined aggregate gradation can be used based on a desired target film thickness.
  - The binder content is determined by back-calculating from the film thickness.
  - Generally, the greater the surface area, the greater the need for additional binder.

Mix Design
Initial Binder Content Determination

SHADES

- The SHADES software will estimate the initial binder content by making use of the surface area of the combined aggregate gradation.

Mix Design
Initial Binder Content Determination

Experience

- If the mix designer is experienced with the aggregates to be used, an estimate for the initial binder content can be made.

Mix Design
Initial Binder Content Determination

Do estimated values meet specifications?

- Once the initial binder content is determined, the remainder of the volumetric properties can be estimated.
- These properties are then compared to the specifications for compliance prior to batching.

Mix Design

Initial Binder Content Determination

- For additional information see:
  - SP-2 from the Asphalt Institute

Mix Design

Batching
Mixing
Sample Preparation
Testing

Mix Design
Batching

- The batching process is used to determine the correct quantities of aggregate and binder to combine for mixing.

Mix Design
Batching

- The batch size should be between 13,000 and 14,000 grams of aggregate.
- The batching must be performed to build up to the target gradation.

Mix Design
Batching

- Go to I.M. 501 for a detailed example on how to perform the batching calculations.

Mix Design
Batching

- The amount of binder to add is determined by the following equation.

$$W_b = \frac{(P_b)\times(W_s)}{(P_s)}$$

Where: W_b = weight of the added binder, g
W_s = weight of the aggregate, g
P_b = percent binder
P_s = percent aggregate (100-P_b)

Mix Design
Batching

Consensus Properties

- The consensus properties of the **combined aggregate** mixture <u>must</u> be checked. This will require that the individual aggregates be batched to achieve the desired gradation.
  - Smaller batches must be prepared of sufficient size to perform the testing.

Mix Design
Batching

Consensus Properties

- The consensus properties must now be checked for acceptability. **WHY?**
- SHADES will **estimate** the consensus properties based on individual results but the specifications are based on the combined aggregates test results.

Mix Design
Batching

Consensus Properties

- Fine Aggregate Angularity (FAA)
  - The FAA is determined by running the test on the blend of the materials.
  - This can be estimated by mathematically combining the FAA results from each of the individual materials.

Mix Design
Batching

Consensus Properties

- Sand Equivalent (SE)
  - The SE is determined by running the test on the blend of materials.
  - This cannot be mathematically combined from the individual results.

Mix Design
Batching

Consensus Properties

- Flat and Elongated Particles
  - The Flat and Elongated Particles is determined by running the test on the blend of materials.
  - This can be estimated by mathematically combining the Flat and Elongated Particles results from each of the individual materials.

Mix Design
Batching

- Once the aggregates have been properly batched, they must be heated prior to mixing.

Mix Design
Mixing HMA

- Heating
  - Before the aggregates and binder are combined, they must be heated to 275° ± 5°F (135° ± 3°C).
  - The mixing bowl and utensils shall also be heated before mixing operations begin.
  - Always keep the mixing bowl buttered.

Mix Design
Mixing HMA

- Follow procedures F-4 through F-7 in I.M. 510 for instructions on:
  - Dry mixing
  - Weighing asphalt binder into mixer
  - Wet mixing

Mix Design
Sample Preparation

- Follow procedures F-8 through F-10 in I.M. 510 for instructions on:
  - Splitting
  - Curing

Mix Design
Testing

- Follow procedures F-11 through F-13 in I.M. 510 for instructions on:
  - Compaction testing
  - G_{mm} testing
  - G_{mb} testing

Mix Design

Batching/Mixing/Sample Preparation/Testing

- For additional information see:
  - SP-2 from the Asphalt Institute
  - MS-2 from the Asphalt Institute

ANALYSIS

Mix Design Analysis

Once all the batching, mixing, preparation and testing are done, the mix designer must still perform the analysis of the mixture. If several different blends are being analyzed, this analysis allows the mix designer to select the best blend to go on and test at different asphalt contents. Then the analysis is performed again to establish the JMF. It is assumed at this point that the mix designer has already checked the aggregate properties to be sure they meet the requirements, so this analysis is to look at the volumetric properties of the mixture.

Several pieces of information are needed to perform the volumetric analysis. The specific gravities of the aggregates, asphalt binder, compacted and uncompacted mixture must be known. The percent asphalt binder in each batch is also required. The combined gradation must also be determined for use in calculating film thickness and filler/bitumen ratio. The height information from the gyratory compactor is needed to determine the percent of G_{mm} at N-initial.

From this information the important properties of the mixture can be determined. It is necessary to calculate all the volumetric properties for each batch. Air voids, VMA, VFA, film thickness and filler/bitumen ratio are the properties that insure the proper amount of asphalt and voids are present. The percent of G_{mm} at N-initial is determined to insure that the compaction of the mixture will not take place too quickly (tenderness).

There are many tools available to the mix designer to aid in the analysis of the trial blends. There are commercially available programs that will analyze mix design data. The SHADES computer program provided free with this class performs all the necessary calculations for the mix designer and produces the required reports.

Mix Design

Analysis

Mix Design

Analysis

- The following items are needed prior to performing the calculations for analysis:
  - P_b
  - G_{mb}
  - G_{mm}
  - G_{sb}
  - G_b
  - Combined Gradation

Mix Design

Analysis

- Calculate the volumetric properties and the following mixture characteristics:
  - Voids
  - VMA
  - VFA
  - Film Thickness
  - Filler/Bitumen Ratio
  - % G_{mm} @ N_{ini}

Mix Design
Analysis

Volumetric Property

- Voids

$$P_a = \frac{G_{mm} - G_{mb}}{G_{mm}} \times 100$$

Mix Design
Analysis

Volumetric Property

- VMA

$$VMA = 100 - \frac{G_{mb} \times P_s}{G_{sb}}$$

Mix Design
Analysis

Volumetric Property

- VFA

$$VFA = \frac{VMA - P_a}{VMA} \times 100$$

Mix Design
Analysis

- To determine the Film Thickness and the Filler/Bitumen Ratio, the G_{se}, P_{ba}, P_{be}, and surface area need to be determined.

Mix Design
Analysis

- G_{se}

$$G_{se} = \frac{100 - P_b}{\frac{100}{G_{mm}} - \frac{P_b}{G_b}}$$

Mix Design
Analysis

- P_{ba}

$$P_{ba} = \frac{(G_{se} - G_{sb})}{(G_{se} \text{ x } G_{sb})} \text{ x } G_b \text{ x } 100$$

Mix Design
Analysis

- P_{be}

$$P_{be} = P_b - \frac{P_{ba} \times P_s}{100}$$

Where: $P_s = 100 - P_b$

Mix Design
Analysis

- Surface Area (SA)
  - The surface area is found by taking the % Passing of the combined gradation times the Surface Area Coefficient at the corresponding sieve size.
    - The surface area for the material above the No. 4 sieve is a constant 0.41.
  - The total surface area is found by adding all of the individual surface area values.

Mix Design
Analysis

- Film Thickness (FT)

$$FT = \frac{P_{be}}{SA} \times 10$$

Mix Design
Analysis

- Filler/Bitumen Ratio (F/B)

$$F/B = \frac{\text{Total \% of minus No. 200 (0.075 mm) material}}{P_{be}}$$

Mix Design
Analysis

- $\% G_{mm}$ @ N_{ini}

$$\% G_{mm} @ N_{ini} = \frac{G_{mb}h_m}{G_{mm}h_x} \text{ x } 100$$

Where:

h_m = height of compacted specimen, mm

h_x = height of compacted specimen at N_{ini} gyrations, mm

Mix Design
Analysis

- Specification compliance?
  - Check I.M. 510 Appendix A.

Mix Design
Analysis

- The SHADES software will automatically determine the volumetric properties and mixture characteristics for specification compliance.

Mix Design
Analysis

- Will trial aggregate blend meet specifications?
  - Perform a single point analysis by estimating what the mixture properties would be at the correct void level.
    - This is accomplished in SHADES by assuming that a 0.2% change in binder content corresponds to a 0.5% change in voids.

Mix Design
Analysis

- Will trial aggregate blend meet specifications?
  - If yes, proceed.
  - If no, go back to aggregate blend selection.

Determination of Optimum Binder Content

Once the mix designer has selected a blend that will meet the specifications, that blend must be tested at several different asphalt contents so that the optimum asphalt content can be determined. If a single batch of the selected blend has already been tested and evaluated, the optimum asphalt content can be estimated using the rule of thumb that 0.2% change in asphalt binder content equals a 0.5% change in air voids.

If the mix designer chooses to skip the blend evaluation step and go to an asphalt variable design immediately, the optimum asphalt content is more difficult to estimate. Experience with similar materials can be used. Or, the mix designer may look at the surface area and absorption of the aggregates. Higher surface areas and higher absorptions generally require more asphalt. The SHADES computer program has tools built in to help the mix designer determine a initial binder content based on film thickness.

Whatever method is used, the mix designer should test the trial blend at three or four different asphalt contents, 0.5% to 1.0% apart. IM 510 provides instruction concerning the bracketing of the optimum binder content. Bracketing means that there must be at least one asphalt content batched above optimum and one below optimum. This is required because the final recommended optimum binder content is determined by assuming a linear relationship of voids versus binder content and calculating the asphalt content that yields the target percent voids. To do this, the calculation needs voids data from a batch with higher than target voids (low P_b) and a batch with lower than target voids (high P_b).

Once the target binder content is established, the other mixture properties at that percent asphalt can be interpolated from the test data. This is done using equations similar to the one used to determine the optimum binder content. The final step is to perform a check on the interpolated data to be certain all specifications have been met.

Mix Design

Determination of Optimum Binder Content

Mix Design – Objective

Determination of Optimum Binder Content

- Conclude if mix design data meets the specifications.
- Compare data on different blends and choose which blend is “best”.
- Calculate optimum P_b.

Mix Design

Determination of Optimum Binder Content

- Bracketing
  - Minimum of three binder contents
  - Should cover a range of at least 1.0%.
    - The final recommended binder content <u>must</u> be bracketed by trial binder contents above and below the optimum binder content.

Mix Design
Determination of Optimum Binder Content

- Bracketing
  - Determine volumetric and other mix characteristics at additional binder contents.

Mix Design
Determination of Optimum Binder Content

- Determine the optimum binder content by interpolating to target voids by using the following equation.

$$\text{Optimum } P_b = \frac{(P_{ah} - P_{at})}{(P_{ah} - P_{al})}(P_{bh} - P_{bl}) + P_{bl}$$

Mix Design
Determination of Optimum Binder Content

$$\text{Optimum } P_b = \frac{(P_{ah} - P_{at})}{(P_{ah} - P_{al})}(P_{bh} - P_{bl}) + P_{bl}$$

Where:

P_{ah} = high air voids
P_{al} = low air voids
P_{at} = target air voids
P_{bh} = high P_b
P_{bl} = low P_b

Mix Design

Determination of Optimum Binder Content

Example

- Determine the optimum binder content given the following information assuming a target voids of 4.0%:

Voids	Binder Content
8.2	4.00
5.2	5.50
3.7	6.20
2.4	7.35

Mix Design

Determination of Optimum Binder Content

- The bracketing pairs are 5.2% voids with 5.50% binder, and 3.7% voids with 6.20% binder.

$$\text{Optimum } P_b = \frac{(5.2 - 4.0)}{(5.2 - 3.7)}(6.20 - 5.50) + 5.50$$

$$\text{Optimum } P_b = \frac{(1.2)}{(1.5)}(0.70) + 5.50 = 6.06\%$$

Mix Design

Determination of Optimum Binder Content

- After determining the optimum binder content at target voids, the volumetric and other mixture characteristics need to be determined for analysis.

Mix Design
Determination of Optimum Binder Content

- The SHADES software will automatically perform the interpolating to target voids and determine the corresponding volumetric and other mixture characteristics.

Mix Design
Determination of Optimum Binder Content

- Does the mixture meet all of the specifications?
  - Check I.M. 510 Appendix A

Mix Design – Objective
Determination of Optimum Binder Content

- Conclude if mix design data meets the specifications.
- Compare data on different blends and choose which blend is “best”.
- Calculate optimum P_b.

REPORTING

Reporting

The last step in the mix design process is producing the documentation and submitting it for approval of the JMF. The SHADES computer program produces the two required reports. The completed SHADES file including forms 955 and 956 are required documentation that must be submitted to the DME for approval. Form 955 is the documentation of the aggregate sources and gradations. The most important information on Form 955 is the production limits for the aggregate stockpiles. These production limits tell the producer how much variation from the target gradation is allowed during the building of the stockpile. The mix designer can set the production limits, but both the aggregate producer and the contractor must sign the 955 to indicate that the aggregates will be produced as indicated.

Form 956 is the mix design documentation. It shows the JMF as well as all the test data generated during the trial mixing process. Copies of these two documents will be distributed to the Engineer, the DME and the contractor once the DME has approved the mix design for use.

It is a requirement that the mix designer submit a copy of the SHADES computer file containing the mix design data to the DME. The DME or his authorized representative will issue the final approved 956. Approval may be based on just a review of the 955 and 956, or the DME may request that the materials be submitted to the District Lab for verification testing. Checking the aggregate specific gravities and/or testing a box of mixture prepared at the optimum binder content is often required.

A new method of approval was instituted in 2002. If the DME and the contractor agree, a test strip may be produced and evaluated for approval of the JMF. This method limits the plant production to the approved quantity. At that point production ceases until test results are available to confirm the quality of the mixture. Producing a mix design which truly represents what will be produced at the plant is always important, but when using the test strip method of approval it is essential.

Reporting

Reporting – Objective

- Use SHADES to generate reports.

Reporting

- What is required?
  - – Form 955
  - – Form 956
  - – Worksheets (DME option)
  - – Approval
  - – Distribution

Reporting

- Form 955
  - Required documentation indicating what materials are to be used and what the production tolerances are.

Reporting

- Form 956 (JMF)
  - Required documentation indicating the results of testing performed by the contractor.
  - Provides the bracketing information for use during production when adjustments are needed.

Reporting

- Worksheets (DME option)
  - Documentation needed at times to check the accuracy of results.

Reporting

- Approval
  - Required prior to the start of paving.
  - Signatures
  - DME Testing
  - Test Strip

Reporting

- Approval
  - Signatures
    - From both the contractor and the aggregate producer(s) on Form 955.
    - From both the contractor and DME on Form 956.

Reporting

- Approval
  - DME Testing
    - May be required to verify the volumetric properties and/or other mixture characteristics.

ADJUSTING

Adjusting Plant Production

Adjustability
Likely Problems
Troubleshooting Charts
Mix Change Approval

Adjusting Plant Production – Objective

- Recognize likely problems.
- Describe possible solutions.
- State how to document changes.
- Name who needs to be informed of changes.

Adjusting Plant Production

Adjustability

Adjusting Plant Production
Likely Problems

- Low Voids
  - What can be done?
  - **Ways to increase voids**
    - Remove binder
    - Increase crushed content
    - Remove fines

Adjusting Plant Production
Likely Problems

- Low VMA
  - What can be done?
  - **Ways to increase VMA**
    - Increase crushed content
    - Remove fines
    - Move combined gradation away from the maximum density line.

Adjusting Plant Production
Likely Problems

- Low Film Thickness
  - What can be done?
  - **Ways to increase film thickness**
    - Increase binder
    - Remove fines by using “cleaner” aggregates
    - Use a coarser gradation

Adjusting Plant Production
Likely Problems

- Gradation
  - What can be done?
    - Change proportions
    - Screen
    - Waste

Adjusting Plant Production
Likely Problems

- Compaction
  - What can be done if tender?
    - Increase crushed content
    - Remove binder
    - Remove fines
  - What can be done if harsh?
    - Decrease crushed content
    - Add binder
    - Add fines

Adjusting Plant Production
Troubleshooting Charts

- I.M. 511 Field Problem Table
- I.M. 511 Lab Problem Table

Adjusting Plant Production
Mix Change Approval

- The contractor is responsible for making changes, as necessary, to achieve target values specified on the JMF. These changes can include adjusting the proportions of aggregate and binder necessary to meet the JMF.

Adjusting Plant Production
Mix Change Approval

- What requires a mix change approval?
  - Target Gradation
  - Target P_b
  - Shut Down
  - Aggregate interchanges
  - Aggregate substitution
    - Geologically similar
    - Less than 15%

Adjusting Plant Production
Mix Change Approval

- Target Gradation
  - If a change in the target gradation is desired, the contractor must obtain approval of a new JMF from the DME.

Adjusting Plant Production
Mix Change Approval

- The contractor may change the target binder content to maintain the required mixture characteristics, provided the appropriate documentation and reporting is performed.

Adjusting Plant Production
Mix Change Approval

- Shut Down
  - If the contractor is forced to shut down the plant because of the moving average for air voids falling outside specifications, the contractor <u>must</u> obtain approval from the DME to restart plant operations.

Adjusting Plant Production
Mix Change Approval

- Aggregate interchanges
  - The contractor may interchange aggregates in order to maintain the target gradation provided the appropriate documentation and reporting is performed.

Adjusting Plant Production

Mix Change Approval

- Aggregate Substitutions
  - The contractor must obtain approval from the DME to perform an aggregate substitution provided the following two conditions are also met:
    - The aggregate is from a geologically similar formation.
    - The aggregate will constitute less than 15% of the mix.

Adjusting Plant Production – Objective

- Recognize likely problems.
- Describe possible solutions.
- State how to document changes.
- Name who needs to be informed of changes.

Adjusting Plant Production

- For additional information see:
  - Asphalt Handbook produced by the Asphalt Institute

SPECIAL ISSUES

Special Issues

WMA
Warm Mix Asphalt has been used for many years in Europe. Many States including Iowa have placed WMA sections and evaluated the performance. The Iowa specifications allow the use of WMA in place of HMA for all bid items unless specifically excluded in the contract documents. There are numerous technologies in use to produce WMA and those technologies must be employed in the mix design. The specific requirements depend on the chosen technology, plant operations and mixture temperatures.

Anti-Strip Agents
Preventing stripping in HMA pavements is a high priority because it often leads to premature failure. Adding anti-strip agents to the mixture may be required by specification when working with high percentages of coarse siliceous aggregates like quartzite and all surface mixtures designated for VT traffic levels. Hydrated lime has been used for many years as an anti-strip agent, but when not handled properly it can be a safety and environmental concern. Liquid anti-strips, while generally not as effective as hydrated lime, can be added to the asphalt binder by the binder supplier, thus eliminating the handling problems at the hot mix plant. Most liquid anti-strips are amines and are very toxic, but are used in small percentages (<2%) of the binder so they are considered safe. However, the mix designer may need to work with the pure liquid anti-strip and should be aware of the hazards and take the necessary precautions for safe handling of toxic materials.

When the specifications call for the use of an anti-strip agent, the contractors have several options. They may elect to add hydrated lime or they may do extra testing during the development of the mix design to prove that the mix does not need an anti-strip agent. If they decide to use a liquid anti-strip, however, they must establish the optimum dosage for the mixture. To establish whether an anti-strip agent is needed or to optimize the dosage, the mix designer must perform the test for moisture susceptibility according to IM 319 using the Hamburg Wheel Tracking Device.

AASHTO T283
The T283 test uses specimens compacted to approximately seven percent voids. Three specimens are saturated with water, exposed to freeze and thaw then conditioned in warm water for twenty-four hours. The indirect tensile strength of these conditioned specimens is compared to that of specimens that have been kept dry. This is called the tensile strength ratio or TSR. If the conditioned specimens have at least eighty percent of the strength of the dry specimens the mixture is acceptable. Iowa no longer uses the T283 test, instead the Hamburg Wheel Tracking test is used.

Hamburg Wheel-Tracking

In January 2013 the T283 test was replaced with the Hamburg Wheel-Tracking Device test. The Hamburg uses steel wheels that track across gyratory specimens that are submerged in warm water. The amount of rutting is measured on each pass of the wheel. If the asphalt begins to strip from the aggregate, there will be a sudden increase in the rate of rutting. When this happens the Stripping Inflection Point or SIP can be determined mathematically. If the SIP occurs too early in the test the mix may be considered moisture susceptible and an anti-strip agent may be needed.

Economic Justification

Specification 2303.02D states that if a mix design is submitted with a recommended asphalt content more than 0.75% above the basic asphalt content shown in the spec. then the contractor must perform an economic evaluation. The economic evaluation involves producing an alternate design that does not exceed the 0.75% criteria and establishing the haul costs of using a different aggregate source with lower asphalt absorption. Most often it is highly absorbent aggregates that cause the high asphalt demands. Occasionally, though, the high asphalt demand is due to excess VMA in the mixture. It is necessary to design mixtures with a little more VMA than the minimum required, but if there is more than two percent extra VMA it can be a waste of asphalt that must fill the space. When this happens the economic evaluation includes proportion changes that might lower the VMA and, in turn, lower the asphalt demand.

RAP

The use of RAP in HMA is common. Certain adjustments must be made when using RAP, since it is proportioned like any other aggregate but it is not just aggregate, it also includes some asphalt. For example, if fifteen percent RAP is used, it does not contribute fifteen percent to the aggregate, but slightly less depending on the asphalt content, maybe fourteen percent. Also, the asphalt content of the mixture must be adjusted to account for the asphalt coming from the RAP. There are equations included in IM 501 that show how to calculate the necessary adjustments to compensate for the asphalt in the RAP. The basic idea is to treat the RAP like any other aggregate and use mathematics to compensate. So, when calculating the combined gradation or the combined specific gravity, small adjustments to the percentages are needed to be correct. The mix designer must be sure to correctly adjust the amount of asphalt added to the trial mix so that the total asphalt will be correct.

RAS

The use of recycled asphalt shingles (RAS) is gaining popularity due to the high asphalt content of shingles in the 20-30% range. RAS is handled in a similar manner to RAP. Often when RAS is used it is combined with RAP. Special requirements apply to RAS for source approval, mix design and plant production.

Slag
Steel slag is an artificial aggregate that is a byproduct of smelting steel. Steel slag has a high specific gravity, normally around 3.200, because it contains a small amount of steel. It often has a very rough texture and many large voids that make it difficult to determine the specific gravity and absorption. Steel slag is a Type 2 Frictional class aggregate and is commonly used in Eastern Iowa in surface mixtures that have special frictional requirements. The high specific gravity and difficulty in testing means the mix designer needs to exercise extra care when including slag in the mixture.

District Differences
It is a simple fact that specifications cannot be written to cover every possible situation. Some specifications are written intentionally to need interpretation by the Engineer or give options to the Engineer. For this reason, the mix designer is likely to encounter significant differences in what is expected when moving from one District to another. Usually, these differences are limited to what each District wants for documentation, what samples need to be submitted for the approval of the JMF or how to coordinate the correlation samples required. For example, one District may require the mix designer to submit all the worksheets used during the mix design process in addition to the usual forms. When beginning the mix design process it is best to inform the District responsible for the job and ask if there are any special requirements. Communication is essential; you know what happens when you assume!

Modified Binders
Modified Asphalt Binders are used occasionally for special purposes. Usually they are specified when higher stiffness is required to prevent shoving and rutting, such as urban areas with high truck traffic or Interstate pavements. A PG binder with a traffic designation of H, V, or E will probably be modified. Because of the higher stiffness, some modified binders will not mix well at normal temperatures. Mixtures made with modified binders sometimes will not compact properly at normal temperatures either. The mix designer should check with the binder supplier to see if a higher temperature is recommended for mixing and compaction when using modified binders. If the binder supplier recommends a temperature higher than 275° F, this information should be communicated to the DME.

Performance Testing
Several new test procedures and new testing equipment are currently being evaluated as mix design and/or field QC mixture performance tests. All of the tests being looked at are stress or strain controlled loading tests. Dynamic modulus, resilient modulus, elastic modulus, dynamic creep and static creep are all measurements of fundamental properties related to vehicle loading. The Iowa D.O.T. has purchased the test equipment to perform these tests and began evaluating mixtures used in Iowa and the new test procedures in 2003.

The AASHTO Design Guide requires results from some of these tests for use in the design of the pavement. When actual measured properties of the materials are used to help design a pavement structure it is called “Mechanistic Design”. Pavement designers have never had a mechanistic design tool for asphalt pavements. The tests being evaluated now will provide the information needed to help the pavement designers implement the new mechanistic design guide. The mix designer needs to be aware of developments in this area because the new tests could begin to impact designs for high ESAL load pavements within the next few years.

Disc-Shaped Compact Tension test (DCT)
One performance test that has been implemented determines the fracture energy required to crack a mix at low temperatures. This test may be used to better determine the need to change the grade of asphalt binder when high percentages of RAP or RAS are used.

Virtual Design
The SHADES computer program includes new tools. One of these new tools is a Virtual Design Tool that allows the mix designer to input some basic data about the aggregates to be used and let the computer predict the mixture properties. In addition to the usual data concerning gradation, angularity, specific gravity and absorption, the virtual design tool needs to know the compactability of the aggregate. This value can be estimated or it can be measured by a new test procedure developed by Dan Seward in the Central Materials Lab. The new test is an extension of the Fine Aggregate Angularity test that applies a load to the aggregate in the volumetric cylinder and measures the amount of compaction that takes place.

While the predictions are not one hundred percent accurate, they can help the mix designer find a trial blend quickly that should meet the requirements. The mix designer can also use this tool to compare several different combinations without actually having to mix and test the trial blends. Current data indicates the Virtual Design Tool will produce accurate results more than fifty percent of the time.

Virtual Check
Another new tool included in SHADES is the Virtual Check, which employs certain known relationships to check on the validity of the trial mix test results. Mix designers have known some of these relationships for many years but have not had a method for checking them. For example, it is well known that a one percent change in asphalt content should produce about a 0.033 difference in the Maximum Specific Gravity of the mixture. The Virtual Check Tool employs this and other physical relationships to graph the trial mix data against the theoretically correct data and compare the two. It will then inform the mix designer whether the test data is a good fit to the theoretical model or not. This

should help the mix designer as well as the Agency approving the design to be comfortable with the test results.

Equiviscous Mixing and Compaction Temperatures
The State of Iowa does not use mixing and compaction temperatures based on the viscosity of the asphalt binder. Some surrounding States do use this method. When using this method, the mix designer must obtain the viscosity of the binder at two different temperatures, graph the viscosity then read the mixing and compaction temperatures from the graph at points where the viscosity is equal to a certain value. This method does not work well with some modified binders because the stiffness (viscosity) of the binder is so high that the temperatures read from the graph would be unrealistically high. The binder supplier will normally be able to provide the needed viscosity data or recommend the temperatures to use. In Iowa, 275° F is used for both mixing and compaction unless the binder supplier recommends a different temperature.

Special Uses
There are other uses for HMA besides highway pavements. One of the more common special uses for HMA is bike trails. Since bike trails do not carry heavy loads the specifications for trails emphasize resistance to aging and cracking instead of resistance to rutting. Such mixtures tend to be rich in asphalt and fine graded.

The Department of Natural Resources (DNR) supplies recycled crushed glass for use in some trail projects. The glass is supplied to the contractor as manufactured sand. The HMA produced with recycled glass is called "glassphalt". Several projects have successfully used glassphalt for both trails and parking lots.

HMA Interlayer
For bid items specifying an HMA Interlayer a special mix design is required. Supplemental Specification SS-15010 contains the requirements for an interlayer mix. The interlayer is a stress absorbing membrane (SAMI) designed to reduce reflective cracking from the underlying pavement. A special highly polymerized asphalt binder PG 58-34E is required and special testing for beam fatigue according to AASHTO T321 is used to be certain the mix is highly flexible and resilient. Interlayers are designed with lower void requirements and high asphalt binder contents.

High Performance Thin Lift
For bid items specifying a High Performance Thin Lift a special mix design is required. Developmental Specification DS-15066 contains the requirements for High Performance Thin Lift (HighPer) mixtures. These mixtures are surface mixtures placed in thinner than usual lifts designed to resist water penetration, rutting and cracking. A special highly polymerized asphalt binder PG 64-34E+ is required and special testing using the Hamburg Wheel Tracker is used to be sure

rutting will not occur. Thin lift mixtures are also designed with lower void requirements and high asphalt binder contents.

Certification Outside Iowa

Iowa has developed reciprosity agreements with several of the surrounding states. Attending mix design school here allows the technician to work in other states without attending their mix design classes and vice versa, only the written test must be taken. Anyone who has attended Superpave Mix Design training at The Asphalt Institute, NCAT, or a Superpave Center may also test out of this mix design class. If you need to work in a surrounding state be sure to contact them first and find out what the requirements are for transferring your certification.

Special Issues

Special Issues – Objective

- Discuss special issues which may be encountered on your project.
- Identify where to go for more information.

Special Issues

- WMA
- Anti-Strip Agents
- AASHTO T283
- Hamburg Wheel-Tracking
- Economic Justification
- RAP
- RAS
- Slag
- District Differences
- Modified Binders
- Performance Testing
- Virtual Design
- Virtual Check
- Equiviscous Mixing/Compaction
- Special uses
- HMA Interlayer
- High Perf. Thin Lift
- Cert. outside Iowa

Special Issues
WMA

- Warm Mix Asphalt will be allowed for use on all bid items unless specifically excluded.
- Special mix design requirements apply depending on the WMA technology, plant operations and temperatures.

Special Issues
Anti-Strip Agents

- When the mix to be designed falls under the criteria listed in specification 2303.02E, an anti-strip additive may be required.
  - The specification deals with the potential use of a anti-strip agent to be used to deal with the stripping potential of the aggregates.

Special Issues
AASHTO T283

- Prior to January 2013, when the use of an anti-strip agent was required, the AASHTO T283 test was performed.
  - This test deals with measuring the stripping potential of the mixture.
  - A minimum Tensile Strength Ratio (TSR) criteria must be met.
  - Still used in some states.

Special Issues
Hamburg Wheel-Tracking Testing

- The AASHTO T283 test has been replaced by the Hamburg Wheel-Tracking device to evaluate moisture sensitivity as described in IM 319.
  - Evaluates the Stripping Inflection Point (SIP) which is the number of wheel passes before the asphalt binder begins to strip from the aggregate.

Special Issues
Economic Justification

- Standard Specification 2303.02D
  - If the asphalt binder content for the combination of aggregates submitted for an acceptable mix design exceeds the basic asphalt binder content by more than 0.75%, the mix design will include an economic evaluation prepared by the Contractor including an alternate mix design that does not exceed the 0.75% limit.

Special Issues
RAP

- There are two different types of RAP with different criteria that must be met.
  - Classified RAP
  - Unclassified RAP
- There are restrictions on the amount of unclassified RAP that can be used.

Special Issues
RAP

- The Contracting Authority provides the detailed information on the properties of the RAP for mix design.

Special Issues
RAP

- When RAP is used in the mix, the proportions of raw aggregate and binder <u>must</u> be adjusted to accommodate for the aggregate and binder in the RAP itself.
- I.M. 501 provides example calculations for adjusting the proportions of aggregate and binder.

Special Issues
RAP

- Percent binder in a mix with RAP ($P_{b(added)}$).

$$P_{b(added)} = \frac{(100)(\text{total intended } P_b) - (\%\ RAP)(P_{b(RAP)})}{100 - (\%\ RAP)(P_{b(RAP)})(0.01)}$$

Where: $P_{b(RAP)} = P_b$ in the RAP

Special Issues
RAP

- Percent of RAP considered to be aggregate (% $RAP_{(aggregate)}$).

$$\% \ RAP_{(aggregate)} = \frac{(\% \ RAP)(1.00 - (P_{b(RAP)})(0.01))}{\% \ virgin\ agg. + (\% \ RAP)(1.00 - (P_{b(RAP)})(0.01))} \ x\ 100$$

Special Issues
RAP

- The % virgin aggregate in a mix with RAP (% virgin agg.).

$$\% \ virgin\ agg. = \frac{(\% \ virgin\ agg.)}{\% \ virgin\ agg. + (\% \ RAP)(1.00 - (P_{b(RAP)})(0.01))} \ x\ 100$$

OR

$$100 - \% \ RAP_{(aggregate)}$$

Special Issues
RAP

- Total P_b in a mix with RAP (Total P_b).

$$Total\ P_b = P_{b(added)} + ((\% \ RAP)(P_{b(RAP)})(0.01)) - ((P_{b(added)})(\% \ RAP)(P_{b(RAP)})(0.0001))$$

Special Issues
RAP

- The proportions of the aggregates must be adjusted by making use of new % virgin agg.
  - The difference between the original % virgin agg. and the new % virgin agg. is distributed over the various aggregates being used.

Special Issues
RAP

- The new percentage of <u>each</u> individual aggregate is adjusted by using the following equation:

$$\%\ \text{Agg}_{x(\text{new})} = \%\ \text{Agg}_{x(\text{original})} + \frac{\%\ \text{Agg}_{x(\text{original})}}{\%\ \text{virgin Agg}_{(\text{original})}}\left(\%\ \text{virgin Agg}_{(\text{new})} - \%\ \text{virgin Agg}_{(\text{original})}\right)$$

Special Issues
RAP

- The aggregate properties of the blend must be computed using the adjusted aggregate percentages.
- The specific gravity of the combined virgin and RAP binder is computed assuming a specific gravity of 1.035 for the RAP binder.

Special Issues
RAP

- In the SHADES software, the RAP gradation and properties must be entered on the last line of the individual aggregate gradation section.
- The P_b in the RAP must also be entered into SHADES.
- SHADES will automatically perform the necessary calculations.

Special Issues
RAS

- Recycled Asphalt Shingles must be from an approved supplier.
- Handled similar to RAP.
- 2/3 of the asphalt in the shingles is considered active and is paid for.
- Some special mix design requirements apply including different criteria for the grade bumping of the asphalt binder.

Special Issues
Slag

- Extremely high specific gravity (approximately 3.20)
- Highly variable absorption characteristics

Special Issues
District Differences

- The DME has a great deal of flexibility in interpreting how the specifications will be enforced.
  - Contact the district office you will be working in if you have specific questions.

Special Issues
Modified Binders

- Modified binders have special needs for design.
  - Possibly a higher mixing temperature
  - Talk with the supplier for recommendations

Special Issues
Performance Testing

- Upcoming tests to better define the performance of the mixture.
- Fracture energy testing is being implemented to better define when grade changes are required when RAP binder replacement exceeds 30% (or 25% when RAS is used).

Special Issues
Virtual Design

- Estimates the compaction of the aggregates through a modified Fine Aggregate Angularity test.
  - Allows for a better starting point for design binder content.

Special Issues
Virtual Check

- Uses mathematical relationships to check on the accuracy of test results.
  - Allows the designer to see if there may be a problem before getting into production.

Special Issues
Equiviscous Mixing/Compaction

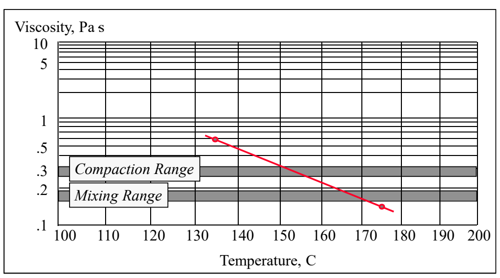
Viscosity

- Viscosity is the resistance to flow.
  - Higher viscosity means less flow.
- At low temperatures, asphalt is viscous.
  - As temperature increases, viscosity decreases and the asphalt becomes more fluid.
- Asphalt must flow to mix with aggregates.
- Should not flow too much during compaction or will drain down (run off).

Special Issues
Equiviscous Mixing/Compaction

- To determine mixing and compaction temperatures:
  - – Measure viscosity at two temperatures
    - Brookfield viscometer
    - Capillary tube viscometer
  - – Plot on temperature-viscosity graph
  - – Find mixing and compaction temperatures by determining where the binder has the appropriate viscosity.

Special Issues
Equiviscous Mixing/Compaction



Special Issues
Equiviscous Mixing/Compaction

Equiviscous Temperatures

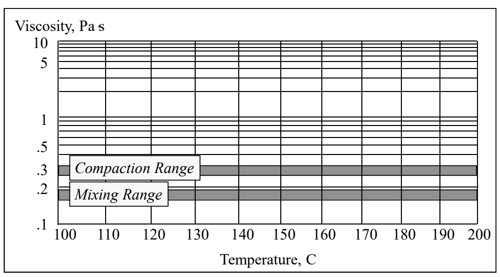
- Asphalt Institute recommendations
- Not new to Gyratory
- Many states follow these or have these built into their specifications
- Others use constant mixing and compaction temperatures
  - – Iowa uses 275°F for mixing and compaction

Special Issues
Equiviscous Mixing/Compaction

Example

- A binder has the following viscosities:
  - 0.400 @ 135°C
  - 0.150 @ 165°C
- Estimate mixing temperature range.
- Estimate compaction temperature range.
- Is this reasonable?

Special Issues
Equiviscous Mixing/Compaction



Special Issues
Equiviscous Mixing/Compaction

Note

- With some modified binders, this approach may yield unrealistically high mixing and compaction temperatures.
- Contact binder producer for realistic temperature ranges.
- Example: a PG 64-28 gave:
  - Mixing temp = 251°C (Used 150°C)
  - Compaction temp = 227°C (Used 140°C)

Special Issues
Special Uses

- Bike Paths
- HMA Interlayer
- High Performance Thin Lift

Special Issues
Technician Certification outside Iowa

- What's different in Iowa?
  - Design Table
  - Mixing/Compaction Temperature
  - % Crushed
  - QC/QA terminology

Special Issues – Objective

- Discuss special issues which may be encountered on your project.
- Identify where to go for more information.

Special Issues

- For additional information see:
  - SP-2 from the Asphalt Institute
  - MS-2 from the Asphalt Institute

SUMMARY

Summary

Summary

Course Objectives

- Identify the steps in HMA mix design
- Perform the steps hands-on

Summary

- Identify the design requirements
- Selecting materials
- Obtaining samples
- Aggregate sample preparation
- Aggregate testing
- Blending

Summary

- Determine initial binder content
- Batching
- Mixing
- Sample Preparation
- Mix testing
- Analysis
- Determine optimum binder content

Summary

- Reporting
- SHADES
- Adjusting mixes
- Identify any special issues

T176

PLASTIC FINES IN GRADED AGGREGATE AND SOILS BY USE OF THE SAND EQUIVALENT TEST

AASHTO T176

Developed by

Multi-Regional Aggregate Training & Certification Group
Revised 2006

Note

Successful completion of the following training materials, including examination and performance evaluations are prerequisites for this training package.

- AASHTO T 176, Standard method of Testing for Plastic Fines in Graded Aggregate and Soils By Use of Sand Equivalent Test.

Reference AASHTO Tests

- AASHTO T 2, Standard Practice for Sampling Aggregate
- AASHTO T 27, Sieve Analysis of Fine and Coarse Aggregate
- AASHTO T 248, Reducing Samples of Aggregate to Testing Size

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Plastic Fines in Graded Aggregate and Soils by Use of the Sand Equivalent Test

Scope

The Sand Equivalent Test uses a liquid solution to separate the clay-like material (fine dust) from the larger material in a sample that passes the No. 4 sieve. Once the clay-like material is separated the percent or amount of material in a sample that has similar characteristics to sand can be determined. A higher sand equivalent value indicates that there is less clay-like material in a sample. Clay-like materials have a direct effect on the performance of Hot Mix Asphalt (HMA) and the amount should be controlled to provide quality bituminous mixtures. A large amount of clay-like particles can coat the aggregate surfaces and prevent the liquid asphalt from completely coating and adhering to the aggregate.

Apparatus

The following equipment is needed to perform the sand equivalent test. The equipment needs to conform to the specifications and dimensions of the standard test method. Additional accessory items are also noted in a list of materials in the standard test method.

- A plastic graduated cylinder with a rubber stopper
- Irrigation Tube
- Weighted foot assembly
- Siphon assembly
- Tinned Measure
- Wide-Mouth Funnel
- A clock or watch
- A mechanical or manual shaker
- Bottle of solution

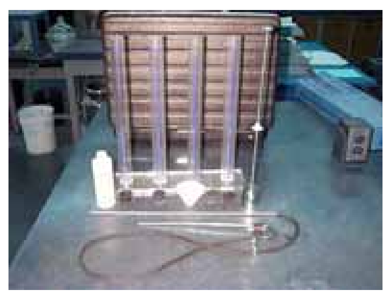

Figure 1 - Graduated Cylinder, Irrigation Tube, weighted foot Assembly and Siphon.

Mechanical Shaker

Note:
The solution is placed on a shelf 915mm ± 25 mm (36 in.±1 in.) above the work surface.

Summary of Test

The sand equivalent value of a prepared sample is determined by placing the sample into a graduated cylinder with the test solution. After the sample has soaked, the cylinder is capped off or sealed. The cylinder is then shaken in a horizontal position to completely mix the sample and solution.

There are three separate methods that can be used to shake a sample. The preferred or recommended method is the method using a mechanical shaker. The other two, the manual shaker or the hand method can be used, but each one has specific requirements that must be maintained to obtain accurate results.

When the mixing is finished the cylinder is stood upright, irrigated and allowed to stand undisturbed. The sample will sink toward the base of the cylinder. The heavier particles will sink to the bottom of the cylinder rapidly and the suspended fine material will slowly settle toward the bottom. After 20 minutes + 15 sec. the top of the suspended material is noted as the clay reading. The sand reading is noted after a weighted assembly is lowered into the cylinder and it comes to rest on the surface of the sand or coarse material that has settled out. Once the readings are obtained a simple calculation is used to determine the sand equivalent value.

Test Precautions

This test method has numerous steps where errors can be introduced, unless certain details are carefully controlled or monitored before and during the test procedure. The prepared solution of calcium chloride, glycerin and formaldehyde solution should be mixed, used and maintained with care. The Material Safety Data Sheets should be used for any safety issues associated with this test when using the noted solution.

Most of the precautions are associated with good laboratory techniques and watching the details. The sample preparation and the shaking of the sample have specific requirements that are needed for accurate test procedures, and test results.

Sample Preparation

The test is conducted on soils or graded aggregate passing the 4.75mm (No. 4) sieve. When separating the sample special care should be made to collect all the minus 4.75mm (No. 4) material. Any clumps or dust should be broken apart and included with the material passing the 4.75mm (No. 4) sieve.

Split the sample into the desired number of test samples, with enough material to slightly overfill the tin measure. Set up each test sample by either one of the alternate methods described in the standard specification, or the referee method (mechanical shaker).

Test Procedure

The following step by step procedure for the mechanical shaker (Reference Method) is recommended to understand the laboratory techniques needed for accurate test results.

1. Allow the initial sample to air dry.

2. Split or quarter the sample until you have slightly more material than it will take to fill a 3 ounce tin cup.

3. Place the tin cup in a larger flat container. A bread pan will work.

4. Take the sample obtained by splitting or quartering and slowly pour the sample into the tin cup.

5. As you pour the sample, gently tap the bottom edge of the tin cup on a hard surface (the bottom of the large flat container will work.)

6. After filling, strike off the top of the tin cup with a straight edge.

7. Oven dry the sample to a constant weight at 110 ± 5°C (230 ± 9°F).

8. Place one of the plastic graduated cylinders under the elevated siphon assembly.

9. Siphon 4.0+/-0.01 inches of working calcium chloride solution into the cylinder.

10. Pour the content of the tin cup into the solution.

11. Tap the bottom of the cylinder several times with the heel of your hand to help release trapped air bubbles and promote thorough wetting of the sample.

12. Let the cylinder and sample stand undisturbed for 10 +/-1 minutes.

13. Place the rubber stopper in the cylinder.

14. Loosen the material from the bottom of the cylinder.

15. Place the cylinder in the Mechanical Shaker.

16. Tighten the screw to hold the cylinder.

17. Turn the Mechanical Shaker on.

18. BE SURE TO HOLD THE MECHANICAL SHAKER IN PLACE, IF IT HAS NOT BEEN ANCHORED TO A FIRM FLAT SURFACE. Allow the machine to shake the sample for 45 ± 1 second.

19. When the shaker is finished, loosen the screw.

20. Remove the cylinder.

21. Remove the stopper.

22. Place the cylinder under the siphon assembly.

23. Place the irrigation tube into the cylinder.

24. Loosen the restraints on the siphon tube.

25. Rinse the material from the cylinder walls as you lower the tube into the cylinder.

26. Force the irrigation tube through the sample.

27. Twist the irrigation tube, forcing the fine material into suspension.

28. Keep forcing and twisting the tube through the sample.

29. Keep doing this until the fluid level reaches approximately 15 inches.

30. Raise the tube, keeping the fluid level at the 15 inch mark.

31. Replace the restraints on the siphon tube.

32. Allow the cylinder and sample to stand undisturbed for 20 minutes +/- 15 seconds.

33. After this time take the Clay reading.

34. Read the top of the Clay suspension. If the suspension level is between lines take the highest reading.

35. Insert the weighted foot assembly. (Refer to the standard test method for specific notes of the weighted foot assemblies.)

36. MAKE SURE THAT YOU DO NOT ALLOW THE INDICATOR TO HIT THE MOUTH OF THE CYLINDER.

37. Lower the assembly into the solution until the foot comes to rest on the sand.

38. Take the sand reading. If the indicator is between 2 lines take the highest reading.

40. Record the clay and sand readings.

41. Enter the clay and sand readings in the Sand Equivalency formula and complete the calculations.

Calculations

Calculate the sand equivalent (SE) value to the nearest 0.1 using the following formula:

$$SE = \frac{Sand\ Reading\ x\ 100}{Clay\ Reading}$$

Common Testing Errors

- Calcium Chloride Solution not mixed properly, used outside of the temperature range or not checked for organic growth.
- Vibrations or jarring while sample is settling out in the solution.
- Improper sample preparations (splitting & test sample preparations.)
- Solution exposed to direct sunlight.
- Sample not irrigated correctly.
- Sample not shaker properly in graduated cylinder.

GLOSSARY

Irrigation Tube - Metal tube pushed thru material to help force clay-like material into suspension.

Weighted Foot Assembly - Device used to measure the height of the nonclay-like material.

Siphon Assembly - A gallon container and flexible hose used to introduce the solution into the irrigation tube.

Mechanical Shaker - Used to agitate the sample and solution before irrigation.

T283

RESISTANCE OF COMPACTED ASPHALT MIXTURES TO MOISTURE-INDUCED DAMAGE

AASHTO T 283

Developed by
FHWA Multi-Regional Asphalt Training & Certification Group
Revised 2006

NOTE

Successful completion of the following training materials, including examination and performance evaluation is a prerequisite for this training package.

< AASHTO T 168, Sampling Bituminous Paving Mixtures

< AASHTO T 312, Standard Method for Preparing and Determining the Density of Hot Mix Asphalt (HMA) by Means of the Superpave Gyratory Compactor.

<

< AASHTO T 209, Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt Paving Mixtures.

< AASHTO T 166, Bulk Specific Gravity of Compacted Hot Mix Asphalt Mixtures Using Saturated Surface-Dry Specimens.

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Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage

Asphalt mixtures made from certain combinations of materials may be sensitive to the presence of water in the finished pavement. Water will cause the asphalt binder to stop sticking to the aggregate. Since the asphalt binder is the “glue” that holds the pavement together, rapid failure of the pavement can be expected if the asphalt cannot stick to the aggregate. This is often referred to as stripping. To help prevent stripping, additives such as hydrated lime or liquid anti-stripping chemicals may be required. AASHTO T 283 is a test method that can be used to determine if the materials used are subject to stripping and can also be used to evaluate the effectiveness of additives.

The test is performed by compacting specimens to an air void level of 6.5 to 7.5 percent. Three specimens are selected as a control and tested without moisture conditioning, and three more are selected to be conditioned by saturating with water and freezing. The specimens are then tested for indirect tensile strength by loading the specimens at a constant rate and measuring the force required to break the specimen. The tensile strength of the conditioned specimens is compared to the control specimens to determine the tensile strength ratio (TSR). This test may also be performed on cores taken from finished pavement.

Common Testing Errors

< Air voids in the conditioned specimens not the same as the unconditioned ones.

< Conditioned specimens not properly saturated with water.

< Conditioned specimens not soaked for 24 hours in a water bath at 60 ± 1°C (140 ± 1.8°F).

TEST METHODOLOGY

Apparatus

< Vacuum container for saturating specimens

< Balance and water bath from T 166

< Water bath able to maintain 60 ± 1°C (140 ± 1.8°F)

< Aluminum pans (cake pans)

< Loading jack and force measuring device

< Loading strips with a curved face to match the side of the specimen

< Forced air oven able to maintain any temperature from room temperature to 176C (350F) within +/- 3C (+/- 5F)

< Freezer able to maintain -18 ± 3°C (0 ± 5°F)

< Plastic wrap and heavy-duty leak proof plastic bags

< 10 mL graduated cylinder

Sample Preparation

If pavement cores are to be tested, a minimum of six cores are required. Separate the cores into two sets of three so that each set has approximately the same average voids. If the layer thickness is less than 63.5mm (2.5 in) use 100mm (4 in) cores. For thicker layer, either 100mm (4 in) or 150mm (6 in) cores may be used.

For laboratory batched mixtures, 100 mm (4 in.) diameter and 63.5 ± 2.5 mm (2.5 ± 0.1in.) thick specimens or 150 mm (6 in.) diameter and 95 ± 5 mm (3.75 ± 0.20 in.) thick specimens are used. The larger diameter specimens should be used if there is 25.0 mm (1 in.) aggregate or larger in the mixture. Mix enough material to produce at least eight specimens at the asphalt content recommended for the mixture. Extra mixture will be needed for trials to establish the compaction required and for determining the maximum specific gravity of the mixture, if these values are not known.

After mixing, place the mixture in the aluminum pans and spread it to about 25 mm (1 in.) thick. Allow the mix to cool to room temperature for 2 ± 0.5 hours. Then put the mixture in the 60°C (140°F) oven for 16 ± 1 hours to cure. After curing, put the mixture in an oven for 2 hours ± 10 minutes at the compaction temperature +/- 3ºC (5ºF). For plant produced mixture, omit the curing and simply bring the mixture to compaction temperature. Compact the specimens to 7 ± 0.5 percent air voids.

Some experimentation will be needed to find the correct compactive effort that will yield the desired voids. When using the Superpave gyratory compactor, the height needed can be calculated from one trial specimen. Other compactors may require several trials before the correct compactive effort can be established.

After removing the specimens from the molds, store them at room temperature for 24 ± 3 hours.

Determine the maximum specific gravity of the loose mixture according to T166. Measure the thickness and diameter and determine the bulk specific gravity of each specimen. Calculate the air voids of each specimen. Sort the specimens into two groups of three so that each group has about the same average voids. One set will be stored at room temperature until tested, the other set will be conditioned before testing. The unconditioned control set should be sealed in plastic wrap or a plastic bag.

Moisture Conditioning

Put the specimens to be conditioned into the vacuum container and fill with distilled water so that at least 25 mm (1 in.) of water is covering them. Apply a partial vacuum (13 - 67 kPa 10-26 in Hg) to the container for about 5 to 10 minutes. Release the vacuum and allow the specimens to sit submerged in the water for another 5 to 10 minutes. Determine the bulk specific gravity of the saturated specimens. Compare the saturated surface dry (SSD) mass of the saturated specimens to the original SSD mass of the specimens before saturation. The difference will be the volume of absorbed water. Compare the volume of absorbed water to the original volume of air voids to determine the amount of saturation. The volume of absorbed water needs to be between 70 to 80 percent of the original volume of air voids. If the volume of absorbed water is less than 70 percent, repeat the vacuum saturation procedure. If the volume of absorbed water is greater than 80 percent, the specimens have been damaged and must be discarded and replaced.

Once properly saturated, wrap the saturated specimens tightly with plastic wrap and place in a plastic bag with 10 mL of water and seal the bag. Place the bag in the freezer at -18 +/- 3ºC (0 +/- 5ºF) for at least 16 hours. Remove the bags from the freezer and place in the water bath at 60 ± 1°C
(140 ± 1.8°F) for 24 ± 1 hours. As soon as possible after putting in the bath, remove the plastic bag and plastic wrap from the specimens.

Test Procedure

After the 24 hour soak, remove the specimens and place in a water bath at 25 ± 0.5°C (77 ± 1°F) for 2 hours ± 10 minutes. The bath should return to 25°C within 15 minutes after the warm specimens are placed in the bath. The unconditioned specimens, still sealed in plastic, also need to be placed in the 25°C bath for at least 2 hours.

Remove the specimen from the bath, measure and record the thickness and place it on its side between the steel loading strips.

Apply the load to the specimen by forcing the bearing plates together at a constant rate of 50 mm (2 in.) per minute. Record the maximum load, then continue to load the specimen until it cracks. Stop the machine, remove the specimen and break it apart at the crack. Look at the inside of the specimen and estimate the percent of stripped aggregate. Record the observations.

Calculations

Calculate the tensile strength using the following equation:

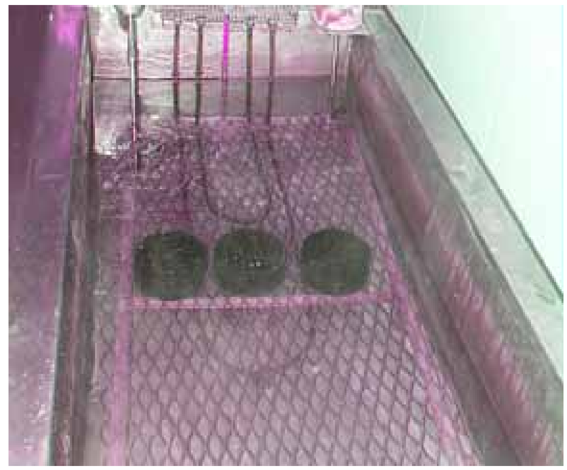
$$S_t = \frac{2P}{\pi\, t\, D}$$

where:

S_t = tensile strength, Pa (psi)
P = maximum load, Newtons (pounds)
t = specimen thickness, mm (inches)
D = specimen diameter, mm (inches)

The tensile strength ratio (TSR) is calculated by dividing the average tensile strength of the conditioned specimens by the average tensile strength of the unconditioned control specimens. TSR is reported to two decimal points.

A TSR value of at least 80 percent is normally required as evidence that the mixture will not be subject to stripping.



TESTING SPECIMENS

GLOSSARY

Tensile strength - a measure of the force required to pull apart a material.

Steel loading strips - square or rectangular steel bars long enough to cover the full thickness of the specimen with one side curved to match the side of the specimen. For 101.6 mm (4 in.) specimens, the strips shall be 12.7 mm (0.5 in.) wide, and for 152.4 mm (6 in.) specimens, the strips shall be 19.05 mm (0.75 in.) wide.

Loading jack - a mechanical device or machine that can apply a constant rate of loading.

T304

UNCOMPACTED VOID CONTENT OF FINE AGGREGATE

AASHTO T 304

Developed by
Multi-Regional Aggregates Training & Certification Group
Revised 2006

NOTE

Successful completion of the following training materials, including examination and performance evaluation are prerequisites for this training package.

- AASHTO T84, Specific Gravity of Fine Aggregates
- AASHTO T11, Materials Finer than 75µm (No. 200) Sieve by Washing.
- AASHTO T27, Sieve Analysis of Coarse and Fine Aggregate

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AASHTO T304, Uncompacted Void Content of Fine Aggregate

Scope

This method determines the loose uncompacted void content of a sample of fine aggregate. When performed on an aggregate sample of a known, standard grading (Method A), this measurement provides an indication of particle shape. The materials' angularity, roundness or surface texture relative to other materials of the same standard grading is indicated by the percent of voids determined by this test. The Gyratory Superpave asphalt mix design method sets minimum requirements for void content that vary depending on traffic loads and depth from the surface of the asphaltic concrete pavement. In this method, the prepared sample is allowed to free-fall through a standard funnel of a specified diameter, from a specified height into a small cylinder of known volume (nominal 100 ml).

The material is then leveled with the top of the calibrated cylinder and weighed. Because the volume and weight of the cylinder are known, the weight of the sample contained in the cylinder can be calculated. Using the Bulk Dry Specific Gravity (As determined by AASHTO T84), the volume of the material in the cylinder is calculated. By subtracting the calculated volume of material from the calibrated volume of the testing cylinder, the volume of voids can be calculated.

When performed on an "as received" sample (Method C), this method can serve as an indicator of the effect the fine aggregate can have on the workability of Portland Cement concrete.

NOTE:
This manual covers Test method A only.

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Summary of Test Method

A sample of sand is prepared in accordance with one of three methods. Method A, a standard gradation, is the most common used. The sample is allowed to free-fall from a funnel into a cylinder of known volume. Using the bulk dry specific gravity of the sample as determined by AASHTO T84, the percent of void space in the cylinder is calculated. This value is known as the Fine Aggregate Angularity Value or FAA.

Typical Test Results

Using Method A, values typically range between 35 to 43 for natural sands and from 43 to 50 for crushed products. Values are obtained from more than one test of the same sample.

Common Testing Errors

- Improper calibration of test cylinder or damage to test cylinder resulting in a change in volume.
- Vibration in test area resulting in over-compaction of sample in test cylinder.
- Erroneous specific gravity used in calculation. A difference of 0.05 specific gravity can cause an error of 1.0-% FAA value.

Apparatus

- ➢ Cylindrical measure approximately 39 mm (1.56 in.) in diameter, 86 mm (3.44 in.) deep with a capacity of approximately 100-mL.
- ➢ Funnel conforming to figure 2 in AASHTO T304.
- ➢ Funnel Stand conforming to figure 2 in AASHTO T304.
- ➢ Glass Plate for calibrating cylindrical measure.
- ➢ Pan large enough to contain funnel stand and to catch overflow material.
- ➢ Metal spatula with a straight edge approximately 100 mm (4.0 in.) long and 20 mm (0.8 in.) wide.
- ➢ Balance accurate and readable to 0.1 grams.

Calibration of Cylindrical Measure

1. Apply a light coat of grease to the top edge of the dry, empty cylindrical measure.

2. Weigh the greased measure and glass plate.

3. Fill the measure with freshly boiled, deionized water at a temperature of 18° to 24° C (64° to 75° F). Record the water temperature.

4. Place the glass plate over the measure, being sure no air bubbles remain.

5. Dry the outer surface of the measure, weigh and record to the nearest 0.1 g.

6. Empty the measure and clean off the grease. Dry the measure, weigh and record to the nearest 0.1 g.

7. Calculate the volume of the measure as follows:

$$V=1000\frac{M}{D}$$

Where:

V = volume of cylinder, mL

M = net mass of water, g.

D = density of water kg/m³

Note: determine the volume to the nearest 0.1 mL.

°F	°C	lb/ft³	kg/m³
65	18.3	62.336	998.54
70	21.1	62.301	997.97
(73.4)	(23.0)	(62.274)	(997.54)
75	23.9	62.261	997.32

Density of Water (ASTM C 29/C 29M)

Procedure – Only Method A will be covered in this procedure, for other methods consult AASHTO T304

1. Weigh and combine the following quantities of fine aggregate, which has been washed, dried and sieved in accordance with AASHTO T11 and T27.

Individual Size Fraction	Mass, g
Passing No. 8 – Retained on No. 16	44
Passing No. 16 – Retained on No. 30	57
Passing No. 30 – Retained on No. 50	72
Passing No. 50 – Retained on No. 100	17
Total	190

NOTE:
The tolerance on each amount is ± 0.2 g.

2. Mix combined sample thoroughly with spatula.

3. Position the jar and funnel section in the stand and center the cylindrical measure.

4. Place finger under opening in funnel to seal opening. Pour mixed sample into funnel and level the material with the spatula.

Pouring sample into funnel

5. Quickly remove finger from funnel and allow sample to free-fall into the calibrated cylinder.

6. Take care not to vibrate or unnecessarily disturb the material in the cylinder to avoid further consolidation. Strike off the excess material above the lip of the cylinder with the spatula edge, held in a vertical position, using one continuous motion.

7. After striking off, remove any excess sand from the outside of the cylinder using a small brush. At this point, additional compaction of the material in the cylinder will not affect the test results and will aid in handling.

8. Weigh the cylinder with the sample and record to the nearest 0.1 grams. Retain and recombine all materials for the next trial.

Weighing the Cylinder

Calculate uncompacted voids content as follows:

$$U = \frac{V-(F \div G)}{V} \times 100$$

Where:

V = Volume of calibrated cylinder in mL (cubic centimeters)
F = Net Mass of Sample in Cylinder (Gross mass minus mass of empty cylinder)
G = Bulk dry specific gravity as determined by AASHTO T84
U = Uncompacted Voids in Percent (reported to nearest 0.1%)

9. Repeat test using recombined sample. Calculate and report average of at least <u>two</u> trials.

GLOSSARY

Voids- Difference between the total volume and the volume occupied only by the aggregate particles. The amount of void space (or air space) is a function of the aggregate gradation, particle shape and texture, and the amount of compaction of the material.

Uncompacted Voids- The amount of void space present when the material is in an uncompacted, unconsolidated state.

Bulk Dry Specific Gravity- The ratio of the mass in air of a unit volume of aggregate at a stated temperature to the mass in air of an equal volume of gas-free distilled water at the stated temperature.

Angularity- A description of the degree of roughness, surface irregularities or sharp angles of the aggregate particles (i.e. particle shape).

D4791

FLAT PARTICLES, ELONGATED PARTICLES, OR FLAT AND ELONGATED PARTICLES IN COARSE AGGREGATE

ASTM D 4791

Developed by

Multi-Regional Aggregate Training and Certification Group

Revised 2006

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NOTE

Successful completion of the following training materials, including examination and performance evaluation are prerequisites for this training package.

- AASHTO D 75, Practice for Sampling Aggregates.
- ASTM D 3665, Practice for Random Sampling of Construction Materials
- AASHTO T 248, Reducing Sample of Aggregate to Testing Size.
- AASHTO T 27, Sieve Analysis of Aggregates.

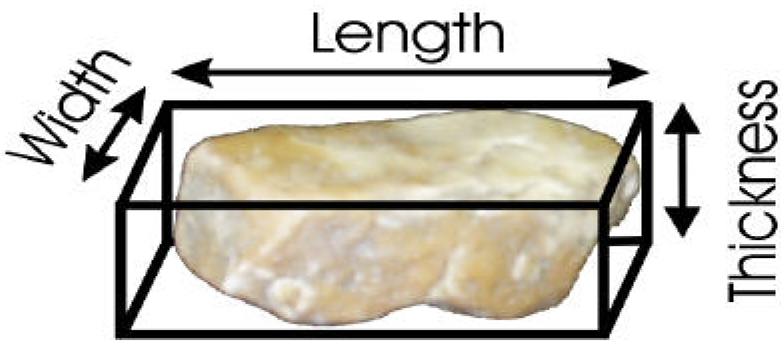
GLOSSARY

Flat and Elongated Particles of Aggregate - Those particles having a ratio of length to thickness greater than a specified value.

Length - the longest dimension.

Thickness - the smallest dimension.

Width - the other dimension.



FLAT PARTICLES, ELONGATED PARTICLES, OR FLAT AND ELONGATED PARTICLES IN COARSE AGGREGATE

This test method covers tests for flat particles, elongated particles, or flat and elongated particles in coarse aggregate. In this text only flat and elongated particles will be covered because at this time the only national specification that references this test is the Superpave Specification, which refers to Flat and Elongated Particles in Coarse Aggregate.

Flat and elongated particles of coarse aggregates have a tendency to fracture more easily than other aggregate particles. When the coarse aggregate does fracture, the gradation will likely change which may be detrimental to the mix. Additionally, flat and elongated particles of aggregate, for some construction uses, may interfere with consolidation and may result in harsh, difficult to place mixtures.

SUMMARY OF TESTING

Individual aggregates of specific sieve sizes are tested for ratios of width to thickness, length to width, or length to thickness. The test is performed on a sample of coarse aggregate reduced from a representative field sample. The sample is sieved to separate each size larger than the 9.5 mm (3/ 8 in.) Sieve. Each size is then tested in a proportional caliper device by setting the caliper to the longer dimension and attempting to fit the smaller dimension of the particle through the other caliper gap, which is a prescribed ration smaller then the larger dimension (i.e., usually a 5:1 ration). Particles are counted or weighed to determine a percentage of flat, elongated, or flat and elongated particle in a sample. Superpave specifications require asphalt mixtures to have less than 10% flat and elongated particles using a 5:1 ratio.

Common Testing Errors

- Not obtaining a representative sample.
- Not reducing the sample properly.
- Not sieving to completion.
- Improper positioning in the machine.

TESTING METHODOLOGY

Apparatus

The following apparatus is needed to perform the test for flat and elongated particles:

- Proportional Caliper Device.
- Balance - Accurate to 0.5% of the mass of the sample.
- Oven or hot plate (if determination is made by mass).

Note: If the proportional caliper is not used, the degree of error could increase dramatically.

Sampling

Sample the coarse aggregate in accordance with AASHTO T 2. Thoroughly mix the sample and reduce it to an amount suitable for testing using the applicable procedures described in AASHTO T 248.

Sample Size

Set up the test sample according to the following table:

If Maximum Size of the Material is: (retained on)	Then Split Out:
9.5 mm (3/8 in.)	1 kg (2 lb.)
12.5 mm (½ in.)	2 kg (4 lb.)
19.0 mm (3/4 in)	5 kg (11 lb.)
25.0 mm (1 in.)	10 kg (22 lb.)
37.5 mm (1 ½ in.)	15 kg (33 lb.)

Note: This is the entire sample (+4 and -4). Put it in the appropriate size pan (or bag) as needed. It will then be sieved out by size. Mark the work sheet as “Flat and Elongated Particles”. (Only test the sizes that are present in the amount of 10% or more of the original sample, in other words the gradation needs to be completed first.)

Test Procedure

1. If determination by mass is required, oven dry the sample to a constant mass at a temperature of 110° ± 5° C. If determination is by particle count, drying is not necessary.

2. Sieve the sample of coarse aggregate to be tested in accordance with test method AASHTO T 27. Reduce each size fraction larger than the 4.75mm (#4) or 9.5 (⅜ in.) sieve that is present in the amount of 10% or more of the original sample in accordance with method AASHTO T 248 until approximately 100 particles are obtained.

3. Use the proportional caliper device positioned at the 5:1 ratio.

4. Set the larger opening equal to the particles longest dimension. The particle is considered flat and/or elongated if the particles thinnest dimension passed through the smaller opening.

5. Test each of the particles in each size fraction and place in one of two groups: (1) Particles with longest to thinnest ratios over 5:1 and (2) Particles with longest to thinnest ratios less than 5:1.

Checking Elongation

Checking Flatness

6. After particles have been classified into the two groups, determine the proportion of the sample in each group by either count or by mass as required.

Calculation

Calculate the percentage of flat and elongated particles to the nearest 1% for each sieve size greater the 9.5mm(⅜ in.).

Note: Follow the rounding rules specified by your state.

Example Calculation

19.0mm (3/ 4 in) Stone

Sieve	25.0mm	19.0mm	12.5mm	9.5mm
% Passing	100	99.4	75.7	46.4
% Retained	0	0.6	23.7	29.3

No test is performed on the 19.0mm size aggregate because it is less than 10 percent of the total sample. It will be assumed that the 19.0mm particles have the same percentage of flat and elongated as the next sieve (12.5mm).

The 12.5mm size material totaled 715.3 grams after reducing to approximately 100 particles. 6.9 grams were classified as flat and elongated, therefore, the percent flat and elongated on the 12.5mm sieve is:

$$\frac{6.9}{715.3} \text{ X } 100 = 1.0\%$$

Likewise, the 9.5mm size totaled 239.7 grams after reduction and 12.2 grams were classified as flat and elongated. The percent flat and elongated on the 9.5mm sieve is:

$$\frac{12.2}{239.7} \text{ X } 100 = 5.1\%$$

The percentage of flat and elongated particles on each sieve is reported to the nearest whole percent.

To calculate the weighted average percent flat and elongated particles for the sample, the percentage calculated for each individual sieve needs to be multiplied by the ratio of the percent retained for that sieve to the total percent retained above the 9.5mm sieve and the results totaled for all sieves.

The total percent retained for the example is 53.6%. The percent flat and elongated on the 19.0 mm sieve is assumed to be 1.0% (same as the 12.5mm size). The percent retained on the 19.0 sieve is 0.6%, therefore, to calculate the weighted average percent:

$$(1.0)\ \frac{0.6}{53.6} = 0.0\%$$

For the 12.5mm sieve the weighted average percent is:

$$(1.0)\ \frac{23.7}{53.6} = 0.4\%$$

And for the 9.5mm sieve the weighted average percent is:

$$(5.1)\ \frac{29.3}{53.6} = 2.8\%$$

Finally, the weighted average percent flat and elongated particles in the coarse aggregate is determined by adding the weighted average percent for each sieve:

$$0.0 + 0.4 + 2.8 = 3.2\%$$

For reporting, round the result to the nearest whole percent.

FLAT AND ELONGATED PARTICLES (ASTM D 4791) WORKSHEET

Project Example Mix Design ID ______ Date ______

Material/Stockpile ID ______ Technician ______

Sieve Sizes	Original Percent Retained	Mass Tested grams	Mass Failing 5:1 ratio (g)	%Flat &Elong. Individual sieve	%Flat & Elong. Weighted Ave.
	A	**B**	**C**	**D**	**E**
37.5mm (1 ½ in.)					
25.0mm (1 in.)					
19.0mm (3/4 in.)	0.6	NA	NA	1.0	0.0
12.5mm (½ in.)	23.7	715.3	6.9	1.0	0.4
9.5mm (3/8 in.)	29.3	239.7	12.2	5.1	2.8
Total % Retained	53.6			Total	3.2

Remarks: Example

Weighted average percent Flat & Elongated particles = 3%

FLAT AND ELONGATED PARTICLES (ASTM D 4791) WORKSHEET

Project ______________________ Mix Design ID __________________ Date __________

Material/Stockpile ID ____________________________ Technician ____________________

Sieve Sizes	Original Percent Retained	Mass Tested grams	Mass Failing 5:1 ratio (g)	%Flat &Elong. Individual sieve	%Flat & Elong. Weighted Ave.
	A	**B**	**C**	**D**	**E**
37.5mm (1 ½ in.)	________	________	________	________	________
25.0mm (1 in.)	________	________	________	________	________
19.0mm (3/4 in.)	________	________	________	________	________
12.5mm (½ in.)	________	________	________	________	________
9.5mm (3/8 in.)	________	________	________	________	________
Total % Retained	________			Total	________

Remark ____

____

____

D5821

DETERMINING PERCENT OF FRACTURED PARTICLES IN COARSE AGGREGATE

ASTM D 5821

Developed by
Multi-regional Aggregate Training & Certification Group
Revised 2006

NOTE

Successful completion of the following training materials, including examination and performance evaluation are prerequisites for this training package.

Reference ASTM Standard Tests

- ASTM C 136 Test Method for Sieve Analysis of Fine and Coarse Aggregate
- ASTM C 702 Practice of Reducing Field Samples of Aggregate to Test Size
- ASTM D 75 Practice of Sampling Aggregate

Reference AASHTO Tests to ASTM Standard Tests Listed Above

- AASHTO T 2 is identical to ASTM D 75
- AASHTO T 248 is identical to ASTM C 702
- AASHTO T 27 does differ slightly with ASTM C 136

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SCOPE

This test procedure determines the amount (percent) of fracture faced rock particles, by visual inspection that meets specific requirements. The fractured face of each rock particle must meet a minimum cross-sectional area (See Terminology). Specifications contain requirements for percentage of crushed rock particles, with the purpose of maximizing shear strength in either bound or unbound aggregate mixtures. This method can be used in determining the acceptability of coarse, dense-graded, and open-graded aggregates with respect to such requirements. This procedure is used primarily for aggregates used in hot-mix asphalt.

TERMINOLOGY

Fractured Face - A fractured face is defined as being caused either by mechanical means or by nature and should **have sharp or slightly blunted edges**. Natural fractures, to be accepted, must be similar to fractures produced by a crusher. A broken surface constituting an area equal to at least 25% of the maximum cross-sectional area of the particle.

Note: The AASHTO method specifies a criteria of 50%.

Fractured Rock Particle - A rock particle having at least one fractured face, or two fractured faces, as required for that class/type of aggregate in the specifications.

EQUIPMENT

A. Sieves - A set of sieves appropriate for the sample type.

B. Balance - appropriate for the size of sample and accurate to 0.1g.

C. Spatula or similar tool to aid in sorting the aggregate particles.

D. Splitter.

E. Pans, bowls, or paper containers.


Non-Fractured Material


Fractured Material


Fractured Material
Does Not Meet Guidelines

SAMPLE PREPARATION

Air-dry the representative sample prior to the coarse gradation process so that there is a clean separation of the particles. A total + 4.75mm (No. 4) sample could be set up for testing or if the nominal maximum size of the aggregate is 19mm (¾ in.) or larger, the + 4.75mm (No. 4) material can be split into two representative fractions. It will be necessary to determine the correct proportions between the two fractions and this may be calculated from gradation results. All the material passing the 9.5mm (⅜ in.) sieve and retained on the appropriate sieves for the selected fractions (normally the 4.75mm (#4) sieve) are weighed and the sum of the weights equal the total +4.75mm (No. 4) material. Then the material from the minus 9.5mm (⅜ in.) fraction is split down to the required minimum 200g (0.5 lb) sample size and tested. Splitting the minus 9.5mm (⅜ in) material is done to reduce the number of aggregate particles that must be inspected, when the sample contains a large amount of material passing the 9.5mm (⅜ in) sieve.

See below for *nominal maximum sieve sizes and minimum sample sizes.

SPLIT SAMPLE AND SINGLE SAMPLE SIZES

NOMINAL MAXIMUM SIEVE SIZES	NOMINAL MAXIMUM SIEVE SIZES	MINIMUM TEST SAMPLE SIZE + #4	
mm	**Inch**	**(grams)**	**(Approx. lbs)**
9.5	⅜”	200	0.5
12.5	½"	500	1
19.0	¾”	1500	3
25.0	1”	3000	6.5
37.5	1½”	7500	16 .5

**** NOTE: Nominal maximum sieve size is defined as the largest sieve size listed in the applicable specification upon which any material is permitted to be retained.***

TEST PROCEDURE

A. Wash and then dry to a constant mass (weight). Weigh the test sample to the nearest 0.1g and record as "Test Sample Weight".

B. Spread the test sample on a clean, flat surface large enough to permit the material to be spread thinly for careful inspection and evaluation.

C. Using the spatula or a similar tool separate the particles into one of the following two categories.

1. **Fractured Particles**, using the criteria of "one or more fractured faces" or "two or more fractured faces" as is consistent with the requirements in the specifications.

2. **Particles not meeting the specified criteria**

D. Determine the mass (or count) of the "Fractured Particles" and " Particles not meeting the specified criteria" separately and record the weights.

COMMON TESTING ERRORS

- Sample not representative

CALCULATION

A. Calculate the percentage of fractured particles for each separate fraction as follows:

$$\text{Percent Fractured Particles } (\mathbf{P}) = \frac{F}{F + N} \times 100$$

Where: F = Weight of crushed particles with at least the specified number of fractured faces, in grams.

N = Weight of the particles not meeting the specified requirements, in grams.

In the example, 19.0 to 9.5 mm (3/4" to 3/8") size:

F = 782
N = 1068

$$\mathbf{P} = \frac{782}{782 + 1068} \times 100 = 42.3\%$$

In the example, 9.5 to 4.75 mm (3/8" - No. 4) size:

F = 385
N = 85

$$\mathbf{P} = \frac{385}{385 + 85} \times 100 = 81.9\%$$

B. Total Percentage of Fractured Particles Retained on the 4.75mm (No. 4) Sieve.

Determine the percentages of the 19.0 to 9.5 mm (3/4” to 3/8") and the 9.5 to 4.75 mm (3/8" to No. 4) fractions using the material retained on the 4.75 mm (No. 4) sieve as 100%.

Example:

19.0 - 9.5 mm (3/4” - 3/8") Material	**=**	3766g
9.5 - 4.75 mm (3/8” - No. 4) Material	**=**	7314g
Total +4.75 mm (No. 4) Material	**=**	11080g

Percent 19.0 - 9.5 mm (3/4” - 3/8") **=** $\frac{3766}{11080}$ **x** 100 **=** 34%

Percent 9.5 - 4.75 mm (3/8" - No. 4) **=** $\frac{7314}{11080}$ **x** 100 **=** 66%

Total Percent Fractured Particles = 100 **x**

(% Fractured Particles 19.0 - 9.5mm [3/4” to 3/8"]) **x** (% of 19.0 - 9.5mm [3/4” to 3/8"] Material)

+

(% Fractured Particles 9.5 - 4.75mm [3/8" - No. 4]) **x** (% of 9.5 - 4.75mm [3/8" - No. 4] Material)

In the Example:

100 [(0.423 x 0.34) + (0.819 x 0.66)] =

100 [(0.144) + (0.541)] = 68.5% Fractured Particle

T203

GENERAL AGGREGATE SOURCE INFORMATION

GENERAL

Only those sources which have been sampled or tested within the last ten years are listed. This listing additionally ranks sources in accordance with a frictional classification as defined herein for aggregates used in Hot Mix Asphalt (HMA) construction, durability class for coarse aggregates used in Portland Cement Concrete (PCC) construction, and Approved Fine Aggregate. Upon request, new sources or different combinations of beds within an existing source can be evaluated for classification. These rankings do not in any way waive the normal quality requirements for the particular types of aggregates indicated in contract documents.

Aggregate sources are continuously updated and the most current version of this IM can be found on the Materials Approved Product List Enterprise (MAPLE) website at https://maple.iowadot.gov/.

Products listed in this document may not always be available. Contact the supplier for availability.

Transload facilites are throughtout the state. Contract the facilites to determine aggregate availability. Transloads Facilites Report

PORTLAND CEMENT CONCRETE AGGREGATES

Aggregates shall be produced from sources approved in accordance with the requirements of Office of Materials IM 409. The engineer may approve scalping of some portion of the coarser fraction.

All aggregates produced and inspected for intended use in contracts under Iowa Department of Transportation Specifications shall be stored in identifiable stockpiles unless they are being delivered as produced.

DURABILITY CLASSIFICATION

The coarse aggregates have been divided into three classes in accordance with their durability level as determined by performance or laboratory testing.

Class 2 durability aggregates will produce no deterioration of pavements of the non-interstate segments of the road system after 15 years and only minimal deterioration in pavements after 20 years.

Class 3 durability aggregates will produce no deterioration of pavements of non-interstate segments of the road system after 20 years of age and less than 5% deterioration of the joints after 25 years.

Class 3i durability aggregates will produce no deterioration of the interstate road system after 30 years of service and less than 5% deterioration of the joints after 35 years.

NOTE: Those sources with a “B” in their durability class designation are approved for 1/2 in. Bridge Deck Overlay/Repair material.

HOT MIX ASPHALT AGGREGATES

Aggregates for HMA construction have been classified into five main functional types in accordance with their frictional characteristics. Those aggregates with the potential to develop the greatest amount of friction under traffic conditions are classified as Type 1 with the potential for friction decreasing as the type number increases. One or more friction types may be specified for use in pavement surface courses. If a type is not specified in the contract documents, Type 5 or better will be acceptable. Tentative bed limitations are shown in this publication.

The frictional classification types are listed and defined in order of descending quality as follows.

Type 1: Aggregates, which are generally, a heterogeneous combination of minerals with coarse-grained microstructure of very hard particles (generally, a Mohs hardness range of 7 to 9) bonded together by a slightly softer matrix. These aggregates are typified by those developed for and used by the grinding-wheel industry such as calcined bauxite (synthetic) and emery (natural). They are not available from Iowa sources. Due to their high cost, these aggregates would be specified only for use in extremely critical situations.

Type 2: Natural aggregates in this class are crushed quartzite and both fine and coarse-grained crushed igneous rocks. The mineral grains in these materials generally have a Mohs hardness range of 5 to 7. Synthetic aggregates in this class are some air-cooled steel furnace slags and others with similar characteristics. For asphalt mixtures, pipestone and sandstone in quartzite may not exceed 5 percent.

Type 3: Natural aggregates in this class are crushed gravels. The crushed gravels shall contain 40% or more igneous and metamorphic particles. Synthetic aggregates in this class are the expanded shales with a Los Angeles abrasion loss less than 35 percent.

Type 4: Aggregates crushed from dolomitic or limestone ledges in which 80 percent of the grains are 20 microns or larger. The mineral grains in the approved ledges for this classification generally have a Mohs hardness range of 3 to 4. For natural gravels, the Type 5 carbonate (see below) particles, as a fraction of the total material, shall not exceed the non-carbonate particles by more than 20 percent.

Type 5: Aggregates crushed from dolomitic or limestone ledges in which 20 percent or more of the grains are 30 microns or smaller.

REVETMENT CLASSIFICATIONS

Revetment or rip-rap is rock or other material used to armor bridge abutments, pilings, and rivers or shorelines against scour and water erosion. The Iowa DOT uses five Classes of Revetment based on the size of the aggregate.See the table below for nominal top size. The Engineer may approve revetment containing material larger than the nominal top size. For this product, individual beds are approved at each source based on quality and bed thickness.

Revetment Class	Nominal top size
Class A	400 pounds
Class B	650 pounds
Class C	450 pounds
Class D and Class E	250 pounds

SOURCE LISTING – Explanation

NOTE: - Number indicates additional source restrictions (see bottom of page) → NOTES

Revetment class approval for size and quality of quarried stone used for river, lake bank, and water-way stabilization → REVETMENT CLASS

Bed number shown for PCC aggregate are those on the formal source approval letter, Beds shown for HMA source are those which have prior approval for use and have the designated friction type. Beds are also indicated for revetment (rip rap) approvals. → BEDS

Source restrictions for L2 Friction HMA surface mix designs. L=limestone (<15% MgO) and D=dolomite (≥15% MgO), defines rock type. → L2 ROCK TYPE

Frictional Classification – as indicated on page 2
Hot Mix Asphalt – Type A and B → FRICT HMA A B

Durability Class for Portland Cement Concrete Coarse Aggregate
("B" indicates acceptability for Bridge Deck Overlay/Repair)
Fine Aggregate (X=PCC and HMA Approval, H=HMA use only) → DUR PCC CA FA

Source Code Number (A-number) used to identify sources.
Ex. A29002: 29=County, 0=crushed stone, 02= unique source identifier
Ex. A29502: 29=County, 5=sand & gravel, 02= unique source identifier
Out of State Sources: Ex. AMN004: MN=State, 0=crushed stone, 04= unique source identifier → CODE

Specific Gravity
DWU-Determine When Used by → BULK SSD SpGr

CODE	OPERATOR		SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA FA	FRICT HMA A B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
29	**DES MOINES**	**DIST 5**	**CRUSHED STONE**								
A29002	L&W QUARRIES INC		YARMOUTH	SE 01 T071 R04W	2.65	3	4 4 4 4 5 5	L L L	15 15 18 20 3 7	 A B C D E A B C D E	1
			SAND AND GRAVEL								
A29502	CESSFORD CONST CO		SPRING GROVE	SW 36 T069 R04W	DWU 2.66	3 X	4 4				

NOTE 1: AASHTO 57 GRADATION MAXIMUM

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	FRICT HMA B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
1	**ADAIR** DIST 4	**CRUSHED STONE**										
A01002	SCHILDBERG CONSTRUCTION CO	MENLO	NE 21 T77N R31W				5	5	L	15A-15C	A B C D E	
								4		14		
A01006	SCHILDBERG CONSTRUCTION CO	HOWE	SW 1 T76N R31W					5		25		
										25B-25E	D	
A01008	SCHILDBERG CONSTRUCTION CO	JEFFERSON	NE 17 T77N R31W					5		20		
								5		25		
										25B-25E	D	
2	**ADAMS** DIST 4	**CRUSHED STONE**										
A02002	SCHILDBERG CONSTRUCTION CO	MT ETNA	SW 14 T73N R34W					4		11-13	D	
A02004	SCHILDBERG CONSTRUCTION CO	CORNING	NE 08 T71N R34W					4		3-5	D	
3	**ALLAMAKEE** DIST 2	**CRUSHED STONE**										
A03002	BRUENING ROCK PRODUCTS INC	WEXFORD	NE 36 T98N R03W	2.7	3i		4	4	D	1C-6		
							4	4	D	1-8		
										1B-8	A B C D E	
A03004	BRUENING ROCK PRODUCTS INC	LANGE	E2 17 T96N R06W	2.6	3		4	4	L	2-5	A B C D E	
A03008	BRUENING ROCK PRODUCTS INC	MCCABE	NE 6 T97N R05W				4	4	L	1-5		
A03010	SKYLINE MATERIALS LTD	RUDE	SE 17 T100NR06W									
A03014	BRUENING ROCK PRODUCTS INC	HAMMEL-BOONIES	SW 2 T99N R06W	DWU	3i		4	4	D	2-4C	A B C D E	
A03022	SKYLINE MATERIALS LTD	LIVINGOOD	SW 7 T96N R06W				4	4	L	4-7		
								4		2-7		
A03026	BRUENING ROCK PRODUCTS INC	BYRNES	SE 25 T99N R06W									
A03028	BRUENING ROCK PRODUCTS INC	LANSING	SW 35 T99N R04W							FULL FACE	A B C D E	
A03036	BRUENING ROCK PRODUCTS INC	SWENSON	SE 19 T96N R05W									
A03038	RIEHM CONSTRUCTION CO INC	RIEHM	SE 7 T100NR04W	DWU	3i		4	4	D	1-4	A B C D E	
A03040	BRUENING ROCK PRODUCTS INC	DEE	SE 21 T99N R04W	DWU	3i		4	4	D	5A-5D	A B C D E	
A03042	BARD MATERIALS	CHURCHTOWN	SW 29 T99N R04W					4		1-3		
							4	4	D	3		
A03046	BRUENING ROCK PRODUCTS INC	MOHS	SW 29 T96N R04W	DWU	2		5	5		1-2		
								5		1-4		
A03048	BRUENING ROCK PRODUCTS INC	POSTVILLE	SW 16 T96N R06W	2.61	3		4	4	L	6-8		
								4		2-5		
A03050	BRUENING ROCK PRODUCTS INC	GREEN	NW 16 T96N R06W	2.63	3		4	4	L	2-3A		
										1-3	A B C D E	
A03052	BRUENING ROCK PRODUCTS INC	ROSSVILLE	NE 35 T97N R05W				4	4	L	1-5	A B C D E	
A03054	BRUENING ROCK PRODUCTS INC	WEST RIDGE	NE 8 T98N R06W									
A03058	BRUENING ROCK PRODUCTS INC	ELON	SW 33 T98N R04W									
A03064	RAINBOW QUARRY LLC	RAINBOW	SE 26 T97N R05W							FULL FACE	D	

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
3	**ALLAMAKEE DIST 2**	**CRUSHED STONE**								**CONTINUED**		
A03064	RAINBOW QUARRY LLC	RAINBOW	SE 26 T97N R05W							1-5	A B C D E	
A03066	SKYLINE MATERIALS LTD	ELSBERN	NW 29 T97N R06W	2.61	3		4	4	L	2	A B C D E	
A03068	BRUENING ROCK PRODUCTS INC	JEFFERSON	SW 30 T97N R05W				5	5	L	2-4		
A03072	STRONG ROCK & GRAVEL	STRONG	SE 24 T99N R04W				4	4	D	1-8	A B C D E	
A03074	RON WEYMILLER	WW	NE 12 T100NR05W									
		SAND AND GRAVEL										
A03502	SKYLINE MATERIALS LTD	HARPERS FERRY	SW 7 T97N R02W	2.67	3iB		3	3				
				2.67		X						
A03506	BRUENING ROCK PRODUCTS INC	HAMMEL-BOONIES	SW 2 T99N R06W			H	4	4				
A03518	BRUENING ROCK PRODUCTS INC	IVERSON	NW 09 T99N R06W			H						
A03520	BRUENING ROCK PRODUCTS INC	IVERSON 2	NE 08 T99N R06W	2.65		X						
4	**APPANOOSE DIST 5**	**CRUSHED STONE**										
A04016	CANTERA AGGREGATES	WALNUT CITY	CT 35 T70N R19W	2.7	2		5	5	L	1-3	D	1
							5	5	L	6	A B C D E	
A04020	CANTERA AGGREGATES	PLANO	5 T69N R19W				5	5	L	1	A B C D E	2
										3	A B C D E	
A04022	CANTERA AGGREGATES	CONFIDENCE	20 T70N R19W				5	5		BED 1		
5	**AUDUBON DIST 4**	**SAND AND GRAVEL**										
A05506	HALLETT MATERIALS CO	EXIRA	SW 8 T78N R35W	2.68	3i		3	3				
				2.66		X						
6	**BENTON DIST 6**	**CRUSHED STONE**										
A06006	WENDLING QUARRIES INC	GARRISON B	NE 33 T85N R11W	2.64	2		4	4	L	6-16		
							5	5	L	6-28		
										6-TOP 2'	A B C D E	
										BED 27		
							5	5	L	32-37		
A06012	WENDLING QUARRIES INC	JABENS	SW 7 T85N R11W	DWU	2		5	5	L	6-11		
				DWU	2		5	5	L	9-12	A B C D E	
				2.63	2		4	4	L	12	A B C D E	
							4	4	L	10-12		
							4	4	L	13-18	D	
							4	4	L	20-23	A B C D E	
										1-5	D	
A06014	WENDLING QUARRIES INC	VINTON-MILROY	S2 10 T85N R10W					4	L	1-4		
										1-7	D	
A06016	WENDLING QUARRIES INC	COOTS	SW 36 T86N R11W							2A ON DOWN	D	

NOTE 1: AASHTO 67 GRADATION #5 40% MAXIMUM; RESTRICTION DOES NOT APPLY TO STRUCTURAL CONCRETE
NOTE 2: BED 1, LOWER HALF ONLY

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR		SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
6	**BENTON**	**DIST 6**	**SAND AND GRAVEL**								**CONTINUED**		
A06504	WENDLING QUARRIES INC		COOTS SAND/VINTON	SW 31 T86N R10W	2.65		X	3	3				
A06508	WENDLING QUARRIES INC		BRIGHT SAND	NW 28 T86N R10W			H						
7	**BLACK HAWK**	**DIST 2**	**CRUSHED STONE**										
A07004	BMC AGGREGATES LC		WATERLOO SOUTH	NW 18 T87N R12W	DWU	3		5	5	L	25		
								4	4	L	17-24		
								4	4	L	32-36	A B C D E	
								5	5	L	5-24		
											1-23	A B C D E	
											17-23	A B C D E	
A07008	BMC AGGREGATES LC		MORGAN	NE 15 T89N R12W	2.48	3i		4	4	L	5		
					2.63	3i		4	4	D	TOP 30' OF 9		
								5	5	L	1		
									5		1-3		
									5		4A-4B		
A07018	BMC AGGREGATES LC		RAYMOND-PESKE	SW 1 T88N R12W	2.66	2		4	4	L	1B-5,2-5		
					DWU	2		4	4	L	3-12,3-13		
					2.59	2		4	4	D	2-10		
					2.59	2		4	4	L	3-10		
								4	4	D	1-10	A B C D E	
								4	4	L	6-10		
A07020	BMC AGGREGATES LC		STEINBRON	SE 1 T88N R11W	2.6	3		4	4	L	1B		
					2.6	2		4	4	L	1A-1B		
A07022	BMC AGGREGATES LC		MESSERLY	NE 8 T90N R14W									
			SAND AND GRAVEL										
A07504	BMC AGGREGATES LC		WATERLOO SAND	SW 9 T89N R13W				3	3				
					2.65		X						
A07506	WENDLING QUARRIES INC		ASPRO	NW 1 T88N R13W				4	4				
					2.65		X						
A07508	BMC AGGREGATES LC		GILBERTVILLE	16 T88N R12W	DWU	2		4	4				
					2.65		X						
A07512	BMC AGGREGATES LC		ZEIEN S&G	NW 23 T87N R12W	2.65		X						
A07518	BMC AGGREGATES LC		JANESVILLE	NE 14 T90N R14W				3	3				
					2.66		X						
A07520	BENTONS SAND & GRAVEL		BENTON'S LAKE	1 T89N R14W	2.66		X						
8	**BOONE**	**DIST 1**	**SAND AND GRAVEL**										
A08504	STRATFORD GRAVEL INC		JENSEN	SE 35 T85N R25W			H						
A08526	STRATFORD GRAVEL INC		POWERS	SE 29 T84N R28W			H						

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
8	**BOONE** **DIST 1**	**SAND AND GRAVEL**								**CONTINUED**		
A08528	STRATFORD GRAVEL INC	LEININGER	SW 26 T85N R25W			H						
9	**BREMER** **DIST 2**	**CRUSHED STONE**										
A09002	BMC AGGREGATES LC	FREDERIKA	NE 12 T93N R13W					5		2-8		
A09006	BMC AGGREGATES LC	TRIPOLI-PLATTE	SW 36 T93N R13W	2.65	3iB		4	4	D	1-6	A B C D E	
				2.65	3iB		4	4	D	1-4	A B C D E	
A09008	BMC AGGREGATES LC	DENVER #2	NE 20 T91N R13W							2	A B C D E	
		SAND AND GRAVEL										
A09508	BMC AGGREGATES LC	TRIPOLI-PLATTE	SW 36 T93N R13W			H						
A09510	CROELL REDI MIX	PLAINFIELD/ADAMS	NE 32 T93N R14W	2.66		X						
A09512	BMC AGGREGATES LC	BOEVERS	NE 31 T92N R11W	2.64		X						
10	**BUCHANAN** **DIST 6**	**CRUSHED STONE**										
A10002	BARD MATERIALS	WESTON-LAMONT	NW 14 T90N R07W	2.61	3iB		4	4	D	1-6	A B C D E	
				2.57	3i		4	4	D	6-7	A B C D E	
				2.65	3i		4	4	D	8-9	A B C D E	
							4	4	D	1-7		
A10004	BMC AGGREGATES LC	BLOOM-JESUP	SW 32 T89N R10W	2.63	3		4	4	L	2-5	A B C D E	
							4	4	L	1-7		
										2-8	D	
A10008	BRUENING ROCK PRODUCTS INC	OELWEIN	NW 2 T90N R09W	2.65	3i		4	4	D	4-5	A B C D E	
							4	4	D	4-6		
A10010	BRUENING ROCK PRODUCTS INC	HAZELTON	NW 11 T90N R09W	2.63	3iB		4	4	D	4	A B C D E	
A10012	BMC AGGREGATES LC	MILLER-INDEPENDENCE	NW 14 T88N R09W									
A10014	BMC AGGREGATES LC	OELWEIN #1	SW 2 T90N R09W				5	5	L	1-12		
A10016	BMC AGGREGATES LC	OELWEIN #2	SE 3 T90N R09W	2.67	3i		4	4	D	13-16		
										13-17	A B C D E	
A10022	BRUENING ROCK PRODUCTS INC	BROOKS	NW 2 T88N R09W	2.6	3i		4	4	L	7		
								5		1-6		
A10024	BMC AGGREGATES LC	RASMUSSEN #2	SE 21 T88N R08W							1-6 + QRY FLR	D	
A10028	WENDLING QUARRIES INC	HERTZBERGER	NE 36 T87N R10W					5				
A10030	BARD MATERIALS	SOUTH AURORA	NW 19 T90N R07W	2.63	3iB		4	4	D	1-3	A B C D E	
A10040	BMC AGGREGATES LC	ZUPKE-OELWEIN	NE 4 T90N R09W									
A10042	BRUENING ROCK PRODUCTS INC	BRANDON I-380	E2 23 T87N R10W									
A10044	BMC AGGREGATES LC	PARKER	NE 6 T88N R10W									
		SAND AND GRAVEL										
A10516	BMC AGGREGATES LC	MILLER	NW 14 T88N R09W	2.65		X						
A10520	BRUENING ROCK PRODUCTS INC	BROOKS	SW 2 T88N R09W	DWU		X						
A10522	BARD MATERIALS	NIEMANN-DECKER	NW 14 T90N R07W	2.65		X						
A10524	BRUENING ROCK PRODUCTS INC	CRAWFORD	SE 10 T90N R07W	2.64		X						

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
11	**BUENA VISTA** **DIST 3**	**SAND AND GRAVEL**										
A11512	BUENA VISTA COUNTY	MARATHON	SE 19 T93N R35W			H	4	4				
A11514	REDINGS GRAVEL & EXCAVATING CO	OATMAN	SW 18 T90N R36W			H	4	4				
A11516	HALLETT MATERIALS CO	SIOUX RAPIDS	W2 12 T93N R37W			H	3	3				
A11518	STRATFORD GRAVEL INC	MOLGAARD	NW 3 T93N R38W			H						
A11520	WETHERELL SAND & GRAVEL	WETHERELL	02 T93N R38W			H						
12	**BUTLER** **DIST 2**	**CRUSHED STONE**										
A12004	BRUENING ROCK PRODUCTS INC	LUBBEN	NW 25 T93N R17W				5	5	L	4-16		
								5		1-21		
										1-20	D	
A12008	BRUENING ROCK PRODUCTS INC	FLORRY-STEERE	CT 8 T93N R17W					5		1-11		
A12010	SKYLINE MATERIALS LTD	CLARKSVILLE	NE 16 T92N R15W				5	5	L	1		
A12014	BMC AGGREGATES LC	OLTMAN	SE 8 T91N R16W				5	5	L	1-4		
										1-TOP 1/2 BED 10	D	
							5	5	L	9-16	D	
							5	5	L	17-18	D	
A12016	BRUENING ROCK PRODUCTS INC	WIEGMANN-BRISTOW	SE 23 T92N R18W							1-11		
A12018	BRUENING ROCK PRODUCTS INC	NEYMEYER	SW 28 T90N R18W									
A12020	BRUENING ROCK PRODUCTS INC	BRUNS #2	NW 21 T91N R18W					5		1-5	D	
		SAND AND GRAVEL										
A12502	CROELL REDI MIX	CLARKSVILLE	NW 1 T92N R16W	2.67	2		4	4				
				2.67		X						
A12516	BRUENING ROCK PRODUCTS INC	JENSEN	S2 18 T93N R16W			X	4	4				
A12518	BMC AGGREGATES LC	SHELL ROCK-ADAMS	NE 3 T91N R15W				3	3				
				2.66		X						
A12520	CROELL REDI MIX	PARKERSBURG	E2 19 T90N R16W	DWU		X						
A12522	BMC AGGREGATES LC	HOBSON	34 T92N R15W	DWU	2	X						
13	**CALHOUN** **DIST 3**	**SAND AND GRAVEL**										
A13502	STRATFORD GRAVEL INC	KRUSE	NE 26 T86N R34W			H	4	4				
A13504	TIEFENTHALER AG-LIME INC	JENSEN	SW 7 T86N R34W	2.67		X						
A13506	MOHR SAND, GRAVEL, & CONST LLC	MOHR	NW 23 T86N R34W	DWU		X						
A13508	STRATFORD GRAVEL INC	PACKER	NE 26 T86N R34W			H	3	3				
A13510	MOHR SAND, GRAVEL, & CONST LLC	SMITH	NW 23 T86N R34W									
14	**CARROLL** **DIST 3**	**SAND AND GRAVEL**										
A14504	STRATFORD GRAVEL INC	REINHART	NW 21 T85N R33W	DWU	2	X						
A14510	TIEFENTHALER AG-LIME INC	LANESBORO	NW 17 T85N R33W	2.72	2		4	4				
				2.68		X						
A14514	TIEFENTHALER AG-LIME INC	MACKE	SW 6 T85N R33W	2.69	2		4	4				

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	FRICT HMA B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
14	**CARROLL** **DIST 3**	**SAND AND GRAVEL**								**CONTINUED**		
A14514	TIEFENTHALER AG-LIME INC	MACKE	SW 6 T85N R33W	2.66		X						
A14516	STRATFORD GRAVEL INC	RICHLAND	NE 23 T83N R33W			H	4	4				
A14518	TIEFENTHALER AG-LIME INC	MILLER	21 T85N R33W	DWU	2							
				DWU		X						
15	**CASS** **DIST 4**	**CRUSHED STONE**										
A15004	SCHILDBERG CONSTRUCTION CO	LEWIS	SE 17 T75N R37W									
A15008	SCHILDBERG CONSTRUCTION CO	ATLANTIC MINE	SW 13 T76N R37W					5		25		
										25B-25E	D	
										20A-20C	D	
A15012	SCHILDBERG CONSTRUCTION CO	HANSEN	SE 29 T76N R36W				5	5	L	15A-C		
16	**CEDAR** **DIST 6**	**CRUSHED STONE**										
A16004	WENDLING QUARRIES INC	LOWDEN-SCHNECKLOTH	NW 4 T81N R01W	DWU	3i		4	4	D	1-4	A B C D E	
A16006	WENDLING QUARRIES INC	STONEMILL	SE 14 T80N R03W	DWU	3iB		4	4	D	4	A B C D E	
										1-4B	D	
A16012	WEBER STONE CO INC	ONION GROVE	NW 14 T82N R02W	2.61	3i		4	4	D	1-7	A B C D E	
A16014	WENDLING QUARRIES INC	TOWNSEND	NW 2 T79N R02W							2-10	A B C D E	
A16022	WENDLING QUARRIES INC	TRICON	N2 9 T82N R04W	DWU	3i		4	4	D	1	A B C D E	
				DWU	3i		4	4	D	1-4	A B C D E	
A16026	WENDLING QUARRIES INC	PEDEN #2	SW 10 T79N R03W									
		SAND AND GRAVEL										
A16502	WENDLING QUARRIES INC	SHARPLISS	NW 12 T79N R03W				4	4				
				2.65		X						
A16506	WEBER STONE CO INC	ONION GROVE	NE 14 T82N R02W	2.65		X						
A16510	CROELL REDI MIX	CEDAR BLUFF	SW 28 T81N R04W	DWU		X						
17	**CERRO GORDO** **DIST 2**	**CRUSHED STONE**										
A17008	MARTIN MARIETTA AGGREGATES	PORTLAND WEST	NE 19 T96N R19W	2.75	3iB		4	4	L	1-8	A B C D E	
A17012	MARTIN MARIETTA AGGREGATES	UBBEN	SW 26 T94N R20W	2.68	2		5	5	L	3		
							5	5	L	1-3		
A17020	MARTIN MARIETTA AGGREGATES	MASON CITY	NE 29 T97N R20W	DWU	3i		5	5	L	7		
				2.73	3		5	5	L	7-9	A B C D E	
							4	4	L	8-9		
							4	4	D	9-15		
										1-6	A B C D E	
A17022	BMC AGGREGATES LC	HOLCIM	SE 19 T97N R20W									
A17024	HEARTLAND ASPHALT INC	RIVERVIEW	NE 29 T96N R19W				4	4	L	1-12		
							4	4	L	1-15		
							4	4	L	13-15		
							5	5	L	13-17		

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
17	**CERRO GORDO** DIST 2	**CRUSHED STONE**								**CONTINUED**		
A17024	HEARTLAND ASPHALT INC	RIVERVIEW	NE 29 T96N R19W				5	5	L	16-17		
A17025	SKYLINE MATERIALS LTD	NISS QUARRY	19 T97N R20W									
		SAND AND GRAVEL										
A17514	MARTIN MARIETTA AGGREGATES	HOLCIM SAND	NE 19 T97N R20W	DWU	3		3	3				
				2.65		X						
A17518	HEARTLAND ASPHALT INC	AIRPORT	NE 8 T96N R21W			H	3	3				
A17520	BMC AGGREGATES LC	TUTTLE	NE 13 T97N R21W	2.64		X						
A17522	BMC AGGREGATES LC	GRAF PIT	NE 20 T97N R20W			X						
A17524	SKYLINE MATERIALS LTD	NISS SAND PIT	19 T97N R20W									
18	**CHEROKEE** DIST 3	**SAND AND GRAVEL**										
A18506	HALLETT MATERIALS CO	CHEROKEE SOUTH	NE 16 T91N R40W	2.7	2		3	3				
				2.69		X						
A18514	L G EVERIST INC	LARRABEE-MONTGOMERY	NE 20 T93N R39W	2.67	3		3	3				
				2.63		X						
A18526	HALLETT MATERIALS CO	CHEROKEE NORTH	SW 23 T92N R40W	2.7	3		3	3				
				2.67		X						
A18528	L G EVERIST INC	WASHTA	SW 31 T90N R41W	2.68	3		3	3				
				2.64		X						
A18534	HALLETT MATERIALS CO	NELSON	CT 23 T92N R40W	2.67	2		3	3				
				2.68		X						
19	**CHICKASAW** DIST 2	**CRUSHED STONE**										
A19004	BRUENING ROCK PRODUCTS INC	DEERFIELD-MAHONEY	SE 33 T97N R14W									
A19008	BRUENING ROCK PRODUCTS INC	BOICE	NE 16 T95N R14W							2-5	D	
		SAND AND GRAVEL										
A19508	SKYLINE MATERIALS LTD	BUSTA	SE 23 T96N R11W	2.65		X	4	4				
A19512	BRUENING ROCK PRODUCTS INC	PEARL ROCK	SE 31 T94N R14W				4	4				
				2.65		X						
A19514	BRUENING ROCK PRODUCTS INC	NASHUA	SW 33 T95N R14W				3	3				
				DWU		X						
A19516	BMC AGGREGATES LC	REWOLDT	NE 25 T94N R13W	2.64		X						
A19520	BMC AGGREGATES LC	ROSONKE	SE 16 T95N R14W			H						
A19522	CROELL REDI MIX	BUCKY'S	NW 3 T95N R11W	2.68	3iB		3	3				
				2.65		X						
20	**CLARKE** DIST 5	**CRUSHED STONE**										
A20002	SCHILDBERG CONSTRUCTION CO	OSCEOLA	NW 12 T72N R26W					5		25A-25E	D	
										20A-20C		1
										20A	A B C D E	

NOTE 1: FRICTION TYPE TO BE DETERMINED WHEN USED ON WINTERSET BEDS 20A-20C

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
20	**CLARKE DIST 5**	**CRUSHED STONE**								**CONTINUED**		
A20002	SCHILDBERG CONSTRUCTION CO	OSCEOLA	NW 12 T72N R26W							25B-25C	A B C D E	
21	**CLAY DIST 3**	**SAND AND GRAVEL**										
A21506	DAVE'S SAND AND GRAVEL INC	EVERLY	SW 31 T97N R38W	2.7	3		3	3				
				2.68		X						
A21516	SIEH SAND & GRAVEL	SPENCER #1	SW 24 T96N R36W	2.69	2		3	3				
				2.66		X						
A21518	HALLETT MATERIALS CO	SPENCER #2	SW 5 T97N R37W			H	4	4				
A21526	CLAY COUNTY	CLAY COUNTY	NW 20 T96N R35W			H						
A21528	DAVE'S SAND AND GRAVEL INC	GOEKEN	NE 5 T96N R38W	DWU	2	H						
A21530	HALLETT MATERIALS CO	BRAUNSCHWEIG	16 T94N R36W			H	3	3				
A21532	CLAY COUNTY	ELSER	CT 3 T94N R36W			H	3	3				
A21534	HALLETT MATERIALS CO	CLARK EVERLY	NW 6 T96N R38W			H						
A21536	HALLETT MATERIALS CO	GILLETT GROVE	NE 3 T94N R36W			H	3	3				
A21538	NSG, LLC	NORGAARD SAND & GRAVEL	NW 20 T96N R35W	2.65		X						
A21540	BD CONSTRUCTION SERVICES LLC	DELOSS	20 T96N R35W			X						
22	**CLAYTON DIST 2**	**CRUSHED STONE**										
A22002	BARD MATERIALS	TWIN ROCK-SCHRADER	NW 14 T94N R05W				4	4	D	1-11		
							4	4	D	3-11	A B C D E	
A22004	SKYLINE MATERIALS LTD	BENTE-ELKADER-WATSON	SW 12 T93N R05W	2.66	2		4	4	L	6-9		
							4	4	D	1-9		
										5-9	A B C D E	
A22008	BARD MATERIALS	ANDEREGG	SE 32 T92N R02W				4	4	D	2-8	A B C D E	
A22010	BARD MATERIALS	OSTERDOCK	SE 2 T91N R03W	2.67	2					2-5		
							4	4		1-8		
										3-8	A B C D E	
A22012	BARD MATERIALS	SCHMIDT	NE 33 T91N R01W	2.66	3i		4	4	D	4B -6		
							4	4	D	2-6	A B C D E	
A22014	SKYLINE MATERIALS LTD	BLUME	NE 9 T93N R03W	2.64	2		4	4	D	1-7		
							4	4	D	1-12	A B C D E	
A22016	BARD MATERIALS	GISLESON	NW 6 T95N R04W	2.66	3i		4	4	D	1-8		
							4	4		1-15	A B C D E	
A22018	CJ MOYNA & SONS INC	ZURCHER	SE 1 T94N R05W				4	4				
A22020	BARD MATERIALS	MUELLER	NE 30 T94N R03W	DWU	3i		4	4	D	1-8	A B C D E	
A22024	MIELKES QUARRY	MIELKE QUARRY	NE 21 T95N R04W				4	4	D	1-2	A B C D E	
A22026	BARD MATERIALS	DOERRING-LUANA	SE 5 T95N R05W							3-5	A B C D E	
A22030	BARD MATERIALS	EBERHARDT	NW 27 T93N R05W	2.72	3		4	4		1-5		
								4		1-8		
										1-6	A B C D E	

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	FRICT HMA B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
22	**CLAYTON DIST 2**	**CRUSHED STONE**								**CONTINUED**		
A22032	BARD MATERIALS	WELLMAN	NW 25 T92N R06W					4		1-6		
A22034	BARD MATERIALS	KRUSE	NW 17 T92N R04W	2.7	3B		4	4		5-11		
				2.7	2		4	4		5-12	A B C D E	
							4	4		2-12		
A22038	BARD MATERIALS	FASSBINDER	SW 9 T92N R03W	2.67	3i		4	4	D	2B -6		
										2-6	A B C D E	
A22040	BARD MATERIALS	HARTMAN	NW 29 T91N R06W	2.68	3i		4	4	D	1-4	A B C D E	
A22042	SKYLINE MATERIALS LTD	MORAREND	CT 35 T92N R03W							1-8		
							4	4	D	1-10		
										1-9	A B C D E	
A22044	BARD MATERIALS	BOGE	SW 18 T91N R02W									
A22046	RECKER ROCK	JOY SPRINGS-BURRACK	NW 19 T91N R06W	2.65	3i		4	4		1		
A22048	SKYLINE MATERIALS LTD	TUCKER	SW 18 T91N R05W							1-3	D	
A22058	SKYLINE MATERIALS LTD	ST. OLAF	NW 25 T94N R05W									
A22060	CROELL REDI MIX	JOHNSON	NW 26 T93N R04W	2.64	3i		4	4	D	2-5	A B C D E	
							4	4	D	1-5		
A22062	CJ MOYNA & SONS INC	SNY MAGILL	SE 22 T94N R03W	2.73	3i		4	4	D	6-10	A B C D E	
A22068	RIVER CITY STONE INC	MILLVILLE	NW 10 T91N R02W	DWU	3i		4	4	D	1-8	A B C D E	
A22070	BRUENING ROCK PRODUCTS INC	BERNHARD/GIARD	NW 35 T95N R04W	DWU	3i		4	4	D	1-3	A B C D E	
A22074	RIVER CITY STONE INC	STRAWBERRY POINT	NE 19 T91N R06W	2.69	3i		4	4	D	1-2	A B C D E	
A22076	BRUENING ROCK PRODUCTS INC	LARSON	NW 8 T93N R05W									
A22078	BRUENING ROCK PRODUCTS INC	LINK	7 T93N R06W									
A22080	BARD MATERIALS	HILINE	NW 8 T91N R03W									
A22084	CJ MOYNA & SONS INC	MOYNA	14 T93N R05W	2.66	3i				L	BED 6-TOP 3' OF 8		
							4	4	L	6-9	A B C D E	
A22086	CJ MOYNA & SONS INC	WILLIE	SW 18 T93N R02W									
A22088	CJ MOYNA & SONS INC	KEPPLER	NW 29 T94N R05W									
A22090	PATTISON COMPANY LLC	FRENCHTOWN	7 T93N R02W	2.68	3iB		4	4	D	S1C-S1D		
				DWU	3		4	4	D	S1B		
				2.68	3		4	4	D	S1B-S1D		
				2.68	3i		4	4	D	G4	A B C D E	
				2.66	3		4	4	D	G2-G3	A B C D E	
				2.72	3i		4	4	D	ONEOTA	A B C D E	
							4	4	D	G2-G4	A B C D E	
							4	4	D	G1	A B C D E	
							4	4	D	G1-G3	A B C D E	
							4	4	D	G5	A B C D E	
							4	4	D	G1-G5		

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
22	**CLAYTON** DIST 2	**CRUSHED STONE**								**CONTINUED**		
A22090	PATTISON COMPANY LLC	FRENCHTOWN	7 T93N R02W				4	4	D	S1A-S1D		
A22092	CJ MOYNA & SONS INC	LARSON	07 T94N R06W									
A22094	CJ MOYNA & SONS INC	BACKES	SE 19 T92N R03W									
		SAND AND GRAVEL										
A22510	SKYLINE MATERIALS LTD	BENTE	SE 15 T93N R05W	2.66		X	4	4				
A22520	BARD MATERIALS	WELTERLEN	SE 32 T91N R05W	2.65		X						
A22522	CJ MOYNA & SONS INC	MOYNA	13 T93N R05W	2.64		X	4	4				
23	**CLINTON** DIST 6	**CRUSHED STONE**										
A23002	PRESTON READY MIX CORP	ELWOOD-YEAGER	NW 8 T83N R02E	DWU	3i		4	4	D	1-2	A B C D E	
							4	4	D	5-6		
A23004	WENDLING QUARRIES INC	BEHR	SW 2 T81N R03E	DWU	3i		4	4	D	1-2A	A B C D E	
							4	4	D	2B		
A23006	WENDLING QUARRIES INC	SHAFFTON	NE 11 T80N R05E	DWU	3i		4	4	D	16-17		
				DWU	3i		4	4	D	17-18		
				DWU	3i		4	4	D	18-19		
				DWU	3i		4	4	D	20-21		
				DWU	3		4	4	D	20-23	A B C D E	
				DWU	3		4	4	D	3-14	D	
							4	4	D	3-15		
										16-21	A B C D E	
A23010	WENDLING QUARRIES INC	GOOSE LAKE	SW 22 T83N R05E				4	4	D	1-10		
										2-4	D E	
A23012	WENDLING QUARRIES INC	TEEDS GROVE	SW 3 T83N R06E							2-4	A B C D E	
A23016	WENDLING QUARRIES INC	LYONS	NW 18 T82N R07E							UPPER OR LOWER LEDGE	D E	
A23026	WENDLING QUARRIES INC	MILL CREEK	NE 22 T82N R06E									
A23028	WENDLING QUARRIES INC	DELMAR	SE 6 T83N R04E									
A23030	WENDLING QUARRIES INC	EDEN VALLEY	4 T83N R01E									
A23032	ANDERSON SAND AND GRAVEL CO	ANDERSON	23 T81N R03E									
		SAND AND GRAVEL										
A23506	WENDLING QUARRIES INC	SCHNECKLOTH	S2 10 T80N R05E				4	4				
				2.66		X						
A23514	ANDERSON SAND AND GRAVEL CO	ANDERSON	NW 23 T81N R03E	2.68		X						
A23516	WENDLING QUARRIES INC	OLSON	NW 23 T81N R02E	DWU		X						
A23518	WENDLING QUARRIES INC	HARKSEN	SE 10 T80N R05E			X						
24	**CRAWFORD** DIST 3	**SAND AND GRAVEL**										
A24512	HALLETT MATERIALS CO	DUNLAP	SE 27 T82N R41W	2.7	2		3	3				
				2.66		X						

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR		SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
25	**DALLAS**	**DIST 4**	**SAND AND GRAVEL**										
A25510	HALLETT MATERIALS CO		PERRY	NW 1 T81N R29W	2.7	2		4	4				
					2.67		X						
A25514	HALLETT MATERIALS CO		BOONEVILLE	S2 26 T78N R26W	2.68	2		3	3				
					2.66		X						
A25516	HALLETT MATERIALS CO		VAN METER SOUTH	21 T78N R27W	2.68	2		3	3				
					2.66		X						
A25518	MARTIN MARIETTA AGGREGATES		RACCOON RIVER SAND	27 T78N R26W	2.66	2		3	3				
					2.65		X						
A25520	LEGACY MATERIALS		LEGACY MATERIALS	29 T78N R26W	DWU	2							
					2.66		X						
A25522	HALLETT MATERIALS CO		BOONEVILLE WEST	25 T78N R27W	2.66	2		3	3				
					2.66		X						
26	**DAVIS**	**DIST 5**	**CRUSHED STONE**										
A26004	DOUDS STONE LLC		LEWIS	W2 2 T69N R12W	2.6	3		4	4	L	1	D E	
								5	5	L	3-7	D E	
									5		3-5	D	
								4	4	L	6-7	D E	
A26006	DOUDS STONE LLC		BROWN	NW 2 T69N R12W	2.6	3		4	4	L	1	D E	
								5	5	L	3-7	D E	
									5		3-5		
								4	4	L	6-7		
			SAND AND GRAVEL										
A26502	DOUDS STONE LLC		ELDON-FRANKLIN	SW 1 T70N R12W	2.67		X						
27	**DECATUR**	**DIST 5**	**CRUSHED STONE**										
A27002	SCHILDBERG CONSTRUCTION CO		GRAND RIVER	NW 22 T70N R27W					5		25A-25C		1
											TOP 5.5'	D	
											BED 25E		
A27008	SCHILDBERG CONSTRUCTION CO		DECATUR	05 T68N R26W							20C	A B C D E	2
									5		25A-25E		3
											25C	D	
											20A	C D E	
28	**DELAWARE**	**DIST 6**	**CRUSHED STONE**										
A28008	BARD MATERIALS		EDGEWOOD WEST	CT 4 T90N R05W	2.69	3i		4	4	D	2B-3B	A B C D E	
					2.66	3		4	4	D	3B	A B C D E	
								4	4	D	1-3B		

NOTE 1: TOP 4' ONLY OF BED 25C
NOTE 2: FRICTION TYPE TO BE DETERMINED WHEN USED FOR BED 20C.
NOTE 3: TOP 2.5' ONLY OF BED 25E.

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	FRICT HMA B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
28	**DELAWARE DIST 6**	**CRUSHED STONE**								**CONTINUED**		
A28010	BARD MATERIALS	TIBBOTT	SW 23 T90N R04W	2.7	3i		4	4	D	1-5	A B C D E	
							4	4	D	1-7		
A28012	BARD MATERIALS	BAHL	SE 22 T89N R06W	2.69	3i		4	4	L	1-4		
A28014	BARD MATERIALS	LOGAN	SW 10 T88N R05W	2.69	3		4	4	L	2-8	A B C D E	
							4	4	L	1-8		
A28016	BARD MATERIALS	WHITE	NW 2 T88N R04W	2.67	3i		4	4	D	1-2	A B C D E	
A28030	BARD MATERIALS	HOPKINTON	NE 18 T87N R03W							1-2	A B C D E	
A28038	BARD MATERIALS	EDGEWOOD EAST	NW 6 T90N R04W	2.68	3i		4	4	D	1B-5	A B C D E	
A28040	BARD MATERIALS	KRAPFL	SE 23 T89N R03W	2.66	3iB		4	4	D	4	D E	
							4	4	D	1-4		
							4	4	D	4-7		
							4	4	D	7		
										1-5	A B C D E	
A28044	BARD MATERIALS	DUNDEE	NE 20 T90N R06W	DWU	3i		4	4	D	2-7		
A28046	BARD MATERIALS	PINS	NW 27 T88N R03W									
A28050	BARD MATERIALS	BUCK CREEK	NW 20 T87N R04W									
A28052	RIVER CITY STONE INC	MANCHESTER	SW 9 T88N R05W	DWU	3		4	4	D	5-8		
										6-8	A B C D E	
										TOP	D	
										LEDGES-N		
A28056	RIVER CITY STONE INC	THORPE	NW 33 T90N R05W							FULL FACE	A B C D E	
A28058	RIVER CITY STONE INC	ROSSOW/MANCHESTER	NW 16 T88N R05W						L	1-8		
		SAND AND GRAVEL										
A28520	RIVER CITY STONE INC	MANCHESTER	SW 10 T88N R05W	2.64		X						
A28526	BARD MATERIALS	HAWK	SW 22 T89N R06W	2.66		X						
A28528	BARD MATERIALS	CAR 6	NW 36 T89N R03W	2.64		X						
A28530	BRUENING ROCK PRODUCTS INC	SUMMERS PIT	NE 24 T89N R06W	2.65		X						
29	**DES MOINES DIST 5**	**CRUSHED STONE**										
A29002	L&W QUARRIES INC	MEDIAPOLIS	SE 1 T71N R04W	2.65	3		4	4	L	15		1
							4	4	L	15-18	A B C D E	
							5	5	L	20		
										3-7	A B C D E	
A29008	CESSFORD CONST CO- SE DIV	NELSON	NE 26 T72N R02W	2.62	3i		4	4	L	21-24	A B C D E	
				DWU	3		4	4	L	8-14		
							4	4	L	7-19		
							4	4	L	7-20	A B C D E	
							4	4	L	15-24	D	
							5	5	L	24-27		

NOTE 1: AASHTO 57 GRADATION MAXIMUM

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	FRICT HMA B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
29	**DES MOINES DIST 5**	**CRUSHED STONE**								**CONTINUED**		
A29008	CESSFORD CONST CO- SE DIV	NELSON	NE 26 T72N R02W							7-14	A B C D E	
										15-20	D	
										25-27	D	
A29012	CESSFORD CONST CO- SE DIV	GEODE	NE 1 T69N R05W				4	4	L	11-12		
							5	5	L	9-13	D E	
							4	4	L	17	A B C D E	
								5		1-5	D E	
		SAND AND GRAVEL										
A29502	CESSFORD CONST CO- SE DIV	SPRING GROVE	SW 36 T69N R03W	DWU	3		4	4				
				2.66		X						
30	**DICKINSON DIST 3**	**SAND AND GRAVEL**										
A30504	HALLETT MATERIALS CO	ROHLIN	NE 6 T98N R36W			H	3	3				
A30508	HALLETT MATERIALS CO	FOSTORIA/LOST	32 T98N R37W	2.71	2		3	3				
				2.67		X						
A30510	WEDEKING PIT & PLANT INC.	WEDEKING	NE 7 T98N R36W	2.71	2		3	3				
				2.66		X						
A30512	DICKINSON COUNTY	WESTPORT	NE 17 T98N R38W			H	4	4				
A30514	HALLETT MATERIALS CO	MILFORD/LEITH	NE 4 T98N R37W	DWU	2	H	3	3				
A30516	COHRS CONSTRUCTION INC	CROSBY	NW 21 T100NR37W			H						
A30518	COHRS CONSTRUCTION INC	SMITH	SE 6 T98N R36W			H						
A30520	COHRS CONSTRUCTION INC	MILFORD/DERNER	NE 14 T98N R37W	DWU	2							
				DWU		X						
A30526	MONEY PIT LLC	MILL CREEK	SW 8 T98N R36W	DWU		X						
31	**DUBUQUE DIST 6**	**CRUSHED STONE**										
A31002	RIVER CITY STONE INC	ROSE SPUR	27 T90N R02E	2.66	3i		4	4	D	1-8	A B C D E	
							4	4	D	1-15		
A31006	BARD MATERIALS	DYERSVILLE EAST	SE 32 T89N R02W	2.69	3i		4	4	D	5-11	A B C D E	
							4	4	D	5-8		
A31008	CJ MOYNA & SONS INC	KLEIN-RICKARDSVILLE	NW 33 T90N R01E	2.66	3i		4	4	D	3A-4B	D E	
							4	4	D	1-4		
										2-4B	A B C D E	
A31010	RIVER CITY STONE INC	BROWN	NW 33 T89N R02E	2.65	3i		4	4	D	3-7		
							4	4	D	2-9		
							4	4	D	9B		
							4	4	D	3-9A		
							4	4	D	3-9B		
A31014	BARD MATERIALS	KURT	N2 35 T87N R02W	2.7	3iB		4	4	D	1-2	A B C D E	
A31018	RIVER CITY STONE INC	MELOY	NW 23 T87N R01E	DWU	3i		4	4	D	1-3	D E	

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	DUR PCC FA	FRICT HMA A	FRICT HMA B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
31	**DUBUQUE** **DIST 6**	**CRUSHED STONE**								**CONTINUED**		
A31018	RIVER CITY STONE INC	MELOY	NW 23 T87N R01E							FULL FACE	A B C D E	
A31020	RIVER CITY STONE INC	SCHLITCHE	SE 11 T89N R02W	DWU	3i		4	4	D	1-4	A B C D E	
A31026	RIVER CITY STONE INC	ARENSDORF	SE 25 T87N R02E	DWU	3i		4	4	D	1-2	A B C D E	
A31028	RIVER CITY STONE INC	THOLE	NW 21 T87N R02E	DWU	3i		4	4	D	1-2		1
										2-3	A B C D E	
										3	D E	
A31030	RIVER CITY STONE INC	KEMP	NE 9 T89N R01W				4	4	D	1-4		
										FULL FACE	A B C D E	
A31032	BRUENING ROCK PRODUCTS INC	REITER	NW 28 T87N R01W	DWU	3i		4	4	D	1B-5	A B C D E	
A31036	RIVER CITY STONE INC	BALLTOWN	SE 5 T90N R01E							1-7	A B C D E	
A31040	RIVER CITY STONE INC	KENNEDY	NW 3 T88N R01W							FULL FACE	A B C D E	
A31042	RIVER CITY STONE INC	GANSEN	NW 9 T87N R02E									
A31046	WENDLING QUARRIES INC	DECKER	SE 24 T87N R02E	DWU	3i		4	4	D	1-5		
										2-5	A B C D E	
A31048	RIVER CITY STONE INC	MCDERMOTT	NE 35 T88N R01W	2.65	3i		4	4	D	2		
A31050	RIVER CITY STONE INC	PLOESSEL-DYERSVILLE	N2 7 T88N R02W	2.74	3i		4	4	D	3-5	D E	
										2-5	A B C D E	
A31052	BARD MATERIALS	EPWORTH-KIDDER	SW 2 T88N R01W	DWU	3i		4	4	D	2		
										FULL FACE	A B C D E	
A31056	RIVER CITY STONE INC	RUBIE	SE 6 T88N R03E	DWU	3iB		4	4	D	5-8	A B C D E	
				DWU	3iB		4	4	D	5-9	A B C D E	
				2.68	3i		4	4	D	5-10	A B C D E	
				2.69	3i		4	4	D	8-10	A B C D E	
										1-10	D	
A31060	BARD MATERIALS	CASCADE EAST	SE 22 T87N R01W	2.7	3iB		4	4	D	2-5	A B C D E	
										1	A B C D E	
A31064	RIVER CITY STONE INC	WEBER	NE 32 T89N R02E				4	4	D	3-9A	A B C D E	
A31066	RIVER CITY STONE INC	FILLMORE	SW 26 T87N R01W	2.7	3i		4	4	D	2-4	A B C D E	
A31068	BARD MATERIALS	DYERSVILLE-MAIERS	SE 19 T89N R02W	2.7	3i		4	4	D	2	D E	
							4	4	D	1-2		
A31070	RIVER CITY STONE INC	GREEN VALLEY	SE 32 T89N R02E									
		SAND AND GRAVEL										
A31512	BARD MATERIALS	BURKLE	SW 19 T89N R02W	2.65		X						
A31514	RIVER CITY STONE INC	FILLMORE	CT 26 T87N R01W	2.63		X						
A31516	BARD MATERIALS	CASCADE-LOCHER	25 T87N R02W	2.65		X						
A31518	BARD MATERIALS	MAIERS	SE 19 T89N R02W	2.65		X						

NOTE 1: TOP 17.0’ ONLY OF BED 2

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
32	**EMMET** DIST 3	**SAND AND GRAVEL**										
A32502	HALLETT MATERIALS CO	ESTHERVILLE	N2 3 T99N R34W	2.7	2		3	3				
				DWU		X						
A32506	EMMET COUNTY	FREY	NW 21 T100N R34W			H	4	4				
A32522	HALLETT MATERIALS CO	OLD ESTHERVILLE S&G	30 T99N R33W			H						
A32524	EMMET COUNTY	PETERSON	SW 34 T100N R34W			H						
A32530	HALLETT MATERIALS CO	ESTHERVILLE/WHITE	SW 16 T100N R34W	DWU	2		4	4				
				DWU		X						
A32534	COHRS CONSTRUCTION INC	ENERSON	28 T100N R34W			H	4	4				
A32538	HALLETT MATERIALS CO	JENSEN	NW 3 T99N R34W	DWU	2							
				DWU		X						
A32540	HALLETT MATERIALS CO	FISHER	NE 33 T98N R32W			H						
A32542	HALLETT MATERIALS CO	GRAETTINGER	SE 33 T98N R33W			H	4	4				
A32544	DUININCK BROS INC	ANDERSON	7 T100N R34W	DWU		X	3	3				
A32546	DUININCK BROS INC	TROPHY RIDGE	SE 25 T99N R34W			H						
A32548	KNOPIK SAND & GRAVEL INC	LILLAND	SE 3 T99N R34W	DWU	3							
				DWU		X						
33	**FAYETTE** DIST 2	**CRUSHED STONE**										
A33002	BMC AGGREGATES LC	ELDORADO-JACOBSEN	SW 17 T95N R08W	2.69	3iB		5	5	L	4-6B	A B C D E	
A33004	BMC AGGREGATES LC	HOUG	SW 11 T94N R08W				5	5	L	1-9		
										3-8	A B C D E	
A33018	BMC AGGREGATES LC	FAIRBANK	SW 28 T91N R10W				4	4	D	5		
								4		1-5		
										1-5C	D	
										5A-5C	A B C D E	
A33020	BMC AGGREGATES LC	YEAROUS	SW 19 T93N R08W				4	4	L	1-10		
										1-10C	D	
A33024	BMC AGGREGATES LC	WAUCOMA	NW 25 T95N R10W	2.69	3iB		5	5	L	2-5		
										1-TOP 4'	A B C D E	
										BED 5		
A33032	BRUENING ROCK PRODUCTS INC	LANDIS	SE 12 T93N R08W				4	4	D	1-5	A B C D E	
A33034	BMC AGGREGATES LC	MCDONOUGH	SE 36 T94N R08W							1-3	D	
A33036	BMC AGGREGATES LC	GRAHAM-HAWKEYE	SW 6 T94N R09W				4	4	L	1-4	A B C D E	
A33038	BMC AGGREGATES LC	PAPE	NE 28 T95N R08W	DWU	3iB		5	5	L	3-5	A B C D E	
										1-3	A B C D E	
A33040	BMC AGGREGATES LC	SINNOTT	25 T93N R09W									
A33044	BRUENING ROCK PRODUCTS INC	FAYETTE 93	30 T93N R08W							FULL FACE	D	
A33046	BMC AGGREGATES LC	HUNT	NE 28 T91N R10W									
A33048	BMC AGGREGATES LC	MEDBERRY	W2 10 T93N R07W									

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	FRICT HMA B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
33	**FAYETTE DIST 2**	**SAND AND GRAVEL**								**CONTINUED**		
A33506	BMC AGGREGATES LC	ALPHA	NW 3 T94N R10W	2.64		X	4	4				
A33508	SKYLINE MATERIALS LTD	DURSCHER	NW 3 T94N R07W			H		4				
A33510	BMC AGGREGATES LC	RANDALIA	NE 30 T93N R09W	2.64		X	4	4				
A33518	BARD MATERIALS	BASSETT	SE 11 T91N R07W				4	4				
				2.65		X						
A33520	BRUENING ROCK PRODUCTS INC	OELWEIN SAND	NE 9 T91N R09W	2.65		X						
A33522	BRUENING ROCK PRODUCTS INC	PAPE	SE 8 T95N R08W	2.65		X						
A33524	CROELL REDI MIX	ROGERS	4 T94N R07W	2.66		X						
A33528	BMC AGGREGATES LC	KASEMEIER	SE 19 T93N R10W	2.64		X						
34	**FLOYD DIST 2**	**CRUSHED STONE**										
A34002	BRUENING ROCK PRODUCTS INC	CARVILLE-BUNN	SW 23 T95N R15W	2.63	2		4	4	L	1-4		
A34004	BRUENING ROCK PRODUCTS INC	MAXSON	SE 7 T94N R17W	2.68	2		5	5	L	4C-19	A B C D E	
				DWU	2		5	5	L	18-25		
							5	5	L	1-17		
A34006	BRUENING ROCK PRODUCTS INC	JOHLAS	SW 7 T94N R15W					5		6-7		
							5	5		1-7	D	
A34008	BRUENING ROCK PRODUCTS INC	WARNHOLTZ	SW 9 T96N R16W	2.7	3i		5	5	L	1-4		
				2.68	2		4	4	D	17-18	A B C D E	
							5	5	L	1-18		
										5-16	D	
A34010	BRUENING ROCK PRODUCTS INC	LACOSTE	SE 25 T97N R17W	2.67	3iB		5	5	L	1-4		
							5	5	L	1-8		
							4	4	L	9-14		
A34012	BRUENING ROCK PRODUCTS INC	WILLIAMS	NW 29 T96N R18W				5	5		8-12		
A34014	BRUENING ROCK PRODUCTS INC	HANNMANN	NE 20 T94N R15W									
A34018	BRUENING ROCK PRODUCTS INC	JONES	N2 26 T97N R17W	2.67	3iB		5	5	L	1-4		
				2.67	3B				L	2-7		
				DWU	3				L	5A-7		
A34020	BRUENING ROCK PRODUCTS INC	JENSEN	SW 25 T94N R16W									
		SAND AND GRAVEL										
A34502	BRUENING ROCK PRODUCTS INC	ROCKFORD	SE 15 T95N R18W	2.68	2		3	3				
				2.65		X						
A34506	BRUENING ROCK PRODUCTS INC	LENT	NE 8 T96N R16W			H	4	4				
A34516	BRUENING ROCK PRODUCTS INC	CEDAR ACRE RESORT	E2 17 T95N R15W	DWU	2							
				2.65		X						
A34518	BRUENING ROCK PRODUCTS INC	ENABNIT	NW 21 T94N R17W			H						
A34520	BRUENING ROCK PRODUCTS INC	FOOTHILL	26 T95N R18W	DWU	2							

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
34	**FLOYD DIST 2**	**SAND AND GRAVEL**								**CONTINUED**		
A34520	BRUENING ROCK PRODUCTS INC	FOOTHILL	26 T95N R18W	2.66		X						
A34522	BRUENING ROCK PRODUCTS INC	ROTTINGHAUS	NE 35 T96N R15W	2.66		X						
35	**FRANKLIN DIST 2**	**CRUSHED STONE**										
A35002	MARTIN MARIETTA AGGREGATES	DOWS	NE 30 T91N R22W				4	4	L	1-4		
							4	4	L	1-12	A B C D E	
							4	4	L	7-12		
							5	5	L	5-6		
										1-13	D	
A35016	BRUENING ROCK PRODUCTS INC	AYRES	1 T92N R19W									
		SAND AND GRAVEL										
A35502	SKYLINE MATERIALS LTD	GENEVA	SW 7 T91N R19W	2.68	2		3	3				
				2.64		X						
A35518	STRATFORD GRAVEL INC	REINKE	SW 22 T91N R20W			H	4	4				
A35520	STRATFORD GRAVEL INC	BRANDT	N2 34 T90N R19W				4	4				
				2.68		X						
A35522	MARTIN MARIETTA AGGREGATES	MCDOWELL SAND	SE 27 T90N R22W	DWU	2		4	4				
				2.61		X						
A35524	HEARTLAND ASPHALT INC	JEST POND	SW 3 T93N R20W			H						
36	**FREMONT DIST 4**	**CRUSHED STONE**										
A36002	SCHILDBERG CONSTRUCTION CO	THURMAN	NW 23 T70N R43W							18	D	
37	**GREENE DIST 1**	**SAND AND GRAVEL**										
A37504	HALLETT MATERIALS CO	JEFFERSON	SW 4 T83N R31W	2.66	2		4	4				
				2.64		X						
A37514	ARCADIA LIMESTONE CO	WRIGHT	NW 5 T84N R32W	2.63		X	4	4				
A37520	CENTRAL IOWA READY MIX DBA GREEN COUNTY MATERIALS	GREENE COUNTY MATERIALS	27 T83N R30W	DWU	2							
				2.65		X						
A37522	STRATFORD GRAVEL INC	HAUPERT	20 T84N R30W			H						
A37524	STRATFORD GRAVEL INC	DAVIS	30 T82N R29W			H						
A37526	HALLETT MATERIALS CO	JEFFERSON-CLARKE	NE 23 T84N R31W			H						
A37528	STRATFORD GRAVEL INC	MUIR	SW 10 T83N R30W			H						
A37530	BEDROCK GRAVEL CO	BEDROCK #3	SW 02 T83N R31W			H						
A37532	STRATFORD GRAVEL INC	MEARS	13 T84N R30W			H						
38	**GRUNDY DIST 1**	**SAND AND GRAVEL**										
A38504	SKYLINE MATERIALS LTD	HERONIMOUS	SE 35 T88N R17W	2.63		X						
A38506	STRATFORD GRAVEL INC	MEESTER	NE 12 T88N R17W	2.63		X						

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR		SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
39	**GUTHRIE**	**DIST 4**	**SAND AND GRAVEL**										
A39508	HALLETT MATERIALS CO		L & L	NE 33 T78N R31W	2.64		X	4	4				
A39510	HALLETT MATERIALS CO		WILLOW CREEK SAND	SE 22 T81N R32W			H						
40	**HAMILTON**	**DIST 1**	**CRUSHED STONE**										
A40006	MARTIN MARIETTA AGGREGATES		GRANDGEORGE	SE 18 T89N R25W	2.57	3iB		4	4	L	11B-TOP		
											13' OF 13		
									5		3-5	D	
								4	4	L	7-11		
								5	5	L	8-11		
								5	5	L	12		
											7-9	D	
											10-13	A B C D E	
			SAND AND GRAVEL										
A40512	STRATFORD GRAVEL INC		ANDERSON	12 T87N R26W	DWU		X						
41	**HANCOCK**	**DIST 2**	**CRUSHED STONE**										
A41002	BMC AGGREGATES LC		GARNER NORTH	SE 11 T95N R24W	2.77	3iB		4	4	D	1-4		
					2.77	3iB		4	4	D	6	A B C D E	
			SAND AND GRAVEL										
A41504	HANCOCK COUNTY		HUTCHINS	E2 27 T96N R26W			H		4				
A41506	HANCOCK COUNTY		KLEMME	26 T95N R24W			H		4				
A41518	HANCOCK COUNTY		AUSTIN	NE 11 T97N R25W			H						
42	**HARDIN**	**DIST 1**	**CRUSHED STONE**										
A42002	MARTIN MARIETTA AGGREGATES		ALDEN	NW 20 T89N R21W	2.56	3iB		4	4	L	0-3		1
					DWU	3iB		4	4	L	3		
					DWU	3		5	5	L	0-1		
											1,3	A B C D E	
A42004	WENDLING QUARRIES INC		GEHRKE	NW 4 T86N R19W							6-8	A B C D E	
								4	4	D	10-11	A B C D E	
			SAND AND GRAVEL										
A42512	CTI READY MIX		HARDIN COUNTY AGGREGATES	SW 31 T87N R19W	DWU		X	4	4				
A42532	MARTIN MARIETTA AGGREGATES		H & M FARMS	27 T89N R20W	DWU	2							
					2.67		X						
43	**HARRISON**	**DIST 4**	**CRUSHED STONE**										
A43002	SCHILDBERG CONSTRUCTION CO		LOGAN	19 T79N R42W				5	5	L	25E		
								5	5	L	25C-25E		
									4		26		
											25B-E &	A B C D E	
											3’ BED 26		
A43004	BEDROCK GRAVEL CO		LOGAN	17 T79N R42W				5	5	L	25E		

NOTE 1: WHEN BED 2 IS VISUALLY APPARENT, IT SHALL NOT EXCEED A THICKNESS OF ONE FOOT IN FULL-FACE OPERATION

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
43	**HARRISON DIST 4**	**CRUSHED STONE**								**CONTINUED**		
A43004	BEDROCK GRAVEL CO	LOGAN	17 T79N R42W				5	5	L	25C-25E		
								4		26		
										25B-E &		
										3' BED 26		
		SAND AND GRAVEL										
A43512	HALLETT MATERIALS CO	WOODBINE-MCCANN	SW 29 T81N R41W	2.68	3i		3	3				
				2.64		X						
44	**HENRY DIST 5**	**CRUSHED STONE**										
A44002	CJ MOYNA & SONS INC	KINNEY	SE 17 T71N R06W									
A44004	DOUDS STONE LLC	MT PLEASANT NORTH	SW 36 T71N R06W					5		2-14		
							4	4	L	13		
A44006	HENRY COUNTY	LEEPER	NE 18 T71N R06W	DWU	2		4	4	D	8-11		
A44008	DOUDS STONE LLC	MT PLEASANT	SW 36 T71N R06W				4	4	L	13-14	D E	
							5	5	L	9-14	D E	
		SAND AND GRAVEL										
A44502	CESSFORD CONST CO- SE DIV	NORTH ROME	SW 29 T72N R07W				4	4				
				2.66		X						
A44504	IDEAL SAND CO AKA IDEAL R/M CO	ENSMINGER-ROME	NW 32 T72N R07W	2.67		X						
A44506	IDEAL SAND CO AKA IDEAL R/M CO	COPPOCK SAND	30 T73N R07W	2.65		X						
45	**HOWARD DIST 2**	**CRUSHED STONE**										
A45004	BRUENING ROCK PRODUCTS INC	STINGER	SE 28 T99N R11W									
A45006	BRUENING ROCK PRODUCTS INC	NELSON	NE 33 T99N R13W	2.54	2		4	4	L	1-3		
				2.54	2		4	4	D	8-9	A B C D E	
A45008	BRUENING ROCK PRODUCTS INC	DOTZLER	NE 23 T99N R12W	2.5	3		4	4	D	7-10A	A B C D E	
A45010	BRUENING ROCK PRODUCTS INC	DALEY	NE 11 T98N R11W	2.59	3		4	4	D	9-11		
										9-10	A B C D E	
A45014	FALK L R- CONSTRUCTION CO	O'DONNEL	SE 8 T97N R14W									
A45018	BRUENING ROCK PRODUCTS INC	LE ROY	NW 10 T100NR14W				4	4	D	3-7		
A45020	BRUENING ROCK PRODUCTS INC	RIECKS	NW 24 T100NR11W							1-5		
A45028	BRUENING ROCK PRODUCTS INC	ELMA	NW 6 T97N R13W	DWU	3		4	4	D	2-3		
A45030	BRUENING ROCK PRODUCTS INC	DIEKEN-TANK	SE 24 T100NR13W									
A45032	SKYLINE MATERIALS LTD	KITCHEN	SE 13 T100NR12W									
A45034	BRUENING ROCK PRODUCTS INC	HOOVER	SE 15 T98N R14W									
		SAND AND GRAVEL										
A45502	BRUENING ROCK PRODUCTS INC	MAPLE LEAF-POTTER	SE 4 T98N R13W			H	4	4				
A45504	SKYLINE MATERIALS LTD	ECKERMAN	NW 33 T100NR11W	DWU	3		4	4				
				2.65		X						
A45508	SKYLINE MATERIALS LTD	SOVEREIGN	SW 1 T98N R12W	DWU	3		3	3				
				2.65		X						

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
45	**HOWARD DIST 2**	**SAND AND GRAVEL**								**CONTINUED**		
A45516	BRUENING ROCK PRODUCTS INC	FREIDERICH	NE 15 T98N R14W	2.67		X	3	3				
A45518	BRUENING ROCK PRODUCTS INC	ELMA	NW 6 T97N R13W	2.67		X						
A45520	BRUENING ROCK PRODUCTS INC	HOOVER	SE 15 T98N R14W	2.66		X						
A45522	BRUENING ROCK PRODUCTS INC	LE ROY	NW 12 T100N R14W	DWU		X						
46	**HUMBOLDT DIST 2**	**CRUSHED STONE**										
A46004	STRATFORD GRAVEL INC	GRIFFITH	SW 24 T91N R30W	DWU	3iB		4	4	L	1-4		
				DWU	3		5	5	L	6-11		
							4	4	L	1-6		
A46006	MARTIN MARIETTA AGGREGATES	HODGES	NE 32 T92N R28W	2.6	3i		4	4	L	10-18		
				DWU	3i		5	5	L	4-8		
										4-18	D	
A46012	PRESTON READY MIX CORP	ANDERSON	29 T92N R29W									
A46014	MARTIN MARIETTA AGGREGATES	PEDERSEN	SW 28 T92N R28W	DWU	3i		5	5	L	17-19		
				DWU	3		5	5	L	4-16	D	
							5	5	L	4-20	D	
							5	5	L	17-20	D	
A46016	STRATFORD GRAVEL INC	ERICKSON	30 T91N R28W									
A46018	MARTIN MARIETTA AGGREGATES	MOORE EAST	W2 30 T92N R30W	2.63	3iB		5	5	L	1-3	A B C D E	
		SAND AND GRAVEL										
A46512	NORTHWEST MATERIALS	WARREN	SW 8 T92N R30W			H		4				
A46516	NORTHWEST MATERIALS	ERICKSON	SW 30 T91N R28W	2.67		X	3	3				
A46518	MARTIN MARIETTA AGGREGATES	PEDERSEN	SW 28 T92N R28W	DWU	2		4	4				
				2.66		X						
A46520	HEARTLAND ASPHALT INC	NORTH BRADGATE	SE 6 T92N R30W			H						
47	**IDA DIST 3**	**SAND AND GRAVEL**										
A47502	HALLETT MATERIALS CO	BATTLE CREEK	5 T86N R41W			H	3	3				
A47504	L G EVERIST INC	CROCKER	NW 6 T89N R41W	2.68	3	H						
48	**IOWA DIST 6**	**SAND AND GRAVEL**										
A48508	WENDLING QUARRIES INC	DISTERHOFT	SE 34 T81N R10W	2.64		X						
49	**JACKSON DIST 6**	**CRUSHED STONE**										
A49002	BARD MATERIALS	BELLEVUE	SW 25 T87N R04E	2.66	3i		4	4	D	1-3	A B C D E	
							4	4	D	0-3		
A49008	WENDLING QUARRIES INC	IRON HILL	SW 16 T85N R02E	DWU	3i		4	4	D	3-6		
							4	4	D	1-6	A B C D E	
A49010	WENDLING QUARRIES INC	ANDREW	NW 21 T85N R03E	2.7	3iB		4	4	D	1B -3		
							4	4	D	1-7		
										1B-5B	A B C D E	
A49012	WENDLING QUARRIES INC	FROST	SE 16 T84N R03E	DWU	3iB		4	4	D	1A -1D		

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR		SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
49	**JACKSON**	**DIST 6**	**CRUSHED STONE**								**CONTINUED**		
A49012	WENDLING QUARRIES INC		FROST	SE 16 T84N R03E				4	4	D	1-2		
											1A-1E	A B C D E	
A49016	WENDLING QUARRIES INC		WEIS	SE 22 T85N R04E							7	A B C D E	
A49020	WENDLING QUARRIES INC		PRESTON	SW 26 T84N R05E	2.66	3i		4	4	D	7-10	A B C D E	
					2.63	3		4	4	D	1-10	D E	
A49021	PRESTON READY MIX CORP		PRESTON R/M	SW 26 T84N R05E	2.66	3i		4	4	D	7-10	A B C D E	
					2.64	3		4	4	D	1-10		
A49022	WENDLING QUARRIES INC		BELLEVUE	SE 23 T86N R04E				4	4		1B-3	A B C D E	
A49024	WENDLING QUARRIES INC		MAQUOKETA EAST	SW 7 T84N R03E	2.61	3i		4	4	D	1-8	A B C D E	
					2.7	3i		4	4	D	7-8		
A49030	WENDLING QUARRIES INC		SPRINGBROOK	15 T85N R04E				4	4				
A49040	WENDLING QUARRIES INC		JOINERVILLE-HAMANN	SE 20 T84N R02E				4	4	D	1-3	A B C D E	
A49042	WENDLING QUARRIES INC		PETERSON	24 T84N R06E				4	4		1-2		
A49044	WENDLING QUARRIES INC		FRANK	NW 14 T87N R04E									
A49046	WENDLING QUARRIES INC		ROWAN	NE 25 T86N R03E									
A49060	BARD MATERIALS		ST DONATUS	18 T87N R04E	2.69	3i		4	4	D	2-3	A B C D E	
A49062	PRESTON READY MIX CORP		JOHNSON	31 T84N R04E									
A49064	WENDLING QUARRIES INC		VEACH	1 T85N R02E	DWU	3i		4	4	D	1-3	A B C D E	
A49066	WENDLING QUARRIES INC		MOREHEAD	NW 13 T85N R01E							1-2	A B C D E	
A49068	BARD MATERIALS		BELLEVUE FARM	SE 25 T87N R04E	2.63	3i		4	4	D	1		
			SAND AND GRAVEL										
A49506	BARD MATERIALS		BELLEVUE	E2 1 T86N R04E	2.64	3iB		3	3				
					2.69		X						
A49516	WENDLING QUARRIES INC		TURNER	NE 7 T84N R07E	2.63	3iB		3	3				
					2.66		X						
A49526	BARD MATERIALS		BELLEVUE FARM	SE 25 T87N R04E	2.64	3iB							
					2.67		X						
A49530	WENDLING QUARRIES INC		PETERSON	SW 18 T84N R07E	2.64	3iB		4	4				
					2.66		X						
A49538	WENDLING QUARRIES INC		MAQUOKETA SAND	SE 13 T84N R02E	2.65		X	4	4				
50	**JASPER**	**DIST 1**	**CRUSHED STONE**										
A50002	MARTIN MARIETTA AGGREGATES		SULLY MINE	SE 16 T79N R17W	2.56	3i		4	4	D	36-41	A B C D E	
											42-47	A B C D E	
			SAND AND GRAVEL										
A50504	MARTIN MARIETTA AGGREGATES		REASNOR	NE 10 T78N R19W				4	4				
					2.66		X						
51	**JEFFERSON**	**DIST 5**	**CRUSHED STONE**										
A51006	DOUDS STONE LLC		FAIRFIELD	NE 9 T71N R10W	DWU	3i		4	4	L	CEDAR FORK		

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	FRICT HMA B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
51	**JEFFERSON** DIST 5	**CRUSHED STONE**								**CONTINUED**		
A51006	DOUDS STONE LLC	FAIRFIELD	NE 9 T71N R10W				4	4	D	10-12	A B C D E	
										LOWER 4'	A B C D E	
										BED 8		
										5-8	A B C D E	
52	**JOHNSON** DIST 6	**CRUSHED STONE**										
A52002	WENDLING QUARRIES INC	FOUR CO.	NW 4 T81N R08W				5	5	L	5-9A		
										9-10	D	
A52004	RIVER PRODUCTS CO INC	CONKLIN	NW 33 T80N R06W	2.66	3iB		4	4	L	3-10	A B C D E	
				DWU	3iB		4	4	L	6-10	A B C D E	
				DWU	3i		5	5	L	23-24		1
							5	5	L	21-22	D	
A52006	RIVER PRODUCTS CO INC	KLEIN	NW 2 T79N R07W	2.66	3iB		4	4	L	3-10	A B C D E	
				2.65	3iB		4	4	L	6-10	A B C D E	
				DWU	3i		5	5		23-24		1
							5	5	L	21-22	D	
A52008	RIVER PRODUCTS CO INC	ERNST	SW 20 T80N R05W	DWU	2					24		
		SAND AND GRAVEL										
A52508	S&G MATERIALS	WILLIAMS	NW 34 T79N R06W	2.65		X	3	3				
A52510	RIVER PRODUCTS CO INC	RIVERSIDE #2	34 T78N R06W	2.65		X	4	4				
A52512	RIVER PRODUCTS CO INC	RIVERSIDE SAND	27 T78N R06W	DWU		X						
53	**JONES** DIST 6	**CRUSHED STONE**										
A53002	BARD MATERIALS	FARMERS-BEHRENDS	NE 14 T86N R03W	2.62	3i		4	4	D	1-5	A B C D E	
							4	4	D	5-7		
				DWU	3		4	4	D	0-5	A B C D E	
A53010	WENDLING QUARRIES INC	BALLOU-OLIN	NE 24 T83N R03W	2.6	3iB		4	4	D	3		
				DWU	3		4	4	D	2-3		
							4	4	D	1-3		
										FULL FACE	A B C D E	
A53014	WEBER STONE CO INC	JACOBS-SCOTCH GROVE	SW 7 T85N R02W							FULL FACE	A B C D E	
A53016	WEBER STONE CO INC	STONE CITY	5 T84N R04W	2.44	3i		4	4	D	2B-3A&B		
										1	A B C D E	
										3	A B C D E	
										2A	A B C D E	
A53018	RIVER CITY STONE INC	FINN	NE 6 T85N R01W	DWU	3i		4	4	D	2-5	A B C D E	
										4-5	D E	
										FULL FACE	D	
A53024	RIVER CITY STONE INC	SULLIVAN	NW 14 T86N R03W	DWU	3i		4	4	D	1-5		
										FULL FACE	A B C D E	

NOTE 1: 1.25 INCH MAXIMUM TOP SIZE

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
53	**JONES** **DIST 6**	**CRUSHED STONE**								**CONTINUED**		
A53026	ROGERS CONCRETE CONST., INC.	ANAMOSA	SW 15 T84N R04W	DWU	3i		4	4	D	1-2 REEF		
A53030	WENDLING QUARRIES INC	WYOMING NORTH	SW 21 T84N R01W									
		SAND AND GRAVEL										
A53522	WEBER STONE CO INC	WEBER	SW 6 T84N R04W	2.64		X						
A53526	BARD MATERIALS	STEPHENS	NW 34 T86N R03W				4	4				
				2.65		X						
A53528	WEBER STONE CO INC	ANAMOSA	NE 14 T84N R04W	2.65		X						
A53530	ROGERS CONCRETE CONST., INC.	ANAMOSA-WOOD'S	CT 15 T84N R04W	2.66		X	3	3				
A53532	BARD MATERIALS	LOES	NE 4 T86N R01W	2.65		X						
54	**KEOKUK** **DIST 5**	**CRUSHED STONE**										
A54002	DOUDS STONE LLC	KESWICK	NW 21 T77N R12W	2.61	2		4	4	D	13-15	A B C D E	1
							4	4	L	8-10		
							4	4	D	13-17		
							4	4	D	13-18		
										13-TOP 4'	D	
										BED 17		
										BED 17	D	
										BTM 21'		
A54004	DOUDS STONE LLC	OLLIE	SW 1 T74N R11W	2.66	3i		4	4	L	13-18	A B C D E	
				2.57	3				L	27-29	A B C D E	1
							4	4	L	13-19		
							4	4	L	27-30		
							4	4		30-37	A B C D E	
								5	L	31-33		
										9-12	A B C D E	
										9-13	D	
										9-18	A B C D E	
										19-26	D	
										30-33	D	
A54008	DOUDS STONE LLC	HARPER	SE 11 T76N R11W				4	4	L	15-24		
							4	4	L	32-37	A B C D E	
							4	4	L	38-40	A B C D E	
										13-22	A B C D E	
A54010	DOUDS STONE LLC	LYLE MINE	NW 13 T74N R13W	DWU	3		4	4	L	40	A B C D E	
							4	4	L	36-38	A B C D E	
							4	4	L	36-40		
55	**KOSSUTH** **DIST 2**	**SAND AND GRAVEL**										
A55506	KOSSUTH COUNTY	WHITTEMORE	NW 16 T95N R30W			H	4	4				
A55508	KOSSUTH COUNTY	IRVINGTON	NW 36 T95N R29W			H		4				

NOTE 1: 1.25 INCH MAXIMUM TOP SIZE

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
55	**KOSSUTH DIST 2**	**SAND AND GRAVEL**								**CONTINUED**		
A55518	REDINGS GRAVEL & EXCAVATING CO	REDING	2 T94N R29W			H						
A55534	KOSSUTH COUNTY	MCGUIRE	25 T95N R29W			H	4	4				
56	**LEE DIST 5**	**CRUSHED STONE**										
A56006	CESSFORD CONST CO- SE DIV	ARGYLE	SE 18 T66N R06W				4	4	L	1-17		
							4	4	D	13-17		
								5		4-12		
A56008	CESSFORD CONST CO- SE DIV	DONNELLSON	SE 5 T67N R06W				4	4	L	10-15		
										10-13	A B C D E	
A56012	CESSFORD CONST CO- SE DIV	VINCENNES	NW 19 T66N R06W									
A56014	CESSFORD CONST CO- SE DIV	BEACH	24 T69N R06W							6-21	A B C D E	
										21	A B C D E	
A56016	DOUDS STONE LLC	HERITAGE	26 T69N R04W	DWU	2		4	4	L	9-11	A B C D E	
							4	4	L	9-10		
								4		6-8		1
										3-5	A B C D E	
A56018	CESSFORD CONST CO- SE DIV	OMG CESSFORD AUGUSTA	NW 25 T69N R04W									
A56020	PNB PROCESSORS LLC	PNB PROCESSORS AUGUSTA	NW 25 T69N R04W							0C	A B C D E	
A56022	CESSFORD CONST CO- SE DIV	VINCENNES SAND PIT QUARRY	SE 32 T66N R06W									
		SAND AND GRAVEL										
A56504	CESSFORD CONST CO- SE DIV	VINCENNES	SE 32 T66N R06W				4	4				
				2.67		X						
A56506	BROCKMAN SAND CO	FT MADISON	SW 11 T67N R05W				4	4				
				2.67		X						
A56508	IDEAL SAND CO AKA IDEAL R/M CO	LEE COUNTY S & G	SE 11 T67N R05W	DWU		X						
57	**LINN DIST 6**	**CRUSHED STONE**										
A57002	WENDLING QUARRIES INC	BETENBENDER-COGGON	SW 3 T86N R06W				4	4	D	8-9		
				DWU	2		4	4	D	8-10		
										1-10	A B C D E	
A57004	WENDLING QUARRIES INC	PLOWER	SE 36 T86N R06W				4	4	D	9-11		
							4	4	D	1-10		
A57006	WENDLING QUARRIES INC	ROBINS	NE 21 T84N R07W	2.57	3i		4	4	L	3		2
										1-3	D	
A57008	WENDLING QUARRIES INC	BOWSER-SPRINGVILLE	SW 29 T84N R05W	DWU	3i		4	4	D	6-7A	A B C D E	
				DWU	3i		4	4	D	7B	A B C D E	
				DWU	3i		4	4	D	6-7B	A B C D E	
				DWU	3i		4	4	D	8-9		

NOTE 1: TOP 6' REMOVED FROM BEDS 6 -8
NOTE 2: 1.25 INCH MAXIMUM TOP SIZE

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
57	**LINN** DIST 6	**CRUSHED STONE**								**CONTINUED**		
A57008	WENDLING QUARRIES INC	BOWSER-SPRINGVILLE	SW 29 T84N R05W				4	4	D	1-4		
A57010	WENDLING QUARRIES INC	TROY MILLS	SE 9 T86N R07W							1-4	D	
A57014	WENDLING QUARRIES INC	SWEETING	NW 18 T85N R08W							1-4	D	
A57018	MARTIN MARIETTA AGGREGATES	CEDAR RAPIDS	NE 15 T82N R06W		3i		4	4	D	3B-5	A B C D E	
				2.47	3i		4	4	D	6-7	A B C D E	
				DWU	3i		4	4	D	2-5	A B C D E	
A57022	CRAWFORD QUARRY CO	LEE CRAWFORD	NW 23 T83N R08W	2.55	3		4	4	L	8		
										3-7	D	
A57026	WENDLING QUARRIES INC	COOK	NW 10 T86N R07W									
A57028	WENDLING QUARRIES INC	CEDAR RAPIDS SOUTH	NW 7 T82N R07W	DWU	3i		4	4	D	6-7	A B C D E	
										1-7	D	
A57030	CJ MOYNA & SONS INC	HENNESSEY	NE 1 T82N R07W							9-14	D	
										15-16	D	
		SAND AND GRAVEL										
A57520	WENDLING QUARRIES INC	IVANHOE	NW 29 T82N R05W	2.66		X	4	4				
A57528	WENDLING QUARRIES INC	BLAIRSFERRY SAND	SW 26 T84N R08W	DWU	2		3	3				
				2.65		X						
A57530	WENDLING QUARRIES INC	HESS	SW 4 T82N R06W	2.65		X						
A57534	MARTIN MARIETTA AGGREGATES	LINN COUNTY SAND	NE 5 T82N R06W	2.64		X						
A57536	CROELL REDI MIX	POWER PLANT	16 T84N R08W	DWU		X						
58	**LOUISA** DIST 5	**CRUSHED STONE**										
A58002	RIVER PRODUCTS CO INC	COLUMBUS JCT.	NW 3 T74N R05W	2.55	3		4	4	D	16-19		
							4	4	D	15-19		
							4	4	D	19-21		
		SAND AND GRAVEL										
A58504	RIVER PRODUCTS CO INC	FREDONIA A(INLAND) & FREDONIA B(RIVER)	SW 17 T75N R04W				4	4				
				2.66		X						
60	**LYON** DIST 3	**SAND AND GRAVEL**										
A60502	PETTENGILL CONC & GRAVEL INC	ROCK RAPIDS #1	NW 33 T100N R45W	2.69	2		3	3				
				2.67		X						
A60504	PETTENGILL CONC & GRAVEL INC	ROCK RAPIDS #2	NE 9 T99N R45W			H	3	3				
A60510	HALLETT MATERIALS CO	OLSON	NW 21 T99N R48W			H	3	3				
A60518	STENSLAND GRAVEL CO	STENSLAND	S2 17 T99N R48W			H	4	4				
A60530	DUININCK BROS INC	KOOIKER	SE 28 T99N R45W			H						
A60534	DUININCK BROS INC	EGEBO	16 T99N R48W			H	3	3				
A60540	SOUTHERN MN CONST CO INC	KANANGEITER	SE 4 T99N R43W			H						

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	FRICT HMA B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
60	**LYON DIST 3**	**SAND AND GRAVEL**								**CONTINUED**		
A60542	KRUSE PAVING INC	EBEN	NW 17 T99N R43W			H						
A60546	HALLETT MATERIALS CO	VANDERBRINK	NW 7 T98N R45W			H	3	3				
A60548	HALLETT MATERIALS CO	O'CONNER	NW 16 T99N R48W			H	3	3				
A60550	HALLETT MATERIALS CO	DENGLER	SW 33 T99N R45W			H						
61	**MADISON DIST 4**	**CRUSHED STONE**										
A61002	SCHILDBERG CONSTRUCTION CO	EARLY CHAPEL-DAGGETT	SW 3 T76N R29W				5	5	L	15A-15C		
								5		12		
								4		14B	A B C D E	
										15B-15C	A B C D E	
A61006	SCHILDBERG CONSTRUCTION CO	92 QUARRY	SW 5 T75N R29W				5	5		15		
A61012	MARTIN MARIETTA AGGREGATES	EAST WINTERSET	SE 27 T76N R27W					5		25		
A61013	SCHILDBERG CONSTRUCTION CO	WINTERSET WEST	SW 28 T76N R27W					5		25E		
										25B-25C	D E	
A61016	PERU QUARRY	PERU	NE 27 T75N R27W									
A61024	MARTIN MARIETTA AGGREGATES	PENN-DIXIE	SW 32 T76N R27W					5		25		
										BED 20A	D E	
										TOP 4'		
A61032	MARTIN MARIETTA AGGREGATES	EARLHAM-THRAILKILL	NE 8 T77N R28W					4		20		
								5		25		
										TOP 4'	D E	
										BED 20A		
										25B-25C	D	
										20A-20C	A B C D E	
										25B-25E	A B C D E	
A61036	SCHILDBERG CONSTRUCTION CO	MONARCH CEMENT OF IOWA	NE 8 T77N R28W					5		25B-25E	A B C D E	
A61038	SCHILDBERG CONSTRUCTION CO	PITZER	05 T76N R29W				5	5	L	15 A-C		
							5	5	L	15 B-C		
62	**MAHASKA DIST 5**	**SAND AND GRAVEL**										
A62502	DOUDS STONE LLC	G71	SW 15 T74N R16W	2.67		X						
63	**MARION DIST 5**	**CRUSHED STONE**										
A63002	MARTIN MARIETTA AGGREGATES	DURHAM MINE	NE 8 T75N R18W	2.5	3i		4	4	L	101		
				2.59	2		4	4	L	88-95	D E	
							4	4	L	87-95		
							4	4	L	95-96	D E	1
A63010	HAMM COMPANIES	KNOXVILLE QUARRY	SE 25 T75N R20W	DWU	3		4	4	L	31A-32D	A B C D E	
										25	A B C D E	
		SAND AND GRAVEL										
A63502	PELLA CONSTRUCTION CO., LTD	BEAN PROPERTY	NE 2 T75N R18W	2.67		X	4	4				
A63512	MARTIN MARIETTA AGGREGATES	NEW HARVEY	11 T75N R18W	DWU	3							

NOTE 1: BOTTOM 5’ ONLY OF BED 95 FOR BEDS 95-96.

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
63	**MARION DIST 5**	**SAND AND GRAVEL**								**CONTINUED**		
A63512	MARTIN MARIETTA AGGREGATES	NEW HARVEY	11 T75N R18W	2.67		X						
64	**MARSHALL DIST 1**	**CRUSHED STONE**										
A64002	MARTIN MARIETTA AGGREGATES	FERGUSON	SW 5 T82N R17W	2.65	3i		4	4	L	10-21		
				2.66	3		4	4	L	10-17		
				DWU	2		4	4	L	8-17	A B C D E	
				2.66	2		4	4	L	8-21		
				DWU	2		4	4	L	2-17		
							4	4	L	1-18		
							4	4	L	8-9	A B C D E	
										0-7	D	
										1-7	A B C D E	
										1-9	A B C D E	
A64004	CESSFORD CONST CO	LE GRAND	SW 36 T84N R17W	2.58	3i		5	5	L	1-7		
				DWU	2		4	4	L	19B-31		
				DWU	2		4	4	L	8		
							4	4	L	1-8		
							4	4	L	8-32		
										8-31	A B C D E	
A64006	CESSFORD CONST CO	LE GRAND WEST	35 T84N R17W				4	4	L	TOP 30' OF QUARRY		
		SAND AND GRAVEL										
A64506	STRATFORD GRAVEL INC	BEACH	NW 9 T85N R20W			H						
A64508	MARTIN MARIETTA AGGREGATES	NEW MARSHALLTOWN	SE 32 T84N R17W	DWU		X						
65	**MILLS DIST 4**	**CRUSHED STONE**										
A65006	SCHILDBERG CONSTRUCTION CO	MALVERN	SE 31 T72N R41W							5A-6	A B C D E	
		SAND AND GRAVEL										
A65502	AMES CONSTRUCTION	PPG BORROW	SE 12 T73N R44W									
66	**MITCHELL DIST 2**	**CRUSHED STONE**										
A66002	FALK L R- CONSTRUCTION CO	DUENOW	SE 8 T99N R17W	2.77	3iB		4	4	D	5	A B C D E	
				2.68	3		5	5	L	13		
							4	4		4		
							5	5	L	6-8	A B C D E	
							4	4	D	9-10		
							4	4	D	11-12		
A66016	FALK L R- CONSTRUCTION CO	LESCH	SW 12 T97N R17W	2.68	3i		5	5	L	6-7		
							5	5	L	1-8		
							4	4	L	9-14		
A66018	FALK L R- CONSTRUCTION CO	DYNES	SW 30 T99N R15W									
A66020	FALK L R- CONSTRUCTION CO	ASPEL	NE 3 T99N R15W									

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
66	**MITCHELL DIST 2**	**CRUSHED STONE**								**CONTINUED**		
A66022	FALK L R- CONSTRUCTION CO	WAGNER	NW 29 T98N R16W				4	4	D	5B-7		
A66024	FALK L R- CONSTRUCTION CO	GRUNDEL	7 T98N R18W									
A66026	SKYLINE MATERIALS LTD	KOSTER	NE 35 T99N R18W									
A66028	ULLAND BROTHERS INC	WINTERS	SW 23 T99N R16W									
A66030	FALK L R- CONSTRUCTION CO	SPRING CREEK	NW 29 T98N R16W									
		SAND AND GRAVEL										
A66502	FALK L R- CONSTRUCTION CO	OSAGE-SCHMIDT	NW 1 T97N R17W				4	4				
				2.63		X						
A66512	FALK L R- CONSTRUCTION CO	KLAAHSEN	SW 36 T99N R18W	2.66		X						
A66514	FALK L R- CONSTRUCTION CO	LOVIK	SW 12 T97N R17W	2.65		X						
A66516	CROELL REDI MIX	BOERJAN	W2 01 T98N R18W	2.62	2							
				2.64		X						
A66518	FALK L R- CONSTRUCTION CO	KITTLESON	NW 36 T99N R18W									
A66520	FALK L R- CONSTRUCTION CO	LESCH	12 T97N R17W	2.65		X						
67	**MONONA DIST 3**	**SAND AND GRAVEL**										
A67502	HALLETT MATERIALS CO	RODNEY	2 T85N R44W	DWU	2		3	3				
				DWU		X						
68	**MONROE DIST 5**	**CRUSHED STONE**										
A68004	DOUDS STONE LLC	EDDYVILLE-SOUTH	SW 2 T73N R16W				4	4	L	6-7		
							4	4	L	11-13		
69	**MONTGOMERY DIST 4**	**CRUSHED STONE**										
A69002	SCHILDBERG CONSTRUCTION CO	STENNETT	NE 27 T73N R38W					4		9A-9B	D	
A69006	CRUSHED AGGREGATE PRODUCTS LLC	RED OAK	NW 12 T72N R39W					4		9		
		SAND AND GRAVEL										
A69504	WESTERN ENGINEERING COMPANY	ELLIOT	13 T73N R38W			H	4	4				
70	**MUSCATINE DIST 6**	**CRUSHED STONE**										
A70002	WENDLING QUARRIES INC	MOSCOW	NW 8 T78N R02W	2.66	3i		5	5	L	11-17	D E	
				DWU	3iB		4	4	D	21A-21B		
				2.69	3iB		4	4	D	21A-24	A B C D E	
				DWU	3iB		4	4	D	21C-24		
				DWU	3i		4	4	D	28	A B C D E	
				DWU	3i		4	4	D	28-29	A B C D E	
							5	5	L	8-17		
								5	L	1-9		
A70008	BLACKHEART SLAG	MONTPELIER	SE 11 T77N R01E				2	2				
		SAND AND GRAVEL										
A70504	WENDLING QUARRIES INC	ATALISSA-MCKILLIP	NW 20 T78N R02W				4	4				
				2.66		X						

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
70	**MUSCATINE DIST 6**	**SAND AND GRAVEL**								**CONTINUED**		
A70506	CEMSTONE AGGREGATES	ACME	N 28 T76N R02W	DWU	3							
				2.67		X						
71	**O'BRIEN DIST 3**	**SAND AND GRAVEL**										
A71504	HALLETT MATERIALS CO	RABE PAULLINA	SW 15 T94N R41W				4	4				
				DWU		X						
A71528	O'BRIEN COUNTY	COUNTY	NW 27 T95N R39W			H	4	4				
A71530	HALLETT MATERIALS CO	ROHLIN	14 T97N R42W			H	4	4				
A71534	HALLETT MATERIALS CO	SHELDON/KLEINWALTERINK	CT 16 T97N R42W			H						
A71536	DAVE'S SAND AND GRAVEL INC	PHLOW CREEK	25 T97N R39W	DWU		X						
72	**OSCEOLA DIST 3**	**SAND AND GRAVEL**										
A72504	NORTHWEST R/M CONCRETE INC	OCHEYEDAN	SW 14 T99N R40W	2.71	2		3	3				
				2.68		X						
A72506	HALLETT MATERIALS CO	ASHTON	SW 28 T98N R42W	2.69	2							
				2.69		X						
A72520	NORTHWEST R/M CONCRETE INC	OCHEYEDAN NORTH	NE 23 T99N R40W			H	4	4				
A72524	STRATFORD GRAVEL INC	BOERHAVE	SE 21 T98N R42W	DWU		X						
A72528	STRATFORD GRAVEL INC	DIRKS	SW 36 T99N R40W			H						
A72530	NORTHWEST R/M CONCRETE INC	BOYD	NW 36 T99N R40W	2.65	2		3	3				
				2.66		X						
A72532	HENNING AGGREGATE	ENGEL	NW 23 T99N R40W	DWU		X						
A72534	HALLETT MATERIALS CO	ASHTON-SEIVERT	28 T98N R42W	2.68	3		3	3				
				2.63		X						
A72538	NORTHWEST R/M CONCRETE INC	MONEY PIT #1	NW 23 T99N R40W	DWU	3							
				DWU		X						
73	**PAGE DIST 4**	**CRUSHED STONE**										
A73004	SCHILDBERG CONSTRUCTION CO	SHAMBAUGH	SW 20 T67N R36W				4	4	L	4-6	D E	
		SAND AND GRAVEL										
A73508	HALLETT MATERIALS CO	SHENANDOAH-CONNELL II	NE 7 T69N R39W	DWU	2							
				2.63		X						
74	**PALO ALTO DIST 3**	**SAND AND GRAVEL**										
A74502	HALLETT MATERIALS CO	EMMETSBURG S&G	36 T96N R33W	2.71	2		3	3				
				2.62		X						
75	**PLYMOUTH DIST 3**	**SAND AND GRAVEL**										
A75502	L G EVERIST INC	AKRON	NW 1 T92N R49W	2.7	3i		3	3				
				2.65		X						
A75516	HALLETT MATERIALS CO	BRUNSVILLE	3 T92N R46W			H	4	4				
A75518	HALLETT MATERIALS CO	HINTON	NW 16 T90N R46W	DWU	3	H	3	3				
A75520	HALLETT MATERIALS CO	MERRILL	2 T91N R46W			H	4	4				

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	FRICT HMA B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
75	**PLYMOUTH DIST 3**	**SAND AND GRAVEL**								**CONTINUED**		
A75524	L&M SAND & GRAVEL INC	G DIRKSEN #2	31 T93N R44W	2.65		X						
A75526	L&M SAND & GRAVEL INC	FRITZ DIRKSEN	5 T92N R44W	DWU		X						
76	**POCAHONTAS DIST 3**	**CRUSHED STONE**										
A76004	MARTIN MARIETTA AGGREGATES	MOORE	SW 25 T92N R31W	2.63	3iB		5	5	L	1A-3	A B C D E	
							4	4	L	3		
							5	5	L	1B-3		
							4	4	L	4-10		1
							5	5	L	4-12		
		SAND AND GRAVEL										
A76514	REDINGS GRAVEL & EXCAVATING CO	MILLER	12 T93N R31W	DWU		X	4	4				
A76516	STRATFORD GRAVEL INC	JANSSEN	SW 1 T90N R31W			H	5	5				
A76518	STRATFORD GRAVEL INC	BANWART	NW 12 T93N R31W	DWU		X						
77	**POLK DIST 1**	**SAND AND GRAVEL**										
A77504	HALLETT MATERIALS CO	DENNY-JOHNSTON	8 T79N R24W	2.71	2		3	3				
				2.66		X						
A77522	HALLETT MATERIALS CO	EDM #2-VANDALIA	NW 8 T78N R23W	2.69	2		3	3				
				2.64		X						
A77530	HALLETT MATERIALS CO	NORTH DES MOINES WHITE	NE 16 T79N R24W	2.65	2		3	3				
				2.66		X						
A77534	MARTIN MARIETTA AGGREGATES	SAYLORVILLE SAND	9 T79N R24W	2.68	2		3	3				
				2.65		X						
A77538	HALLETT MATERIALS CO	NORTH DES MOINES HOVELAND	15 T79N R24W	2.66	2		3	3				
				2.66		X						
A77540	HALLETT MATERIALS CO	P-HILL EAST	9 T78N R23W	2.66		X						
78	**POTTAWATTAMIE DIST 4**	**CRUSHED STONE**										
A78002	SCHILDBERG CONSTRUCTION CO	CRESCENT	35 T76N R44W				4	4	L	25B-25C		
							5	5	L	25B-25E	A B C D E	
							5	5	L	25D-25E		
								4		26A-26E	A B C D E	
										20A-20C	D	
										27A-27B	D	
A78006	SCHILDBERG CONSTRUCTION CO	MACEDONIA	NE 28 T74N R40W							16	D	
		SAND AND GRAVEL										
A78504	WESTERN ENGINEERING COMPANY	OAKLAND	SW 23 T75N R40W	2.65	3i		4	4				
				2.65		X						
A78506	SCHILDBERG CONSTRUCTION CO	CRESCENT	NE 34 T76N R44W			H	4	4				

NOTE 1: TYPE A HMA MUST BE THE END PRODUCT FROM CRUSHING +2" MATERIAL FROM BEDS 4-10.

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR		SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
79	**POWESHIEK**	**DIST 1**	**CRUSHED STONE**										
A79002	MARTIN MARIETTA AGGREGATES		MALCOM MINE	SE 4 T80N R15W	2.58	2		4	4	L	10C-13	A B C D E	
								4	4	L	14-15		
80	**RINGGOLD**	**DIST 4**	**CRUSHED STONE**										
A80002	SCHILDBERG CONSTRUCTION CO		WATTERSON	SE 19 T67N R29W					5		7		
81	**SAC**	**DIST 3**	**SAND AND GRAVEL**										
A81502	HALLETT MATERIALS CO		SACTON-LAKEVIEW	S2 8 T86N R36W	2.72	3		3	3				
					2.67		X						
A81504	HALLETT MATERIALS CO		AUBURN	NW 2 T86N R35W	2.68	2		3	3				
					2.64		X						
A81506	HALLETT MATERIALS CO		SAC CITY	NW 36 T88N R36W	DWU		X	4	4				
A81514	TIEFENTHALER AG-LIME INC		CARNARVON S&G	NE 16 T86N R36W	2.68	2		3	3				
					2.66		X						
A81520	STRATFORD GRAVEL INC		UREN	SE 11 T87N R36W	2.67		X	3	3				
A81522	HALLETT MATERIALS CO		ULMER	SW 28 T87N R35W			H	4	4				
A81528	HALLETT MATERIALS CO		WALL LAKE	NW 18 T86N R36W	2.7	3							
					2.67		X						
A81530	HALLETT MATERIALS CO		LEITZ NORTH	SE 29 T87N R35W	DWU		X						
A81534	HALLETT MATERIALS CO		EARLY	SE 22 T89N R37W	2.68		X						
A81536	TIEFENTHALER AG-LIME INC		DAIKER	NE 12 T86N R35W	DWU		X						
A81538	BEDROCK GRAVEL CO		HEIM	SE 12 T86N R35W			H						
A81540	TIEFENTHALER AG-LIME INC		COLBURN	13 T87N R35W			H						
A81542	HALLETT MATERIALS CO		WALL LAKE BOYER	13 T86N R37W	2.7	3							
					2.66		X						
A81544	HALLETT MATERIALS CO		ULMER-MEISTER	SE 28 T87N R35W	DWU	2	X						
A81546	BEDROCK GRAVEL CO		MEISTER	SE 07 T86N R36W	DWU	3		4	4				
					DWU		X						
A81548	STRATFORD GRAVEL INC		PHILLIPS	NW 23 T87N R36W			H						
A81550	MOHR SAND, GRAVEL, & CONST LLC		HOSTENG-HAGGE	1 T87N R36W	DWU		X						
A81552	BEDROCK GRAVEL CO		BEDROCK - WL	17 T86N R36W	2.66		X						
82	**SCOTT**	**DIST 6**	**CRUSHED STONE**										
A82002	RIVERSTONE GROUP INC		MCCAUSLAND(MC39)	W2 17 T80N R04E	DWU	3i		4	4	D	17-19		1
					DWU	3		4	4	D	1-16		
											1-19	A B C D E	2
A82004	RIVERSTONE GROUP INC		NEW LIBERTY(MC41)	NE 33 T80N R01E	DWU	3iB		4	4	D	1-2	A B C D E	

NOTE 1: TOP 32’ OF BED 19
NOTE 2: BEDS 7-9 NOT TO EXCEED 25% OF LIFT WHEN PRODUCING REVETMENT STONE

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
82	**SCOTT DIST 6**	**CRUSHED STONE**								**CONTINUED**		
A82004	RIVERSTONE GROUP INC	NEW LIBERTY(MC41)	NE 33 T80N R01E	DWU	3i		4	4	D	3-4	A B C D E	
A82006	RIVERSTONE GROUP INC	LECLAIRE(MC38)	NW 35 T79N R05E	2.71	3i		4	4	D	14-29	A B C D E	
				DWU	3i		4	4	D	28-29		
				DWU	3i		4	4	D	30		
				DWU	3		4	4	D	2-13	A B C D E	
										2-32	A B C D E	
A82008	LINWOOD MINING & MINERALS CORP	LINWOOD MINE	SW 13 T77N R02E	2.67	3iB		5	5	L	20-25		
				2.7	3iB		5	5	L	27-30B	A B C D E	
				DWU	3i		4	4	D	33-41		
				DWU	3		5	5	L	19		
							4	4	L	24-25		
83	**SHELBY DIST 4**	**SAND AND GRAVEL**										
A83506	HALLETT MATERIALS CO	HARLAN-REINIG	NW 30 T79N R38W	2.65	3i							
				2.65		X						
A83508	BEDROCK GRAVEL CO	JACKSONVILLE	12 T79N R37W			H						
84	**SIOUX DIST 3**	**SAND AND GRAVEL**										
A84502	VALLEY SAND & GRAVEL	VANZEE	NW 20 T97N R46W	2.69	2		3	3				
				2.67		X						
A84506	C&R GRAVEL INC	HUDSON-OSTERCAMP	SE 7 T96N R47W	DWU	2		3	3				
				2.69		X						
A84510	L G EVERIST INC	HAWARDEN-NORTH	22 T95N R48W	2.67	3i		3	3				
				2.67		X						
A84518	STRATFORD GRAVEL INC	VON ARB	SE 15 T94N R44W			H	4	4				
A84520	SIOUX COUNTY	CHATSWORTH	SW 28 T94N R48W			H	4	4				
A84522	HALLETT MATERIALS CO	HYMAN	SW 31 T96N R47W			H	3	3				
A84524	VALLEY SAND & GRAVEL	GROTH	NW 36 T97N R48W			H	3	3				
A84528	L G EVERIST INC	HIGMAN-CHATSWORTH	W2 28 T94N R48W	2.69	2		4	4				
				DWU		X						
A84532	CLEVERINGA EXCAVATING LLC	LASSON	32 T94N R44W	DWU	2	X	3	3				
A84534	STRATFORD GRAVEL INC	CLEVERINGA	25 T95N R44W			H	3	3				
A84536	VALLEY SAND & GRAVEL	VANBEEK	NE 16 T97N R46W	DWU	3		3	3				
				DWU		X						
A84538	VALLEY SAND & GRAVEL	VAN'T HUL	SE 23 T97N R47W	DWU	3							
				2.67		X						
85	**STORY DIST 1**	**CRUSHED STONE**										
A85006	MARTIN MARIETTA AGGREGATES	AMES MINE	SW 24 T84N R24W	2.69	3iB		5	5	L	47, 49-50	A B C D E	
				2.68	3iB		5	5	L	47		
				DWU	3iB		4	4	L	49-50		

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
85	**STORY DIST 1**	**CRUSHED STONE**								**CONTINUED**		
A85006	MARTIN MARIETTA AGGREGATES	AMES MINE	SW 24 T84N R24W				4	4	L	28-39		
		SAND AND GRAVEL										
A85510	HALLETT MATERIALS CO	AMES SOUTH	18 T83N R23W	2.66	2		3	3				
				2.65		X						
A85512	INROADS PAVING & MATERIALS LLC	INROADS AMES SAND	S2 18 T83N R23W			H	3	3				
86	**TAMA DIST 1**	**CRUSHED STONE**										
A86002	WENDLING QUARRIES INC	MONTOUR	NW 9 T83N R16W	2.61	3i		5	5	L	1-7		
				2.63	3i		4	4	L	13-20		
							4	4	L	8-12	A B C D E	
							4	4	L	8-20	D	
		SAND AND GRAVEL										
A86502	WENDLING QUARRIES INC	FLINT	NW 3 T82N R15W	DWU	3i		3	3				
				2.65		X						
88	**UNION DIST 4**	**CRUSHED STONE**										
A88002	SCHILDBERG CONSTRUCTION CO	THAYER	SE 35 T72N R28W					5		25A-25E		
								5		25E		
										20B	D	
										25B-25E	A B C D E	
89	**VAN BUREN DIST 5**	**CRUSHED STONE**										
A89002	DOUDS STONE LLC	DOUDS MINE	SE 25 T70N R11W	2.5	2		4	4	D	6-13	B C D E	
				DWU	2		5	5	L	16-19		1
A89006	CESSFORD CONST CO	FARMINGTON-COMANCHE	NE 5 T67N R08W	2.69	3i		5	5	L	3		
				2.52	2		4	4	L	16-17	A B C D E	
								4		18-22		
							5	5	L	5-12	D	
										14-15	D	
										18-23	D	
A89008	DOUDS STONE LLC	SELMA-GARDNER	NW 16 T70N R11W	2.69	3		4	4	L	11	A B C D E	
							5	5	L	7-10		
							5	5	L	7-11		
							4	4	L	14-21	A B C D E	
							4	4	L	22-31	A B C D E	
							4	4	L	14-31	A B C D E	
A89012	CANTERA AGGREGATES	CRANE	NW 20 T70N R11W				4	4		9-10	D E	2

NOTE 1: BED 16 ABOVE BRECCIA THROUGH BED 19 BELOW CAP ROCK
NOTE 2: TOP 6' OF BEDS 9-10

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
90	**WAPELLO** **DIST 5**	**SAND AND GRAVEL**										
A90506	DOUDS STONE LLC	OTTUMWA SAND	5 T71N R13W	2.66		X	3	3				
A90508	GEO TECH MATERIALS	STEVENSON	SE 30 T71N R12W	2.66		X						
					3							
A90510	DOUDS STONE LLC	CHILLICOTHE	31 T73N R14W	DWU	2							
				DWU		X						
92	**WASHINGTON** **DIST 5**	**CRUSHED STONE**										
A92002	DOUDS STONE LLC	WEST CHESTER	NE 19 T76N R08W	2.64	3i		4	4	L	5-7		
				DWU	3		4	4	L	14-16	A B C D E	
										8-9	A B C D E	
A92006	DOUDS STONE LLC	COPPOCK	NE 30 T74N R07W				5	5	L	3-4		
A92008	RIVER PRODUCTS CO INC	PEPPER-KEOTA FIELD	SW 31 T76N R09W							2-20	D	
										22-28	D	
										29-36	D	
A92014	DOUDS STONE LLC	COPPOCK NORTH	SE 19 T74N R07W				4	4	L	6-8	A B C D E	
							4	4	L	13		
		SAND AND GRAVEL										
A92502	RIVER PRODUCTS CO INC	RIVERSIDE	NE 10 T77N R06W				4	4				
				2.65		X						
94	**WEBSTER** **DIST 1**	**CRUSHED STONE**										
A94002	MARTIN MARIETTA AGGREGATES	FT DODGE MINE	SW 24 T89N R29W	2.64	3iB		4	4	L	36-42	A B C D E	
A94008	STRATFORD GRAVEL INC	BUSKE	SE 36 T90N R29W				5	5	L	1-11		
		SAND AND GRAVEL										
A94502	NORTHWEST MATERIALS	YATES	SW 1 T89N R29W				4	4				
				2.63		X						
A94522	AUTOMATED S&G	CROFT	NW 14 T89N R29W	2.65		X						
A94526	STRATFORD GRAVEL INC	BUSKE	SE 36 T90N R29W				3	3				
				2.67		X						
A94528	STRATFORD GRAVEL INC	CONDON	NW 19 T90N R30W			H						
A94530	AUTOMATED S&G	RASCH	10 T89N R29W			H						
A94532	STRATFORD GRAVEL INC	REIGELSBERGER	NE 01 T89N R29W	2.67		X	4	4				
96	**WINNESHIEK** **DIST 2**	**CRUSHED STONE**										
A96002	SKYLINE MATERIALS LTD	KENDALLVILLE	NE 33 T100N R10W	2.68	3B		4	4	L	3-7		
								4		1-7		
										2-9	A B C D E	
A96004	SKYLINE MATERIALS LTD	HOVEY	SW 28 T98N R08W	2.64	3B		4	4	L	1-4		
							4	4	L	1-6		
							4	4	L	5-6		

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
96	WINNESHIEK DIST 2	CRUSHED STONE								CONTINUED		
A96004	SKYLINE MATERIALS LTD	HOVEY	SW 28 T98N R08W							2-6	A B C D E	
A96005	BRUENING ROCK PRODUCTS INC	MCGEE	NW 19 T99N R10W									
A96007	BRUENING ROCK PRODUCTS INC	JACKSON	NE 31 T96N R10W									
A96011	BRUENING ROCK PRODUCTS INC	GJETLEY	NE 08 T98N R07W	2.72	3iB		4	4	D	1-3		
A96015	BRUENING ROCK PRODUCTS INC	MARTIN	SW 18 T96N R09W				5	5	L	1-3		
A96017	BRUENING ROCK PRODUCTS INC	SKYLINE B	CT 10 T98N R08W	2.63	3B		5	5	L	1-3		
							4	4	L	4-8		
							4	4	L	4-11	A B C D E	
A96019	SKYLINE MATERIALS LTD	ENGELHARDT	NW 33 T98N R10W									
A96021	BRUENING ROCK PRODUCTS INC	QUANDAHL	23 T99N R08W									
A96040	SKYLINE MATERIALS LTD	LOCUST	NE 11 T99N R08W									
A96046	BRUENING ROCK PRODUCTS INC	SERSLAND-SMORSTAD	SE 9 T97N R07W									
A96048	BMC AGGREGATES LC	LOVE #1	NW 30 T96N R10W							1-10	D	
A96049	BMC AGGREGATES LC	LOVE #2	SW 30 T96N R10W				5	5	L	1-10	D	
A96050	BRUENING ROCK PRODUCTS INC	BULLERMAN-FESTINA	SE 14 T96N R09W					4		1-3		
A96052	SKYLINE MATERIALS LTD	ESTREM	SW 4 T97N R07W	2.62	3i		5	5	L	2-4		
							5	5	L	1-8		
										2-8	A B C D E	
A96054	SKYLINE MATERIALS LTD	HORSESHOE BEND	SW 20 T97N R09W									
A96060	SKYLINE MATERIALS LTD	BURR OAK	SE 23 T100N R09W				4	4				
										3-5	A B C D E	
A96064	BRUENING ROCK PRODUCTS INC	STIKA	NW 15 T97N R10W	2.57	3i		4	4	L	1-4A		
							4	4	D	1-8B		
										5A-8B	A B C D E	
A96072	BRUENING ROCK PRODUCTS INC	MCKENNA NORTH	SW 34 T100N R09W									
A96078	BRUENING ROCK PRODUCTS INC	BUSTA	NW 30 T96N R10W									
A96090	BRUENING ROCK PRODUCTS INC	MCKENNA SOUTH	SE 28 T99N R09W	2.62	3iB		5	5	L	1-5		
							4	4	L	6A-7	A B C D E	
A96094	SKYLINE MATERIALS LTD	CAROLAN	SE 27 T99N R09W									
		SAND AND GRAVEL										
A96502	SKYLINE MATERIALS LTD	DECORAH	NE 22 T98N R08W				4	4				
				2.63		X						
A96506	SKYLINE MATERIALS LTD	FREEPORT	NE 7 T98N R07W	2.65		X						
A96520	SKYLINE MATERIALS LTD	SWEDES BOTTOM	NE 6 T98N R08W	2.63		X	4	4				
A96522	BRUENING ROCK PRODUCTS INC	WOHLSEORS	NW 17 T98N R10W			H						
A96526	BRUENING ROCK PRODUCTS INC	STIKA	NW 15 T97N R10W			X						
A96528	BRUENING ROCK PRODUCTS INC	GJETLEY	NE 8 T98N R07W	2.65		X	4	4				
A96530	SKYLINE MATERIALS LTD	CARLSON-FREEPORT	NE 13 T98N R08W	2.63		X						

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR		SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
96	**WINNESHIEK**	**DIST 2**	**SAND AND GRAVEL**								**CONTINUED**		
A96532	BRUENING ROCK PRODUCTS INC		SCHMITT	NE 34 T96N R09W	2.66		X	3	3				
97	**WOODBURY**	**DIST 3**	**SAND AND GRAVEL**										
A97502	HALLETT MATERIALS CO		CORRECTIONVILLE-BUCK	NW 13 T89N R42W	DWU	3		3	3				
					DWU		X						
A97510	HALLETT MATERIALS CO		CORRECTIONVILLE-COCKBURN	SE 11 T88N R43W			H	3	3				
A97516	HALLETT MATERIALS CO		ANTHON	5 T87N R43W	2.72	3		3	3				
					2.67		X						
A97518	BEDROCK GRAVEL CO		SMITHLAND	35 T86N R44W	2.69	3		3	3				
					2.67		X						
A97520	BEDROCK GRAVEL CO		CORRECTIONVILLE-BREESIE	1 T88N R43W			H	4	4				
A97528	HALLETT MATERIALS CO		EDWARDS	SE 23 T89N R42W	DWU		X						
A97530	NELSTAR		NELSTAR	14 T88N R43W			H						
A97532	STRATFORD GRAVEL INC		CREASEY	SE 09 T89N R44W	DWU		X						
A97534	HALLETT MATERIALS CO		ANTHON-TRUITT	05 T87N R43W			H						
A97538	HALLETT MATERIALS CO		ANTHON-WRIGHT	NE 28 T88N R43W	DWU	3							
					2.65		X						
98	**WORTH**	**DIST 2**	**CRUSHED STONE**										
A98010	BMC AGGREGATES LC		FERTILE	SW 36 T98N R22W	2.73	3B		4	4	D	15-20	A B C D E	
					DWU	2				D	15-29		
					DWU	2		4	4	D	21-29		
								4	4	D	5-20		
								4	4	D	15-23		
									4	D	5-10		
									4	D	5-14		
A98014	FALK L R- CONSTRUCTION CO		STEVENS	NW 1 T98N R20W	DWU	3		4	4	L	4-7	A B C D E	
					2.77	3		4	4	L	8-11B	A B C D E	
					2.73	3		4	4	L	4-11B	A B C D E	
									5		1-3		
A98016	ULLAND BROTHERS INC		EMIL OLSON-BOLTON	SW 10 T99N R20W	DWU	3i		5	5	L	1		
					2.75	2		4	4	L	2-5A		
								4	4	D	3-5B		
								4	4	L	3-7		
									5		1-7		
											2-5B	A B C D E	
A98020	FALKSTONE LLC		TRENHAILE	SE 9 T99N R20W	DWU	3		5	5	L	1		
					DWU	2		4	4	D	2A1		
					DWU	2		4	4	D	2A2	A B C D E	
					DWU	2		4	4	D	2A1-2A2	A B C D E	

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
98	**WORTH** **DIST 2**	**CRUSHED STONE**								**CONTINUED**		
A98020	FALKSTONE LLC	TRENHAILE	SE 9 T99N R20W				4	4	D	2B-3		
										2B1-3	A C D E	
							4	4	D	4-7	A B C D E	
										2B1-7	A C D E	
							4	4	D	4-6		
		SAND AND GRAVEL										
A98502	FALKSTONE LLC	RANDALL TRANSIT MIX	NW 31 T100N R20W	DWU	2		4	4				
				2.66		X						
A98504	BMC AGGREGATES LC	FERTILE	NW 36 T98N R22W	DWU	2		3	3				
				2.63		X						
A98518	FALK L R- CONSTRUCTION CO	COOPER	NE 12 T98N R20W			H		4				
A98522	ULLAND BROTHERS INC	EMIL OLSON-BOLTON	SW 10 T99N R20W			H						
A98524	FALKSTONE LLC	TRENHAILE	NE 09 T99N R20W	2.64		X						
A98526	FALK L R- CONSTRUCTION CO	MOUW	SE 31 T100N R20W			H						
99	**WRIGHT** **DIST 2**	**CRUSHED STONE**										
A99002	MARTIN MARIETTA AGGREGATES	VOSS	36 T90N R26W	2.59	3i		4	4	L	8	A B C D E	
								5		3-7		
A99004	STRATFORD GRAVEL INC	LESHER	SE 26 T90N R26W									
		SAND AND GRAVEL										
A99502	WRIGHT MATERIALS CO	WRIGHT	NW 12 T93N R24W	2.65	3		3	3				
				2.63		X						
A99506	STRATFORD GRAVEL INC	LESHER	SE 26 T90N R26W			H	4	4				
A99510	STRATFORD GRAVEL INC	MEINEKE	NE 14 T90N R23W				4	4				
				2.65		X						
A99514	MARTIN MARIETTA AGGREGATES	VOSS	36 T90N R26W			H						
A99518	STRATFORD GRAVEL INC	REICHTER	SE 6 T92N R26W			H						
A99520	STRATFORD GRAVEL INC	DENNIS PETERSON	NE 15 T90N R23W			H						
A99522	STRATFORD GRAVEL INC	LOUX	SW 10 T91N R23W			H						
A99524	WRIGHT MATERIALS CO	STECHER	13 T93N R23W	2.63		X						
IL	**ILLINOIS** **DIST 5**	**CRUSHED STONE**										
AIL002	CESSFORD CONST CO	BIGGSVILLE-HENDERSON CO	17 T10N R04W							6-8	A B C D E	
AIL014	CESSFORD CONST CO	DALLAS CITY-HENDERSON CO	SW 36 T08N R07W	DWU	3i		4	4	L	5A-6		1
								4	L	2-3		
							5	5	L	8-10		
										5-6	A B C D E	
AIL020	GRAY QUARRIES INC	HAMILTON-HANCOCK CO	NE 31 T05N R08W	2.65	3		4	4	L	2	A B C D E	1

NOTE 1: AASHTO 57 GRADATION MAXIMUM

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
IL	**ILLINOIS** **DIST 5**	**CRUSHED STONE**								**CONTINUED**		
AIL020	GRAY QUARRIES INC	HAMILTON-HANCOCK CO	NE 31 T05N R08W	DWU	3		4	4	L	4		
				DWU	2		5	5		7		
AIL046	BLUFF CITY MINERALS LLC	BLUFF CITY MINERALS-MADISON CO	11 T05N R10W	DWU	2				L	1-7		
		SAND AND GRAVEL										
AIL526	BLUFF CITY MINERALS LLC	BLUFF CITY SAND-MADISON CO	14 T05N R10W	2.64		X						
	DIST 6	**CRUSHED STONE**										
AIL006	RIVERSTONE GROUP INC	MIDWAY(MC45)-ROCK ISLAND CO	SW 16 T18N R02E	DWU	3iB		4	4	D	1-5		
				DWU	3i		4	4	D	6		
										1-6	A B C D E	
AIL010	RIVERSTONE GROUP INC	ALLIED(MC30)-ROCK ISLAND CO	14 T17N R02W	DWU	3i		4	4	D	18	A B C D E	
				2.72	3i		4	4	L	16-17	A B C D E	
				2.69	3		5	5	L	7-13	A B C D E	
										14	A B C D E	
AIL016	RIVERSTONE GROUP INC	CLEVELAND(MC31)-HENRY CO	SW 31 T17N R02E	DWU	3i		4	4	D	5,6,7,8		1
										1-4	A B C D E	
										5	A B C D E	
										6	A B C D E	
										7	A B C D E	
										8	A B C D E	
AIL028	WENDLING QUARRIES INC	TURNBAUGH-MT CARROLL-CARROLL CO	SW 10 T24N R04E	DWU	3		4	4	D	3-7	A B C D E	
AIL042	MILL CREEK MINING	SAVANNA-CARROLL CO	SE 13 T24N R03E									
AIL048	MILL CREEK MINING	MILL CREEK MINING-ROCK ISLAND	25 T17N R02W									
		SAND AND GRAVEL										
AIL502	RIVERSTONE GROUP INC	ALBANY(MC@511)-ROCK ISLAND CO	SW 34 T21N R02E	2.67		H						
AIL522	RIVERSTONE GROUP INC	CORDOVA INLAND(MC17)-ROCK ISLAND CO	7 T20N R02W	DWU	3iB							
				2.67		X						
KS	**KANSAS** **DIST 4**	**SAND AND GRAVEL**										
AKS504	HOLLIDAY SAND & GRAVEL CO	FRISBIE- PLANT #3-JOHNSON CO	32 T11S R23E	2.63		X						2
AKS506	BUILDERS CHOICE AGGREGATES	OAKLAND SAND PLANT-SHAWNEE	23 T11S R16E	DWU		X						3
AKS508	BUILDERS CHOICE AGGREGATES	SILVER LAKE SAND PLANT-SHAWNEE	20 T11S R15E	DWU		X						3
MN	**MINNESOTA** **DIST 2**	**CRUSHED STONE**										
AMN004	MILESTONE MATERIALS	POOL HILL-HOUSTON CO	SW 33 T101N R04W	DWU	3i		4	4	D	1-8	A B C D E	
AMN006	SKYLINE MATERIALS LTD	OTTERNESS-FILLMORE CO	E2 11 T101N R08W	2.75	3i		4	4	D	1-2		
AMN008	MINNESOTA PAVING AND MATERIALS	NEW ULM QTZ QUARRY-NICOLLET CO	SW 35 T110N R30W	2.63	3i		2	2		BED 1		
AMN010	MARTIN MARIETTA AGGREGATES	ST CLOUD-GRANITE-STEARNS CO	19 T124N R28W	DWU	3i		2	2		FULL FACE		

NOTE 1: LEDGES 2-10 APPROVED FOR CLASS 3I CONCRETE STONE. LEDGE 2 = BED 5, LEDGES 3-9 = BEDS 6-7,AND LEDGE 10= BED 8.
NOTE 2: FOR PRESTRESS AND PRECAST APPLICATIONS ONLY
NOTE 3: FOR PRECAST PCC ONLY

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	FRICT HMA B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
MN	**MINNESOTA** DIST 2	**CRUSHED STONE**								**CONTINUED**		
AMN014	SKYLINE MATERIALS LTD	BIG SPRINGS-FILLMORE CO	SW 9 T101NR10W					4		1-6		
AMN018	ULLAND BROTHERS INC	GRAND MEADOW-MOWER CO	NE 9 T103NR14W									
AMN030	MILESTONE MATERIALS	GENGLER-HOUSTON CO	SW 16 T102NR05W	DWU	3B		4	4	D	1-2		
										1-4	A B C D E	
AMN034	MILESTONE MATERIALS	ENGRAV-HOUSTON CO	NE 24 T101NR08W	DWU	3i		4	4	D	1A-2B	A B C D E	
AMN044	MILESTONE MATERIALS	BIESANZ-WINONA CO	SW 19 T107NR07W	DWU	3i		4	4	D	1-2		
AMN046	MILESTONE MATERIALS	43 QUARRY-WINONA CO	NW 16 T106NR07W	DWU	3i		4	4	D	1-2		
AMN052	MILESTONE MATERIALS	ABNET-HOUSTON CO	SW 2 T104NR05W	DWU	3i		4	4	D	4-5		
				DWU	3		4	4	D	1-3		
		SAND AND GRAVEL										
AMN504	BRUENING ROCK PRODUCTS INC	NEW ALBIN-HOUSTON CO	9 T101NR04W			H	4	4				
AMN516	ULLAND BROTHERS INC	OLSON-FREEBORN CO	NW 31 T102NR20W	DWU		X	4	4				
AMN518	SKYLINE MATERIALS LTD	LANESBORO-FILLMORE CO	SE 7 T104NR10W	DWU		X						
AMN522	AGGREGATE INDUSTRIES	PRAIRIE ISLAND #3-GOODHUE CO	23 T114NR15W	DWU	2	X						1
AMN524	AGGREGATE INDUSTRIES	HASTINGS #2-DAKOTA CO	2 T114NR17W			H						
AMN532	ULLAND BROTHERS INC	LARSON-FREEBORN CO	25 T102NR21W			H						
AMN536	AGGREGATE INDUSTRIES	ELK RIVER-SHERBURNE CO	9 T33N R26W	DWU	3i							
				DWU		X						
AMN538	ULLAND BROTHERS INC	SHADE-MOWER CO	NW 4 T101NR18W	DWU		X						
AMN544	AGGREGATE INDUSTRIES	LAKEVILLE-DAKOTA CO	06 T114NR19W	DWU	2	X						1
AMN546	M.R. PAVING & EXCAVATION	WALLNER-BROWN CO	NW 24 T110NR30W			HL						2
AMN548	CEMSTONE AGGREGATES	HENDERSON-SIBLEY CO	23 T113NR26W	DWU	2	H						
AMN550	DAKOTA AGGREGATES	SACHS-DAKOTA CO	W2 24 T114NR19W	DWU	3i		3	3				
				DWU		X						
AMN552	EUREKA SAND AND GRAVEL INC	WINDMILL-DAKOTA CO	12 T113NR20W	DWU		X						
AMN554	ANNANDALE ROCK PRODUCTS	ANNENDALE-WRIGHT CO	35 T121NR28W	DWU		X						
AMN558	AGGREGATE INDUSTRIES	ST CROIX-CHISAGO CO	SW 21 T33N R19W	DWU	2		3	3				
				DWU		X						
AMN560	DAKOTA AGGREGATES	ROSEMOUNT-DAKOTA CO	NE 33 T115NR19W	DWU	3	X	3	3				
AMN564	MIDWEST ASPHALT CORPORATION	HASTINGS-MAR FARMS-DAKOTA CO	SE 11 T114NR17W	DWU	3	H	3	3				
AMN566	BARTON SAND & GRAVEL CO	ELK RIVER-SHERBURNE CO	10 T33N R26W	DWU	3i		3	3				
				DWU		X						
AMN568	AGGREGATE INDUSTRIES	EMPIRE-DAKOTA CO	E2 5 T114NR19W	DWU	3	X	3	3				
AMN570	WINONA AGGREGATE	WINONA AGGREGATE-WINONA CO	18 T107NR07W	DWU	3i		3	3				
AMN572	GROUND ZERO SERVICES	KUESTER #3-NICOLLETT CO	NE 15 T109NR29W	DWU		X						

NOTE 1: SAND IS LIMITED TO PRECAST ONLY
NOTE 2: APPROVED FOR CLASS L FINE AGGREGATE.

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR		SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
MN	**MINNESOTA**	**DIST 2**	**SAND AND GRAVEL**								**CONTINUED**		
AMN577	HOLCIM-MWR, INC.		GREY CLOUD SAND AND GRAVEL-WASHINGTON	SE 31 T27N R21W									
		DIST 3	**CRUSHED STONE**										
AMN024	MARTIN MARIETTA AGGREGATES		YELLOW MEDICINE-YELLOW MEDICINE CO	SW 28 T116NR39W	DWU	3i		2	2		BED 1		
AMN026	L G EVERIST INC		BIG STONE-BIG STONE CO	26 T121NR46W	DWU	3i		2	2				
AMN032	MINNESOTA PAVING AND MATERIALS		SIOUX ROCK-COTTONWOOD CO	SE 8 T107NR35W	DWU	3i		2	2		BED 1	A B C D E	1
AMN042	DUININCK BROS INC		SCOTT-ROCK CO	14 T104NR45W	DWU	3i		2	2				
AMN048	RED ROCK QUARRY		RED ROCK-COTTONWOOD CO	12 T107NR36W				2	2				
AMN050	L G EVERIST INC		JASPER STONE-ROCK CO	NE 6 T104NR46W							ENTIRE LEDGE	A B C D E	
AMN054	HARDROCK AGGREGATE		HOOGLAND QUARRY-ROCK CO	NW 23 T104NR45W	DWU	3i		2	2		1	A B C D E	
			SAND AND GRAVEL										
AMN528	HANCOCK CONCRETE CO		POPE-POPE CO	NW 8 T125NR37W	DWU	2							
					DWU		X						2
AMN540	DUININCK BROS INC		SCOTT-ROCK CO	21 T104NR44W			H						
AMN562	NORTHERN CON-AGG, LLP		LUVERNE-ROCK CO	1 T102NR45W	DWU		X						
AMN574	HENNING AGGREGATE		LINDEMANN SOUTH-NOBLES CO	SW 35 T101NR42W	DWU		X						
AMN576	HENNING AGGREGATE		TILSTRA-ROCK CO	SW 36 T101NR45W	DWU	3i	X	4	4				
AMN578	DUININCK BROS INC		KRUSE PIT-NOBLES CO	35 T101NR42W					X				
MO	**MISSOURI**	**DIST 4**	**CRUSHED STONE**										
AMO032	SCHILDBERG CONSTRUCTION CO		GRAHAM-NODAWAY CO	NW 36 T63N R37W				4	4	L	1-4		
AMO040	S&A CONSTRUCTION LTD		SOUTH ALLENDALE-WORTH CO	SW 17 T65N R30W							CAPTAIN CREEK	A B C D E	
AMO048	NORRIS QUARRIES LLC		BREIT-ANDREW CO	28 T59N R35W									
AMO060	MARTIN MARIETTA - KC DISTRICT		RANDOLPH MINE-CLAY CO	3 T50N R32W	2.68	3i				L	1-4		
			SAND AND GRAVEL										
AMO520	PIERCE SAND		STANBERRY-GENTRY CO	15 T63N R32W	2.65		X						
AMO522	PIERCE SAND		GUILFORD-NODAWAY CO	17 T62N R34W			H						
		DIST 5	**CRUSHED STONE**										
AMO002	L&W QUARRIES INC		KAHOKA-CLARK CO	NE 17 T65N R07W	DWU	2		4	4	L	2A-3B	A B C D E	3
								4	4	L	14-16		
AMO012	NORRIS QUARRIES LLC		DR. JEFFERIES-HARRISON CO	NW 3 T66N R26W				5	5	L	25C-25E		
											25C-25D	D E	
AMO018	NORRIS QUARRIES LLC		ROUTE C-DAVIESS CO	NE 30 T61N R28W				5	5	L	2-5		
AMO020	SWAN LAND IMPROVEMENT OF MO LLC		RIDGEWAY-HARRISON CO	NE 1 T64N R27W									
AMO022	NEW FRONTIER MATERIALS		IRON MT-ST FRANCIS CO	NW 31 T35N R04E	DWU	3i		3	3				
AMO024	CENTRAL STONE CO#1		HUNTINGTON-RALLS CO	NE 17 T56N R06W	2.68	3i		4	4	L	6-9		

NOTE 1: BED 1 IS THE ENTIRE FACE.
NOTE 2: FOR CONCRETE PIPE PLANT ONLY

RECENTLY ACTIVE AGGREGATE SOURCES

NOTE 3: CLASS 2 PCC APPROVAL FOR STRUCTURES ONLY.

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	FRICT HMA B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
MO	**MISSOURI DIST 5**	**CRUSHED STONE**								**CONTINUED**		
AMO024	CENTRAL STONE CO#1	HUNTINGTON-RALLS CO	NE 17 T56N R06W	2.68	3		4	4	L	6-11	A B C D E	
AMO030	KNOX COUNTY STONE CO	EDINA-KNOX CO	NE 25 T62N R12W				4	4	L	1-9		
							4	4	L	10-17		
AMO044	CENTRAL STONE CO#1	NEW LONDON-RALLS CO	NE 24 T56N R05W									
AMO046	NORRIS QUARRIES LLC	BETHANY-HARRISON CO	SW 1 T63N R28W				4	4	L	20A-20C		
							5	5	L	25A-25E		1
AMO050	NORRIS QUARRIES LLC	PRINCETON-MERCER CO	N2 3 T64N R24W				4	4	L	20A-20C		
							5	5	L	25A-25E		
										20A	A B C D E	
AMO054	CENTRAL STONE CO#1	BUTLER HILL-ST FRANCIS CO	05 T34N R06E				2	2				2
AMO056	NORRIS QUARRIES LLC	TRENTON-GRUNDY CO	24 T61N R25W									
AMO058	TRAP ROCK & GRANITE QUARRIES LLC	PIT #3-IRON CO	SE 12 T35N R03E	DWU	3i							
		SAND AND GRAVEL										
AMO502	IDEAL SAND CO AKA IDEAL R/M CO	WAYLAND-CLARK CO	SW 21 T65N R06W				3	3				
				2.66		X						
AMO516	NORRIS QUARRIES LLC	MOUNT MORIAH-HARRISON CO	12 T64N R26W	2.65		X						
AMO518	CENTRAL STONE CO#1	TAYLOR-MARION CO	NW 1 T59N R06W			H						
AMO524	CENTRAL STONE CO#1	CS61 LAGRANGE S&G-LEWIS CO	13 T60N R06W	DWU		X						
NE	**NEBRASKA DIST 3**	**SAND AND GRAVEL**										
ANE538	HANK STALP GRAVEL CO	WEST POINT-CUMING CO	SE 28 T22N R06E	2.64		X						
	DIST 4	**CRUSHED STONE**										
ANE002	MARTIN MARIETTA AGGREGATES	WEEPING WATER MINE-CASS CO	3 T10N R11E	2.68	3iB		5	5	L	10A-10B	D E	
				2.68	3iB		5	5	L	9-10B	D E	3
				2.68	3		5	5	L	9-10B	D E	4
				2.68	2		5	5	L	9-10B	D E	5
							5	5	L	9-10A&B		
ANE010	MARTIN MARIETTA AGGREGATES	FT CALHOUN-WASHINGTON CO	SE 1 T17N R12E	2.64	3iB		5	5	L	5-6		
				2.64	3iB		5	5	L	1-TOP 5' BED 4		
							4	4	L	25B-25C	D	
							5	5	L	25B-25E	A B C D E	

NOTE 1: LESS THE TOP 4' OF BEDS 25A-25E
NOTE 2: RHYOLITE PIT #1 AND GRANITE PIT #2 ARE BOTH FRICTION TYPE 2
NOTE 3: IF THE COARSE AGGREGATE DOES NOT EXCEED 45% OF THE TOTAL AGGREGATE IN THE CONCRETE MIX AND BED 9 IS LESS THAN 4’ THICK AT THE TIME OF PRODUCTION, BED 9 CAN BE INCORPORTED WITH BEDS 10A&B, WITH A DURABILITY CLASS OF 3IB.
NOTE 4: IF THE COARSE AGGREGATE DOES NOT EXCEED 50% OF THE TOTAL AGGREGATE IN THE CONCRETE MIX AND BED 9 IS LESS THAN 4’ THICK AT THE TIME OF PRODUCTION, BED 9 CAN BE INCORPORTATED WITH BEDS 10A&B, WITH A DURABILITY CLASS 0F 3.
NOTE 5: IF THE COARSE AGGREGATE EXCEEDS 50% OF THE TOTAL AGGREGATE IN THE CONCRETE MIX AND BED 9 IS LESS THAN 4’ THICK AT THE TIME OF PRODUCTION, BED 9 CAN BE IMCORPORATED WITH BEDS 10A%B, WITH A DURABILITY CLASS OF 2.

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	DUR PCC FA	FRICT HMA A	FRICT HMA B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
NE	**NEBRASKA DIST 4**	**CRUSHED STONE**								**CONTINUED**		
ANE010	MARTIN MARIETTA AGGREGATES	FT CALHOUN-WASHINGTON CO	SE 1 T17N R12E				5	5	L	25E		
										20A-20C	A B C D E	
										26A-26E	A B C D E	
ANE012	MARTIN MARIETTA AGGREGATES	SPRINGFIELD-SARPY CO	28 T13N R12E									
		CLASS V AGGREGATE FOR CONC										
ANE504	LYMAN-RICHEY SAND & GRAVEL	WATERLOO #40-DOUGLAS CO	SW 19 T15N R10E	2.62	3		4	4				
				2.62		X						
ANE544	MALLARD SAND & GRAVEL	VALLEY-DOUGLAS CO	NE 6 T15N R10E	2.62	3		4	4				
				2.62		X						
ANE548	MARTIN MARIETTA AGGREGATES	WEST CENTER SAND-DOUGLAS CO	32 T15N R10E	2.62	3		4	4				
				2.62		X						
ANE552	MARTIN MARIETTA AGGREGATES	WATERLOO SAND-DOUGLAS CO	SW 08 T15N R10E	2.62	3							
				2.62		X						
ANE560	LYMAN-RICHEY SAND & GRAVEL	PLANT #45-DODGE CO	W 06 T17N R09E	2.62	3		4	4				
				2.62		X						
ANE564	MARTIN MARIETTA AGGREGATES	NORTH VALLEY SAND-DOUGLAS CO	15 T16N R09E	2.62	3		4	4				
				2.62		X						
ANE566	LYMAN-RICHEY SAND & GRAVEL	PLANT #52-SARPY CO	SE 9 T13N R10E	2.62	3		4	4				
				2.62		X						
SD	**SOUTH DAKOTA DIST 3**	**CRUSHED STONE**										
ASD002	L G EVERIST INC	DELL RAPIDS-MINNEHAHA CO	SW 10 T104NR49W	2.64	3iB		2	2		BED 1	A B C D E	
ASD004	KNIFE RIVER	SIOUX FALLS QUARTZITE-MINNEHAHA CO	13 T101NR50W	2.64	3iB		2	2		1	A B C D E	
ASD006	L G EVERIST INC	EAST SIOUX-MINNEHAHA CO	SE 27 T101NR48W	DWU	3i		2	2		1-2B	A B C D E	
				DWU	3i		2	2		4	A B C D E	
							2	2		3		
ASD008	SPENCER QUARRIES	SPENCER-HANSON CO	24 T103NR57W		3iB		2	2		BED 1	A B C D E	1
ASD012	MITCHELL QUARRY	MITCHELL QUARRY-HANSON CO	4 T102NR59W							1	A B C D E	
		SAND AND GRAVEL										
ASD502	BOYER SAND & ROCK INC	BOYER-UNION CO	10 T95N R48W	DWU	2	H	4	4				
ASD518	MYRL & ROYS PAVING INC	MCVAY-LINCOLN CO	SE 17 T98N R48W			H	3	3				
ASD520	BOYER SAND & ROCK INC	BOYER NORTH-UNION CO	NE 1 T95N R48W			H	3	3				
ASD522	L G EVERIST INC	BROOKINGS-BROOKINGS CO	S2 31 T110NR49W	DWU		X						
ASD526	KNIFE RIVER	CORSON-MINNEHAHA CO	23 T102NR48W	DWU	2	X						
ASD528	L G EVERIST INC	EAST SIOUX-MINNEHAHA CO	SE 27 T101NR48W	DWU		X						
ASD530	KNIFE RIVER MIDWEST, LLC	SANDBULTE-UNION CO	01 T95N R48W			H	3	3				

NOTE 1: FOR PRECAST ONLY.

RECENTLY ACTIVE AGGREGATE SOURCES

CODE	OPERATOR	SOURCE NAME	LOCATION	BULK SSD SpGr	DUR PCC CA	FA	FRICT HMA A	B	L2 ROCK TYPE	BEDS	REVETMENT CLASS	NOTES
WI	**WISCONSIN DIST 2**	**CRUSHED STONE**										
AWI022	MILESTONE MATERIALS	KINGS BLUFF-LA CROSSE CO	NE 25 T18N R08W	DWU	3		4	4	D	1-4		
				DWU	2		5	5	D	1-5		1
AWI036	MILESTONE MATERIALS	TORK-WOOD CO	NW 1 T22N R05E									
AWI038	ROCKY MOUNTAIN ENTERPRISES	ATHENS-MARATHON CO	SE 24 T30N R04E	DWU	3i		2	2				
AWI040	MILESTONE MATERIALS	JACKSON COUNTY IRON MINE-JACKSON CO	22 T21N R03W				2	2				
AWI042	MILESTONE MATERIALS	MERRILLAN-CLARK CO	SW 13 T23N R03W				2	2				
AWI044	PRAIRIE SAND & GRAVEL	SLAMA-CRAWFORD CO	17 T07N R06W	DWU	3i		4	4	D	3-8A		
AWI046	COUNTY MATERIALS CORPORATION	HAHN-VERNON CO	13 T13N R06W	DWU	3		4	4	D	2-4		
		SAND AND GRAVEL										
AWI502	PRAIRIE SAND & GRAVEL	PRAIRIE DU CHIEN-CRAWFORD CO	24 T07N R07W	2.67	3i	X	4	4				
AWI506	PRAIRIE SAND & GRAVEL	KRAMER-CRAWFORD CO	NE 12 T07N R07W				3	3				
				2.68		X						
AWI508	PRAIRIE SAND & GRAVEL	BARN-CRAWFORD CO	SE 12 T07N R07W	2.69		X						
AWI512	MILESTONE MATERIALS	GIBBS-EAU CLAIRE CO	NE 25 T25N R09W			H						
AWI514	HOLST EXCAVATING	HAGER CITY-PIERCE CO	NE 33 T25N R18W	DWU	3i		3	3				
				DWU		XL						2
AWI516	MILESTONE MATERIALS	SCHEER-TREMPEALEAU CO	19 T18N R08W	DWU		X						
AWI522	COUNTY MATERIALS CORPORATION	RIB FALLS PLANT-MARATHON CO	NE 16 T29N R05W	DWU		X						
AWI524	COUNTY MATERIALS CORPORATION	HAEF-TREMPEALEAU CO	NE 19 T18N R08W	DWU	3i		3	3				2
				2.66		XL						
AWI526	HAAS & SONS	MILAS-CLARK CO	NW 3 T29N R03W	DWU		X						
AWI528	MILESTONE MATERIALS	NELSON-COLUMBIA CO	NW 12 T13N R06E	DWU	3							
				DWU		X						
AWI530	COUNTY MATERIALS CORPORATION	TOWNLINE-ROCK CO	NE 1 T01N R12E									
AWI532	ROCK ROAD COMPANIES INC.	WOLF-DOUSMAN-WAUKESHA	6 T06N R18E		2							
						X						
	DIST 6	**CRUSHED STONE**										
AWI004	MILESTONE MATERIALS	ROCK SPRINGS-SAUK CO	SW 28 T12N R05E				2	2				
AWI030	BARD MATERIALS	HAVERLAND-GRANT CO	NW 26 T02N R02W	DWU	3i		4	4	D	1-3		
AWI048	MILESTONE MATERIALS	HOGAN-GRANT CO	23 T01N R02W									
		SAND AND GRAVEL										
AWI504	BARD MATERIALS	VOGT-GRANT CO	17 T90N R03E	2.67	3i		3	3				
				2.67		X						

NOTE 1: BED 1- TOP 16' OF BED 5
NOTE 2: APPROVED FOR L CONCRETE MIXES

APPROVED PRODUCERS
WITH QC PROGRAMS

PRODUCER	STREET ADDRESS	CITY, STATE, ZIP	PHONE	PHONE 2	
A					
AGGREGATE INDUSTRIES	2915 WATERS ROAD STE 105	EAGAN, MN 55121	(651)683-0600		
ALEXANDRIA GRAVEL PRODUCT, LLC	PO BOX 38	ALEXANDRIA, MN 56308	(320)762-5620		
AMES CONSTRUCTION	2500 COUNTY RD 42W	BURNSVILLE, MN 55306	(952)435-7106		
ANDERSON AGGREGATES	PO BOX 628	HUMBOLDT, IA 50548	(515)890-1743		
ANDERSON SAND AND GRAVEL CO	2578 270TH AVE	DEWITT, IA 52742	(563)659-5506		
ARCADIA LIMESTONE CO	19011 CRYSTAL AVENUE	ARCADIA, IA 51430	(712)689-2299		
B					
BARD MATERIALS	2021 325TH AVENUE	DYERSVILLE, IA 52040	(563)875-7145	(563)875-7860	(FAX)
BARTON SAND & GRAVEL CO	7200 HEMLOCK LANE N	MAPLE GROVE, MN 55369	(763)425-4191		
BD CONSTRUCTION SERVICES LLC	P O BOX 1134	SPENCER, IA 51301	(712)363-1499		
BEDROCK GRAVEL CO	1002 HWY 59 S	SCHLESWIG, IA 51461	(712)676-3752		
BELLCO OF NEBRASKA INC	2826 SOUTH AVE	COUNCIL BLUFFS, IA 51503	(712)322-8501	(712)322-8526	(FAX)
BENTONS SAND & GRAVEL	905 CENTER STREET	CEDAR FALLS, IA 50613	(319)266-2621	(319)266-5926	(FAX)
BLACKHEART SLAG	5401 VICTORIA AVE SUITE 110	DAVENPORT, IA 52807	(563)359-8251		
BLENDED EQUIPMENT SOLUTIONS	108 5TH AVE SW	ALTOONA, IA 50009	(515)393-9631		
BMC AGGREGATES LC	101 BMC DRIVE	ELK RUN HEIGHTS, IA 50707	(319)235-6583	(319)235-7065	(FAX)
BOOMERANG CORPORATION	13225 Circle Dr., Suite A	Anamosa, IA 52205	(319)462-4435		
BOON CONSTRUCTION CO	N 5399 STATE HWY 73	NEILLSVILLE, WI 54456	(715)743-4262		
BOYER SAND & ROCK INC	4162 BIRCH AVENUE	HAWARDEN, IA 51023	(712)552-2308		
BRIDGEPORT MATERIALS	2241 PORT NEAL ROAD	SERGEANT BLUFF, IA 51054	(712)253-8449		
BROCKMAN SAND CO	2397 263RD AVE P.O. BOX 312	FORT MADISON, IA 52627	(319)372-7138		
BRUENING ROCK PRODUCTS INC	325 WASHINGTON STREET P.O. BOX 127	DECORAH, IA 52101	(563)382-2933	(563)382-8375	(FAX)
BUILDERS CHOICE AGGREGATES	6721 NW 17TH ST	TOPEKA, KS 66618	(785)233-7263		
BUSHMAN EXCAVATING INC	600 FAIRFAX ROAD	FAIRFAX, IA 52228	(319)551-8092		
C					
C&R GRAVEL INC	3864 Cheery Ave.	Hudson, SD 57034	(712)541-2130		
CANTERA AGGREGATES	1847 100TH STREET	CORYDON, IA 50060	(641)872-2800		
CAP, LLC	3150 RUSTIN STREET	SIOUX CITY, IA 51105	(402)925-8011		
CARNARVON SAND & GRAVEL	811 N. 10TH ST	DENISON, IA 51442	(712)263-3582		
CAVE CRUSHING INC	5139 B AVE	MARCUS, IA 51035	(712)261-0565		
CEMSTONE AGGREGATES	2025 CENTRE POINTE BLVD, STE 300	MENDOTA HEIGHTS, MN 55120	(651)688-9292		
CENTRAL IOWA READY MIX DBA GREEN COUNTY MATERIALS	5550 NE 22ND STREET	DESMOINES, IA 50313	(515)266-5173		
CENTRAL STONE CO#1	RR 1 P.O. BOX 236	HANNIBAL, MO 63401-9622	(573)735-4525		

APPROVED PRODUCERS
WITH QC PROGRAMS

PRODUCER	STREET ADDRESS	CITY, STATE, ZIP	PHONE	PHONE 2
C Continued				
CESSFORD CONST CO	2320 ZELLER AVENUE	LE GRAND, IA 50142	(641)479-2435	(641)479-2003 (FAX)
CESSFORD CONST CO- SE DIV	3808 OLD HWY 61	BURLINGTON, IA 52601	(319)753-2297	(319)753-0926 (FAX)
CJ MOYNA & SONS INC	24412 HWY 13	ELKADER, IA 52043	(563)245-1442	
CLEVERINGA EXCAVATING LLC	4451 KENNEDY AVE	ALTON, IA 51003	(712)737-4763	
COHRS CONSTRUCTION INC	15700 NORTH TRADEWIND DR	SPIRIT LAKE, IA 51360	(712)832-3714	
CON-STRUCT, INC.	305 S. DAYTON AVE.	AMES, IA 50010	(515)232-6443	
CONCRETE INC	1710 EAST MAIN STREET	MARSHALLTOWN, IA 50158	(641)752-3696	
CONCRETE TECHNOLOGIES INC	1001 SE 37TH ST	GRIMES, IA 50111	(515)240-9433	
CONRECO INC	4901 G STREET	OMAHA, NE 68117	(402)733-4100	(402)733-5774 (FAX)
CORELL RECYCLING	200 SOUTH 13TH STREET	WEST DES MOINES, IA 50265	(515)223-8010	
COUNTY MATERIALS CORPORATION	205 NORTH ST. POB 100	MARATHON, WI 54448	(715)848-1365	
CRAWFORD QUARRY CO	HWY 94 NW P.O. BOX 1027	CEDAR RAPIDS, IA 52046	(319)396-5705	
CROELL REDI MIX	POB 430	NEW HAMPTON, IA 50659	(641)394-3770	
CRUSHED AGGREGATE PRODUCTS LLC	2325 S. 27TH AVE	OMAHA, NE 68105	402-345-9723	
CTI READY MIX	1001 SE 37TH ST	GRIMES, IA 50111	(515)276-9567	
D				
DAVE'S SAND AND GRAVEL INC	1070 330TH STREET	EVERLY, IA 51338	(712)834-2515	
DES MOINES ASPHALT & PAVING	5109 NW BEAVER DRIVE	JOHNSTON, IA 50131	(515)262-8296	
DOUDS STONE LLC	13133 ANGLE RD SUITE B P.O. BOX 187	OTTUMWA, IA 52501	(641)683-1671	(641)683-1673 (FAX)
DUININCK BROS INC	408 6TH ST P.O. BOX 208	PRINSBURG, MN 56281	(320)978-6011	
E				
ELDER CORPORATION	5088 EAST UNIVERSITY AVE	PLEASANT HILL, IA 50327	(515)266-3111	
F				
FALK L R- CONSTRUCTION CO	227 W 4TH STREET P.O. BOX 189	ST ANSGAR, IA 50472-0189	(641)713-4569	
FALKSTONE LLC	227 W 4TH STREET P.O. BOX 189	ST ANSGAR, IA 50472-0189	(641)713-4569	
FLOYD RIVER MATERIALS	32138 HICKORY AVE	SIOUX CITY, IA 51101	(712)233-1111	
FORT DODGE ASPHALT CO	2516 7TH AVENUE SOUTH	FORT DODGE, IA 50501	(515)573-3124	
FS INC	12630 Beaverdale Rd	West Burlington, IA 52601	(319)759-0979	
G				
GEO TECH MATERIALS	13091 EAGLE DRIVE	DOUDS, IA 52551	(641)799-1235	
GIZA CONTRACTING	1739 COMMERCE RD	CRESTON, IA 50801	641-782-8820	

APPROVED PRODUCERS
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PRODUCER	STREET ADDRESS	CITY, STATE, ZIP	PHONE	PHONE 2
G Continued				
GRAY QUARRIES INC	P. O. BOX 386	HAMILTON, IL 62341	(217)847-2712	
GREENE COUNTY REDI MIX DBA HAMILTON REDI MIX	1295 ORCHARD AVE	JEFFERSON, IA 50129	(515)370-2066	
GRIMES ASPHALT & PAVING	5550 NE 22ND ST.	DES MOINES, IA 50313	(515)986-3649	
GROUND ZERO SERVICES	308 FOURTH ST	COURTLAND, MN 56021	(507)354-3973	
H				
HALLETT MATERIALS CO	2401 SE TONES DRIVE SUITE 13	ANKENY, IA 50021	(515)266-9928	(515)263-3878 (FAX)
HAMM COMPANIES	609 Perry Place PO BOX 17	Perry, KS 66073	(785)597-5111	
HANCOCK CONCRETE PRODUCTS, LLC	17 ATLANTIC AVENUE	HANCOCK, MN 56244	(320)392-5207	(320)392-5155 (FAX)
HANK STALP GRAVEL CO	1598 RIVER ROAD	WEST POINT, NE 68788	(402)372-5491	(402)372-5477 (FAX)
HARDROCK AGGREGATE	1338 221ST STREET	HARDWICK, MN 56134	(612)655-1504	
HEARTLAND ASPHALT INC	2601 SOUTH FEDERAL AVE	MASON CITY, IA 50401	(641)424-1733	
HEIMES EXCAVATING & UTIL CO	9144 SOUTH 147TH ST	OMAHA, NE 68138	(402)894-1000	
HENNING AGGREGATE	201 LOUISIANA AVE	ADRIAN, MN 56110	(612)655-1504	
HENNINGSEN CONST. INC.	1407 SW 7th	Atlantic, IA 50022		
HOLCIM-MWR, INC.	2815 Dodd Road, Suite 101	Eagan, MN 55121	(612)961-2218	
I				
IDEAL SAND CO AKA IDEAL R/M CO	3902 MT PLEASANT ST P.O. BOX 416	WEST BURLINGTON, IA 52655	(319)754-4747	
INROADS PAVING & MATERIALS LLC	4224 HUBBELL AVE STE 1	DES MOINES, IA 50317	(515)348-8148	
IOWA DRAINAGE INC	703 E. GILMAN ST P.O. BOX 7	SHEFFIELD, IA 50475	(641)892-4330	
IRON MOUNTAIN TRAPROCK CO	1325 HIGHWAY N	IRONTON, MO 63650	(314)223-0830	
J				
JB HOLLAND CONSTRUCTION INC	2092 HWY 9 WEST	DECORAH, IA 52101	(563)382-2901	
K				
KINNEY & SONS EXCAVATING AND GRADING INC.	1105 W. Washington St. Suite 102	Mt. Pleasant, IA 52641		
KNIFE RIVER	1201 WEST RUSSELL	SIOUX FALLS, SD 57104	(605)357-6000	
KNIFE RIVER MIDWEST, LLC	2220 HAWKEYE DRIVE	SIOUX CITY, IA 51104	(712)252-2766	
KNOPIK SAND & GRAVEL INC	1574 375TH AVE	ESTHERVILLE, IA 51334	(712)362-4231	
KOSSUTH COUNTY	114 W. STATE ST.	ALGONA, IA 50511	(515)295-3320	
L				
L G EVERIST INC	300 S. PHILLIPS AVE SUITE 200	SIOUX FALLS, SD 57117	(605)334-5000	

APPROVED PRODUCERS
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PRODUCER	STREET ADDRESS	CITY, STATE, ZIP	PHONE	PHONE 2	
L Continued					
L&M SAND & GRAVEL INC	426 2ND AVE NE	LE MARS, IA 51031	(712)546-5359		
L&W QUARRIES INC	P. O. BOX 335	CENTERVILLE, IA 52544	(641)437-4830	(641)437-4837	(FAX)
LA HARV CONST CO INC	P. O. BOX 267	FOREST CITY, IA 50436	(641)581-3643		
LANGMAN CONSTRUCTION, INC.	220-34TH AVENUE	ROCK ISLAND, IL 61201	(309)786-8944		
LEGACY MATERIALS	35740 UTE COURT	BOONEVILLE, IA 50038	515)336-2245		
LESSARD CONTRACTING INC	P. O. BOX 705	SERGEANT BLUFF, IA 51054	(712)252-4131		
LIBERTY READY MIX	3921 121ST ST	URBANDALE, IA 50323	(515)278-4807		
LINWOOD MINING & MINERALS CORP	5401 VICTORIA AVE SUITE 110	DAVENPORT, IA 52807	(563)359-8251	(563)344-3730	(FAX)
LUNDELL CONSTRUCTION CO, INC	1420 EAST RICHLAND ST	STORM LAKE, IA 50588	(712)732-4059		
LYMAN-RICHEY SAND & GRAVEL	4315 CUMING STREET	OMAHA, NE 68131	(402)558-2727		
M					
MALLARD SAND & GRAVEL	P. O. BOX 638	VALLEY, NE 68064	(402)359-5287		
MANATTS INC	1755 OLD 6 ROAD P.O. BOX 535	BROOKLYN, IA 52211	(641)522-9206	(641)522-9407	(FAX)
MANATTS SAND & GRAVEL	1928 340TH STREET P.O. BOX 87	TAMA, IA 52339	(641)484-4022		
MARK ALBENESIUS, INC.	608 152ND STREET	SOUTH SIOUX CITY, NE 68776	(402)494-2815	(402)494-2873	(FAX)
MARTIN MARIETTA - KC DISTRICT	7381 W. 133RD STREET - SUITE 401	OVERLAND PARK, KS 66213	(816)452-1219		
MARTIN MARIETTA AGGREGATES	11252 AURORA AVE	DES MOINES, IA 50322	(515)254-0030	(515)254-0035	(FAX)
MASHUDA CONTRACTORS, INC	POB 16	PRINCETON, WI 54968	(920)295-3329		
MAXIM TRUCKING INC	902 WEST 8TH STREET	PELLA, IA 50219	(641)780-2050		
MCCARTHY IMPROVEMENT COMPANY	5401 VICTORIA AVENUE	DAVENPORT, IA 52807	(563)529-6084		
MELLER EXCAVATING & ASPHALT , INC.	3321 190TH ST	FORT MADISON, IA 52627	(319)372-7410		
MIELKES QUARRY	13303 SPOOK CAVE RD	MCGREGOR, IA 52157	(563)539-4227		
MILESTONE MATERIALS	920 10TH AVE NORTH P.O. BOX 189	ONALASKA, WI 54650	(608)783-6411	(608)783-4311	(FAX)
MILL CREEK MINING	510 10TH AVE EAST	MILAN, IL 61264	(309)787-1414		
MILLER MATERIALS	3303 JOHN DEERE ROAD	SILVIS, IL 61282	(563)529-5060		
MINNESOTA PAVING AND MATERIALS	14475 QUIRAM DR	ROGERS, MN 55374	(763)428-8886		
MITCHELL QUARRY	41390 257th St.	Mitchell, SD 57301	(605)630-6270		
MOBILE CRUSHING & RECYCLING, INC.	2663 OSCEOLA AVENUE	OTHO, IA 50569	(515)576-8080		
MOHR SAND, GRAVEL, & CONST LLC	P.O. BOX 232 104 ASH STREET	LOHRVILLE, IA 51453	(712)210-7078		
MONEY PIT LLC	6340 180TH ST	OCHEYEDAN, IA 51354	(712)758-3729		
MURPHY HEAVY CONTRACTING CORP	101 ROOSEVELT ST	ANITA, IA 50020	(712)762-3386	(712)762-4197	(FAX)
MYRL & ROYS PAVING INC	1300 NORTH BAHNSON AVE	SIOUX FALLS, SD 57103	(605)334-3204	(605)334-0468	(FAX)
N					
NELSTAR	210 WALNUT	MERIDEN, IA 51037	(712)443-8832		

APPROVED PRODUCERS
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PRODUCER	STREET ADDRESS	CITY, STATE, ZIP	PHONE	PHONE 2
N Continued				
NEW FRONTIER MATERIALS	1325 STATE HWY N	IRON MOUNTAIN, MO 63650	(608)692-3451	
NORRIS QUARRIES LLC	219 3RD ST P.O. BOX 190	CAMERON, MO 64429	(816)324-0310	
NORTHERN CON-AGG, LLP	1450 131ST STREET	LUVERNE, MN 56156	(507)283-2124	
NORTHWEST MATERIALS	16 NORTH TAFT ST P.O. BOX 632	HUMBOLDT, IA 50548	(515)332-4208	(515)332-3653 (FAX)
NORTHWEST R/M CONCRETE INC	6340 180TH ST	OCHEYEDAN, IA 51354	(712)758-3683	
NORWALK READY MIX	1411 NW Main St	Elkhart, IA 50073	(515)829-8674	
NORWALK READY MIX	1411 NW Main St. 834 SE Creekview Dr.	Elkhart, IA 50073	(515)829-8674	
NSG, LLC	2935 HIGHWAY 18	DICKENS, IA 51333	(712)836-2345	
NU AGGREGATES	300 NORKA DRIVE	AKRON, IA 51001	(712)568-2181	
O				
OMNI ENGINEERING	2991 G Street 14012 Giles Rd., Omaha, NE 68138	Omaha, NE 68107		
P				
PARR CONTRACTING, LLC	11329 State Hwy 141	Mapleton, IA 51034	(712)870-4856	
PATRICK M PINNEY CONTRACTORS, INC	1915 FLOYD BLVD P.O. BOX 5107	SIOUX CITY, IA 51102	(712)252-2774	
PATTISON COMPANY LLC	23656 GREAT RIVER ROAD	GARNAVILLO, IA 52049	(563)964-2984	
PBI CONSTRUCTION	4953 D AVE	MARCUS, IA 51035	(712)376-4886	
PELLA CONSTRUCTION CO., LTD	P. O. BOX 25	PELLA, IA 50219	(641)628-3840	
PERFORMANCE GRADING LLC	1404 - 800TH ST	HARLAN, IA 51537	(402)682-2464	
PERU QUARRY	2587 265TH ST	PERU, IA 50222	(515)468-0315	
PETERSON CONTRACTORS INC	104 BLACKHAWK P.O. BOX A	REINBECK, IA 50669	(319)345-2713	
PETTENGILL CONC & GRAVEL INC	800 NORTH BOONE	ROCK RAPIDS, IA 51246	(712)472-2571	
PIERCE SAND	220 S. OAK	STANBERRY, MO 64489	(660)562-8645	
PNB PROCESSORS LLC	P.O. BOX 80	DENMARK, IA 52624	(319)470-0050	
PORTZEN CONSTRUCTION	205 Stone Valley Drive	Dubuque, IA 52003	(563)542-3574	
PRAIRIE SAND & GRAVEL	P. O. BOX 210	PRAIRIE DU CHIEN, WI 53821	(608)326-6471	
PRESTON READY MIX CORP	P. O. BOX 399	PRESTON, IA 52069	(563)689-3381	
Q				
QBQ INDUSTRIES, LLC	2577 SOUTH AVE	COUNCIL BLUFFS, IA 51503	(608)314-4868	
R				
RAINBOW QUARRY LLC	800 VOLNEY RD	MONONA, IA 52159	(563)535-7606	
RECKER ROCK				

APPROVED PRODUCERS
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PRODUCER	STREET ADDRESS	CITY, STATE, ZIP	PHONE	PHONE 2	
R Continued					
RECYCLED AGGREGATE PROD CO	2131 18TH STREET	SIOUX CITY, IA 51105	(712)252-7732		
RED ROCK QUARRY	12226 KNOX AVE	SANBORN, MN 56083	(507)648-3382		
REDINGS GRAVEL & EXCAVATING CO	2001 EAST OAK STREET	ALGONA, IA 50511	(515)295-3661		
REILLY CONSTRUCTION CO	110 MAIN STREET P.O. BOX 99	OSSIAN, IA 52161	(563)532-9211	(563)532-9759	(FAX)
RIEHM CONSTRUCTION CO INC	2340 9TH ST SW	WAUKON, IA 52172	(563)568-3314		
RIVER CITY STONE INC	3747 CONSTRUCTORS COURT P.O. BOX 160	KEILER, WI 53812-0160	(608)568-3433		
RIVER PRODUCTS CO INC	3273 DUBUQUE ST NE P.O. BOX 2120	IOWA CITY, IA 52244-2120	(319)338-1184	(319)353-6606	(FAX)
RIVERSTONE GROUP INC	4640 East 56th Street	Davenport, IA 52807	(309)757-8250	(309)757-8257	(FAX)
ROCK ROAD COMPANIES INC.	301 W B-R Townline Rd	Janesville, WI 53546			
ROCKY MOUNTAIN ENTERPRISES	6515 COUNTY HIGHWAY H	ATHENS, WI 54411	(715)257-1440	(715)257-1140	(FAX)
ROGERS CONCRETE CONST., INC.	22802 COUNTY RD E-34	ANAMOSA, IA 52205	(319)462-4290		
S					
S&A CONSTRUCTION LTD	P. O. BOX 20	ALLENDALE, MO 64420	(660)786-2233		
S&G MATERIALS	4213 SAND ROAD SE	IOWA CITY, IA 52240	(319)354-1667		
SADLER CONSTRUCTION INC.	1905 N Iowa Ave PO Box 185	Eagle Grove, IA 50533	515-448-3856		
SCHILDBERG CONSTRUCTION CO	P. O. BOX 358	GREENFIELD, IA 50849	(641)743-2131		
SCHMILLEN CONST INC	4772 C AVE	MARCUS, IA 51035-0488	(712)376-2249		
SEAN NEGUS CONSTRUCTION LLC	11828 N 34TH AVE	OMAHA, NE 68112	(402)740-5320		
SHIPLEY CONTRACTING	2671 240TH STREET	FORT MADISON, IA 52625	(319)372-1804		
SIEH SAND & GRAVEL	101 WEST 18TH STREET P.O. BOX 1503	SPENCER, IA 51301	(712)836-2244	(712)262-4580	
SKYLINE MATERIALS LTD	325 WASHINGTON STREET POB 127	DECORAH, IA 52101	(563)382-2933	(563)382-8375	(FAX)
SPENCER QUARRIES	25341 430TH AVE	SPENCER, SD 57374	(605)246-2344		
SPI, INC	5424 1/2 S.Lewis Blvd.	Sioux City, IA 51106	(712)540-1177		
STENSLAND GRAVEL CO	1741 ASHLEY AVE	LARCHWOOD, IA 51241	(712)477-2280		
STERZINGER CRUSHING INC	3273 290TH AVE	TAUNTON, MN 56291	(507)872-6547		
STONER SAND	33463 EAST 250TH	RIDGEWAY, MO 64481	(660)824-4211		
STRATFORD GRAVEL INC	600 HIGHWAY 175 PO BOX 229	STRATFORD, IA 50249	(515)838-2475		
STRONG ROCK & GRAVEL	721 SOUTH FRONT ST	LANSING, IA 52151	(563)880-8150		
SWAIN CONSTRUCTION INC.	6002 NORTH 89TH CIRCLE	OMAHA, NE 68134	(402)571-1110		
SWAN LAND IMPROVEMENT OF MO LLC	28542 E 230TH PLACE	RIDGEWAY, MO 64481	(660)872-6221		
SWAN ROCK & SAND PRODUCTS LLC	27453 210TH AVE P.O. BOX 111	CINCINNATI, IA 52549	(641)658-2474		
T					
TIEFENTHALER AG-LIME INC	11975 HAWTHORNE AVE P. O. BOX 157	BREDA, IA 51436	(712)673-2686		

APPROVED PRODUCERS
WITH QC PROGRAMS

PRODUCER	STREET ADDRESS	CITY, STATE, ZIP	PHONE	PHONE 2
T Continued				
TRAP ROCK & GRANITE QUARRIES LLC	11313 HWY N	IRONTON, MO 63650	(573)546-4016	
TRI STAR QUARRIES	11278 474TH ST	PLANO, IA 52581	(641)649-2666	
U				
ULLAND BROTHERS INC	2400 MYERS ROAD	ALBERT LEE, MN 56007	(507)373-1960	(507)433-1819
UNITED CONTRACTORS, INC	3101 SW BROOKSIDE DRIVE	GRIMES, IA 50111	(515)669-6897	
V				
VALLEY CONSTRUCTION COMPANY	3610 78TH AVENUE WEST	ROCK ISLAND, IL 61201	(309)787-0209	
VALLEY SAND & GRAVEL	POB 9	ROCK VALLEY, IA 51247	(712)476-2063	
VIKING AGGREGATES	5550 NE 22nd St	Des Moines, IA 50313		
W				
WEATHERTON CONTRACTING CO., INC.	307 N 16TH STREET P.O. BOX 151	BERESFORD, SD 57004	(605)763-2078	
WEBER STONE CO INC	12791 STONE CITY ROAD	ANAMOSA, IA 52205	(319)462-3581	(319)462-3585 (FAX)
WEDEKING PIT & PLANT INC.	13810 253RD AVE	SPIRIT LAKE, IA 51360	(712)336-2981	
WENDLING QUARRIES INC	P. O. BOX 230	DEWITT, IA 52742	(563)659-9181	(563)659-3393 (FAX)
WEST DES MOINES SAND CO	3888 WALNUT WOODS DR	DES MOINES, IA 50265	(515)287-2340	
WESTERN ENGINEERING COMPANY	P. O. BOX 350	HARLAN, IA 51537	(712)755-5191	
WINONA AGGREGATE	6930 WEST 5TH STREET	MINNESOTA CITY, MN 55987	(507)454-2913	
WRIGHT MATERIALS CO	1127 HWY 69 P. O. BOX 244	BELMOND, IA 50421	(641)444-3920	

IM 319

MOISTURE SENSITIVITY TESTING OF ASPHALT MIXTURES

SCOPE

This test method identifies the Iowa DOT modifications to AASHTO T324, Hamburg Wheel-Track Testing of Compacted Asphalt. Moisture susceptibility of asphalt paving mixtures is based on the stripping inflection point (SIP) calculated from test measurements.

REFERENCED DOCUMENTS:

AASHTO R 30, Standard Practice for Mixture Conditioning of Hot-Mix Asphalt (HMA)
IM 322, Sampling Uncompacted Asphalt
IM 350, Determining Maximum Specific Gravity of Asphalt Mixtures
IM 325G, Method of Test for Determining the Density of Asphalt Using the Superpave Gyratory Compactor (SGC).
AASHTO T 324, Hamburg Wheel-Track Testing of Compacted Hot-Mix Asphalt (HMA)

APPARATUS

See AASHTO T 324, Hamburg Wheel-Track Testing of Compacted Hot-Mix Asphalt (HMA)

SPECIMEN PREPARATION

For plant produced material, collect a 70 lb sample per IM 322. Prepare two gyratory test specimens per IM 325G for each test wheel conforming to the mold geometrics. Compact specimens to 7% (± 1%) air voids (93% of G_{mm} per IM 350). Apply the following Short-Term Oven Aging protocols:

1. Mix Design Testing (Lab Mixed/Lab Compacted).
   HMA and Foamed WMA: 2 hours at 275F
   WMA (additive): 2 hours at 240F

2. Production Testing (Plant Mixed/Lab Compacted)
   HMA: Minimize reheating
   WMA (foamed and additive): 2 hours at 275F

PROCEDURE

1. Place molds containing the specimens into the mounting trays, compacted side up.

2. The test temperature shall be 40°C for PG 58-XX S binders and 52-XX S or H binders. For all other grades use 50°C. Condition specimens for 45 minutes after achieving test temperature. At no time should specimens be submerged longer than 60 ± 5 minutes prior to test initiation.

3. Lower wheel onto specimens

4. Set the wheel-tracker to shut off after 20,000 passes or when the maximum LVDT displacement is 20 mm. Set the data acquisition to record deformation every 20th pass for the 1st 1,000 cycles and every 50th pass thereafter.

5. Perform the HWT test as per equipment manufacturer's instructions.

STRIPPING INFLECTION POINT (SIP)

Use the most current version of the Iowa DOT Hamburg Software (https://iowadot.gov/Construction_Materials/HMA/Hamburg_Software_version_2-01.xlsm) to determine the SIP. The software is developed for machines manufactured by Precision Metal Works and Troxler, where deformation is measured at 11 locations along the track. Contact the Bituminous Engineer when using other machines.

Measurement locations 3 through 9 will be used for analysis for samples tested on the Iowa DOT Central Materials machine. For each measurement location, the deformation curve is characterized by a 6th degree polynomial determined through least-squares multiple regression. If the curve has an R^2 greater than or equal to 90.0%, the creep and stripping slopes are calculated. If not, the sensor is considered invalid and is not used in the analysis.

The SIP, creep slope, and stripping slope are calculated for each valid sensor for each wheel. The final SIP and slopes are the average of both wheels provided both sides of the device contain the same mix. If the ratio between the average stripping slope and the average creep slope is less than 2.0, the SIP is invalid and the mix is considered passing.

Details:
The creep slope represents the rate of rutting in the linear region of the deformation curve prior to the onset of tertiary flow. The stripping slope is the rate of rutting in the linear region of the post tertiary deformation curve to the end of the test. The stripping inflection point (SIP) is the point of intersection of these two slopes.

Stripping Slope:
The stripping slope is calculated prior to the creep slope. First, the maximum rutting slope (absolute value) nearest the end of the test is found. This is accomplished by using Solver to find the pass number nearest the end of the test (strip pass) at which the first derivative of the deformation curve is smallest (rutting is a negative value). The slope of the curve is then evaluated at this pass number to give the stripping slope. The stripping slope intercept is then found using point slope form. Note: the first derivative is synonymous with slope.

Creep Slope:
To calculate the creep slope, the pass at which the absolute value of the rutting slope is the smallest prior to the strip pass is first found. This is accomplished first using Solver to find the pass (creep pass) at which the second derivative is zero (prior to the strip pass). The first derivative of the deformation curve is then evaluated at the creep pass, resulting in the creep slope.

SIP:
The intersection of the creep slope and the stripping slope is found mathematically setting the equations for both lines equal and solving for the pass number.

OPTIMIZING ANTI-STRIP ADDITIVES

During the mixture design phase, if the contractor's SIP results do not meet the minimum requirements of 2303.02, E, 2, d, the Contractor shall select an anti-strip additive for use in the mix. The anti-strip additive shall be evaluated and optimized as indicated below. The contractor will be paid at the specified rate for incorporating the anti-strip additive into the mixture provided it is effective in achieving the minimum requirements. The Engineer will obtain samples of the plant produced mixture for moisture sensitivity testing in the Central Laboratory.

To optimize an anti-strip additive, the contractor shall test the mixture at a minimum of three different dosages of the anti-strip additive to determine the effectiveness and optimum rate of addition to the mix. The dosages tested shall cover the range of dosages recommended by the supplier of the anti-strip additive or, in the case of hydrated lime, at dosages agreed to by the District Materials Engineer (DME). The Contractor shall include the data from the moisture susceptibility testing in the electronic file (SHADES) and submit the file to the DME. The DME will evaluate the data and select an optimum dosage of anti-strip additive based on effectiveness and economic evaluation.

IM 321

METHOD OF TEST FOR COMPACTED DENSITY OF ASPHALT MIXTURES (DISPLACEMENT METHOD)

SCOPE

This IM provides the method of test used in determining the bulk specific gravity (G_{mb}), bulk density, of laboratory-compacted specimens of asphalt or cores takes from compacted asphalt pavements.

APPARATUS

- A balance having a capacity of 5000 grams or more and accurate to 0.5 gram.
- Water container of sufficient size to allow a submerged sample to not touch the sides or bottom.
- Suspension apparatus (sample holder) – "wire suspending the container shall be the smallest practical size to minimize any possible effects of a variable immersed length. The suspension apparatus shall be constructed to enable the container to be immersed to a depth sufficient to cover it and the test sample during weighing. Care should be taken to ensure no trapped air bubbles exist under the specimen" (AASHTO T166-00).
- Spatula or putty knife
- Clean cloth

Balance, Sample Holder, and Water Container

PROCEDURE

SAMPLE PREPARATION

Field Cores

1. Allow the core to attain laboratory room temperature prior to testing. Cores stored in refrigerated units must be removed and allowed to stand at least 2 hours at room temperature prior to testing. Under no circumstances shall the cores be submerged in water prior to testing.

2. Clean off all loose particles, base materials, and prime oils that are stuck to the sample. The portion of the sample that needs to be cleaned may be lightly warmed and scraped with a putty knife.

3. If water was used in cutting the sample, the specimen shall be surface-dried before testing.

Laboratory Compacted Specimens

1. Cool lab-compacted specimens to laboratory room temperature before testing.

2. Clean off all loose particles that are stuck to the specimen.

TEST PROCEDURE FOR DENSITY

1. Fill the water container with water at approximately 77°F to a depth sufficient to ensure that the sample holder and sample are completely submerged during testing.

2. Connect the wire to the balance at the point provided on the balance.

3. Connect the holder to the wire and place in the water bath filled with water and tare the balance.

4. Weigh the sample in air (W_1).

5. Weigh the suspended sample completely submerged in water targeted at 77° ± 5°F (W_2). The reading must be taken when the balance stabilizes.

> **NOTE:** The balance will normally be considered to have stabilized when the weight reading doesn't change by more than 0.1 gram over a 10 to 30 second time span.

6. Remove the sample from the water and immediately, with a damp cloth, blot the free water from the surface of the sample. Then, immediately weigh the sample again in air (W_3).

> **NOTE:** Care should be taken not to rub any particles from the edges or corners when blotting the free water.

7. Calculate the G_{mb} bulk density and report the result to three decimal places.

CALCULATIONS

The calculation for determining G_{mb} is as follows:

$$G_{mb} = \frac{W_1}{W_3 - W_2}$$

DOCUMENTATION

The Engineer will manually record W_1, W_2, and W_3 on a paper copy of the HMA Core Worksheet. Upon completion of recording all weights for all cores, the Engineer and Contractor will review, agree upon, and initial the completed HMA Core Worksheet and both will retain a copy for their project files.

The HMA Core Worksheet can be downloaded at https://iowadot.gov/consultants-contractors/construction-materials/hot-mix-asphalt-hma.

IM 325G

METHOD OF TEST FOR DETERMINING THE DENSITY OF ASPHALT USING THE SUPERPAVE GYRATORY COMPACTOR (SGC)

SCOPE

This method describes the procedures for compacting asphalt samples using the SGC and determining their percent compaction. This method consolidates the provisions of AASHTO T312 and makes the following exceptions:

- Compaction temp

REFERENCED DOCUMENTS

Standard Specification 2303 Flexible Pavement
AASHTO T312 Standard Method for Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor
IM 321 Compacted Density of Asphalt Concrete
IM 357 Preparation of Bituminous Samples for Test

APPARATUS

- SGC, including a device for measuring and recording the height of the specimen throughout the compaction process. The compactor may also include a printer or a computer and software for collecting and printing the data.
- Specimen molds per AASHTO T312
- Thermometer with a range of 38 to 200°C (100 to 400°F).
- Balance with a minimum capacity of 6,000 gram and readable to at least 1 gram.
- Forced Draft Oven capable of maintaining a constant temperature of 177 ± 3°C (350 ± 5°F) and large enough to hold 2 molds and mix pans.
- Pan between approximately 200 in.^{2} and 300 in.^{2} in size.
- Safety equipment: insulated gloves, long sleeves, apron, etc.

General Equipment:

- Calibration equipment recommended by compactor manufacturer
- Paper discs with a diameter of 150 mm (6 in.).
- Lubricating materials recommended by compactor manufacturer
- Scoop or trowel for moving mixture
- Funnel or other device for ease of loading mixture into mold.

PROCEDURE

CALIBRATION

The means of calibrating the gyratory vary with different manufacturers. Refer to the operation manual and manufacturer's recommendations of the particular brand and model of gyratory available for use. Calibration of the following items should be verified at the noted intervals unless manufacturer's recommendations are more stringent:

Item	Tolerance	Calibration Interval
Height	Record to nearest 0.1 mm, Compact to 115 ± 5 mm	Daily
Angle (Internal)	1.16° ± 0.02°	See IM 208
Pressure	600 ± 18 kPa	See IM 208
Speed of Rotation	30.0 ± 0.5 gyrations per minute	See IM 208
Mold dimension	149.90 to 150.00 mm[1]	See IM 208
Platen dimension	149.50 to 149.75 mm	See IM 208

1. Molds with inside diameters up to 150.20 mm, measured according to AASHTO T312 may be used.

COMPACTOR PREPARATION

1. Turn the compactor on and allow for warm-up before proceeding.

2. Lubricate the mold or gyratory parts as recommended by the manufacturer.

3. Perform the height calibration per manufacturer's recommendations.

4. Set the specified number of gyrations, N_{des}.

TESTING

1. Obtain the material for the test specimen by following the procedure in IM 357.

2. Weigh into separate pans for each specimen the amount of asphalt mixture required which will result in a compacted specimen 115 ± 5 mm in height. Spread the material uniformly in the pan to between 1 to 2 in. of thickness.

   > This will normally be about 4700 grams.

3. Heat the pans of loose asphalt mixture in the oven to a temperature of 135 ± 2°C (275 ± 5°F) as checked by a thermometer with the bulb in the center of the mixture sample. The oven temperature may not exceed 143°C (290°F).

   > Heat WMA mixtures to 240 ± 5°F.

   a. Heat the mold, base plate, top plate (if used) and funnel (if used) in the oven for each specimen compacted for a minimum of 30 minutes. In between tests, a minimum of 5 minutes reheating should be used.

4. Place a paper disc in the bottom of the mold. Place the mixture into the mold in one lift. A funnel or other device may be used to place the mixture into the mold. Take care to avoid segregating the mix in the mold, but work quickly so that the mixture does not cool excessively during loading. Level the mix in the mold and place a paper disc on top.

5. Place the mold in the gyratory.

6. If the desired number of gyrations (N_{des}) has not been entered into the gyratory, do that now. The number of gyrations to apply is determined from the Job Mix Formula (JMF).

> **NOTE:** Some gyratories allow charging the mold with mix after the mold has been positioned in the compactor.

7. Apply the load to the mixture in the mold.

8. Apply the gyratory angle to the specimen.

9. Compact to N_{des}.

10. After compaction is complete, remove the angle from the specimen, and raise the loading ram if needed (this is done automatically on some gyratories).

11. Extrude the specimen from the mold. Take care not to distort the specimen when removing the specimen from the mold. Remove the paper discs while the specimen is still warm to avoid excessive sticking.

12. Record or print the height data for each specimen compacted.

> **NOTE:** A cooling period of 5 to 10 minutes before extruding the specimen may be necessary with some mixtures; a fan may help speed the cooling process.

13. After the specimens have cooled, they may be tested for bulk specific gravity, G_{mb} per IM 321.

IM 350

DETERMINING MAXIMUM SPECIFIC GRAVITY OF ASPHALT MIXTURES

SCOPE

This test method is intended to determine the maximum specific gravity (G_{mm}) of asphalt paving mixtures, commonly referred to as Rice specific gravity. This method uses a flask pycnometer and is based on Iowa Test Method 510 and AASHTO procedure T209. Instructions for the use of a metal bowl type pycnometer are also included.

REFERENCED DOCUMENTS

AASHTO T209 Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures

IM 357 Preparation of Bituminous Mix Sample for Test Specimens

Iowa Test Method 510 Method of Test for Determining Maximum Specific Gravity of Bituminous Paving Mixtures Using a Flask Pycnometer

APPARATUS

- Balance 10,000-gram minimum capacity and capable of weighing to the nearest 0.1 gram
- Pycnometer (four-liter, thick-walled glass Erlenmeyer flask without side discharge nozzle, with top surface of opening ground plane and smooth, and with rubber stopper hose connection)
- Mechanical vibratory device designed to firmly hold the pycnometer while vibrating.
- Vacuum pump or water aspirator for evacuating air from the pycnometer
- Manometer for measuring absolute pressure - **NOTE:** The manometer must not be connected to the vacuum tube coming from the pump, but is to be connected to the pycnometer through a separate tube.
- Thermometers, ASTM 15F (30 to 180°F) [ASTM 15C (-2 to 80°C)], softening point and a general purpose – of suitable range – with graduations every 0.5°F (0.2°C). Electronic thermometric devices meeting or exceeding these requirements may also be used.
- Large, flat, weighing pan about 16 in. x 24 in. x 2 3/4 in. (400 mm x 600 mm x 70 mm) with one end formed in the shape of a chute, for cooling and weighing the sample and for transferring the sample into the pycnometer.
- Glass 4 in. x 4 in. (100 mm x 100 mm) cover plate for accurate filling of pycnometer flask
- Scoop, spatula or trowel, and bulb syringe
- Elevated water container, with gravity discharge valve and tubing, of sufficient capacity to conduct a complete test
- Funnel for transferring sample from weighing pan into the pycnometer

- Equipment meeting AASHTO T209 will also be considered acceptable.

PROCEDURE

Pycnometer Calibration

Calibration of the pycnometer will be performed prior to being put in service. Pycnometer calibration will be performed by accurately determining the weight of water at 77 ± 0.5°F (25 ± 0.2°C) required to fill it. Accurate filling of the flask pycnometer may be ensured by the use of the cover plate. A calibration table may be produced by filling the pycnometer with water at 72°F and at 82°F (22.2°C and 27.8°C).

The following notes apply to both the Erlenmeyer flask apparatus and the alternate equipment meeting AASHTO T209.

NOTE: It is recommended that the calibration of the pycnometer be confirmed at least once a week or when a correlation problem exists.

NOTE: Cover plate and flask pycnometer combinations are not interchangeable. The cover plate used for calibration should also be used for routine testing. If a different cover plate is used, however, the calibrated weight used in G_{mm} determinations must be appropriately adjusted by the difference in weight between the original cover plate and its replacement.

Test Procedure

1. Obtain and transfer to the large, flat pan a test sample weighing between 2,000 and 2,500 grams by following the procedure in IM 357.

2. The ignition oven and G_{mm} sample portions of the field sample are normally taken first and the gyratory density samples obtained from the remainder. When there is insufficient material in the sample for all the required tests, additional material may be obtained by re-heating and re-mixing density specimens, or the sample may be obtained solely from density specimens. Results obtained with density specimen material must be so identified on the report.

   NOTE: Heat the density specimens only long enough to allow the specimens to be broken up and thoroughly mixed, using care not to overheat.

3. Separate the particles of the warmed sample so that the conglomerates of fine aggregate particles are not larger than 1/4 in. (6 mm). Use care not to fracture the aggregate particles. Discard any fractured particles found. Allow to cool to room temperature.

4. If using the flask pycnometer, add about 2 1/2 in. (60 mm) of water at about the same temperature as the sample to the calibrated pycnometer. Tare the pycnometer and water. Transfer the sample into the pycnometer. Determine the sample weight by weighing the pycnometer to the nearest 0.1 gram. Alternately, the sample weight may be determined by weighing the large, flat pan and sample contents to the nearest 0.1 gram, transferring the sample to the calibrated pycnometer, then weighing the empty pan and determining the difference.

If using the metal bowl type pycnometer, it is not required that water be added to the pycnometer prior to placing the sample in the pycnometer and the sample weight may be determined by weighing the pycnometer empty and weighing it again after the sample has been added and determining the difference.

5. If necessary, add water to cover the sample. Remove any loosely trapped air by stirring, being sure to avoid the loss of any sample.

6. Fill the flask pycnometer to about 6 in. (150 mm) from the top with water at the same temperature as that already present.

   NOTE: Water may be pulled into the vacuum pump if the pycnometer is filled too high.

   NOTE: The general-purpose thermometer or thermometric device, which has been calibrated with the ASTM 15F (15C) thermometer, may be used to determine temperatures for routine testing. The ASTM 15F (15C) thermometer must be used for determining temperatures when calibrating the pycnometer and for referee testing. If the thermometric device is calibrated and traceable to NIST standards it may be used in place of the ASTM thermometer.

7. Insert rubber stopper, or, if using a metal bowl type pycnometer, place the transparent plastic lid on the bowl, assure a proper seal and connect vacuum hose. Apply the vacuum necessary to attain between 1.0 in. and 1.2 in. (25 mm and 30 mm) of mercury (H_g) absolute pressure, as measured by a manometer, to the pycnometer contents for 15 minutes. During the vacuum period agitate the pycnometer and contents using a mechanical vibratory device. This will facilitate the removal of gas bubbles trapped in the mix and on the interior surface of the pycnometer.

8. Slowly release the vacuum and remove the vacuum apparatus from the pycnometer and fill with water to the top of the pycnometer. Allow the water filled pycnometer to stand 10 minutes

9. Tip the flask pycnometer slightly and use a glass cover plate and bulb syringe to add water until the pycnometer is completely full and no air bubbles are present. If using a metal bowl type pycnometer, place the vented metal lid on the bowl and assure that water escapes through the vent indicating that all air bubbles have been expelled.

10. Dry the outside of the pycnometer and glass plate or top with a clean cloth, chamois or paper towel, and weigh to the nearest 0.1 gram. Immediately after weighing, remove the glass plate or top and determine the temperature of the water to the nearest 0.5°F (0.2°C) with the general purpose thermometer or thermometric device.

11. Pour off water and dispose of sample.

CALCULATIONS

$$G_{mm} = \frac{W \times R}{W + W_1 - W_2}$$

Where: W = Weight of sample, g

W_1 = Weight of pycnometer filled with water at test temperature, g. (This value must be determined anytime the test temperature changes from the calibration temperature by more than ± 0.5°F (0.2°C).

W_2 = Weight of pycnometer filled with water and sample, g

R = Correction multiplier obtained from Table 2

$$R = \frac{d_t}{0.99707}$$

Where: d_t = density of water at test temperature, g/cc

0.99707 = density of water at 77°F (25°C), g/cc

Note: If the temperature of the water in the pycnometer at the completion of the test is less than 72°F (22.2°C) or greater than 82°F (27.8°C) compensation for the expansion of the asphalt must be included in the calculations as shown in AASHTO T209.

CORRECTION MULTIPLIER FOR SPECIFIC GRAVITY DETERMINATION

TABLE 1 – DENSITY OF WATER (°C)

°C	0	1	2	3	4	5	6	7	8	9
10	0.99973	0.999633	0.999525	0.999404	0.999271	0.999127	0.998971	0.998803	0.998624	0.998435
20	0.99823	0.998023	0.997802	0.997570	0.997329	0.997077	0.996816	0.996545	0.996265	0.995976
30	0.99568	0.995371	0.995056	0.994733	0.994400	0.994061	0.993714	0.993359	0.992996	0.992626
40	0.99225	0.99187	0.99147	0.99107	0.99066	0.99025	0.98982	0.98940	0.98896	0.98852
50	0.98807	0.98762	0.98715	0.98669	0.98621	0.98573				

TABLE 2 – R CORRECTION MULTIPLIER (Correction to 25°C)

°C	0	1	2	3	4	5	6	7	8	9
10	1.0027	1.0026	1.0025	1.0023	1.0022	1.0021	1.0019	1.0017	1.0016	1.0014
20	1.0012	1.0009	1.0007	1.0005	1.0003	1.0000	0.9997	0.9995	0.9992	0.9989
30	0.9986	0.9983	0.9980	0.9976	0.9973	0.9970	0.9966	0.9963	0.9959	0.9955
40	0.9952	0.9948	0.9944	0.9940	0.9936	0.9932	0.9927	0.9923	0.9919	0.9914
50	0.9910	0.9905	0.9900	0.9896	0.9891	0.9886				

TABLE 3 – DENSITY OF WATER (°F)

°F	0	1	2	3	4	5	6	7	8	9
60	0.999040	0.998982	0.998859	0.998764	0.998664	0.998562	0.998455	0.998346	0.998232	0.998115
70	0.997997	0.997874	0.997749	0.997619	0.997489	0.997353	0.997216	0.997074	0.996929	0.996783
80	0.996632	0.996481	0.996325	0.996168	0.996006	0.995844	0.995676	0.995505	0.995335	0.995159
90	0.994984	0.994802	0.994622	0.994436	0.994251	0.994059	0.993866	0.993673	0.993475	0.993277
100	0.993074	0.992872	0.992664	0.992458	0.992246	0.992030	0.99182	0.99160	0.99138	0.99116
110	0.99093	0.99071	0.99048	0.99025	0.99001	0.98977	0.98954	0.98930	0.98906	0.98881
120	0.98857	0.98832	0.98807	0.98782	0.98757	0.98731	0.98705	0.98679	0.98653	0.98626
130	0.98606									

TABLE 4 – R CORRECTION MULTIPLIER (Correction to 77°F)

°F	0	1	2	3	4	5	6	7	8	9
60	1.0020	1.0019	1.0018	1.0017	1.0016	1.0015	1.0014	1.0013	1.0012	1.0010
70	1.0009	1.0008	1.0007	1.0005	1.0004	1.0003	1.0001	1.0000	0.9999	0.9997
80	0.9996	0.9994	0.9992	0.9991	0.9989	0.9988	0.9986	0.9984	0.9983	0.9981
90	0.9979	0.9977	0.9975	0.9974	0.9972	0.9970	0.9968	0.9966	0.9964	0.9962
100	0.9960	0.9958	0.9956	0.9954	0.9952	0.9949	0.9947	0.9945	0.9943	0.9941
110	0.9938	0.9936	0.9934	0.9932	0.9929	0.9927	0.9924	0.9922	0.9920	0.9917
120	0.9915	0.9912	0.9910	0.9907	0.9905	0.9902	0.9899	0.9897	0.9894	0.9892
130	0.9890									

IM 380

VACUUM-SATURATED SPECIFIC GRAVITY & ABSORPTION OF COMBINED OR INDIVIDUAL AGGREGATE SOURCES

SCOPE

This test method is intended to determine the specific gravity and absorption of combined aggregate for asphalt mix designs only. This method uses a flask pycnometer and a vacuum system.

REFERENCED DOCUMENTS

AASHTO T209 Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures
IM 336 Methods of Reducing Aggregate Field Samples to Test Samples

TEST METHOD

A. Apparatus

1. Balance, 10,000-gram minimum capacity and capable of weighing to the nearest 0.1 gram.

2. Pycnometer, four-liter, thick-walled, glass Erlenmeyer flask (without side discharge nozzle, with top surface of opening ground plane and smooth, and with rubber stopper hose connection) or other suitable pycnometer.

3. Vacuum pump or water aspirator for evacuating air from the pycnometer.

4. Thermometers, ASTM 15F (30°F to 180°F [ASTM 15C (2°C to 80°C)]), softening point and a general-purpose thermometer of suitable range with graduations every 0.5°F (0.2°C).

5. Large, flat weighing pan about 16 in. by 24 in. by 2 3/4 in. with one end formed in the shape of a chute, for cooling and weighing the sample and for transferring the sample into the pycnometer.

6. Glass 4 in. by 4 in. cover plate for accurate filling of pycnometer flask. This is for use with the glass flask.

7. Scoop, spatula or trowel, and bulb syringe.

8. Elevated water container, with gravity discharge valve and tubing, of sufficient capacity to conduct a complete test.

9. Funnel for transferring sample from weighing pan into the pycnometer.

> **<u>NOTE</u>:** The manometer must not be connected to the vacuum tube coming from the pump, but is to be connected to the pycnometer through a separate tube.

10. Manometer for measuring absolute pressure.

11. Equipment meeting AASHTO T-209 or ASTM D-2041 will also be considered acceptable.

B. Pycnometer Calibration

Prior to being put in service, a pycnometer calibration will be performed by accurately determining the mass of water at 77°F ± 0.5°F (25°C ± 0.2°C) required to fill the pycnometer. Accurate filling of the pycnometer is assured by the use of a cover plate.

> **<u>NOTE</u>:** It is necessary to verify the calibration of each pycnometer before using and to periodically check the calibration thereafter to detect any change in weight due to wear or changes in the mineral content of the water. This is done by accurately filling the pycnometer with water at any temperature recorded on the calibration sheet, drying the outside of the pycnometer, and weighing the pycnometer, water, and proper cover plate.

> **<u>NOTE</u>:** Cover plate and pycnometer combinations are not interchangeable! The cover plate used for calibration should also be used for routine testing. If a different cover plate is used, however, the calibrated weight used in the specific gravity determinations must be appropriately adjusted by the difference in weight between the original cover plate and its replacement.

This applies to both Erlenmeyer flask apparatus and the alternate equipment identified in A11 above.

C. Specific Gravity Test Procedure

1. Obtain a test sample of at least 2000 grams of oven dried individual source aggregate or combined aggregate. Combined aggregate samples are built up to asphalt mix design proportions by following IM 336.

2. Weigh the oven-dried test sample to the nearest 0.1 gram.

3. Transfer the sample into the calibrated pycnometer, which contains water to a depth of about 2 1/2 in.

4. Add water, if necessary to cover the sample. Agitate the sample to remove any loosely trapped air.

5. Insert rubber stopper and connect vacuum hose. Apply a vacuum to attain between 1.0 in. and 1.2 in. (25.5 mm and 30 mm) H_g (mercury) absolute pressure, as measured by a manometer, to the flask contents for 30 minutes. During the vacuum time period agitate the flask and contents continually by using a mechanical vibratory device, or manually by shaking and rolling the flask at intervals of about 2 minutes. This will facilitate the removal of air bubbles trapped in the sample and on the interior surface of the glass.

6. Remove the vacuum apparatus from the pycnometer and fill with water to the top of the neck of the pycnometer. Allow the water filled pycnometer to stand for 20 minutes.

7. Tip the pycnometer slightly and use a glass cover plate and bulb syringe to add water until the pycnometer is completely full.

8. Dry the outside of the pycnometer and glass plate with a clean cloth, chamois or paper towel, and weigh to the nearest 0.1 gram. Immediately after weighing, remove the glass plate and determine the temperature of the water to the nearest 0.5°F (0.2°C) degree with the general-purpose thermometer.

D. Calculation of Vacuum Apparent Specific Gravity (G_{sa})

Calculate the vacuum apparent specific gravity (lines 1 through 11 of the data sheet, Appendix A) of the aggregate sample as follows:

$$\text{Apparent Specific Gravity} = \frac{WR}{W + W_1 - W_2}$$

Where: W = weight of dry sample, grams

W_1 = weight of pycnometer filled with water at test temperature, grams. (This value must be determined anytime the test temperature changes from the calibration temperature by more than ± 0.5°F (± 0.3°C)

W_2 = weight of pycnometer filled with water and sample, grams

R = correction multiplier (from table)

$$R = \frac{d_t}{0.99707}$$

Where: d_t = density of water at test temperature, grams/cc (from table)
0.99707 = density of water at 77°F (25°C) grams/cc

E. Absorption Test Procedure

1. After determining the specific gravity, pour water from the sample through a No. 200 (75-µm) mesh sieve.

2. Remove the sample from the flask and wash the sample over a No. 200 (75-µm) mesh sieve.

3. Split the sample on a No. 8 (2.36-mm) sieve. This may require using water. If water is used, the wash water from the fine portion is passed through a No. 200 (75-µm) sieve.

> **<u>NOTE</u>:** If less than 10% of the material passes the No. 8 (2.36-mm) sieve, the material passing the No. 8 (2.36-mm) sieve may be discarded.
>
> **<u>NOTE</u>:** If more than 90% of the material passes the No. 8 (2.36-mm) sieve, the material retained on the No. 8 (2.36-mm) sieve may be discarded.

4. Place the coarse portion [plus No. 8 (2.36-mm) sieve] of the sample on a bath towel and roll the sample around by holding on to each end of the towel. (The towel will absorb most of the free water from the aggregate particles.)

5. Place the coarse portion of the sample in a large, flat pan or on a clean hard surface. Observe when the particles develop a dull appearance and leave no streaks of moisture when moved indicating a saturated surface-dry (SSD) condition. This usually requires only about 2 to 3 minutes.

6. After the coarse particles obtain an SSD appearance immediately weigh to the nearest 0.1 gram.

7. Place the fine portion [minus No. 8 (2.36-mm) sieve] in a large pan and dry to a SSD condition by stirring and turning the particles continuously so they will dry evenly. When the material becomes free flowing and there is no tendency for the finer particles to adhere to a cool, dry steel spatula, the material is considered to be in a SSD condition.

   To aid the removal of the free water, the fine sample may be placed in a 150-mm or larger Buchner funnel containing an appropriate filter paper. A vacuum is then applied to the flask, which collects the water until the water is dripping from the funnel at a rate of 1 to 2 drops per second. The fine sample is then transferred to the large, flat pan for drying to a SSD condition as above.

   The use of a hot plate placed in front of, or in back of, a fan to circulate air over the sample to aid in obtaining an SSD condition is permissible.

> **<u>NOTE</u>:** Free water accumulates at the bottom of the pan. Paper towel may be used to dry the pan. **DO NOT** attempt to dry the sample with the paper towel.

8. Immediately after the fine portion of the sample has attained an SSD condition, weigh to the nearest 0.1-gram.

9. Re-combine the coarse and fine portions of the saturated-surface-dry sample, dry to a constant weight (mass) on a hot plate or in an oven and weigh to the nearest 0.1-gram (coarse and fine portions may be dried separately).

F. Calculation of Water Absorption, %Abs (Vacuum Method)

Calculate the water absorption (lines 12 through 17 of the data sheet, Appendix A) of the aggregate sample as follows:

$$\%\ \text{Abs} = \frac{(W_a + W_b - W_c)(100)}{W_c}$$

Where: W_a = saturated surface-dry (SSD) weight of coarse portion
W_b = saturated surface-dry (SSD) weight of fine portion
W_c = combined dry weight of coarse and fine portion

G. Bulk Dry Specific Gravity (G_{sb})

This test method determines the vacuum apparent specific gravity (G_{sa}) of individual or combined aggregate sources. For the purpose of asphalt mix design; the aggregate bulk specific gravity (G_{sb}) is needed. Aggregate bulk specific gravity (lines 18 through 20 of the data sheet, Appendix A) may be determined from apparent specific gravities as follows:

$$G_{sb} = \frac{G_{sa}}{1 + (\text{ABS})(G_{sa})}$$

Where: ABS = %Abs/100
%Abs = percent absorption

CORRECTION MULTIPLIER FOR SPECIFIC GRAVITY DETERMINATION

TABLE 1 – DENSITY OF WATER (°C)

°C	0	1	2	3	4	5	6	7	8	9
10	0.99973	0.999633	0.999525	0.999404	0.999271	0.999127	0.998971	0.998803	0.998624	0.998435
20	0.99823	0.998023	0.997802	0.997570	0.997329	0.997077	0.996816	0.996545	0.996265	0.995976
30	0.99568	0.995371	0.995056	0.994733	0.994400	0.994061	0.993714	0.993359	0.992996	0.992626
40	0.99225	0.99187	0.99147	0.99107	0.99066	0.99025	0.98982	0.98940	0.98896	0.98852
50	0.98807	0.98762	0.98715	0.98669	0.98621	0.98573				

TABLE 2 – R CORRECTION MULTIPLIER (Correction to 25°C)

°C	0	1	2	3	4	5	6	7	8	9
10	1.0027	1.0026	1.0025	1.0023	1.0022	1.0021	1.0019	1.0017	1.0016	1.0014
20	1.0012	1.0009	1.0007	1.0005	1.0003	1.0000	0.9997	0.9995	0.9992	0.9989
30	0.9986	0.9983	0.9980	0.9976	0.9973	0.9970	0.9966	0.9963	0.9959	0.9955
40	0.9952	0.9948	0.9944	0.9940	0.9936	0.9932	0.9927	0.9923	0.9919	0.9914
50	0.9910	0.9905	0.9900	0.9896	0.9891	0.9886				

TABLE 3 – DENSITY OF WATER (°F)

°F	0	1	2	3	4	5	6	7	8	9
60	0.999040	0.998982	0.998859	0.998764	0.998664	0.998562	0.998455	0.998346	0.998232	0.998115
70	0.997997	0.997874	0.997749	0.997619	0.997489	0.997353	0.997216	0.997074	0.996929	0.996783
80	0.996632	0.996481	0.996325	0.996168	0.996006	0.995844	0.995676	0.995505	0.995335	0.995159
90	0.994984	0.994802	0.994622	0.994436	0.994251	0.994059	0.993866	0.993673	0.993475	0.993277
100	0.993074	0.992872	0.992664	0.992458	0.992246	0.992030	0.99182	0.99160	0.99138	0.99116
110	0.99093	0.99071	0.99048	0.99025	0.99001	0.98977	0.98954	0.98930	0.98906	0.98881
120	0.98857	0.98832	0.98807	0.98782	0.98757	0.98731	0.98705	0.98679	0.98653	0.98626
130	0.98606									

TABLE 4 – R CORRECTION MULTIPLIER (Correction to 77°F)

°F	0	1	2	3	4	5	6	7	8	9
60	1.0020	1.0019	1.0018	1.0017	1.0016	1.0015	1.0014	1.0013	1.0012	1.0010
70	1.0009	1.0008	1.0007	1.0005	1.0004	1.0003	1.0001	1.0000	0.9999	0.9997
80	0.9996	0.9994	0.9992	0.9991	0.9989	0.9988	0.9986	0.9984	0.9983	0.9981
90	0.9979	0.9977	0.9975	0.9974	0.9972	0.9970	0.9968	0.9966	0.9964	0.9962
100	0.9960	0.9958	0.9956	0.9954	0.9952	0.9949	0.9947	0.9945	0.9943	0.9941
110	0.9938	0.9936	0.9934	0.9932	0.9929	0.9927	0.9924	0.9922	0.9920	0.9917
120	0.9915	0.9912	0.9910	0.9907	0.9905	0.9902	0.9899	0.9897	0.9894	0.9892
130	0.9890									

GENERAL REWRITE – PLEASE READ CAREFULLY.

AGGREGATE SPECIFIC GRAVITY
FOR COMBINED OR INDIVIDUAL SOURCES

County: Project No.: Date:

Project Location:

Contractor:

Mix Type: Course: Size:

Aggregate Sources: Size:

Sample Identification: Lab. No.

1	Pycnometer No.		
2	Sample Weight	W	
3	Weight Pyc. & Water@Test Temp. (Calibration)	W1	
4	Total Weight (Line 2 + Line 3)	W+W1	
5	Weight Pyc. & Sample & Water	W2	
6	Weight Displaced Water (Line 4 - Line 5)		
7	Test Temp. of Water, (Degrees F)		
8	R Multiplier (Chart)	R	
9	Vac. Apparent Sp. Gr. {(W) X (R)/(Line 6)}	G_{sa}	

		+#8	-#8
10	Weight SSD Material		
11	Weight of Dry Material		
13	Weight of Absorbed Water (Line 10 - Line 11)		
14	Total Weight Absorbed (Line 13 (+#8 + -#8))		
15	Total Weight Dry Material (Line 11 (+#8+ -#8))		
16	% Abs, {(100) X (Line 14)/(Line 15)}		

17	ABS=%Abs/100, (Line 16/100)		
18	1 + (ABS) X (Gsa), {(1+(Line 17)) X (Line 9)}		
19	Bulk Dry Sp. Gr. (Line 9/Line 18)	G_{sb}	

IM 500

****THIS IS A NEW IM. – PLEASE READ CAREFULLY.****

ASPHALTIC TERMINOLOGY

SCOPE

This IM describes the terminology associated with asphaltic materials.

LIQUID ASPHALT TERMINOLOGY

Asphalt Cement – See **Binder**

Binder – A dark brown to black cementitious material, which occurs in nature or is obtained in petroleum processing. Also commonly referred to Asphalt Cement (AC).

Bitumen – See **Binder**

Cutback Asphalt – Liquid asphalt composed of asphalt binder and a petroleum solvent. Cutback asphalts have three types (Rapid Curing (RC), Medium Curing (MC), and Slow Curing (SC)). The petroleum solvent, also called diluents, can have high volatility (RC) to low volatility (SC).

Emulsified Asphalt – Composed of asphalt binder and water, and a small quantity of emulsifying agent, which is similar to detergent. They may be of either the Anionic, electro-negatively-charged asphalt globules, or Cationic, electro-positively-charged asphalt globules types, depending upon the emulsifying agent. Emulsified asphalt is produced in three grades (Rapid-Setting (RS), Medium-Setting (MS), and Slow-Setting (SS)).

Flux or Flux Oil – A thick, relatively nonvolatile fraction of petroleum, which may be used to soften asphalt binder to a desired consistency.

Foamed Asphalt – A combination of high temperature asphalt binder and water to produce foaming.

Gilsonite – A form of natural asphalt, hard and brittle, which is mined.

Modified Binder – These are asphalt binders, which have been physically- and/or chemically-altered (usually with an additive) to bring the characteristics of the binder to what is desired for the application. This process includes polymer modification.

Performance Graded Asphalt (PG) – The identification associated with the grading of the binder. Prior identification methods have been penetration and viscosity grading. For example, a PG 64-22 would indicate a performance-graded binder with a high temperature confidence of 64°C and a low temperature confidence of -22°C.

Viscosity – The property of a fluid or semifluid that enables it to resist flow. The higher the viscosity, the greater the resistance to flow.

AGGREGATE TERMINOLOGY

Absorption – The property of an aggregate particle to take in and hold a fluid. For our purposes usually asphalt binder or water.

Aggregate – Any hard, inert, mineral material used for mixing in graduated fragments. It includes sand, gravel, crushed stone, and slag.

Coarse Aggregate – The aggregate particles retained on the #4 (4.75 mm) sieve.

Coarse-Graded Aggregate – A blend of aggregate particles having a continuous grading in sizes of particles from coarse through fine with a predominance of coarse sizes. A gradation below the maximum density line.

Cold-Feed Gradation – The aggregate proportioning system employing calibrated bins to deliver aggregate to the dryer (see IM 508 for additional information).

Fine Aggregate – Aggregate particles passing the #4 (4.75 mm) sieve.

Fine-Graded Aggregate – A blend of aggregate particles having a continuous grading in sizes of particles from coarse through fine with a predominance of fine sizes. A gradation above the maximum density line.

Gradation – The description given to the proportions of aggregate on a series of sieves. Usually defined in terms of the % passing successive sieve sizes.

Lime – A product used to enhance the bond between aggregate and asphalt binder. It is composed of dust from crushed limestone. Hydrated lime is often specified for surface mixes.

Manufactured Sand –The predominately minus #4 (4.75 mm) material produced from crushing ledge rock or gravel.

Mineral Filler – A finely divided mineral product at least 70 percent of which will pass a #200 (75 µm) sieve. Pulverized limestone is the most commonly manufactured filler, although other stone dust, hydrated lime, Portland cement, fly ash and certain natural deposits of finely divided mineral matter are also used.

Natural Sand – A loose, granular material found in natural deposits.

Open-Graded Aggregate – A blend of aggregate particles containing little or no fine aggregate and mineral filler and the void spaces in the compacted aggregate are relatively large.

Slag – A byproduct of steel production.

Well-Graded Aggregate – Aggregate that is uniformly graded from coarse to fine.

MIX TERMINOLOGY

Asphalt Cement Concrete – See **Hot Mix Asphalt**

Asphalt Leveling Course – Lift(s) of HMA of variable thickness used to eliminate irregularities in the contour of an existing surface prior to overlay.

Asphalt Overlay – One or more lifts of HMA constructed on an existing pavement. The overlay may include a leveling course to correct the contour of the old pavement, followed by uniform course or courses to provide needed thickness.

Base Course – Lift(s) of HMA pavement placed on the subgrade or subbase on which successive layers are placed.

Binder Course – See **Intermediate Course**

Full-Depth® Asphalt Pavement – The term Full-Depth® certifies that the pavement is one in which asphalt mixtures are employed for all courses above the subgrade or improved subgrade. A Full-Depth® asphalt pavement is laid directly on the prepared subgrade.

Hot Mix Asphalt (HMA) – Asphalt binder/aggregate mixture produced at a batch or drum-mixing facility that must be spread and compacted while at an elevated temperature. To dry the aggregate and obtain sufficient fluidity of the binder, both must be heated prior to mixing – giving origin to the term “hot mix.”

Intermediate Course – An HMA pavement course between a base course and a surface course.

Job Mix Formula (JMF) – The JMF is the mix design used to begin a HMA project. It is also used as the basis for the control of plant produced mixture. It sets the proportions of the aggregate and amount of asphalt binder.

Mixed-In-Place (Road Mix) – An HMA course produced by mixing mineral aggregate and cutback or emulsified asphalt at the road site by means of travel plants, motor graders, or special road-mixing equipment.

Plant Mix – A mixture, produced in an asphalt mixing facility that consists of mineral aggregate uniformly coated with asphalt binder, emulsified asphalt or cutback asphalt.

Sand Asphalt – A mixture of sand and asphalt binder, cutback or emulsified asphalt. It may be prepared with or without special control of aggregate grading and may or may not contain mineral filler. Either mixed-in-place or plant-mix construction may be employed.

Sheet Asphalt – A hot mixture of binder with clean angular, graded sand and mineral filler.

Surface Course – The top lift(s) of HMA pavement, sometimes called asphalt wearing course.

Warm-Mix Asphalt (WMA) – Similar to HMA but produced by using additives that allow the mix to be produced, placed and compacted at lower temperatures.

MISCELLANEOUS TERMINOLOGY

Asphalt Joint Sealer – An asphalt product used for sealing cracks and joints in pavements and other structures.

Average Absolute Deviation (AAD) – The absolute value of the difference of a test result from a specified value, averaged for a specified set of values.

Cold-In-Place Recycling – A method of rehabilitating the HMA surface by milling, adding a stabilizing agent, relaying and compacting in a continuous operation (see IM 504 for additional information).

Durability – The property of an asphalt paving mixture that describes its ability to resist the detrimental effects of air, water and temperature. Included under weathering are changes in the characteristics of asphalt, such as oxidation and volatilization, and changes in the pavement and aggregate due to the action of water, including freezing and thawing.

Fatigue Resistance – The ability of asphalt pavement to withstand repeated flexing caused by the passage of wheel loads.

Field Density – The density ($G_{mb\ (field)}$) of HMA based on field roller compaction.

Field Voids – The percent by volume of air voids in cores cut from the finished pavement.

Flexibility – The ability of an asphalt paving mixture to be able to bend slightly, without cracking, and to conform to gradual settlements and movements of the base and subgrade.

Fog Seal – A light application of emulsion diluted with water that is applied without mineral aggregate cover.

Lab Density – The density ($G_{mb\ (lab)}$) of HMA based on laboratory compaction.

Lab Voids – The percent by volume of air voids in laboratory compacted specimens.

Pay Factor – A calculated multiplier used to determine adjustments to payment to the contractor. Pay factors greater than 1.000 are referred to as "incentive" and pay factors less than 1.000 are referred to as "disincentive" or "penalties"

Percent Within Limits (PWL) – A statistical estimation of the percentage of a material that falls between specified limits based on sampling and testing of the material. PWL is used to calculate the pay factor.

Permeability – The resistance that an asphalt pavement has to the passage of air and water into or through the pavement.

Recycled Asphalt Pavement (RAP) – HMA removed and processed, generally by milling. This material may be stored and used in mixtures in addition to virgin aggregate and binder. This is also referred to as Reclaimed Asphalt Pavement.

Recycled Asphalt Shingles (RAS) – Roofing shingles, either waste from a shingle manufacturer or tear off shingles from reroofing operations. Shingles contain a high percentage of asphalt as well as fibers and fine aggregate. Shingles are processed into a fine material and handled similar to RAP.

Seal Coat – A thin asphalt surface treatment used to waterproof and improve the texture of an asphalt wearing surface. Depending on the purpose, seal coats may or may not be covered with aggregate. The main types of seal coats are aggregate seals, fog seals, emulsion slurry seals and sand seals.

Skid Resistance – The ability of asphalt paving surface, particularly when wet, to offer friction against the tire surface.

Slurry Seal – A mixture of emulsified asphalt, fine aggregate and mineral filler, with water added to produce flowing consistency.

Specific Gravity – The weight to volume relationship of material in relation to water.

Stability – The ability of asphalt paving mixtures to resist deformation from imposed loads. Unstable pavements are marked by channeling (ruts), and corrugations (washboarding).

Surface Treatments – A broad term embracing several types of asphalt or asphalt-aggregate applications, usually less than 1 in. (25 mm) thick, to a road surface. The types range from a light application of emulsified or cutback asphalt (Fog seal) to a single or multiple surface layers made up of alternating applications of asphalt and aggregate (chip seal).

Tack Coat – A very light application of asphalt, usually asphalt emulsion diluted with water. It is used to ensure a bond between the existing pavement surface and the overlay.

CONSTRUCTION TERMINOLOGY

Batch Plant – This type of HMA production plant is used to produce individual batches of mix by making use of a pugmill (see IM 508 for additional information).

Certified Plant Inspection (CPI) – A specified method of quality control using a Certified Plant Inspector (see Section 2521 of the Standard Specification for additional information).

Cold-Feed – The device used to combine the various aggregates, in the correct proportions.

Drum Plant – This type of HMA production plant is a continuously operating plant, which mixes the aggregate, asphalt binder and RAP (if used) in the drum (See IM 508 for additional information).

Quality Management of Asphalt (QMA) – A specified quality control procedure where the contractor is responsible for the mix design and the control of the mix properties during production (see IM 511 for additional information). The agency is responsible for quality assurance and verification.

Workability – The ease with which paving mixtures may be placed and compacted.

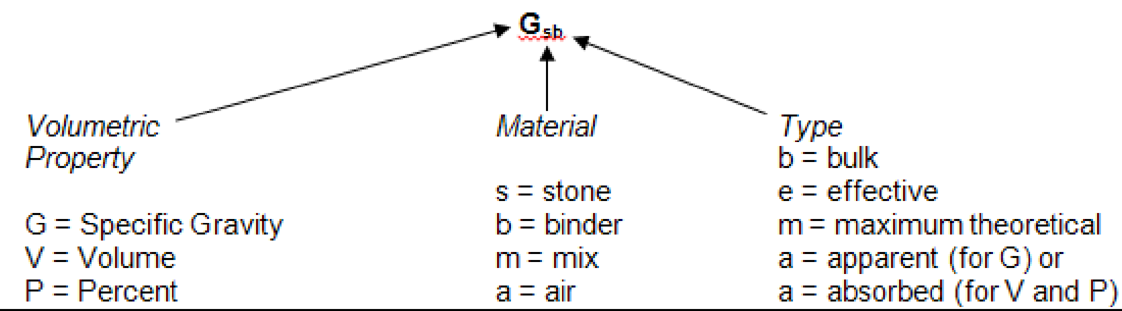
IM 501

ASPHALTIC EQUATIONS
& EXAMPLE CALCULATIONS

SCOPE

This IM describes the equations associated with asphaltic materials. In addition, there are a number of example calculations showing how to determine various properties.

NAMING CONVENTION



DEFINITIONS

P_a	=	% of air voids in compacted hot mix asphalt mixture (percent of total volume) **Lab Voids** for gyratory specimens or **Field Voids** for cores
P_b	=	% of asphalt binder in the hot mix asphalt mixture
$P_{b(RAP)}$	=	% of asphalt binder in RAP material
$P_{b(add)}$	=	% of virgin asphalt binder needed to add to the mix to achieve the total intended binder content
$P_{b(added)}$	=	% of virgin asphalt binder in the hot mix asphalt mixture. Does not include the asphalt binder from the RAP
P_s	=	% of combined aggregate in the hot mix asphalt mixture
	=	100 – P_b - other non-aggregate components
P_{ba}	=	% of asphalt binder absorbed by aggregate, aggregate basis
$P_{ba\ (mix)}$	=	% of asphalt binder absorbed by aggregate, mix basis
P_{be}	=	effective asphalt binder, %, mixture basis
% Abs	=	% water absorption of the individual or combined aggregate
ABS	=	fraction of water absorption of the individual or combined aggregate

	=	% Abs/100 ABS is always used in the calculations rather than % Abs.
G_{sa}	=	apparent specific gravity of the aggregate
G_{se}	=	effective specific gravity of the combined aggregate
G_{sb}	=	bulk specific gravity of the aggregate (dry basis)
$G_{sb(SSD)}$	=	bulk specific gravity of the aggregate (SSD basis) Used for Portland Cement Concrete **NOT ASPHALT!!!**
G_b	=	specific gravity of the asphalt binder at 25°C (77°F)
$G_{b\ (effective)}$	=	effective specific gravity of the combined new and recycled asphalt binder at 25°C (77°F)
% New AC	=	percentage of the total binder that is virgin (not from RAM)
G_{mm}	=	maximum specific gravity of the hot mix asphalt mixture. Often referred to as the Rice specific gravity, solid specific gravity or solid density.
G_{mb}	=	bulk specific gravity of compacted hot mix asphalt mixture
$G_{mb(measured)}$	=	G_{mb} of gyratory specimen as determined from test procedure in IM 321
$G_{mb(corrected)}$	=	corrected G_{mb} of gyratory specimen at N_{des}, also called **Lab Density**. $G_{mb(corrected)}$ and $G_{mb(measured)}$ will be the same when compacting to N_{des} so no correction is necessary.
$G_{mb(field\ core)}$	=	bulk specific gravity of pavement cores (also **$G_{mb(field)}$** or **Field Density**)
VMA	=	% voids in mineral aggregate, (percent of bulk volume), compacted mix
V_t	=	design target air voids, %
VFA	=	% voids filled with asphalt binder
N_{ini}	=	Number of gyrations used to measure initial compaction.
N_{des}	=	Number of gyrations used to measure design compaction. G_{mb} for Lab Density is determined at N_{des}.
N_{max}	=	Number of gyrations used to measure maximum compaction.
N_x	=	Level of compaction, where x is the number of gyrations.
R	=	temperature correction multiplier obtained from IM 350 Table 2 App. A

d_t	=	density of water at test temperature, g/cc
h_{max}	=	the height of the specimen at N_{max}, mm
h_{des}	=	the height of the specimen at N_{des}, mm
h_x	=	the height of the specimen at any gyration level N_x, mm
C_x	=	percent of compaction expressed as a percentage of G_{mm} Where x is the number of gyrations (this is normally N_{ini} or N_{max})
S	=	slope of the compaction curve
FT	=	Film Thickness, microns
SA	=	Surface Area, m^2/kg
F/B	=	Filler/Bitumen Ratio also called Fines/Bitumen Ratio
σ_{n-1}	=	Sample Standard Deviation
$\bar{X}$	=	sample average

FORMULAS

All calculations shown have been rounded for ease of presentation. Normally calculations will involve maintaining more significant figures throughout the intermediate calculations and only rounding the final result. The values generated by the software specified by the DOT will be the accepted results for reporting purposes.

All specific gravity calculations will be reported to 3 decimal places. Binder content is reported to 2 decimal places. Percent voids, VMA and VFA are reported to 1 decimal place.

Unless noted as otherwise, the following information is given to perform the calculations for a mix not containing RAS. Any additional needed information will be provided with the sample calculation.

P_b = 5.75%	G_{sa} = 2.667	$G_{mb\ (field)}$ = 2.215
P_s = 100 – 5.75 = 94.25%	G_{se} = 2.659	$G_{mb\ (measured)}$ = 2.310
% Abs = 1.39	G_{sb} = 2.572	$G_{mb\ (corrected)}$ = 2.273
ABS = 1.39/100 = 0.0139	$G_{sb(SSD)}$ = 2.608	% RAP = 10.0%
G_b = 1.031	G_{mm} = 2.438	$P_{b(RAP)}$ = 5.00%
% minus #200 (75 µm) sieve = 5.0%		

VOLUMETRIC EQUATIONS

To convert the specific gravity of asphalt binder from one temperature to another, the following two equations are used.

G_b (at 60°F) $= \dfrac{G_b \text{ (at 77° F)}}{0.9961}$ $= \dfrac{1.031}{0.9961} = 1.035$

G_b (at 77°F) $= 0.9961 \times G_b \text{ (at 60°F)}$ $= 0.9961 \times (1.035) = 1.031$

$G_{b\,(effective)}$ with RAM

$$= \frac{100}{\dfrac{\%\,New\,AC}{G_b} + \dfrac{100 - \%\,New\,AC}{1.030}}$$

% Abs

$$= \frac{W_a + W_b - W_c}{W_c} \times 100$$

$$= \frac{1315.7 + 690.3 - 2000.0}{2000.0} \times 100 = 0.30\%$$

Where: W_a = Saturated-Surface-Dry (SSD) weight of coarse portion, 1315.7 g
W_b = Saturated-Surface-Dry (SSD) weight of fine portion, 690.3 g
W_c = Combined dry weight of coarse and fine portion, 2000.0 g

% $Abs_{(combined)}$

$$= [\%\,Abs_1 \times (P_{s1})] + [\%\,Abs_2 \times (P_{s2})] + [\%\,Abs_3 \times (P_{s3})] + \ldots$$

$$= 0.67(0.50) + 1.23(0.05) + 2.21(0.45) = 1.39\%$$

Where: % Abs_1 = 0.67% P_{s1} = 50%
% Abs_2 = 1.23% P_{s2} = 5%
% Abs_3 = 2.21% P_{s3} = 45%

G_{sa}

$$= \frac{W \times R}{W + W_1 - W_2} = \frac{(2000.0)(1.0000)}{2000.0 + 6048.0 - 7298.1} = 2.667$$

Where: W = Weight of dry sample, 2000.0 g
W_1 = Sample weight of pycnometer filled with water at test temperature, 6048.0 g
W_2 = Sample weight of pycnometer filled with water and sample, 7298.1 g

R = Multiplier to correct temperature to 77°F = 1.0000 @ 77°F

G_{sb}

$$= \frac{G_{sa}}{1 + (ABS) \times (G_{sa})} \qquad = \frac{2.667}{1 + (0.0139)(2.667)} = 2.572$$

$G_{sb\ (combined)}$

$$= \frac{100}{\frac{P_{s1}}{G_{sb1}} + \frac{P_{s2}}{G_{sb2}} + \frac{P_{s3}}{G_{sb3}} + ..} \qquad = \frac{100}{\frac{50.0}{2.657} + \frac{5.0}{2.642} + \frac{45.0}{2.640}} = 2.649$$

Where: P_{s1} = 50.0% G_{sb1} = 2.657
P_{s2} = 5.0% G_{sb2} = 2.642
P_{s3} = 45.0% G_{sb3} = 2.640

G_{se}

$$= \frac{P_s}{\frac{100}{G_{mm}} - \frac{P_b}{G_b}} \qquad = \frac{100 - 5.75}{\frac{100}{2.438} - \frac{5.75}{1.031}} = 2.659$$

G_{mm}

$$= \frac{W \times R}{W + W_1 - W_2} \qquad = \frac{(2020.0)(1.0000)}{2020.0 + 6048.0 - 7239.5} = 2.438$$

Where: W = Sample weight of sample, 2020.0 g
W1 = Sample weight of pycnometer filled w/water at test temperature, 6048.0 g
W_2 = Sample weight of pycnometer filled w/water and sample, 7239.5 g
R = Multiplier to correct temperature to 77°F = 1.0000 @ 77°F

To correct the density of water to 77°F the R multiplier is used. The value of R is given in the tables in IM's 350 and 380 for temperatures from 60 to 130°F. R is calculated as follows:

R

$$= \frac{d_t}{0.99707} \qquad = \frac{0.99707}{0.99707} = 1.0000$$

Where: d_t = density of water at temperature t = 0.99707 g/cc at 77°F.

G_{mb}
(or $G_{mb\ (measured)}$)

$$= \frac{W_1}{W_3 - W_2} \qquad = \frac{4800.0}{4805.6 - 2727.7} = 2.310$$

Where: W_1 = Sample Dry weight, 4800.0 g
W_2 = Sample weight in water, 2727.7 g
W_3 = Sample weight in air, SSD, 4805.6 g

P_a (lab voids)

$$= \frac{G_{mm} - G_{mb}}{G_{mm}} \times 100 \qquad = \frac{2.438 - 2.310}{2.438} \times 100 = 5.3\%$$

$\%G_{mm}$ (field core)

$$= \frac{G_{mb(field\ core)}}{G_{mm(lot\ avg.)}} \times 100 \qquad = \frac{2.215}{2.438} \times 100 = 90.9\%$$

P_a (field voids)

$$= 100 - \%G_{mm} \qquad = 100 - 90.9 = 9.1\%$$

VMA

$$= 100 - \left[\frac{G_{mb} \times P_s}{G_{sb}}\right] \qquad = 100 - \frac{(2.310)(94.25)}{2.572} = 15.4\%$$

VFA

$$= \frac{VMA - P_a}{VMA} \times 100 \qquad = \frac{15.4 - 5.3}{15.4} \times 100 = 65.6\%$$

P_{ba}

$$= \frac{(G_{se} - G_{sb})}{(G_{se} \times G_{sb})} \times G_b \times 100 \qquad = \frac{2.659 - 2.572}{(2.659)(2.572)} \times 1.031 \times 100 = 1.31\%$$

P_{be}

$$= P_b - \left[\frac{P_{ba} \times P_s}{100}\right] \qquad = 5.75 - \frac{(1.31)(94.25)}{100} = 4.52\%$$

$P_{ba\ (mix)}$ $= P_b - P_{be}$

F/B (fines/bitumen)

$$= \frac{\text{Total \% of minus \#200 material}}{P_{be}} \qquad = \frac{5.00}{4.52} = 1.11$$

Where: Total % of minus #200 (75 µm) includes both virgin aggregate and RAM when used

GYRATORY EQUATIONS

If compacting to N_{max} a correction to the measured G_{mb} must be performed. The corrected G_{mb} (**$G_{mb\ (corrected)}$**) is then used in the calculations for **P_a** (lab voids) and **VMA.**

To correct G_{mb} from the measured value at N_{max} to the corrected value at N_{des}:

$G_{mb\ (corrected)}$ (lab density)

$$= (G_{mb\ (measured)}) \times \frac{h_{max}}{h_{des}} \qquad = (2.310)\frac{117.5}{119.4} = 2.273$$

Where: h_{max} = 117.5 mm (the height at N_{max}) and h_{des} = 119.4 (the height at N_{des})

To find the percent of maximum specific gravity ($\%G_{mm}$) at a specific gyration (N_x):

C_x ($\%G_{mm}$)

$$= \frac{(G_{mb(measured)}) \times (h_{max})}{(G_{mm}) \times (h_x)} \text{ x } 100$$

Given:

N_{ini} = 8 gyrations	h_8 = 135.4 mm
N_{des} = 109 gyrations	h_{109} = 119.4 mm
N_{max} = 174 gyrations	h_{174} = 117.5 mm

C_8

$$= \left(\frac{(2.310) \text{ x } (117.5\text{mm})}{(2.438) \text{ x } (135.4\text{mm})}\right) \text{ x } 100 = 82.2\%$$

C_{109}

$$= \left(\frac{(2.310) \text{ x } (117.5\text{mm})}{(2.438) \text{ x } (119.4\text{mm})}\right) \text{ x } 100 = 93.2\%$$

C_{174}

$$= \left(\frac{(2.310) \text{ x } (117.5\text{mm})}{(2.438) \text{ x } (117.5\text{mm})}\right) \text{ x } 100 = 94.7\%$$

To find the slope of the gyratory compaction curve:

S $= \frac{(\log(N_{max}) - \log(N_{ini}))}{C_{max} - C_{ini}} \qquad = \frac{(\log(174) - \log(8))}{0.947 - 0.822} = 10.7$

Where: C_{max} and C_{ini} are expressed as decimals.

RAP FORMULAS

To determine the percent of asphalt binder to add to a mix containing RAP (**$P_{b(add)}$**) to achieve the total intended P_b shown on the JMF (this the value to which the plant controls are set):

$P_{b(add)}$

$$= \frac{[(100) \times (\text{total intended } P_b)] - [(\%\,RAP) \times (P_{b(RAP)})]}{100 - [(\%\,RAP) \times (P_{b(RAP)}) \times (0.01)]}$$

$$= \frac{(100)(5.75) - (10.0)(5.00)}{100 - (10.0)(5.00)(0.01)} = 5.28\%$$

To determine the percent of aggregate contributed by the RAP in the total aggregate blend:

$\%\,RAP_{(aggregate)}$

$$= \frac{(\%\,RAP) \times [1.00 - (P_{b(RAP)} \times 0.01)]}{\%\text{ virgin agg.} + [(\%\,RAP) \times (1.00 - (P_{b(RAP)} \times 0.01))]} \text{ x } 100$$

$$= \frac{(10.0)(1.00 - (5.00)(0.01))}{90.0 + (10.0)(1.00 - (5.00)(0.01))} \text{ x } 100 = 9.55\%$$

To determine the actual percent virgin aggregate in the total aggregate blend containing RAP:

% virgin agg.

$$= \frac{\%\text{ virgin agg.}}{\%\text{ virgin agg.} + [(\%\,RAP) \times (1.00 - (P_{b(RAP)} \times 0.01))]} \text{ x } 100$$

$$= \frac{90.0}{90.0 + (10.0)(1.00 - (5.00)(0.01))} \text{ x } 100 = 90.45\%$$

To determine the total percent asphalt binder in a mix containing RAP:

Total P_b $= P_{b(added)} + [(\%\,RAP) \times (P_{b(RAP)}) \times (0.01)] - [(P_{b(added)}) \times (\%\,RAP) \times (P_{b(RAP)}) \times (0.0001)]$

$$= 5.28 + (10.0)(5.00)(0.01) - (5.28)(10.0)(5.00)(0.0001) = 5.75\%$$

Where: $P_{b(added)}$ is the actual percent of virgin asphalt binder added to the mix from the tank stick, flow meter or batch weights - **not the $P_{b(add)}$ determined above which is the original determination on the JMF**.

FRICTION AGGREGATE CALCULATIONS

Percent Retained on #4 Sieve:

$$\textbf{\% +\#4 Frictional aggregate} = \frac{(\text{\% frictional agg. retained on \#4 }) \times (\text{\% frictional agg. in total blend})}{(\text{\% retained on \#4 of total blend})}$$

Example: The aggregate blend contains 20% quartzite as the Type 2 friction class aggregate, the quartzite gradation shows 90% **retained** on the #4 sieve, and the combined gradation of the blend shows 60% **retained** on the #4 sieve:

% +#4 frictional aggr. in total blend = +#4 Type 2 $= \frac{(90)(20)}{60} = 30\%$

Percent Passing the #4 Sieve:

$$\textbf{\% −\#4 Type 2 aggregate} = \frac{(\text{\% passing \#4 of Type 2 aggr, }) \times (\text{\% Type 2 agg. in total blend})}{(\text{\% passing \#4 of total blend})}$$

Example: For a single Type 2 aggregate:
Quartzite Type 2 aggregate is 20% of the total blend and has 58% passing the #4 sieve. The combined gradation of the total blend has 65% passing the #4 sieve.

% −#4 Type 2 in the total blend $= \frac{(58) \times (20)}{65} = 17.8\%$

If more than one Type 2 aggregate is included in the blend the gradations of the Type 2 aggregates must be combined first in the numerator to determine the percent passing the #4 sieve for the Type 2 aggregate as shown in the following example.

Example: For multiple Type 2 aggregates:
Three quartzite aggregates are included in the total blend. The graded quartzite aggregate is 20% of the total blend and has 58% passing the #4 sieve. The quartzite

man sand is 10% of the total blend and has 100% passing the #4 sieve. The quartzite chip is 5% of the total blend and has 5% passing the #4 sieve. The combined gradation of the total blend has 65% passing the #4 sieve.

The % Type 2 in the total blend combined −#4 is:

% −#4 Type 2 in the total blend $= \frac{[(58 \times 20) + (100 \times 10) + (5 \times 5)]}{65} = 33.6\%$

Fineness Modulus

The fineness modulus of the Type 2 (FM_{Type2}) material is expressed as 600 minus the total of the percents passing each of the six sieves from the #4 to the #100 sieves divided by 100 and then multiplied by the percentage of Type 2 aggregate in the total blend expressed as a decimal.

$$FM_{Type2} = \frac{[600 - (P_4 + P_8 + P_{16} + P_{30} + P_{50} + P_{100})]}{100} \times P_{Type\,2}$$

Where:

P_x is the percent passing sieve #x (x = #4, #8, #16, #30, #50, and #100)

$P_{Type\,2}$ is the percent of Type 2 aggregate in the total blend expressed as a decimal

When more than one Type 2 aggregate is included in the total blend the gradations of the Type 2 aggregates must be combined first to determine the percent passing each of the six sieves for the total Type 2 aggregate as shown in the following example.

Example:

Given: The following gradations of the three Type 2 aggregates and the percentages in the total blend:

Percent Passing	3/4	1/2	3/8	#4	#8	#16	#30	#50	#100	#200
20% Graded Quartzite	100	98	78	58	48	38	28	18	8.0	4.0
10% Quartzite Man Sand				100	75	52	33	22	7.0	2.0
5% Quartzite Chip	100	95	35	5.0	4.5	4.0	3.5	3.0	2.0	1.0

The total percent Type 2 quartzite in the total blend is 20+10+5=35%

To combine the gradations of the Type 2 aggregates, multiply the percent passing each sieve (#4 to #100) for each aggregate by the percent of that aggregate in the total blend, sum the results individually for each sieve then divide the sum by the total percent Type 2 in the total blend as shown below. Express the result to two significant figures.

Combined gradation of the Type 2 for the #4 sieve: $= \frac{(58 \times 20) + (100 \times 10) + (5 \times 5)}{35} = 62$

Perform this same calculation for each of the other five sieves, #8, #16, #30, #50 and #100

Percent Passing	3/4	½	3/8	#4	#8	#16	#30	#50	#100	#200
Total Type 2 Combined				62	50	37	26	17	6.9	

$$FM_{Type2} = \frac{[600 - (62 + 50 + 37 + 26 + 17 + 6.9)]}{100} \times 0.35 = 1.40$$

FILM THICKNESS EXAMPLE:

SIEVE ANALYSIS % PASSING													
Sieve	in. (mm)	1 (25.0)	3/4 (19.0)	1/2 (12.5)	3/8 (9.5)	#4 (4.75)	#8 (2.36)	#16 (1.18)	#30 (0.600)	#50 (0.300)	#100 (0.150)	#200 (0.075)	
Combined Grading		100	100	95	86	68	47	38	26	10	5.4	3.9	
Surface Area Coefficient						0.0041	0.0082	0.0164	0.0287	0.0614	0.1229	0.3277	TOTAL
Surface Area	(m^2/kg)	0.41				0.28	0.39	0.62	0.75	0.61	0.66	1.28	5.00

The surface area (**SA**) is found by taking the % Passing times the Surface Area Coefficient. The Surface Area for the material above the #4 sieve is a constant 0.41. The total surface area is found by adding all of the individual surface area values.

SA (for each sieve) $= (\%\ \text{Passing}) \times (\text{Surface Area Coefficient})$

$= (38)(0.0164) = 0.62$ (for the #16 sieve above)

Where: The Surface Area Coefficients are constants.

FT (Film Thickness) $= \frac{P_{be}}{SA} \text{ x } 10$ $= \frac{4.52}{5.00} \text{ x } 10 = 9.0$

MISCELLANEOUS

Optimum P_b

$$= \frac{(\text{high voids - target voids})}{(\text{high voids - low voids})} \times (\text{high } P_b \text{ - low } P_b) + \text{low } P_b$$

Where: Target voids = 4.0

	P_b	P_a	
(low P_b =)	4.75	5.5	(= high voids)
(high P_b =)	5.75	3.0	(= low voids)
	6.75	1.2	

Since the target voids of 4.0% falls between 5.5 and 3.0 they are the high voids and low voids respectively. The asphalt contents associated with those voids are used as the low P_b and high P_b respectively.

$$= \frac{(5.5 - 4.0)}{(5.5 - 3.0)} \text{ x } (5.75 - 4.75) + 4.75 = 5.35\%$$

% Moisture

$$= \frac{\text{Wet Wt. Sample - Dry Wt. Sample}}{\text{Dry Wt. Sample}} \text{ x } 100$$

Where: Wet Wt. Sample = 2100.0 g
Dry Wt. Sample = 2000.0 g

$$= \frac{2100.0 - 2000.0}{2000.0} \text{ x } 100 = 5.0\%$$

To adjust the height of a G_{mb} specimen to reach the intended height, the following equation is used.

Adjusted sample weight

$$= \frac{(\text{trial sample weight}) \times (\text{intended height})}{\text{trial sample height}}$$

$$= \frac{(4775.0)(115.0)}{109.5} = 5014.8$$

G_{sb} (from $G_{sb(SSD)}$)

$$= \frac{G_{sb(SSD)}}{1 + ABS} \qquad = \frac{2.608}{1 + 0.0139} = 2.572$$

Percent of Lab Density

$$= \frac{G_{mb(\text{field core})}}{G_{mb}} \text{ x } 100 \qquad = \frac{2.215}{2.273} \text{ x } 100 = 97.4\%$$

Min. P_b

$$= \frac{[(G_b)(G_{se})(VMA - V_t) + (G_b)(100 - VMA)(G_{se} - G_{sb})]}{(G_b)(G_{se})(VMA - V_t) + (G_b)(100 - VMA)(G_{se} - G_{sb}) + (G_{se})(G_{sb})(100 - VMA)} \text{ x } 100$$

$$= \frac{[(1.031)(2.659)(15.4 - 4.0) + (1.031)(100 - 15.4)(2.659 - 2.572)]}{(1.031)(2.659)(15.4 - 4.0) + (1.031)(100 - 15.4)(2.659 - 2.572) + (2.659)(2.572)(100 - 15.4)} \text{ x } 100 = 6.29\%$$

You have 13,000 grams of aggregate and 650 grams of asphalt binder. Determine the asphalt binder content (P_b) of the mixture.

P_b

$$= \frac{W_b}{W_s + W_b} \text{ x } 100 \qquad = \frac{650}{13000 + 650} \text{ x } 100 = 4.76\%$$

Where: W_b = Weight of the asphalt binder, g
W_s = Weight of the aggregate, g
P_b = Percent binder of the mix, mix basis

You have 13,000 grams of aggregate. You want to prepare a mixture having 5.5% asphalt binder content based on the total mix. Determine the weight of the asphalt binder you need to add to the aggregate.

W_b

$$= \frac{(P_b) \times (W_s)}{(P_s)} \qquad = \frac{(5.5)(13000)}{100 - (5.5)} = 756.6$$

Where: W_b = Weight of the added binder, mix basis, g
W_s = Weight of the aggregate, g

<u>QUALITY INDEX (QI) EXAMPLE %G_{mb} Method</u>:
(This example is applicable for calculating outliers for G_{mb} and gradation)

For use on projects not using the PWL specifications

Given: lab. lot average $G_{mb(corrected)}$ = 2.408
field G_{mb} of individual cores: 2.319, 2.316, 2.310, 2.298, 2.242, 2.340, and 2.345.
% of lab density = 94%, 95%, or 96%. For this example 95% is used.

Determine the average field density (G_{mb}) of the seven cores.

$\bar{x}$

$$= \frac{2.319 + 2.316 + 2.310 + 2.298 + 2.242 + 2.340 + 2.345}{7} = 2.310$$

The sample standard deviation is determined as follows:

σn-1

$$= \sqrt{\frac{\sum (x - \bar{x})^2}{n - 1}} \qquad = \sqrt{\frac{0.007}{7 - 1}} = 0.034$$

Where:
x = individual sample value
n = number of samples
$\bar{x}$ = average of all samples

The Quality Index for density shall be determined according to the following calculation:

Q.I. (Density)

$$= \frac{(\text{Avg. } G_{mb})_{\text{FIELD LOT}} - ((\%\text{ Density})_{\text{SPECIFIED}} \times (\text{Avg. } G_{mb})_{\text{LAB LOT}})}{(\text{Std. Dev. } G_{mb})_{\text{FIELD LOT}}}$$

QI

$$= \frac{2.310 - (0.95)(2.408)}{0.034} = 0.66$$

The QI is less than 0.72. Check for outliers. To test for a suspected outlier result, apply the appropriate formula.

Suspected High Outlier

$$= \frac{\text{Highest } G_{mb} - \text{Avg. } G_{mb}}{\sigma_{n-1}} \qquad = \frac{2.345 - 2.310}{0.034} = 1.03$$

Suspected Low Outlier

$$= \frac{\text{Avg. } G_{mb} - \text{Lowest } G_{mb}}{\sigma_{n-1}} \qquad = \frac{2.310 - 2.242}{0.034} = 1.99$$

The highest density or lowest density shall not be included if the suspected outlier result is more than 1.80 for seven samples. The quality index shall then be recalculated for the remaining six samples.

The suspected low outlier result is greater than 1.80 for seven samples, therefore the core with the lowest density, 2.242, is an outlier.

Recalculate the QI for the remaining six densities (excluding the outlier).

Avg. $G_{mb\ (field\ lot)(new)}$ = 2.321 = **$\sigma_{n-1\ (new)}$** = 0.018

$QI_{(new)}$

$$= \frac{2.321 - (0.95)(2.408)}{0.018} = 1.88$$

<u>GRADATION EXAMPLE (Combined Gradation)</u>:

Assume the proportions of the individual aggregates are as follows: 50% ¾" Minus, 5% ⅜" Chips, and 45% Nat. Sand. Then using the following gradations for the individual aggregates, determine the combined gradation.

% Passing										
Sieve Size	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200
3/4" Minus	100	90	75	43	21	17	15	12	9.8	7.4
3/8" Chip	100	100	70	32	5	1.8	1.5	1.1	0.9	0.7
Nat. Sand	100	100	100	100	80	65	40	9	1.0	0.5
combined	_______	_______	_______	_______	_______	_______	_______	_______	_______	_______

To determine the combined gradation, take each individual material % Passing times the percentage of that material in the blend. For example, take the 50% of the 3/4" Minus material times the % Passing for that material.

3/4" Minus Portion % Passing #200 sieve: $= 7.4 \times \frac{50}{100} = 3.7$

Do the same thing with each of the other aggregates and sieve sizes to obtain the following:

3/4" Minus	50.0	45.0	37.5	21.5	10.5	8.5	7.5	6.0	4.9	3.7
3/8" Chip	5.0	5.0	3.5	1.6	0.3	0.1	0.1	0.1	0.0	0.0
Nat. Sand	45.0	45.0	45.0	45.0	36.0	29.3	18.0	4.1	0.5	0.2

Next, sum the individual sieve sizes to get the combined gradation. This will result in the following combined gradation.

Combined	100.0	95.0	86.0	68.1	46.8	37.9	25.6	10.2	5.4	3.9

BATCHING EXAMPLE:

You have been directed to prepare a 13,000-gram batch of aggregate composed of the aggregates used above with the same proportions. The ¾" Minus has been split into four size fractions by sieving on the 12.5 mm, 9.5 mm and 4.75 mm sieves. The ⅜" Chip has been split into three size fractions by sieving on the 9.5 mm and 4.75 mm sieves. The Nat. Sand is one size fractions passing the 4.75 mm sieve. Complete the following batching sheet by determining the mass of each aggregate needed, the percentage of each size fraction and the weight of each size fraction.

Weight ¾" Minus @ 50% = __________ grams

Sieve	% Passing	Size Fraction	% In Size Fraction	Weight Needed Each Fraction	Cumulative Weight
19 mm	100				
12.5 mm	90	-19 + 12.5	________	________	________
9.5 mm	75	-12.5 + 9.5	________	________	________
4.75 mm	43	-9.5 + 4.75	________	________	________
		-4.75	________	________	________
			________		

Weight ⅜" Chip @ 5% = __________grams

Sieve	% Passing	Size Fraction	% In Size Fraction	Weight Needed Each Fraction	Cumulative Weight
12.5 mm	100				
9.5 mm	70	-12.5 + 9.5	________	________	________
4.75 mm	32	-9.5 + 4.75	________	________	________
		-4.75	________	________	________
			________		

Weight Nat. Sand @ 45% = __________grams

Sieve	% Passing	Size Fraction	% In Size Fraction	Weight Needed Each Fraction	Cumulative Weight
4.75 mm	100	-4.75	________	________	________
			________		

The weight of each material is found by taking the percentage of the blend each material is times the total batch weight. For example, the weight of the ¾" Minus is found by taking 50% of the 13,000 gram batch, or 6,500 grams.

The % In Size Fraction column is found by subtracting the % Passing from one size by the previous size % Passing. For example, the % In Size Fraction for the –19 + 12.5 Size Fraction is found by subtracting 90% Passing the 12.5 mm sieve from 100% Passing the 19 mm sieve. This process is repeated for each size fraction. The last line in the % In Size Fraction column is found by adding each of the individual values above it. The total should be 100.0%.

The Weight Needed Each Fraction is found by taking the % In Size Fraction value and multiplying it by the total mass of that aggregate. For example, for the ¾" Minus material, there is 10% in the –19 + 12.5 size fraction. Take this 10% times the mass of 6,500 grams to get the Weight Needed value of 650 grams.

The Cumulative Weight is found by taking the first value in the Weight Needed column and placing it in the first spot for the Cumulative Weight column. For example, there was 650 grams needed in the previous example. This value would go on the first line of the Cumulative Weight column.

Each successive line requires adding the corresponding Weight Needed value with the previous Cumulative Weight value. Below are the solutions for the example shown above.

Weight ¾" Minus @ 50% = 6500.0 grams

Sieve	% Passing	Size Fraction	% In Size Fraction	Weight Needed Each Fraction	Cumulative Weight
19 mm	100				
12.5 mm	90	-19 + 12.5	10.0	650.0	650.0
9.5 mm	75	-12.5 + 9.5	15.0	975.0	1625.0
4.75 mm	43	-9.5 + 4.75	32.0	2080.0	3705.0
		-4.75	43.0	2795.0	6500.0
			100.0		

Weight ⅜" Chip @ 5% = 650.0 grams

Sieve	% Passing	Size Fraction	% In Size Fraction	Weight Needed Each Fraction	Cumulative Weight
12.5 mm	100				
9.5 mm	70	-12.5 + 9.5	30.0	195.0	6695.0
4.75 mm	32	-9.5 + 4.75	38.0	247.0	6942.0
		-4.75	32.0	208.0	7150.0
			100.0		

Weight Nat. Sand @ 45% = 5850.0 grams

Sieve	% Passing	Size Fraction	% In Size Fraction	Weight Needed Each Fraction	Cumulative Weight
4.75 mm	100	-4.75	100.0	5850.0	13000.0
			100.0		

The Cumulative Weight at the end of the batching should always equal the desired total batch weight.

Determination of Tons of Asphalt Binder Used

Determine the tons of asphalt binder used in the mix for a given day using the following information:

Weights of all Binder @ 60°F = 8.67 lbs./gal.
Beginning tank stick 18,000 gal. @ 296°F
28.0 tons Binder hauled in during the day's run
Ending tank stick 16,000 gal. @ 296°F
Volume correction factor for correcting Binder @ 296°F to Binder @ 60°F = 0.9200

The difference between the beginning and ending tank stick readings is the first place to start. There were 2,000 gal. of binder used plus all of the binder hauled in during the day.

To combine these quantities, they must be converted to tons. First the gallons used must be corrected to 60°F. Since the temperature is the same for the beginning and ending tank stick readings the correction can be done on the difference between the two readings. If the temperatures were different for the two readings, the temperature correction would need to be done on the individual readings before the difference is determined.

2,000 gal binder @ 296°F $= (2000 \text{ gal @ } 296°\text{F}) \times 0.9200 = 1840 \text{ gal @ } 60°\text{F}$

This value must then be converted to the tons of binder.

1840 gal @ 60°F $= \dfrac{(1840 \text{ gal}) \times (8.67 \text{ lbs./gal.})}{2000 \text{ lbs./ton}} = 7.98 \text{ tons}$

This value in addition to the 28.0 tons of binder hauled in during the day is the amount used in the mix that day.

Tons of binder used in mix $= 28.0 \text{ tons} + 7.98 \text{ tons} = 35.98 \text{ tons binder}$

DETERMINING CORRECTION FACTORS FOR COLD FEED VS. IGNITION OVEN

		Sieve Sizes - Percent Passing												Surface
		1 1/2"	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200	Area
SU4-30D	Ign. Oven	100.0	100.0	99.0	89.0	77.0	47.0	31.0	20.0	14.0	8.6	6.4	5.2	4.60534
4-A	Cold-Feed	100.0	100.0	99.0	89.0	76.0	47.0	29.0	19.0	13.0	7.8	5.6	4.4	4.13424
Correction Factor		0.0	0.0	0.0	0.0	-1.0	0.0	-2.0	-1.0	-1.0	-0.8	-0.8	-0.8	-0.5

The correction factor is determined by taking the percent passing an ignition oven sieve and subtracting it from the percent passing of the corresponding cold-feed sieve. For example, there is 31 percent passing the number #8 sieve for the ignition oven and 29 percent passing the #8 sieve for the cold-feed. The correction factor for this sieve size is -2.0. The correction factor is applied to the ignition oven test results for I.M. 216 comparison.

This same procedure is used regardless of using a single gradation or multiple gradations to determine the correction factors. If multiple gradations are used, the correction factor is determined for each individual result and the resulting correction factors averaged for each sieve.

QUALITY INDEX (QI) FIELD VOIDS EXAMPLE %G_{mm} Method:
For use on projects using the PWL specifications

Given: Field G_{mb} of individual cores: 2.319, 2.316, 2.310, 2.298, 2.242, 2.340, 2.345, 2.310.
Lot Average G_{mm} = 2.501

Determine the average field density $\{(\text{Avg } G_{mb})_{(\text{FIELD LOT})}\}$ of the eight cores.

$\bar{x}$

$$= \frac{2.319 + 2.316 + 2.310 + 2.298 + 2.242 + 2.340 + 2.345 + 2.310}{8} = 2.310$$

The sample standard deviation (**σ_{n-1}**) of G_{mb} for the field lot {(Std. Dev. $G_{mb})_{FIELD\ LOT}$} is determined as follows:

σ_{n-1}

$$= \sqrt{\frac{\sum (x-\bar{x})^2}{n-1}} \qquad = \sqrt{\frac{0.007}{8-1}} = 0.032$$

Where: x = individual sample value
n = number of samples
$\bar{x}$ = average of all samples

The Lower and Upper Quality Indexes for field voids shall be determined according to the following calculations:

QI_U (Field Voids)

$$= \frac{(\text{Avg. } G_{mb})_{FIELD\ LOT} - (0.915 \text{ x Lot Avg. } G_{mm})}{(\text{Std. Dev. } G_{mb})_{FIELD\ LOT}}$$

QI_L (Field Voids)

$$= \frac{(0.965 \text{ x Lot Avg. } G_{mm}) - (\text{Avg. } G_{mb})_{FIELD\ LOT}}{(\text{Std. Dev. } G_{mb})_{FIELD\ LOT}}$$

Example:

QI_U (Field Voids)

$$= \frac{2.310 - (0.915 \text{ x } 2.501)}{0.032} = 0.67$$

QI_L (Field Voids)

$$= \frac{(0.965 \text{ x } 2.501) - 2.310}{0.032} = 3.23$$

If the QI produces a PWL that results in less than 100% pay, check for outliers. To test for a suspected outlier result, apply the appropriate formula.

Suspected High Outlier $= \frac{\text{Highest } G_{mb} \text{ - Avg. } G_{mb}}{\sigma_{n-1}} = \frac{2.345 - 2.310}{0.032} = 1.09$

Suspected Low Outlier $= \frac{\text{Avg. } G_{mb} \text{ - Lowest } G_{mb}}{\sigma_{n-1}} = \frac{2.310 - 2.242}{0.032} = 2.13$

The highest density or lowest density shall not be included if the suspected outlier result is more than 1.80 for eight samples. The quality index shall then be recalculated for the remaining seven samples.

The suspected low outlier result is greater than 1.80 for eight samples, therefore the core with the lowest density, 2.242, is an outlier.

Recalculate the upper and lower QI for the remaining seven densities (excluding the outlier).

Avg. $\mathbf{G_{mb\,(field\,lot)(new)}}$ = 2.320 $\boldsymbol{\sigma_{n-1\,(new)}}$ = 0.020

$\mathbf{QI_{U\,(new)}}$ $= \frac{2.320 - (0.915) \times (2.501)}{0.020} = 1.58$

$\mathbf{QI_{L\,(new)}}$ $= \frac{(0.965) \times (2.501) - 2.320}{0.020} = 4.67$

DETERMINATION OF PERCENT WITHIN LIMITS (PWL)

Field Voids

Calculate the upper and lower QI for field voids. Using Table 6 in AASHTO R 9-97 Appendix C and the QI value, the PWL can be determined using a sample size of N=8. A sample size of N=8 is always used regardless of the actual number of samples. The program provided by the Iowa DOT will calculate the PWL automatically using a best fit equation between QI values.

The PWL used for pay factor determination is based on a combination of the upper and lower PWLs calculated from the QI_U and QI_L. In this case the PWLs determined by the best fit equation for the QI_U (1.58) and QI_L (4.67) are 95.6 and 100.0 respectively.

Example:

PWL = (PWL_U + PWL_L) – 100 = (95.6 + 100.0) – 100 = 95.6

PWL Table for N=8 (from AASHTO R 9-97 Appendix C Table 6)

QI	PWL	QI	PWL	QI	PWL	QI	PWL	QI	PWL
0.00	50.00	0.50	68.43	1.00	83.96	1.50	94.44	2.00	99.24
0.05	51.89	0.55	70.16	1.05	85.26	1.55	95.17	2.05	99.45
0.10	53.78	0.60	71.85	1.10	86.51	1.60	95.84	2.10	99.61
0.15	55.67	0.65	73.51	1.15	87.70	1.65	96.45	2.15	99.74
0.20	57.54	0.70	75.14	1.20	88.83	1.70	97.01	2.20	99.84
0.25	59.41	0.75	76.72	1.25	89.91	1.75	97.51	2.25	99.91
0.30	61.25	0.80	78.26	1.30	90.94	1.80	97.96	2.30	99.96
0.35	63.08	0.85	79.76	1.35	91.90	1.85	98.35	2.35	99.98
0.40	64.89	0.90	81.21	1.40	92.81	1.90	98.69	2.40	100.00
0.45	66.67	0.95	82.61	1.45	93.65	1.95	98.99	2.45	100.00

Note: For QI values less than zero, subtract the table value from 100.

The best fit equation used in the spreadsheet software to calculate the upper or lower PWL is:

PWL = $3E-10x^6+0.2019x^5-3E-09x^4-4.123x^3-2E\text{-}08x^2+37.881x+50$

Where: x = QI_U or QI_L

<u>QUALITY INDEX (QI) LAB VOIDS EXAMPLE:</u>

Based on the weekly lot of HMA produced with a minimum of eight test values, determine the average and standard deviation for the air voids.

Quality Index for Air Voids Upper Limit (QI_U)

QI_U

$$= \frac{(\text{Target } P_a + 1) - \text{Avg. } P_a}{\text{Std. Dev. } P_a}$$

Quality Index for Air Voids Lower Limit (QI_L)

QI_L

$$= \frac{\text{Avg. } P_a - (\text{Target } P_a - 1)}{\text{Std. Dev. } P_a}$$

Using Table 6 in AASHTO R 9-97 Appendix C and a sample size of N=8 determine the upper and lower QI limits. A sample size of N=8 is always used regardless of the actual number of samples. The program provided by the Iowa DOT will calculate the PWL automatically using a best fit equation between QI values. No rounding is done until the final PWL is determined.

Example:

Given the following weekly lot air void information and a target air void of 4.0% determine the upper and lower limits for the QI for air voids: 3.1, 3.9, 4.2, 4.5, 4.5, 4.1, 4.3, 4.5

$P_{a(avg)}$

$$= \frac{3.1 + 3.9 + 4.2 + 4.5 + 4.5 + 4.1 + 4.3 + 4.5}{8} = 4.1375$$

Std. Dev. P_a

$$= \sqrt{\frac{\sum (x - \bar{x})^2}{n - 1}} \qquad = \sqrt{\frac{1.55875}{8 - 1}} = 0.471888$$

QI_U

$$= \frac{(4.0 + 1) - 4.1375}{0.471888} = 1.827763$$

QI_L

$$= \frac{4.1375 - (4.0 - 1)}{0.471888} = 2.410528$$

DETERMINATION OF PERCENT WITHIN LIMITS (PWL)

Lab Voids

After calculating the quality indices for the Lab Voids for a particular lot, the PWL values can be obtained from tables provided in FHWA Technical Advisory T 5080.12, June 23, 1989. The direct calculation with an example is provided herein. (Equations taken from: *Belz, M.H., Statistical Methods for the Process Industries. John Wiley & Sons. New York. 1973.* Explanation presentation taken from: *Freeman & Grogan, Statistical Acceptance Plan for Asphalt Pavement Construction Appendix B. U.S. Army Corps of Engineers Technical Report GL-98-7.1998.*)

Cacluating PWL involves the use of the beta probability distribution defined over the interval $0 \le x \le 1$. The shape of the beta distribution is a function of two parameters: α and β.

$$f(x) = \begin{cases} \frac{1}{B(\alpha,\beta)} x^{\alpha-1}(1-x)^{\beta-1} & (0 \le x \le 1) \\ 0 & (x < 0,\ x > 1) \end{cases}$$

Where α and β are greater than -1, also α and β are not restricted to assuming integer values. The value B(α, β) is defined as:

$$B(\alpha,\beta) = \frac{\Gamma(\alpha)\Gamma(\beta)}{\Gamma(\alpha+\beta)}$$

Where Γ is the gamma function and can be calculated using the GAMMA function in Microsoft Excel. In Excel, GAMMA uses the following equation:

$$\Gamma(M) = \int_0^\infty t^{M-1} e^{-t} dt$$

NOTE: The gamma function extends the factoral to non-integer values and Γ(M+1)=M*Γ(M).

The shape of the beta distribution is dependent on sample size (designated as n). The parameters, α and β, for the beta distribution are calculated as:

$$\alpha = \beta = \frac{n}{2} - 1 \quad for \quad n \geq 3$$

After calculating a quality index for the lot, QI_U or QI_L (designated generically as Q in the following equation) is transformed into x(β) by:

$$x(\beta) = \frac{1}{2}(1 - \frac{Q\sqrt{n}}{n-1})$$

Example. Results for thirteen laboratory void measurements for a lot of HMA are shown below in the table. The value “n” represents the number of observations, 13. The target laboratory air voids is 4.0% with limits ± 1%.First, the sample mean and sample standard deviation are calculated.

Lab air voids (%)	Average Air Voids (%)	Sample Standard Deviation
2.3	3.444	0.58
3.0		
3.0		
3.2		
3.1		
4.0		
4.1		
3.8		
3.0		
3.4		
3.4		
3.9		
4.4		

Next, the QI_U and QI_L are calculated. The upper quality limit is 5.0% and the lower quality limit is 3.0%.

$$QI_L = \frac{\bar{X} - Lower\ Quality\ Limit}{s} = \frac{3.444 - 3.0}{0.5839} = 0.7605$$

$$QI_U = \frac{Upper\ Quality\ Limit - \bar{X}}{s} = \frac{5.0 - 3.444}{0.5839} = 2.6646$$

Where:
QI_L = quality index relative to the lower specification limit
QI_U = quality index relative to the upper specification limit
$\bar{X}$ = sample mean or average for the lot
s = sample standard deviation for the lot

The quality index value represents the distance in sample standard deviation units that the sample mean is offset from the specification limit. A positive quality index value represents the number of sample standard deviation units that the sample mean falls inside the specification limit. Conversely, a negative quality index value represents the number of sample standard deviation units that the sample mean falls outside the specification limit.

Next, the percent of non-conforming for the upper and lower specification limit must be calculated. The percent non-conforming is calculated by transforming quality index into x(β), a value "x" within the beta distribution. The lower quality index is transformed to $x(\beta)_L$ by:

$$x(\beta)_L = \frac{1}{2}\left(1 - \frac{QI_L\sqrt{n}}{n-1}\right) = \frac{1}{2}\left(1 - \frac{0.7605\sqrt{13}}{13-1}\right) = 0.3857$$

The upper quality index is transformed to $x(\beta)_U$ by:

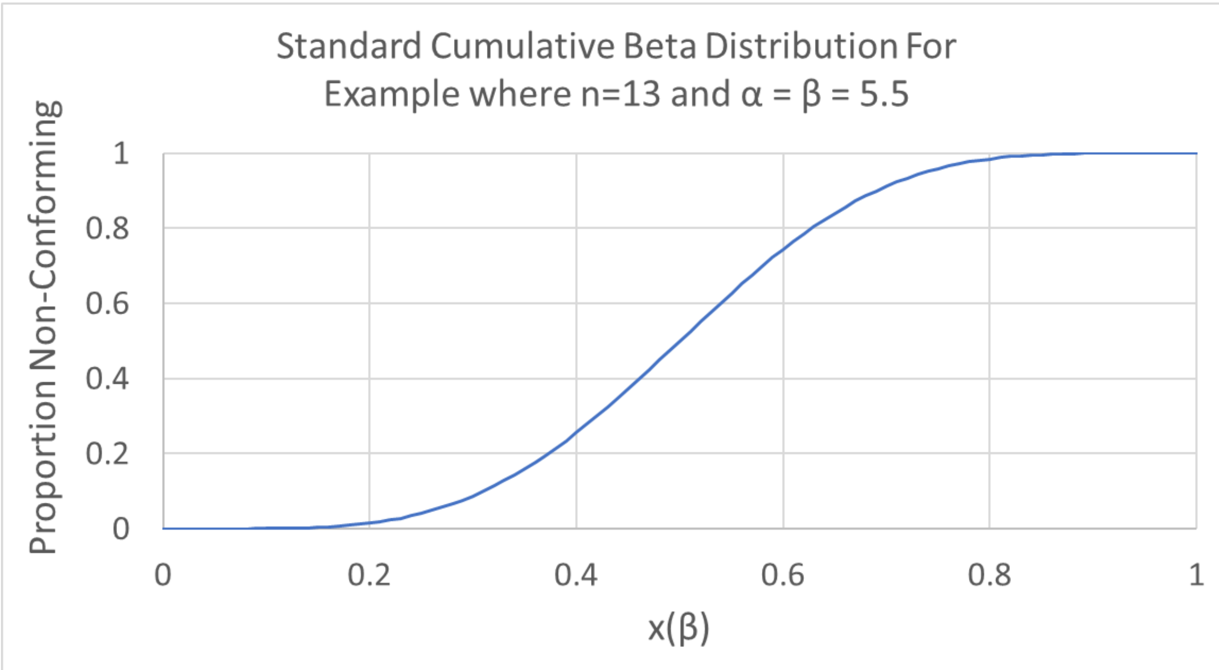
$$x(\beta)_U = \frac{1}{2}\left(1 - \frac{QI_U\sqrt{n}}{n-1}\right) = \frac{1}{2}\left(1 - \frac{2.6646\sqrt{13}}{13-1}\right) = 0.0997$$

The probability of obtaining air voids less than the lower limit (3.0%) is equal to the probability of finding an x(β) less than 0.3857 within the beta distribution defined by the following α and β.

$$\alpha = \beta = \frac{n}{2} - 1 = \frac{13}{2} - 1 = 5.5$$

The beta probability can be obtained from most commercial spreadsheet software using built-in functions that can be included in user-generated equations. For example, the built-in function in Microsoft Excel include BETADIST(x, α, β, A, B), where x is the value at which to evaluate the function (shown as $x(\beta)_L$ or $x(\beta)_U$ above); α and β are the beta distribution parameters; and A and B are the lower and upper beta distribution boundaries, respectively. Plugging both the known A and B (0 and 1, respectively) and the calculated x, α, and β into the function, BETADIST(0.3857, 5.5, 5.5, 0, 1) produces 0.226347 which represents 22.6% as non-conforming for the lower specification limit. The lower PWL is 77.37%. The upper specification limit for x, α, and β into the function, BETADIST(0.099678, 5.5, 5.5, 0, 1) produces 0.000504 which represents 0.05% non-conforming. The upper PWL is 100%.

This figure represents the cumulative Beta Distribution function for the example. NOTE: This distribution will change for lots with different sample sizes.



The PWL used for pay factor determination is based on a combination of the PWLs calculated from the QI_U and QI_L.

PWL = $(PWL_U + PWL_L)$ -100 = (100 + 77.37) – 100 = 77.37

DETERMINATION OF PAY FACTOR

The pay factor is determined from the tables in the Basis of Payment section 2303.05 BASIS OF PAYMENT of the specification. A PWL of 90.0 results in a pay factor of 1.000. Equations are used to determine the pay factor for other PWL values.

Example:

Using the PWL determined above for Lab Voids of 77.37 and the specified equation for a Lab Voids PWL of 50.0-89.9:

Lab Voids:

PF (Pay Factor) = 0.00625 × 77.37 + 0.4375 = 0.921

Using the PWL determined above for Field Voids of 95.6 and the specified equation for a Field Voids PWL of 90.1-99.9:

Field Voids:

PF (Pay Factor) = 0.006000 × 95.6 + 0.4600 = 1.034

DETERMINING AVERAGE ABSOLUTE DEVIATION (AAD) FOR LAB VOIDS

AAD is calculated by determining the absolute difference between the target and the individual test results and then averaging those values.

Example:

Target Voids P_a = 4.0
Individual P_a = 3.8, 4.2, 4.1, 3.7, 3.5

Sample	Difference	Deviation from Target	Absolute Deviation from Target
1	(4.0 - 3.8)	0.2	0.2
2	(4.0 - 4.1)	-0.1	0.1
3	(4.0 - 4.2)	-0.2	0.2
4	(4.0 - 3.7)	0.3	0.3
5	(4.0 - 3.5)	0.5	0.5

AAD (Lab Voids) $$= \frac{0.2 + 0.1 + 0.2 + 0.3 + 0.5}{5} = 0.3$$

DETERMINING MOVING AVERAGE ABSOLUTE DEVIATION (AAD) FOR LAB VOIDS

Calculate the absolute deviation from target (ADT_i) for sample, *i,* using the following equation:

$$ADT_i = |Pa_i - Target\ Pa|$$

Where,
i = Sequential production sample, *i*
ADT_i = Absolute deviation from target for sample, *i*
Pa_i = Laboratory air voids test result for sample, *i*
Target Pa = Target laboratory air voids for mixture
| | = Absolute value

Calculate the moving average ADT for *i* ≥ 4 using the following equation:

$$\left|\frac{ADT_i + ADT_{i-1} + ADT_{i-2} + ADT_{i-3}}{4}\right|$$

Where,
i = Sequential production sample, *i*
ADT_i = Absolute deviation from target for sample *i*
| | = Absolute value

IM 505

INSTRUCTIONS FOR RAM IN ASPHALT MIXTURES

GENERAL

This IM describes requirements for processing, storing, documenting, and sampling & testing of Recycled Asphalt Materials (RAM) intended for use in asphalt mixtures. RAM shall apply to Recycled Asphalt Pavement (RAP) and Recycled Asphalt Shingles (RAS).
All notifications and documentation shall be submitted to the District Materials Engineer (DME) based on the District responsible for the location of the initial RAM stockpile.

PROCESSING

A) RAP

RAP suitable for asphalt mixtures shall be processed by milling and/or crushing up to a maximum particle size of 1.5 inches. The Contractor shall notify the Engineer and DME 48 hours before processing begins.

Additional screening or blending may be done to achieve a more uniform stockpile. This processing may be done as the stockpile is built or as part of the asphalt plant production. Additional actions that may improve the consistency of the RAP include further crushing to reduce top size, screening into coarse and fine fractions, or blending by proportioning through a calibrated two-bin cold feed. Each individual RAP stockpile being incorporated into asphalt mixtures must have a dedicated totalizer for measuring quantities during production. When using multiple RAP stockpiles for a single mix, if the required number of totalizers are not available pre-blend the piles to the JMF proportions under the direction of the DME.

B) RAS

End users of RAS which also receive raw, unprocessed shingles and process the material for incorporation into an asphalt mixture, shall be considered a shingle Supplier and must adhere to Materials IM 506.

STORAGE

A) RAP

Place stockpiles on a base with adequate drainage, sufficient to prevent contamination, constructed in layers to minimize RAP segregation and ensure a workable face. Track equipment may operate on the stockpile during its construction.

To meet Classified RAP criteria, separate stockpiles shall be constructed for each source of RAP based on the quality of aggregate, type and quantity of asphalt binder, and size of processed material. Notify the Engineer and DME 48 hours prior to blending Classified RAP materials of the same aggregate quality to retain Classified status.

B) RAS

Place stockpiles on a base with adequate drainage sufficient to prevent contamination.

Separately stockpile pre-consumer RAS from post-consumer (tear-off) RAS. RAS may be pre-blended with RAP under the direction of the Engineer. Notify the Engineer and DME 48 hours prior to blending RAS materials with other materials or adding to a RAS stockpile. Equipment must be calibrated to ensure proper proportioning of blended piles. The Engineer may require verification testing for asphalt content, gradation, aggregate specific gravity, aggregate absorption, and fine aggregate angularity before the pile may be used.

DOCUMENTATION OF RAM STOCKPILES

A) RAP

Stockpiled RAP material will only retain its Classified status when the following documentation requirements are met. No documentation is required when the RAP is used on the project it came from, or a tied project.

- Identification of the project from which the material was removed.
- Mix data from the original project including mixture type.
- Aggregate classification.
- Location and depth in the pavement structure.
- Extracted gradation information, if available.
- Description of stockpile location and quantity.
- Form 820009r (see Appendix A) is completed by the RAP owner and a copy is forwarded to the DME within 10 calendar days of completing the stockpile.
- Any special handling, treatment or conditions of the RAP or its use should be described on this form.
- Maps shall provide details that depict the stockpile site, including adjacent stockpiles of RAP or aggregates, permanent plant equipment, and landmarks.

Maps and signs shall identify the stockpile by RAP Identification Number.
The DME will review Form 820009r for accuracy. Portions of the form including assigning the RAP identification number, aggregate quality type, crushed particle and friction type credit, average values for extracted aggregate gradation, aggregate bulk specific gravity, aggregate absorption and asphalt binder content will be furnished by the DME.

Notify the DME at least 48 hours before relocating or reprocessing a Classified RAP stockpile for future use (not intended for a specific project). The notification shall include the estimated quantity of RAP being relocated or reprocessed and the new location of the stockpile. Relocation of RAP shall be reported on the appropriate Form (820009r) and submitted to the DME within 10 calendar days of completing the relocation. Reprocessing a Classified RAP stockpile may require additional sampling, testing, and a new Form (820009r) with reassignment of a RAP Identification Number.

Before January 1st of each year, the Contractor shall update Form 820009r on the status of each RAP stockpile. Report the estimated quantity of RAP removed for the construction season completed and the available RAP in each stockpile for future use.

B) RAS

The following documentation is required for owners of stockpiled RAS:

- Form 820009ras (see Appendix B) is completed by the stockpile owner and a copy is forwarded to the DME within 10 calendar days of completing the stockpile.
- Any special handling, treatment or conditions of the RAS should be described on this form.
- A record of addition and consumption of the RAS stockpile should be documented on this form.

- Maps shall provide details that depict the stockpile site, including adjacent stockpiles of RAP or aggregates, permanent plant equipment, and landmarks.
- Maps and signs shall identify the stockpile by RAS Identification Number.

The DME will review forms for accuracy. Portions of the form including assigning the stockpile identification number, average values for extracted aggregate gradation, and asphalt binder content will be completed by the DME.

Notify the DME at least 48 hours before relocating or reprocessing a RAS stockpile for future use (not intended for a specific project). The notification shall include the estimated quantity of RAS being relocated or reprocessed and the new location of the stockpile. Relocation of RAS shall be reported on the appropriate Form (820009ras) and submitted to the DME within 10 calendar days of completing the relocation. Reprocessing a RAS stockpile may require additional sampling, testing, and a new Form (820009ras) with reassignment of a RAS Identification Number.

Before January 1st of each year, the Contractor shall update Form 820009ras on the status of each RAS stockpile. Report the estimated quantity of RAS removed for the construction season completed and the available RAS in each stockpile for future use.

SAMPLING & TESTING

1. Mix Design

A) RAP

A certified Level I Aggregate Technician shall obtain the samples. Significant mixture differences in the pavement to be recycled may require separate stockpiles and samples. A sampling plan shall be developed by the Contractor and approved by the DME prior to sampling.

Samples for mix design obtained from the RAP stockpile are preferred, but not always available when the mix designs are performed. Samples shall be obtained from at least 3 locations. When stockpile samples are not available, RAP samples shall be obtained by milling a minimum of 50 feet of project length at each sample location. Other methods of sampling for mix design may only be used with the approval of the DME.

Obtain sufficient material for contractor mix design testing and owner agency RAP extraction testing as recommended in Materials I.M. 510. A representative 30 pound sample split from the total sample shall be delivered to the District Materials Laboratory for extraction testing. Results of the extraction test will be provided to the Contractor within 4 weeks of sample delivery.

B) RAS

When RAS is to be used on an existing contract, the DOT will perform mix design testing on samples from the certified stockpile dedicated to the project at the plant. Samples may also be collected at an in-state source. For out-of-state sources, the DME may approve mix design sampling and testing to be coordinated by the Contractor and Supplier at a qualified lab for preliminary information. Mix designs may then be given conditional approval pending DOT results. When the Contractor retains possession of the RAS, the DOT will sample and test. DOT results shall be available prior to start-up. Adjustments to the mix design may be required.

When mix design development needs to be expedited for an active DOT contract and the Supplier has not had sufficient time to certify the pile's quality (gradation and deleterious content), extraction samples may be taken by the District directly at the Supplier's site provided the material is certified free of asbestos containing materials (ACM). Provide a certification letter to the DME using guidelines in Materials IM 506 Appendix E. The Central lab will run extraction and material quality (gradation and deleterious content) testing on the sample. In the event of a failing quality test, the District may sample and test (gradation and deleterious) again after the Supplier has certified the material quality.

A certified Level I Aggregate Technician shall obtain the samples. RAS shall be sampled using methods similar to those for fine aggregate. Samples for mix design testing shall be obtained from at least 3 locations. A sampling plan shall be developed by the Contractor and approved by the DME prior to sampling.

Obtain sufficient material for contractor mix design testing and owner agency extraction testing as recommended in Materials I.M. 510. Samples shall be witnessed and secured. A representative 30 pound sample split from the total sample shall be delivered to the District Materials Laboratory for extraction testing. Results of the extraction test will be provided to the Contractor within 4 weeks of sample delivery.

Include extracted asphalt content and dry RAS gradation in testing.

In lieu of a sieve analysis on the extracted aggregate, the following gradation may be assumed for the RAS aggregate:

Shingle Aggregate Gradation	
Sieve Size	Percent Passing by Weight
3/8 in.	100
No. 4	95
No. 8	85
No. 16	70
No. 30	50
No. 50	45
No. 100	35
No. 200	25

2. Classified RAP Quality Control

When the contractor elects to perform RAP quality control, use one of the following quality control sampling programs. A certified Level I Aggregate Technician shall obtain the samples.

- Stockpiles – The Contractor shall obtain a representative sample of RAP from the stockpile for each 1000 tons of RAP placed in the stockpile.
- Asphalt Plant – The Contractor shall obtain a representative sample of RAP from the RAP feed belt for each 7000 tons of mixture produced.

The Contractor shall use the ignition oven (Materials I.M. 338) or chemical extraction (AASHTO T 164) to extract the aggregate from the RAP sample. Calibration of the asphalt binder content from the ignition oven extraction is not required for the RAP quality control program. The gradation of the extracted RAP aggregate and the un-calibrated asphalt binder content shall be logged and charted within 24 hours of sampling. Report results to the DME upon completion of testing.

3. Undocumented RAP Stockpiles

To retain Classified RAP status for undocumented sources, the stockpile shall be uniform in gradation and binder content. The contractor shall perform ignition oven (Materials IM 338) testing for aggregate gradation and binder content at 1/1000 tons as the stockpile is built or during processing of the stockpile. Regardless of tonnage, a minimum of three tests shall be required. Interior samples from the stockpile cross section shall be included in quality control testing. The contractor shall perform and report aggregate specific gravity and absorption testing at the above frequencies. Retain a split portion of each sample for testing by the Iowa DOT. The District may, at their discretion, select any of the samples to test a burn-off gradation for verification and validate the contractor's testing based on IM 216 tolerances. If tolerances are not met, the District may deem the pile as unclassified or perform additional testing to determine if the Contractor's test results are satisfactory.

Gradation and asphalt content uniformity will be based on the standard deviation requirements listed in Table 1. If the Contractor results satisfy the requirements in Table 1, ~~the District will select a sample to test a burn-off gradation for verification. If the tolerances in IM 216 are met, the Contractor's results will be validated and~~ the pile will be classified. ~~Asphalt content need not be verified with IM 216 tolerances.~~ Log, chart, and report all test results to the DME using the spreadsheet *(http://www.iowadot.gov/Construction_Materials/hma/CertifiedRAPWorksheet.xlsx)*. The procedure outlined in Materials I.M. 501 will be used to identify an outlier on each sieve size and binder content.

Table 1: Variability requirements for Classified RAP from Undocumented Source

Property	Maximum Standard Deviation
1 ½ (% Passing)	5.0
1 (% Passing)	5.0
¾ (% Passing)	5.0
⅜ (% Passing)	5.0
#4 (% Passing)	5.0
#8 (% Passing)	5.0
#30 (% Passing)	5.0
#200 (% Passing)	1.5
Asphalt Content (%)	0.50

The DME will provide notification of Classified status when the above requirements are satisfied.

Only when the owner of the stockpile of a RAP material is an asphalt contractor, the Iowa Department of Transportation or a local agency, should RAP samples be submitted to the Office of Construction & Materials for Vacuum Extraction of Bitumen and Mechanical Analysis of Extracted Aggregate. Ownership of the RAP should be verified so the test results are provided to the rightful owner.

These tests on samples representing stockpiles of any RAP not owned by one of the owners described in the preceding paragraph, shall not be submitted to Office of Construction &

Materials for testing, unless directed by the DME. Until it is certain that these RAP materials will be used in Department projects, the owner may be advised to seek a qualified commercial testing lab to perform these tests.

CREDIT FOR FRICTION AND CRUSHED PARTICLES

The Engineer will use the following guidelines to determine credit for friction and crushed particles when blending multiple piles or milling multiple lifts:

- Credit will be weighted based on paving histories and lift thickness obtained from the historical records where possible
- When no documentation exists, but the year of paving is known, the Engineer may assign credit according to the specification requirement at the time of original paving.

Example:

Your firm is milling 3” of existing pavement using 1 pass of the mill. Of that 3”, 2” is from a surface mix, 1” was from a base mix.
From the paving records you determine the base mix had:

A. 20% crushed clean 3/4” type 4 limestone with 15% passing the number 4 sieve.
B. 20% crushed 3/4” type 4 limestone with 36% passing the number 4 sieve.
C. 10% crushed 1/2” type 4 limestone with 42% passing the number 4 sieve.
D. 25% crushed type 4 limestone manufactured sand with 97% passing the number 4 sieve.
E. 25% type 5 washed sand with 98% passing the number 4 sieve.

From the paving records you determine the surface mix had:

F. 17% crushed 3/4” type 3 gravel with 6% passing the number 4 sieve.
G. 16% crushed 3/8” type 4 limestone with 57% passing the number 4 sieve.
H. 11% crushed 1/2” type 4 limestone with 42% passing the number 4 sieve.
I. 32% crushed limestone manufactured sand with 95% passing the number 4 sieve.
J. 24% type 5 washed sand with 98% passing the number 4 sieve.

The base lift is 1”/ 3” or 33.33% of the rap.
The surface lift is 2”/ 3” or 66.67% of the rap.
Aggregate A from above was 20% of the original base mix aggregate. The base was 33 1/3% of the total rap milled. 85% was retained on the 4. 15% passed the 4. For this rap blend:

- Aggregate A contributed (20%)*(33 1/3%)*(85%) or 5.67% (see below) Type 4 plus 4 sieve material to the aggregate total.
- Aggregate A contributed (20%)*(33 1/3%)*(15%) or 1% (see below) Type 4 minus 4 sieve material to the aggregate total.

This can be done with every aggregate (as shown below).

	Base					Surface							
A number	Axxxxx	Axxxxx	Axxxxx	Axxxxx	Axxxxx	Axxxxx	Axxxxx	Axxxxx	Axxxxx	Axxxxx			
Common name	¾" C.L.	¾" - L.S.	½" - L.S.	Man. Sand	W. Sand	¾" Cr. Gr	3/8" - L.S.	½" - L.S.	Man Sand	W. Sand			
Percent of original mix	20	20	10	25	25	17	16	11	32	24			
Volumetric % (Ratio of lift compared to total lift milled)	33%	33%	33%	33%	33%	67%	67%	67%	67%	67%	0%	0%	
% (percent of total mix)	6.67	6.67	3.33	8.33	8.33	11.33	10.67	7.33	21.33	16.00	0	0	
Retained (+4)	85	64	58	3	2	94	43	58	5	2	100	100	
Passing (-4)	15	36	42	97	98	6	57	42	95	98	0	0	
Aggregate percentage as a decimal	0.066667	0.066667	0.033333	0.083333	0.083333	0.113333	0.106667	0.073333	0.213333	0.16	0	0	
Aggregate Type	4	4	4	4	5	3	4	4	4	5	0	0	
Type 2 or better	No	No	No	No	No	No	No	No	No	No	No	No	
Type 3 or better	No	No	No	No	No	Yes	No	No	No	No	No	No	
Type 4 or better	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	No	No	
Crushed y-yes n-no	Y	Y	Y	Y	N	Y	Y	Y	Y	n			
Type___ or better	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	No	No	Total
Plus 4 type 4 credit =	5.67	4.27	1.93	0.25	0.00	10.65	4.59	4.25	1.07	0.00	0.00	0.00	32.68
Plus 4 type 3 credit =	0.00	0.00	0.00	0.00	0.00	10.65	0.00	0.00	0.00	0.00	0.00	0.00	10.65
Plus 4 type 2 credit =	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Minus 4 type 4 credit =	1.00	2.40	1.40	8.08	0.00	0.68	6.08	3.08	20.27	0.00	0.00	0.00	42.99
Minus 4 type 3 credit =	0.00	0.00	0.00	0.00	0.00	0.68	0.00	0.00	0.00	0.00	0.00	0.00	0.68
Minus 4 type 2 credit =	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Plus 4	5.667	4.267	1.933	0.250	0.167	10.653	4.587	4.253	1.067	0.320	0.000	0.000	33.16
Minus 4	1.000	2.400	1.400	8.083	8.167	0.680	6.080	3.080	20.267	15.680	0.000	0.000	66.84

% plus 4 type 4 **or Better**=32.68/33.16=	98.5%
% plus 4 type 3 **or Better**=10.65/33.16=	32.1%
% plus 4 type 2 **or Better**=0/33.16=	0.0%
% minus 4 type 2 **or Better**=0/66.84=	0.0%
% minus 4 type 3 **or Better**=.68/66.84=	1.0%
% minus 4 type 4 **or Better**=42.99/66.84=	64.3%

Type 5 aggregate	13.00%
Type 4 aggregate	75.67%
Type 3 aggregate	11.33%
Type 2 aggregate	0.00%

Crushed credit in %= 75.67

% plus 4 type 4 =(32.68-10.65)/33.16=	66.4%
% plus 4 type 3 =10.65/33.16=	32.1%
% plus 4 type 2 =0/33.16=	0.0%
% minus 4 type 4 = (42.9-68)/66.84=	63.3%

% minus 4 type 3 =.68/66.84=	1.0%
% minus 4 type 2 =42.99/66.84=	0.0%

Note: Type three or two aggregate is shown as type four or better. When sorting by type this material cannot be counted more than once.

*****GENERAL REWRITE – PLEASE READ CAREFULLY.*****

RAP STOCKPILE REPORT (Form 820009r)

820009r (January 2010)

RAP Stockpile Report			**RAP Stockpile ID #**		
□ **Classified** □ **Certified**					
Stockpile Owner:					
SOURCE OF RAP (Classified only)	Project No.		Dates of Removal		
Route No.	From Milepost		To Milepost		
Removal Depth	JMF No(s)	Mix Type / Size	Crushed Particle %		

LOCATION OF RAP STOCKPILE:			
County	Section	Township	Range
Description of stockpile base:			
Processing remarks:			

STOCKPILE QUANTITY INVENTORY LOG		
Date	Quantity	Disposition (Project No. and use)
		Total initial stockpile quantity

Average EXTRACTION TEST RESULTS		**Aggregate Characteristics**	
Gradation	Lab Report nos.		
3 / 4	Moisture % =	Aggregate Type	
1 / 2	Pb =		
3 / 8	Gsb =	Crushed Particles	%
No. 4	Abs% =		
No. 8	FAA =	Aggr Friction Type 2	%
No. 16	XRF Results		
No. 30	Al_2O_3 =	Aggr Friction Type 3	%
No. 50	MgO =		
No. 100	Deleterious=	Aggr Friction Type 4	%
No. 200	Recycled PCC =		
Shaded boxes to be completed by the District Materials Engineer			

Stockpile Owner Representative		Date
District Materials Representative		Date

NEW – PLEASE READ CAREFULLY.

RAS STOCKPILE REPORT (Form 820009ras)

820009ras (October 2011)

RAS Stockpile Report		**RAS Stockpile ID #**	
Stockpile Owner:			
SOURCE OF RAS			
☐ **Post Consumer Scrap (Tear-offs)**		☐ **Post Manufactured Scrap**	
LOCATION OF RAS STOCKPILE:			
County	Section	Township	Range
Description of stockpile base:			
Processing remarks:			

STOCKPILE INVENTORY LOG					
RAS Addition			RAS Consumption		
Date	Quantity	Supplier	Date	Quantity	Disposition (Project No. and use)
					Total initial stockpile quantity

Average EXTRACTION TEST RESULTS		
Dry RAS Gradation		Lab Report nos.
3 / 4		Moisture % =
1 / 2		
3 / 8		Pb =
No. 4		
No. 8		
No. 16		
No. 30		
No. 50		
No. 100		
No. 200		

Shaded boxes to be completed by the District Materials Engineer

Stockpile Owner Representative		Date
District Materials Representative		Date

IM 510

METHOD OF DESIGN OF ASPHALT MIXTURES

SCOPE

The design of asphalt mixtures involves determining an economical blend of aggregates that provides a combined gradation within the limits of the specifications and a determination of the percent of asphalt binder to mix with the aggregate blend, which provides a mix, which meets volumetric specifications. Trial mixes prepared with different binder contents are tested for mix properties and the results are analyzed to select the binder content that is judged to be most satisfactory for the intended use of the mix.

This IM will cover the sample preparation procedure, aggregate blend selection, binder content selection and the evaluation of the test results. Individual test method IMs are referenced for measuring the properties of individual mixes.

> **NOTE:** The aggregate variable and asphalt binder variable blends are important tools needed by the production control technician for field adjustment of the Job Mix Formula (JMF).

Appendix A of this IM contains the criteria for Gyratory mix design.

REFERENCED DOCUMENTS:

Standard Specification 4127 Aggregate for Flexible Paving Mixtures
AASHTO R-35 Practice for Superpave Volumetric Design for Hot Mix Asphalt (HMA)
ASTM D7313 Standard Test Method for Determining Fracture Energy of Asphalt-Aggregate Mixtures Using the Disk-Shaped Compact Tension Geometry
IM 302 Sieve Analysis of Aggregates
IM 306 Determining the Amount of Material Finer than the #200 (75 µm) Sieve in Aggregate
IM 336 Methods of Reducing Aggregate Field Samples to Test Samples
IM 321 Method of Test for Compacted Density of Asphalt Mixtures (Displacement)
IM 319 Moisture Sensitivity Testing of Asphalt Mixtures
IM 325G Method of Test for Determining the Density of Asphalt Using the Superpave Gyratory Compactor (SGC)
IM 350 Determining Maximum Specific Gravity of Asphalt Mixtures
IM 357 Preparation of Asphalt Mix Samples for Test Specimens
IM 369 Determining Specific Gravity of Asphalt Binder
IM 380 Vacuum-Saturated Specific Gravity & Absorption of Combined or Individual Aggregate Sources
IM 501 Equations & Example Calculations

APPARATUS

- Thermometers: Armored-glass, dial type or digital thermometer with metal stems is recommended. A range of 50° to 400°F (10° to 200°C) with graduations of 5°F (2°C) is required.

- Balances: 20,000-gram capacity, 0.1 gram resolution for mix design and production testing.

- Forced Draft Oven, 350°F (177°C) minimum with controls sensitive to ± 5°F (3°C), minimum size, 7 cu. ft. for production testing or mix design.

> **NOTE:** Experience has shown that a 15 cu. ft. or larger oven may be desirable.

- Mixer: Hobart 19 liters with Dough Hook, Model A-200, or equivalent for Mix Design.
- Safety equipment: insulated gloves, long sleeves, apron, etc.
- Pans of sufficient size for splitting and curing of samples.

General Equipment:

- Scoop or trowel for moving mixture.

PROCEDURE

A. MATERIALS SELECTION

The Contractor selects the aggregate and Recycled Asphalt Materials (RAM) sources and the source of asphalt binder. Aggregate sources and types, individual gradations, crushed particle amount, aggregate friction type, binder grade, and other specific requirements should be checked prior to submitting materials and the 955 form to the laboratory. The gradation of the combined aggregate submitted for trial mix testing shall meet the requirements of the Contract Documents.

The Contractor must notify the District Materials Engineer prior to sampling aggregate stockpiles and RAM. A stockpile of at least 500 tons must be produced so that representative samples of the processed material can be obtained. The target gradation, for each source, to be reported on the 955 form is the average gradation for the stockpile as determined by using the Quality Control and Monitor samples. Enter the target gradation for each source into the SHADES Mix Design program.

Representative RAM samples shall be sent into the laboratory designated by the Engineer for material classification (for State work this is the Central Materials Laboratory). The laboratory will report the results of the tests normally within 15 working days. The following information will be provided for RAP: Fine Aggregate Angularity, Extracted P_b, gradation, and specific gravity of aggregate. The % friction aggregate, % crushed, and types of aggregate will be provided if available. Extracted binder content of RAS samples will be provided.

Binder Bumping
For mixtures not containing RAS
When the amount of recycled binder from RAP exceeds 20.0% of the total asphalt binder, the designated binder grade will be adjusted by lowering both the high and low

temperature PG grade by 6°C while maintaining the AASHTO M332 traffic designation letter on the contract. The MSCR test temperature shall be the new adjusted high temperature PG grade (i.e. PG 58-28H becomes PG 52-34H with a test temperature of 52°C). If the anticipated RAM binder percent exceeds 30.0% of the total, the selection of the binder grade shall be based on testing performed by the Contracting Authority.

For mixtures containing RAS, adjust the contract binder grade as follows:

a. When the amount of recycled binder is inclusively between 15.0% and 25.0%, adjust the grade by lowering both the high and low temperature PG grade by 6°C while maintaining the AASHTO M332 traffic designation letter on the contract. The MSCR test temperature shall be the new adjusted high temperature PG grade (i.e. PG 58-28H becomes PG 52-34H with a test temperature of 52°C).

b. When the amount of recycled binder exceeds 25.0% of the total asphalt binder, the selection of the binder grade shall be based on testing performed by the Contracting Authority.

When binder replacement exceeds 30.0% (25.0% for mixtures containing RAS), grade selection is based on fracture energy as measured by the Disk-Shaped Compact Tension Test (DCT) (ASTM D7313-07a) at no additional cost to the contracting authority. The average of two specimens shall meet the following minimum fracture energy requirements tested at 10°C warmer than the low climatic temperature (normally specified as the low temperature PG grade on the contract):

- Very High Traffic (VT) 690 J/m^2
- High Traffic (HT) 460 J/m^2
- Standard Traffic (ST) 400 J/m^2

The adjusted grade shall meet the same MSCR recovery requirements as the contract binder grade. No adjustments will be made to the contract unit price for required changes to the asphalt binder grade.

Warm Mix Asphalt (WMA)

1. WMA Process Selection

a. **WMA Technology**

Select the WMA process that will be used in consultation with the specifying agency and technical assistance personnel from the WMA suppliers. Consideration should be given to a number of factors including: (1) available performance data, (2) the cost of the warm mix additives, (3) planned production and compaction temperatures, (4) planned production rates, (5) plant capabilities, and (6) modifications required to successfully use the WMA process with available field and laboratory equipment.

b. **WMA Temperatures**

Determine the temperatures that will be used for plant mixing (production) and field compaction. Binder grade selection depends on the plant production temperature. See Table 1 for production temperatures below which the high temperature grade of the binder should be increased one level.

2. Binder Grade Selection for WMA

Increase the high temperature performance grade based on the proposed production temperature. Increase the high temperature performance grade by one grade when the plant discharge temperature is less than that specified in Table 1.

RAM: If more than 20.0% but less than 30.0% of the total binder contribution is from a recycled source, the designated high temperature binder grade will remain unchanged if the production temperature falls below that indicated in Table 1.

Table 1 - Production Temperatures below which the High Temperature Grade Should be Increased One Grade.

Specified PG High Temperature Grade	Aging Index (AI)[1]											
	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6
	Minimum WMA Mixing Temperature Not Requiring PG Grade Increase, °F											
52	<215	<215	<215	<215	<215	<215	220	220	225	225	230	230
58	<215	<215	<215	220	225	230	235	235	240	240	245	245
64	<215	<215	220	230	235	235	240	245	245	250	250	250
70	<215	220	230	240	245	245	250	255	255	260	260	260

Note: 1. $AI = \frac{(G^*/\sin\delta)_{RTFOT}}{(G^*/\sin\delta)_{Tank}}$ at the high temperature performance grade temperature.

3. **WMA Additives**
   Use additives as required by the proposed WMA process or to obtain acceptable coating, workability, compactibility, and moisture susceptibility.

B. JOB MIX FORMULA (JMF)

The JMF together with the specifications provides the initial basis for setting up and starting the job.

To avoid possible delays in the approval of the JMF, the District Materials Engineer should be notified that the Contractor is preparing a JMF. The District Materials Engineer will normally review the complete trial JMF within five working days. The District Materials Engineer may approve a laboratory mix design outside of the gradation control points, provided the plant produced mixture meets the specifications in all respects. It is expected that this would be considered only when the anticipated aggregate gradation is expected to result in a plant produced mixture within specifications.

C. MATERIAL PREPARATION

Approximately 250 lbs. of the combined aggregate will normally be required for the design work. If aggregate variable blends are to be tested prior to the asphalt variable design work, approximately 500 lbs. of aggregate may be necessary. This will allow enough material for the following:

1. Four mix samples of a minimum 13,000-gram batch.

> **NOTE:** If a 2nd Rice sample is desired, a minimum of 14,000 grams is recommended.

2. One sample of each individual aggregate for vacuum saturated specific gravity and absorption (IM 380).

3. Approximately 50 lbs. of material will be used for mix design verification when required.

To prepare the aggregate and RAM samples the following steps should be followed:

4. Obtain samples of each individual source material by following the procedure in IM 336. Perform a sieve analysis on each of the individual materials according to IM 302 and IM 306. Weigh the retained and passing portions of the aggregate, and calculate the percent retained on each sieve split by the following equation:

$$Z = \frac{X}{X + Y} \text{ x } 100$$

Where: "X" = weight of the retained portion, g
"Y" = weight of the passing portion, g
"Z" = percent of the total sample retained

5. Aggregates and RAM must be air dried to a surface dried condition prior to further preparation.

6. Review aggregate gradations as indicated on the 955 form. If the gradation result, for each individual aggregate, found in Step C.4 is within the production tolerance of the gradation indicated on the 955 form, an initial split is made by sieving on the screen size that will most nearly result in a 50-50 percent split. When the screen size selected for the initial split is coarser than the #4 sieve, additional splits shall be made on all sieves down to and including the #4 which retain at least 10% of the material. If the gradation result is outside the production tolerance of the gradation indicated on the 955 form, sieving on each sieve size down to an including the #8 sieve is performed. All sieving must be done to completion.

> **NOTE:** Sieving on each sieve size down to and including the #8 sieve is always an option even if the gradation results found in Step C.4 are within the production tolerances.

7. In no case shall any sample or sample portion be split on a #16 or smaller size sieve.

8. After sample splitting is complete, dry the individual portions of the aggregate for a minimum of 6 hours in an oven at a temperature of 275° ± 10°F (135° ± 6°C) for HMA mixtures, or until the aggregates reach a constant weight when weighed at 30 minute intervals. Use 60°F (15°C) above the proposed production temperature for WMA mixtures.

> **<u>NOTE:</u>** RAM is not oven-dried.

9 Prior to aggregate blend selection, the aggregate source properties, the bulk dry specific gravity and absorption of the individual aggregate samples as well as the specific gravity of the binder at 77°F (25°C) must be determined. In addition, the consensus properties of the individual aggregates may be determined to estimate the combined aggregate properties. Properties of RAM sources are as provided by the Contracting Authority.

> **<u>NOTE</u>:** G_b at 77°F (25°C) may be obtained from certifying documents or test reports (IM 369). Certifying documents may report G_b at 60°F (15°C).

D. AGGREGATE BLEND SELECTION

This section explains the selection of an aggregate blend determined to be the most appropriate blend that will meet the design criteria. The mix designer may establish an aggregate blend based on past experience or by evaluating multiple blends. The shape of the gradation plotted on the 0.45 power gradation chart generally reflects the void space available for asphalt. Gradations that closely follow the maximum density line generally have minimal void space.

1. Select a minimum of three blends, which cover a broad range of aggregate properties (shape, texture, gradation, etc…).

2. Check the aggregate consensus properties of each blend as specified in Appendix A.

3. Select a trial asphalt binder content for each of the proposed blends by one of the five methods below. The asphalt binder used for trial mixes shall be of the same grade as indicated on the 955 form and shall be from the same source when possible.

   a. Experience
   b. SHADES Mix Design Program
   c. AASHTO R-35
   d. Calculated surface area of the aggregate (See Note.)

   > **<u>NOTE</u>:** The asphalt film thickness obtained at a given binder content is related to the surface area and asphalt absorption of the aggregate. Higher surface areas will generally, but not always, require higher binder content.

   e. Table 2303.02-2 in Standard Specification 2303 for Basic Asphalt Binder Content.
4. Check that the trial asphalt binder content selected for each aggregate blend could meet the film thickness criteria specified in Appendix A.

5. Use the procedure in the "Mixture Batching, Curing & Testing" section to batch, cure and test trial blends.

6. Evaluate the mixture properties of each trial blend as specified in Appendix A.

Mixes that meet the design criteria may proceed to asphalt binder variable design. Aggregate blend selection should take into consideration the source availability, ability to adjust field production and source cost.

E. ASPHALT BINDER CONTENT SELECTION

Normal trial mixes are prepared at a minimum of three different asphalt binder contents to assure close bracketing of the final recommended design binder content. The final recommended binder content must be bracketed by trial binder contents above and below, unless the air voids are within 0.25% of the design target, in which case no additional points are needed. Contractor prepared mix designs may require a mixture prepared at the recommended design binder content for DOT mix design verification.

Select an initial trial asphalt binder content by one of the five methods below. The binder used for trial mixes shall be of the same grade as indicated on the 955 form and shall be from the same source when possible.

a. Experience
b. SHADES Mix Design Program
c. AASHTO R-35
d. Calculated surface area of the aggregate (See Note.)

> **NOTE:** The asphalt film thickness obtained at a given binder content is related to the surface area and asphalt absorption of the aggregate. Higher surface areas will generally, but not always, require higher binder content.

e. The basic asphalt binder content table from Step D.3

> **NOTE:** To avoid wasted effort in the laboratory when using unfamiliar materials, the mix designer is encouraged to perform a single point analysis of the volumetric properties prior to performing the complete (multi point or bracketing) analysis. For the purposes of adjusting the trial binder content to the proper void level, the following general rule applies: A 0.2% change in asphalt binder content is approximately a 0.5% change in air voids.

Anti-stripping Agents

See Article 2303.02, E, 2, g for allowed use. For HMA designs which use a liquid anti-stripping agent, if the agent also acts as a compaction aid then after the optimum binder content has been selected, compact an additional specimen (with binder that has been dosed with the agent) to ensure the target air void content is met. If air voids have changed by more than 0.5% then adjust the binder content accordingly to achieve target voids prior to production.

F. MIXTURE BATCHING, CURING & TESTING

The following procedures should be used for the batching, curing and testing of mixes. These procedures are to be used for both the “aggregate blend selection” and “asphalt binder content selection” phases of mix design. For WMA mixtures not utilizing a water-injection system, the WMA technology should be used in fabricating specimens in the mixture design phase. Methods for WMA specimen preparation are process specific. Consult the manufacturer for detailed WMA specimen fabrication procedures

1. Accurately batch the aggregates in the correct proportions to obtain the desired batch weight. The desired amount of RAM plus an additional 100 grams, to compensate for moisture loss, will be weighed in a separate pan. The individual aggregate split sample batch weight is determined by the following equation:

   Split sample aggregate batch weight = (A)(B)(C)

   Where: A = total aggregate batch weight desired
   B = individual aggregate in total aggregate batch weight, %
   C = split portion of individual aggregate, %

   > **NOTE:** If RAM is included in the mix, the aggregate proportions must be adjusted for the purpose of determining the combined aggregate gradation and combined specific gravity. Use the formulas in IM 501.

2. Determine the amount of asphalt binder needed for each trial mix batch as follows:

$$\text{Binder Weight} = \frac{(\text{aggregate batch weight}) \times (\text{Target } P_b)}{(100 - \text{Target } P_b)}$$

   > **NOTE:** If RAM is included in the mix, the $P_{b\ (added)}$ content must be determined. Use the formulas in IM 501.

3. For HMA mixtures, separately heat the combined aggregate batch and binder to 275° ± 5°F (135° ± 3°C) as checked by a thermometer in the pan of aggregate. For WMA mixtures, heat the combined aggregate batch and binder containing the WMA technology (at the dosage recommended by the manufacturer) to the proposed production temperature ± 5°F (± 3°C). The mixing bowl and utensils shall also be heated before mixing operations begin. Always keep the mixing bowl buttered.

   > **NOTE:** It generally takes 4 hours to bring aggregates & binder to

mixing temperature. RAM will be heated in a separate pan for a maximum of 2 hours to minimize binder aging.

4. Weigh the required amount of RAM into the mixing bowl; pour the heated aggregate into the bowl and dry mix for 15 seconds on speed 1. Stop mixer.

5. Add the required amount of binder and mix for 15 seconds on speed 1. Stop mixer, shift to speed 2 and continue to mix for 45 seconds. Stop mixer.

6. Lower the mixing bowl and clean the dough hook and the bottom and side of the bowl by scraping with a spatula. Incorporate any adhering mixture or binder back into the sample within 2 minutes from the start of the cleaning operation.

7. Raise the bowl and continue mixing for 15 seconds on speed 2. Then repeat Step F.6 and again stir any adhering mix or binder back into the sample with the spatula.

8. Break the samples down according to IM 357.

   a. Take 2 samples of approximately 5000 gram each for gyratory compaction.

   b. Take a sample of a minimum of 2000 gram for G_{mm} determination.

9. Spread the material into a pan such that the material is 1 to 2 in. (25 to 50 mm) thick.

10. For HMA mixtures, cure all samples for 2 hours at 275°F (135°C). For WMA mixtures, cure all samples for 2 hours at the proposed field compaction temperature. 1 hour into curing, all samples are removed, thoroughly stirred and placed back into the oven for remainder of curing time.

11. Place approximately 4700 grams of material into the mold for gyratory specimens. Compact HMA specimens at 275°F (135°C) and WMA specimens at the proposed field compaction temperature per IM 325G.

    a. If necessary, adjust the weight of the sample to achieve the required test specimen height.

$$\text{Adjusted sample weight} = \frac{(\text{trial sample weight})(\text{intended height})}{\text{trial sample height}}$$

    b. Adjust the weight of the sample 1.25% for every 1% change in binder content.

12. Test loose mix at each binder content for maximum specific gravity per IM 350.

13. Measure the density (G_{mb}) of the compacted specimens per IM 321.

G. MIXTURE PERFORMANCE EVALUATION

A binder content is selected that will produce percent air voids in the compacted specimens equal to the target air void value. The test data and calculated results at the selected binder content are compared to the criteria specified in Appendix A. Interpolation may be necessary. Mixture designs may also be tested using IM 319 when required by the specifications.

DOCUMENTATION

The link to SHADES is provided here:
http://www.iowadot.gov/Construction_Materials/hma/SHADES.xlsm
A copy of the SHADES computer file containing all the test data must be submitted to the DME for approval of the JMF. For WMA mixture designs, report proposed production temperature, compaction temperature, WMA technology, additional equipment requirements from the manufacturer, manufacturer name, proposed dosage rate, and any manufacturer recommendations on the 956 form. The signed JMF report (956) (including economic justification when required) shall be required prior to paving. See Appendix B for more information.

Distribution of the documents:

District Materials Engineer
Project Engineer

ASPHALT MIXTURE DESIGN CRITERIA

Overview of the Asphalt Mixture Design Criteria Chart (Table 1)
The Asphalt Mixture Criteria chart identifies the aggregate, mixture volumetric, and laboratory density requirements for mixtures designed under the gyratory mix design system. The chart is formatted to correspond with the bid item designations. The bid item designations classify each mixture by the maximum 20-year traffic load (ST-Standard Traffic, HT-High Traffic, VT-Very High Traffic), the intended pavement layer (surface, intermediate, base), the mixture size (based on nominal maximum aggregate size), and the surface layer friction requirement. A designation of "**HMA HT Surface ½ L-3**" describes the HMA mixture for high traffic, surface layer, ½-inch mixture size, with level 3 friction aggregate. Frictional aggregate requirements can be found in Standard Specification 2303.

The column to the right of the mixture designation define the required level of compaction (N value) and the target density (expressed as percent of G_{mm}) associated with each level of compaction. Note that the required density of a given level of compaction varies for different traffic levels and pavement layers. For example, the ST surface/intermediate, N_{des}=50, mixture requires 96 percent of G_{mm} (4.0% air voids). The N_{des}=50 base mixture for ST requires 97.0 percent of G_{mm} (3.0% air voids).

The middle column identifies the film thickness requirement.

The aggregate properties are defined in the right columns. The quality of the aggregate (Type A or B) is further specified in Standard Specification 4127. The crush value specifies the minimum amount of crushed aggregate required. The Fine Aggregate Angularity and Sand Equivalent values are consensus properties of the fine aggregate portion of the mix. Table Note 1 defines the allowable quantity of flat and elongated aggregate for all mixtures.

For any specified asphalt mixture, the mix design criteria are found by reading across the table. The asphalt mixtures are grouped by traffic levels.

Gradation Requirements
The individual aggregate gradation requirements for HMA mix designers are contained on Form 955.

The combined aggregate shall meet the gradation requirements on Table 2.

Table 1

<table>
<tr><th colspan="2" rowspan="2">Mix Designation</th><th colspan="2">Gyratory Density</th><th rowspan="2">Film Thickness</th><th colspan="4">Aggregate [1]</th></tr>
<tr><th>N_{des}</th><th>Design (Target) % G_{mm}</th><th>Quality Type</th><th>Crush (min)</th><th>FAA</th><th>Sand Equivalent</th></tr>
<tr><td rowspan="3">ST</td><td>Surface</td><td rowspan="3">50</td><td rowspan="2">96.0</td><td rowspan="3">8.0-15.0</td><td>A</td><td>60</td><td rowspan="2">40</td><td rowspan="3">40</td></tr>
<tr><td>Intermediate</td><td rowspan="2">B</td><td rowspan="2">45</td></tr>
<tr><td>Base</td><td>97.0</td><td>--</td></tr>
<tr><td rowspan="3">HT</td><td>Surface</td><td rowspan="3">75</td><td rowspan="2">96.0</td><td rowspan="3">8.0-15.0</td><td rowspan="2">A</td><td>75</td><td rowspan="2">43</td><td rowspan="3">45</td></tr>
<tr><td>Intermediate</td><td rowspan="2">60</td></tr>
<tr><td>Base</td><td>96.5</td><td>B</td><td>40</td></tr>
<tr><td rowspan="3">VT</td><td>Surface</td><td rowspan="3">95</td><td rowspan="2">96.0</td><td rowspan="3">8.0-15.0</td><td rowspan="2">A</td><td rowspan="2">85</td><td rowspan="2">45</td><td rowspan="3">45</td></tr>
<tr><td>Intermediate</td></tr>
<tr><td>Base</td><td>96.5</td><td>B</td><td>75</td><td>40</td></tr>
<tr><td></td><td>HMA Interlayer [2]</td><td>50</td><td>≥98.0</td><td>≥80</td><td>A</td><td>45</td><td>40</td><td>50</td></tr>
<tr><td></td><td>HMA Thin Lift [3]</td><td>50</td><td>≥98.0</td><td>≥8.0</td><td>A</td><td>50</td><td>40</td><td>50</td></tr>
<tr><td></td><td colspan="8">(1) Flat & Elongated 10% maximum at a 5:1 ratio.
(2) See Table 3 for additional requirements.
(3) See Table 4 for additional requirements.</td></tr>
</table>

Table 2

Aggregate Gradation Control Points												
Sieve Size	Mix Size – Control Points (% Passing)											
	1 inch		3/4 inch		1/2 inch		3/8 inch		HMA Interlayer		HMA Thin Lift	
	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.
1 1/2 inch	100											
1 inch	90	100	100									
3/4 inch		90	90	100	100							
1/2 inch				90	90	100	100					
3/8 inch						90	90	100	100		91	100
No. 4								90	80	100		90
No. 8	19	45	23	49	28	58	32	67	60	85	27	63
No. 16 (1)				28		32			40	70		
No. 30 (2)				24		25			25	55		
No. 50									15	35		
No. 100									8	20		
No. 200	1	7	2	8	2	10	2	10	6	14	2	10

(1) Only applies to surface and intermediate mixtures for HMA VT designs.

(2) Only applies to surface and intermediate mixtures for HMA HT designs.

Table 3

Performance Requirements for HMA Interlayer (2)		
Test	Requirement	Notes
AASHTO T-321	Minimum 100,000 cycles to failure	1

(1) Failure criterion at 2,000 microstrain shall be 50% of the initial flexural stress measured at the 200th load cycle.

(2) Use a PG 58-34E binder. Testing may be verified by the Engineer on field produced mix. Do not open to traffic until mat has cooled to below 150°F.

Table 4

Performance Requirements for High Performance Thin Lift (1)		
Test	Requirement	Notes
AASHTO T-324	At the 8,000th wheel pass, the rut depth must be less than or equal to 4.00 mm	1

(1) Use a PG 64-34E+ binder with a minimum 90% MSCR recovery. Do not open to traffic until mat has cooled to below 150°F.

MIX DESIGN DOCUMENTATION

GENERAL
Assign a mix design number with the following format: ABDYY-D000
Where "YY" is the two-digit year, "D" is the district number, and "000" is a 3-digit number identifying the JMF number.

When a significant change (as defined in 2303) is made to the original JMF, amend the mix design number with an "RX". For example ABD14-6017 is the 17th JMF in 2014 for District 6. When a significant mix change is made, the new mix design number would be ABD14-6017R1. Subsequent changes from the original design would require "R2, R3, etc".

For mix designs transferred from one project to another a new mix design number will be required when the following have occurred.

- There have been two or more aggregate or RAP source changes.
- The blend percentage has varied more than 10% from the original design for any individual aggregate or RAM.
- Recycled shingles have been added or removed from the design.

The new design may be validated by testing a single point or by evaluating current production test results.

A typical Mix Design Report and a Proportion/Production Limits Form is shown below.

Form 956 ver. 10.14

Iowa Department of Transportation

Highway Division - Office of Materials
HMA Gyratory Mix Design

Mix Data

Nmax

County :	Jones	Project : HSIPX-151-4(125)--3L-53		Letting Date :	7/16/2013
				Mix No. :	ABD14-6017
Mix Size (in.) :	1/2	Type A	Contractor : Mathy d/b/a R.C.Paving	Contract #:	53-1514-125
Mix Type:	HMA 1M	No Frictn Req	Design Life ESAL's : 1,000,000	Date:	04/29/14
Intended Use :	Shoulder		Location : MP 63.05 - 92.31	On US 151 from Monticello to Jct. US 61 29.26 mi.	

Aggregate	% in Mix	Source ID	Source Location	Beds	Gsb	%Abs	FAA	Friction
5/8" x3/8"	30.0%	A31066	River City Stone/Fillmore	2-4	2.696	1.37	48.0	4
3/8" x 3/16"	20.0%	A31066	River City Stone/Fillmore	2-4	2.695	1.31	48.0	4
Natural Sand	35.0%	A31514	River City Stone/Fillmore		2.593	1.20	40.0	5
Classified RAP	15.0%	ABC12-15	15% ABC12-15 (5.56 % AC)		2.578	2.29	43.1	4

Job Mix Formula - Combined Gradation (Sieve Size in.)

	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200
Upper Tolerance	100	100	100	87	60	45		26			5.8
	100	**100**	**97**	**80**	**53**	**40**	**33**	**22**	**9.0**	**4.6**	**3.8**
Lower Tolerance	100	100	90	73	46	35		18			1.8

Home

Asphalt Binder Source and Grade: . Paul Park Refinery Co. LLC (St. Paul Park, MN PG 58-28

Gyratory Data

% Asphalt Binder	4.70	**4.86**	5.20	5.70	
Corrected Gmb @ N-Des.	2.404	**2.412**	2.428	2.432	
Max. Sp.Gr. (Gmm)	2.491	**2.486**	2.477	2.460	
% Gmm @ N- Initial	90.3	**90.9**	92.0	92.7	
%Gmm @ N-Max	96.5	**97.0**	98.0	98.8	
% Air Voids	3.5	**3.0**	2.0	1.1	
% VMA	13.3	**13.1**	12.8	13.2	
% VFA	73.6	**77.1**	84.6	91.4	
Film Thickness	9.33	**9.67**	10.29	11.38	
Filler Bit. Ratio	0.91	**0.88**	0.82	0.74	
Gse	2.677	**2.679**	2.683	2.684	
Pbe	4.19	**4.34**	4.62	5.11	
Pba	0.53	**0.55**	0.61	0.63	
% New Asphalt Binder	82.9	**83.5**	84.7	86.1	
Combined Gb @ 25°C	1.0330	**1.0330**	1.0330	1.0331	

Number of Gyrations
N-Initial
7
N-Design
68
N-Max
104

Gsb for Angularity
Method A
2.593

Pba / %Abs Ratio
0.41

Slope of Compaction Curve

			Combined	Contribution From RAM
Aggregate Type Used	A			
G_{sb}	2.641	% Friction Type 4 (+4)	93.1	3.8
G_{sa}	2.745	Or Better	93.1	3.8
% Water Abs	1.44	% Friction Type 3 (+4)	0.0	0.0
S.A. m^2 / Kg.	4.49	Or Better	0.0	0.0
Angularity-method A	41	% Friction Type 2 (+4)	0.0	0.0
% Flat & Elongated	0.2	% Friction Type 2 (-4)	0.0	0.0
Sand Equivalent	89	Type 2 Fineness Modulus	0.0	0.0
Virgin G_b @ 25°C	1.0336	% Crushed	59.0	8.6
Anti-Strip Dose (%)	0.00			
Stripping Inflection Point				

Mix Check
Good

Pb Range Check
1.00

RAM Check
OK

Specification Check
Comply

Moisture Sensitivity Check
Not Required

Disposition : An asphalt content of 4.9% is recommended to start this project.
Data shown in 4.86% column is interpolated from test data.
The % ADD AC to start project is 4.1%

Comments :

Copies to :	Mathy d/b/a R.C.Paving	Roger Boulet	Manchester Const.	Dist. 6 Lab.
	Producer		Area Inspector	HMA Tech.

Mix Designer & Cert.# : C. Morgan & D.Lohrer EC-347 & EC-177 Signed : C. Morgan & D. Lohrer

Form 955 ver. 10.14

Iowa Department of Transportation

Highway Division-Office of Materials
Proportion & Production Limits For Aggregates

Production Limits

County : Jones Project No.: HSIPX-151-4(125)--3L-53 Date: 04/29/14
Project Location: On US 151 from Monticello to Jct. US 61 29.26 mi. Mix Design No.: ABD14-6017
Contract Mix Tonnage: 70,000 Course: Shoulder Mix Size (in.): 1/2
Contractor: Mathy d/b/a R.C.Paving Mix Type: HMA 1M Design Life ESAL's: 1,000,000

Material	Ident #	% in Mix	Producer & Location	Type (A or B)	Friction Type	Beds	Gsb	%Abs
5/8" x3/8"	A31066	30.0%	River City Stone/Fillmore	A	4	2-4	2.696	1.37
3/8" x 3/16"	A31066	20.0%	River City Stone/Fillmore	A	4	2-4	2.695	1.31
Natural Sand	A31514	35.0%	River City Stone/Fillmore	A	5		2.593	1.20
Classified RAP	ABC12-15	15.0%	15% ABC12-15 (5.56 % AC)	A	4		2.578	2.29

Type and Source of Asphalt Binder: PG 58-28 St. Paul Park Refinery Co. LLC (St. Pau

Individual Aggregates Sieve Analysis - % Passing (Target)

Material	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200
5/8" x3/8"	100	100	90	35	6.0	5.5	5.0	4.5	4.0	3.5	3.0
3/8" x 3/16"	100	100	100	100	33	6.5	6.0	5.5	5.0	4.5	4.0
Natural Sand	100	100	100	100	93	80	65	40	10	1.5	1.0
Classified RAP	100	100	99	97	79	62	49	37	23	15	12

Preliminary Job Mix Formula Target Gradation

Upper Tolerance	100	100	100	87	60	45		26			5.8
Comb Grading	100	100	97	80	53	40	33	22	9.0	4.6	3.8
Lower Tolerance	100	100	90	73	46	35		18			1.8
S.A.sq. m/kg	Total	4.49		+0.41	0.22	0.33	0.54	0.63	0.55	0.57	1.25

Clear Add Limits Production Limits for Aggregates Approved by the Contractor & Producer. Home

Sieve Size in.	30.0% of mix 5/8" x3/8" Min	Max	20.0% of mix 3/8" x 3/16" Min	Max	35.0% of mix Natural Sand Min	Max	15.0% of mix Classified RAP Min	Max		
1"	100.0	100.0	100.0	100.0	100.0	100.0				
3/4"	100.0	100.0	100.0	100.0	100.0	100.0				
1/2"	80.0	100.0	100.0	100.0	100.0	100.0				
3/8"	28.0	42.0	98.0	100.0	100.0	100.0				
#4	0.0	13.0	23.0	37.0	90.0	100.0				
#8	0.0	10.0	0.0	11.0	75.0	85.0				
#30	0.0	8.0	0.0	9.0	36.0	44.0				
#200	0.0	4.0	0.0	4.0	0.0	1.5				

Comments:

Copies to: Mathy d/b/a R.C.Paving Roger Boulet Manchester R.C.E. Dist. 6 Lab
Producer's Area Inspector HMA Tech.

~~The above target gradations and production limits have been discussed with and agreed to by an authorized~~
representative of the aggregate producer.

Signed: ____________________ Signed: ____________________
Producer Contractor

GENERAL REWRITE

ALLOWABLE RAP USAGE BY WEIGHT

Mix Designation	Aggregate Quality Type	Unclassified RAP	Classified RAP
HMA ST S	A	0%	Limited by binder replacement
HMA ST I	B	10%	No Limit
HMA ST B	B	10%	No Limit
HMA HT S	A	0%	Limited by binder replacement
HMA HT I	A	0%	No Limit
HMA HT B	B	10%	No Limit
HMA VT S	A	0%	Limited by binder replacement
HMA VT I	A	0%	No Limit
HMA VT B	B	10%	No Limit

IM 511

CONTROL OF ASPHALT MIXTURES

SCOPE

This IM describes the Quality Control/Quality Assurance (QC/QA) procedures for monitoring and controlling plant-produced asphalt concrete mixtures on Quality Management of Asphalt (QMA) projects.

REFERENCE DOCUMENTS

Standard Specification 2303 Flexible Pavement
IM 204 Inspection of Construction Project Sampling & Testing
IM 205A Securing Samples
IM 208 Materials Laboratory Qualification Program
IM 213 Technical Training and Certification Program
IM 216 Guidelines for Validating Test Results
IM 301 Aggregate Sampling & Minimum Size of Samples for Sieve Analysis
IM 302 Sieve Analysis of Aggregates
IM 319 Moisture Sensitivity Testing of Asphalt Mixtures
IM 320 Method of Sampling Compacted Asphalt Mixtures
IM 321 Method of Test for Compacted Density of Hot Mix Asphalt (HMA)(Displacement)
IM 322 Sampling Uncompacted Hot Mix Asphalt
IM 323 Method of Sampling Asphaltic Materials
IM 325 Compacting Asphalt Concrete by the Marshall Method
IM 325G Method of Test for Determining the Density of Hot Mix Asphalt (HMA) Using the Superpave Gyratory Compactor (SGC)
IM 336 Reducing Aggregate Field Samples to Test Samples
IM 337 Method to Determine Thickness of Completed Courses of Base, Subbase & Hot Mix Asphalt
IM 338 Method of Test to Determine Asphalt Binder Content & Gradation of Hot Mix Asphalt (HMA) by the Ignition Method
IM 350 Method of Test for Determining the Maximum Specific Gravity of Hot Mix Asphalt (HMA) Mixtures
IM 357 Hot Mix Asphalt (HMA) Mix Sample for Test Specimens
IM 501 Equations and Example Calculations
IM 510 Method of Design of Hot Mix Asphalt Mixes

RESPONSIBILITIES

Appendix A contains an outline of the responsibilities required for all parties. Refer to IM 213 Appendix C for individual certification requirements.

SAMPLING & TESTING

Sample and test according to Section 2303. Only the information obtained from random samples as directed and witnessed by the Engineer and validated by comparison to one or more of the paired samples tested by the Contracting Authority will be used for specification compliance. Additional samples of aggregate and uncompacted asphalt mixture may be taken by the contractor to provide better quality control. The results of testing done on additional samples will be for informational purposes only and do not need to be reported.

All testing done by the Contractor that is used as part of the acceptance decision shall be performed in qualified labs by certified technicians. Gyratory compactors not utilized in the independent assurance testing (IM 208 Appendix C) will not be allowed on QMA projects without permission from the District Materials Engineer (DME).

Retain samples taken for acceptance purposes until the contractor's results have been validated.

A. UNCOMPACTED ASPHALT MIXTURE

The specific ton or truckload to begin sampling will be determined by the Engineer using the spreadsheet (https://iowadot.gov/Construction_Materials/hma/hmarandomsamples.xlsx). The total estimated daily production is divided into equal sublots based on the number of samples determined from Table 2303.03-5.

EXAMPLE
Estimated production = 4,501 tons
Number of Samples = 5
Approximate sublot size = 4501/5 = 900 tons

When production of a bid item is expected to exceed three production days (small quantities excluded) and conditions/resources reasonably allow, test samples immediately "hot-to-hot" (without allowing the sample to cool) for at least one day at the beginning of production to aid in any future investigation of non-correlation that may arise throughout production.

Calibrate the Rice pycnometer at the beginning of a project and anytime that a correlation problem occurs.

B. COMPACTED ASPHALT MIXTURE

1. For class I compaction, the width subjected to the random sampling shall coincide with the width eligible for PWL incentive/disincentive. This width shall be the nominal width of the travelled lane unless otherwise determined by the Engineer. Take samples from no less than 1 foot from the unconfined edge of a given pass of the placing equipment, except when the width of a single pass of the paver exceeds the width eligible for random sampling by more than 1 foot (i.e. For a 14-foot paving width on a 12-foot wide lane, a core location could randomly fall exactly 12 feet from centerline, assuming a two lane roadway. The outside 2 feet would then be deducted from the field voids lot quantity).

2. The Engineer will provide inspection staff to direct and witness the sampling and perform G_{mb} measurement during a time agreed between the Engineer and the Contractor. The Engineer should make every effort to meet the Contractor's schedule.

3. The Engineer will transport the cores in accordance with IM 320, or secure the cores for transport by the contractor. The Engineer and Contractor will determine that cores are not damaged. The Engineer will decide if a core is damaged prior to testing.

C. ASPHALT BINDER

Sample and test according to IM 204. For DSR verification tests performed at the District laboratory, if the G*/sinδ falls below 1.0, obtain a quart sample for full analysis and test all remaining 4 oz. samples until the area of noncompliance is isolated.

The Engineer may price adjust the asphalt binder for the following quality characteristics

- G*/sinδ (un-aged)
- Percent Recovery
- M-value

VALIDATION

A. Defined

Validation is defined as the ability of two labs to achieve similar (statistically equivalent) test values on split or paired samples.

B. Aggregate Gradation Correction Factor

When comparing the cold-feed gradation to the ignition oven extracted gradation, a correction factor to adjust the extracted gradation must be determined in accordance with IM 501. Validation of the cold-feed gradation will be determined by comparing the cold-feed gradation and the corrected extracted gradation as shown on the comparison report for Cold-Feed & Ignition Oven in IM 216 Appendix A. The correction factors will be established by comparing an Agency cold-feed sample to an Agency ignition oven extracted sample. The Engineer may witness and secure a split cold-feed sample according to IM 205 Appendix A for validation in lieu of an ignition oven sample, in which case a correction factor is not needed.

C. Validation Requirements

1. When any of the following events occur, validation has not been achieved or maintained:
   a. The difference between test results on each of two consecutive split/paired samples exceeds the IM 216 tolerance.
   b. The difference between test results on any two of three consecutive split/paired samples exceeds the IM 216 tolerance.
2. Consecutive samples may be either validation samples tested sequentially with another lab or mix specific samples when other mixes are being tested for validation between the two labs. It may be necessary to examine validation of test results on consecutive samples **of the same mix** if more than one mix is being tested between the two labs. Validation problems sometimes only occur during testing of specific mix samples.
3. When validation for a particular test has not been achieved, all results for that day are considered invalid for that test.
4. To achieve or reestablish validation, a minimum of two consecutive test results must meet IM 216 tolerances.
5. When noncomplying material has been removed, the test results corresponding with the material will remain in the validation decision.

DISPUTE RESOLUTION

A. Investigation

When validation is not achieved or maintained, the DME will act as appropriate to resolve split/paired test result differences by choosing among the strategies below. The DME shall report the results of the investigation to the Contractor upon its conclusion. The DME may consider results from the Independent Assurance Program in the investigation. When non-validation of test results cannot be explained by an assignable cause as determined by the DME, the Engineer's results will be used for acceptance.

1. Retest the same sample
2. The District labs will test additional verification samples.
3. The DME will review the sampling and testing procedures of both labs
4. The DME will immediately test samples sent in by the Contractor without allowing cool down and reheating (hot-to-hot testing).
5. Both labs will test samples using comparable reheat periods.
6. The DME will establish a correction factor based on the reheat evaluation outlined in Appendix B.
7. Both labs will test a sample that was taken and split by the Engineer.
8. Both labs and a third laboratory designated by the Contracting Authority will test a sample split three ways. The 3rd lab for state projects will normally be the Central Materials Lab.
9. The DME will establish a correction factor for the Contractor's gyratory compactor based on the procedure described in Appendix C. The correction factor for G_{mb} should not exceed 0.030.
10. Verify both labs are compacting to the number of gyrations specified in the contract documents.

B. Quality Assurance Protocol
1. Resolution decisions by the Iowa DOT Central Materials Laboratory will be final.
2. During the period of production when validation cannot be achieved, the Engineer's test results will be used for acceptance of the lot. The use of the Engineer's test values for acceptance will be retroactive to the time when the first sample exceeded the validation tolerance. Similarly, when validation is regained, the use of the Contractor's test results for acceptance is retroactive to the first test used to reestablish validation.
   a. Over the period which validation cannot be achieved for aggregate gradation, the Engineer's test results will be used for the entire gradation and applied to any calculations involving the gradation for the entire lot.
   b. If validation cannot be achieved between the ignition oven extracted gradation and the Contractor's cold-feed gradation, the Agency will run cold-feed gradations for validation in place of the ignition oven.
   c. Over the period which validation cannot be achieved on-uncompacted asphalt mixture tests for G_{mm} or G_{mb}, the Engineer's test results will be used as follows:
      i. For lots under the PWL acceptance plan,
      The Engineer's results and any other valid contractor's results for the lot will be used in the calculations for field voids and lab voids.
      ii. For all other lots, the Engineer's results will be used for any calculations involving that particular test value.
      iii. Use a maximum lot pay factor of 1.000 for lab voids and field voids when the Engineer's results are used for any portion of the lot.

PRODUCTION TOLERANCES
Production tolerances are listed in the Section 2303.

Investigate variations between two consecutive test results in G_{mb} or G_{mm} of more than 0.030 promptly since these tests reflect significant changes in binder content, aggregate properties and/or gradation. In some cases variations may be attributed to segregation, thoroughness of mixing, sampling procedure, and changes in aggregate production.

If the test results in a series of split/paired samples (minimum of 3 samples) are not variable and random (results are consistently higher or results are consistently lower) and the difference between each split/paired test result is greater than half of the IM 216 tolerance, the DME may establish a correction factor for the Contractor's gyratory compactor based on the procedure described in Appendix C. The correction factor for G_{mb} should not exceed 0.030.

REPORTING

For each production sample of loose asphalt mixture the Contractor will determine, report, and plot G_{mb}, G_{mm} and P_a. Binder content measurement by an approved method will be determined, reported, and plotted daily. Gradation will be determined, reported and plotted daily. Make the inter lab correlation reports available.

Test results are to be recorded and plotted in the computer programs provided by the Iowa DOT (https://iowadot.gov/construction_materials/Hot-mix-asphalt-HMA). The computer programs act as a tool for documenting project data and applying the specification. The specification and IMs will always govern when errors are encountered in the software. Microsoft Excel 2007 (or newer) is required (or equivalent spreadsheet software capable of reading and writing *.xlsm and *.xlsx file types). The recommended minimum system requirements include a 2.3 Ghz processor or higher with at least 2 GB of physical memory and a wireless network adapter with internet access. Copies of the electronic spreadsheet file containing the completed Daily HMA Plant Report shall be provided to the DME and the Engineer within 4 hours of beginning operations on the next working day. The Engineer may extend this time on days when longitudinal joint cores are sampled and tested. Alternatively in these cases, the Engineer may accept partially completed reports until results are available. Use electronic mail (or DocExpress®) as the method of delivery unless otherwise approved by the Engineer. Copies of computer files containing the project information shall be furnished to the Engineer on a CD or portable memory device upon project completion. An additional copy of the files shall be furnished to the DME on a CD or portable memory device.

Keep the charts current and available showing both individual sample results and moving average values for both lab voids and absolute deviation from target. Base moving average values on four consecutive sample results.

MIXTURE AND BINDER SUBSTITUTIONS

At no additional cost to the Contracting Authority, the Engineer may approve the substitution of any mix design which meets or exceeds the requirements of the original mix. Mixture substitutions shall be gyrated to the same level as the original mix requirements. Binder substitutions have an equal or better low temperature PG grade and MSCR designation.

EXAMPLE

Original Mix

ST Intermediate with a PG 58-28S

Requested Substitution

HT L-2 Surface with a PG 58-28H

The request would be approved provided the HT Surface mix is gyrated to the same level as a ST Intermediate with lab voids within the target range. The binder substitution would be approved since it meets or exceeds the low and high temperature grade and has an equal or better letter designation. The aggregate quality of a HT Surface also meets or exceeds that of a ST Intermediate. The Engineer may approve an alternate maximum aggregate size.

A polymer modified binder may be substituted into the JMF provided the original PG grade and temperature spread is met or exceeded. In this case, verify the JMF target air voids are met at the design binder content. If the original JMF required moisture susceptibility testing and has consistently demonstrated acceptable SIP values in the field, the original anti-strip agent (if needed) and dosage rate may be used in lieu of IM 319 re-evaluation. Plant produced mix will still be tested for moisture susceptibility.

ADJUSTING (TROUBLESHOOTING)

The Contractor is responsible for making changes, as necessary, to achieve target values specified on the JMF. These changes can include adjusting the proportions of aggregate and asphalt binder necessary to meet the JMF. If a change in the target gradation is desired, obtain approval of a new JMF from the DME. Changes in the target gradation cannot be set outside of the control points. The Contractor may change the target binder content to maintain the required mixture characteristics, provided the appropriate documentation and reporting is performed. The Contractor may change binder sources provided the Engineer receives written notification (or e-mail) prior to the substitution. Report all changes in proportions on the Daily HMA Plant Report.

The addition of new materials to the JMF may be approved by the Engineer without evaluating mix volumetrics in the laboratory if the materials are produced from geologically comparable sources, do not constitute more than 15 % of the total aggregate, meet quality requirements, and produce mixes that meet design criteria. When aggregates are introduced from sources that are not geologically comparable or otherwise differ significantly, complete laboratory mix design testing and approval is required.

When a stockpile of recycled asphalt materials (RAM) constitutes less than 15% of the JMF, it may be substituted by another source of equivalent classification and quality (Classified or Unclassified) to finish the project. In this case, update the JMF by entering the new RAM binder content, specific gravity, gradation, and absorption into SHADES. Verify the volumetrics remain compliant with the specifications by testing a lab compacted sample.

Moving averages and the gyratory compaction slope assist in identifying potential problems before they arise. Watch the trends in the moving averages (approaching a specification limit) and the slope of the compaction curve. The slope of the compaction curve of plant-produced material shall be monitored and variations in excess of ± 0.40 of the mixture design gyratory compaction curve slope may indicate potential problems with uniformity of the mixture.

TABLE OF RESPONSIBILITY

QUALITY ACTION	CPI & QMA	SMALL QTY.
General		
Use of Qualified Labs & Certified Technicians	CONTR/RCE	CONTR
Use of Certified Labs & Qualified Technicians	DME/CTRL	DME/CTRL
Preparation of the Job Mix Formula (JMF)	CONTR(2)	CONTR(2)
Approval of the JMF	DME	DME
Calibration of the Plant	CONTR	CONTR
Monitoring of Plant Operations	DME/RCE(1)	DME/RCE(1)
Inspection of Plant Operations	CONTR(1)	CONTR(1)
Asphalt Binder		
Direct & Witness Verification Sample of Asphalt Binder	RCE/DME(3)	NA
Sample Asphalt Binder	CONTR(3)	NA
Secure Verification Sample of Asphalt Binder	RCE/DME	NA
Transport Verification Sample of Asphalt Binder	CONTR/RCE	NA
Run & Report Verification Sample of Asphalt Binder	DME/CTRL	NA
Aggregate		
Direct & Witness Verification Sample of Combined Aggregate	RCE(4)	NA
Sample Combined Aggregate	CONTR(4)	CONTR(4)
Direct & Witness Splitting of Combined Aggregate Sample	RCE(5)	NA
Secure Verification Sample of Combined Aggregate	RCE	NA
Transport Verification Sample of Combined Aggregate	CONTR/RCE	NA
Run & Report QC Tests on Combined Aggregate Gradation	CONTR(5)	CONTR(5)
Run & Report Verification Tests on Combined Aggregate Gradation	DME/RCE(5)	NA
Report Validation per IM 216 on Combined Aggregate Gradation	DME/RCE	NA
Obtain & Transport Verification Samples of Coarse Aggregate Quality	DME(4)	NA
Run & Report Verification Tests on Coarse Aggregate Quality	CTRL	NA
Loose Hot Mix		
Determine Loose Hot Mix Paired Sample Frequency/Location	RCE(3)	CONTR
Direct & Witness Verification Sample of Loose Hot Mix	RCE(3)	NA
Sample Loose Hot Mix Paired Samples	CONTR(3)	CONTR(3)
Secure Verification Sample of Loose Hot Mix	RCE	NA
Transport Verification Sample of Loose Hot Mix	CONTR/RCE	NA
Run & Report QC Tests on Loose Hot Mix Samples	CONTR(1)	CONTR(1)
Run & Report Verification Tests on Loose Hot Mix Samples	DME(1)	NA
Report Validation of Hot Mix Tests	CONTR(1)	NA
Evaluate Test Results/Take Action when Validation Fails	DME	NA
Compacted Hot Mix		
Determine Density Coring Frequency/Location	RCE(3)	RCE(3)
Direct & Witness Coring & Transport to QC Lab	RCE(3)	RCE(3)
Obtain Core Samples & Prepare Samples at the QC Lab	CONTR	CONTR
Run Density Testing on Cores	RCE(3)	RCE(3)
Record Density Testing Measurements on Cores	RCE(3)	RCE(3)
Report Density Testing Results on Cores	CONTR(1)	CONTR(1)
Revisions		
Adjust Production to Maintain JMF Targets	CONTR	CONTR
Report Plant Adjustments	CONTR(1)	CONTR(1)
Approve Revisions to JMF Targets	DME	DME
Shut Down Production when Required	CONTR	CONTR

NOTES:

(1) Must be done by Certified Level I HMA Technician
(2) Must be done by Certified Level II HMA Technician
(3) Must be done by Certified HMA Sampler
(4) Must be done by Certified Aggregate Sampler. Technician
(5) Must be done by Certified Aggregate. Technician

ABBREVIATIONS:

CPI = Certified Plant Inspection
QMA = Quality Mgmt. of Asphalt
RCE = Project Engineer
CONTR = Contractor
DME = District Materials
CTRL = Central Materials

REHEAT EVALUATION

The contractor's QMA laboratory technician shall split the sample selected for correlation. The split will provide material for 3 individual maximum specific gravity, G_{mm}, test samples and material for 3 sets of laboratory density, G_{mb}, specimens.

The contractor's technician will split and retain sufficient material for 2 G_{mm} test samples and 2 sets of laboratory density specimens. The remainder of the field sample will be submitted to the DOT laboratory. From this portion the DOT laboratory will split and test an additional G_{mm} sample and an additional set of laboratory density specimens, after reheating.

Immediately after splitting, the contractor's technician will return one set of laboratory density samples to the oven and heat to compaction temperature. Once compaction temperature is reached, this set is removed from the oven, compacted as per IM 325 or IM 325G, cooled to ambient temperature and G_{mb} determined. The second set of samples is cooled to ambient temperature, reheated to compaction temperature then compacted as per IM 325 or IM 325G, cooled to ambient temperature and G_{mb} determined. This dual testing is intended to indicate the differences in test results, which can be expected, between samples tested on the original heat of the mixture and those tested at a later time (hot-to-cold testing).

The contractor's technician will cool and separate both G_{mm} samples. The contractor's technician will test one G_{mm} sample. The second G_{mm} sample will be sealed in a plastic bag and submitted to the appropriate DOT laboratory for testing. The DOT laboratory will test the sample without any significant reheating (not more than 5 minutes oven reheating to facilitate breaking up sample).

Interlaboratory correlation, as specified in IM 208, will be determined by comparing G_{mm} results obtained by the contractor to those obtained by the DOT laboratory on the G_{mm} samples split by the contractor. The laboratory density obtained by the contractor on the G_{mb} specimens prepared from the reheated portion will be compared to the G_{mb} determined by the DOT laboratory on G_{mb} specimens prepared from the reheated portion of the original split sample. If the test results compared are within the tolerances specified in IM 208, then the reheat procedure shall be performed when required by the District Materials Engineer. If the test results are not within the tolerances specified in IM 208, additional testing on the same or subsequent samples will be required.

The District Materials Engineer may waive the reheat testing if the test results indicate no significant difference caused by reheating of samples. Additional correlation testing may be performed at any time at the request of the contractor or the District Materials Engineer. The information obtained by the dual testing described above may be used when monitoring the daily comparison of contractor's test results to DOT laboratory test results when reheating of samples is involved. All samples shall be retained until permission to discard them is obtained from the DOT laboratory.

This outline is to serve only as a guide to the steps in the correlation procedure. All tests noted in this outline must be performed in accordance with the applicable IM.

1. Contractor Testing Responsibilities

   A. Obtain field sample and split to obtain 2 sets of laboratory density, G_{mb}, specimens and 2 Maximum specific gravity, G_{mm}, specimens and submit the remainder of field sample to DOT laboratory for testing.

   B. Bulk Density Testing

      1) Set #1 – Immediately after splitting, return specimens to the oven, reheat to compaction temperature, compact specimens as per IM 325 or IM 325G, cool to ambient temperature and test for density.

      2) Set #2 – Cool to ambient temperature, return to oven, reheat to compaction temperature, compact as per IM 325 or IM 325G, cool to ambient temperature and test for density.

      3) Compare values obtained in #1 and #2 to determine possible reheat factor.

   C. Maximum Density Testing

      1) Sample #1 – Cool sample and perform Rice Test.

      2) Sample #2 – Cool sample, place in plastic bag and submit to the DOT laboratory for testing.

   D. Submit remainder of field sample to DOT laboratory for testing.

2. DOT Laboratory Testing Responsibilities

   A. Bulk Density Testing

      1) From the field sample supplied by the contractor, split one set of G_{mb} specimens, place in oven, heat to compaction temperature, compact as per IM 325 or IM 325G, cool to ambient temperature and test for density.

   B. Maximum Density Testing

      1) From the field sample supplied by the contractor, split one G_{mm} specimen and perform Rice Test.

      2) Test the G_{mm} sample supplied by the contractor.

      3) Compare values obtained in #1 and #2 to determine possible deviation in G_{mm} results that might occur between the Contractor's split G_{mm} sample and the DOT G_{mm} sample split from a field sample.

PROCEDURE FOR ESTABLISHING A CORRECTION FACTOR FOR G_{mb}

The procedure used for establishing a correction factor is as follows:

PROCEDURE A

1. Obtain one sample of sufficient plant produced material for 12 G_{mb} specimens and split per IM 357 into 6 specimens each between the contractor and engineer. This should provide enough material that 6 gyratory specimens may be compacted at both labs. The sample should be representative, but sampling procedure IM 322 is not required.

2. The material must be handled and compacted in the same manner by the contractor and engineer (hot-to-hot or cold-to-cold).

3. Compact the specimens per IM 325G.

4. Perform density testing on the compacted specimens per IM 321.

5. Average the 6 G_{mb} results for each lab.

The difference between the average G_{mb} results from the two labs will be considered the correction factor. **NOTE:** Unless otherwise decided on by the Engineer, only 1 correction factor will be established for a given mix design.

PROCEDURE B

The engineer may use the results of 3 consecutive QC/QA split tests in lieu of a single 12 split sample. There can be no significant change to the mix between the 3 tests and no adjustments to the gyratory compactors. The material must be handled and compacted in the same manner by the contractor and engineer (hot-to-hot or cold-to-cold). The contractor's QC results will be averaged and the engineer's QA results will be averaged with the difference being the correction factor to be applied.

****THIS IS A NEW APPENDIX. – PLEASE READ CAREFULLY.****
TROUBLESHOOTING FLEXIBLE PAVING MIXTURES

PLANT TROUBLESHOOTING

Asphalt Binder

If Computed Percent Binder is High:

a. Check tank stick readings and computations.
b. Check to be sure that all mix produced was included in the computations.
c. Check for spilled, wasted, or otherwise used asphalt cement.
d. Check to be sure all asphalt listed as **added** during the period should be included.
e. Check truck scales and total mix made.
f. Check cold-feed and pump setting.
g. Check aggregate delivery level for uniformity.

If Computed Percent Binder is Low:

a. Check tank stick readings and computations.
b. Check total mix made.
c. Check to be sure that all asphalt added during the period is included.
d. Check cold-feed and pump setting.
e. Check for plugged nozzle.
f. Check pumping pressures.
g. Check strainer screen.
h. Check truck scales.

Gradation

Non-compliant cold-feed gradation and other production mix irregularities may result from the following causes:

- Sample not representative of lot (Multiple hot bins)
- Improper bin balance
- Test errors, weights, calculations, etc.
- Incorrect cold-feed settings
- Non-uniform cold-feed delivery
- Stockpile segregation
- Stockpile contamination
- Storage bin segregation
- Intermingling of aggregates in stockpiles and/or feeders
- Wet, non-uniform stockpiles
- Degradation

MIX TROUBLESHOOTING

The tables below are intended to provide guidance on dealing with the most common problems, which arise during the production of asphalt concrete mixture. The first table deals with problems, which can show up in the laboratory setting and the second table deals with problems, which can appear in the field.

The following example explains how to read the tables. Both tables are read downward. The shaded regions are the items to be considered for adjusting purposes.

Lab Problem Table

The first step is to identify which lab problem is occurring. If “Low Voids” is the identified problem, move down the column to the “Step 1 Check”. Assuming the first check is to be made on the “Binder Content”, move down the column to “Step 2 If”. If the Binder Content is high proceed to “Step 3 Verify”. Each of the shaded items identified in the “Step 3 Verify” should be looked at before proceeding further. Assuming that the items in “Step 3 Verify” are on target, go to “Step 4 Do”. In this case, the action to be taken in “Step 4 Do” is to “Lower Binder” in the mix. In all cases, the items in the “Step 3 Verify” are assumed to be within the allowable tolerances and won’t fall outside of allowable tolerances if the action in “Step 4 Do” is taken.

LAB PROBLEM		Low Voids			High Voids			Low Film Thickness			High Film Thickness			Low VMA			High VMA		
Step 1-Check	Binder Content	■			■			■			■								
	Gradation		■			■			■			■		■	■		■	■	
	Agg. SG (Gsb)			■			■									■			■
	Agg. Abs.									■			■						
Step 2-If	Low Binder				■			■											
	High Binder	■									■								
	Low -200					■						■					■		
	High -200		■						■					■					
	Off JMF Target			■			■			■			■		■	■		■	■
Step 3-Verify	Filler Bitumen Ratio	■	■		■	■		■	■		■	■		■	■		■	■	
	Film Thickness	■	■		■	■								■	■		■	■	
	VMA	■	■		■	■													
	Field Compaction	■	■			■		■	■	■	■	■	■						
	Voids							■	■		■	■		■	■		■	■	
	Individual Agg. Sources			■			■			■			■			■			■
Step 4-Do	Decrease Binder	■									■								
	Increase Binder				■			■											
	Lower -200		■						■					■					
	Increase -200					■						■					■		
	Adjust Agg. Proportions		■	■		■	■		■	■		■	■	■	■	■	■	■	■
	Recompute Volumetrics			■			■			■			■			■			■

Field Problem Table

The first step is to identify which field problem is occurring. If “High Field Voids” is the identified problem, move down the column to the “Step 1 Check”. Assuming the first check is to be made on the “Lab Voids”, move down the column to “Step 2 If”. If the Lab Voids are high proceed to “Step 3 Verify”. Each of the shaded items identified in the “Step 3 Verify” should be looked at before proceeding further. Assuming that the items in "Step 3 Verify" are on target, go to "Step 4 Do". In this case the process of looking at the "Step 3 Verify" would lead to the Lab Problem Table and cause one of the actions for High Lab Voids to be used.

In all cases, the items in the "Step 3 Verify" are assumed to be within allowable tolerances and won't fall outside of allowable tolerances if the action in "Step 4 Do" is taken.

FIELD PROBLEM		Low Field Voids		High Field Voids		Tender Mix				Low Density Q.I.		Agglomerates	Uncoated Aggr.		Brown Rock			Stripping
Step 1 - Check	Stockpiles											■						
	Aggr. Absorption														■			
	Binder Content												■			■		
	Lab Voids	■		■		■				■								
	Film Thickness						■											
	Mixing Time													■				
	Moisture in Mix							■										■
	Mix Temp at Plant		■		■												■	
	Mat Temp								■		■							
Step - 2	Low	■			■	■					■		■	■		■		
	High		■	■			■		■						■		■	
	Yes							■				■						■
Step 3 -Verify	Filler/Bitumen Ratio												■			■		
	Film Thickness												■			■		
	Voids												■			■		
	Field Compaction																■	
	Aggr. Breakdown		■		■													
	Individual Aggr. Sources		■		■										■			
	Moisture		■		■												■	
	Amount of Clay binder											■						
	Go to Lab Problem Table	■		■		■	■			■								
Step 4 - Do	Increase Binder												■			■		
	Lower Temp		■						■								■	
	Increase Temp				■						■							
	Cover Loads				■													
	Increase Aggr. Dryer Time							■										■
	Screen											■						
	Adjust Aggr. Proportions														■			
	Increase Wet Mixing Time													■				

SPEC 2303

Section 2303. Flexible Pavement

2303.01 DESCRIPTION.

A. Design, produce, place, and compact flexible paving mixtures using proper quality control. Construct to the dimensions specified in the contract documents.

B. A surface course is the top lift. An intermediate course is the next lower lift or lifts. Use intermediate course mixtures for leveling, strengthening, and wedge courses. A base course is the lift or lifts placed on a prepared subgrade or subbase.

2303.02 MATERIALS.

A. Asphalt Binder.
Use the specified Performance Graded (PG) asphalt binder meeting the requirements of Section 4137. For shoulder mixtures refer to Section 2122. For base widening mixtures refer to Section 2213. Adjustments to the contract binder grade may be required according to Article 2303.02, C, 6.

B. Aggregates.

1. Individual Aggregates.
- **a.** Use virgin mineral aggregate as specified in Section 4127.
- **b.** When specified, furnish friction aggregate from sources identified in Materials I.M. T203.
  - **1) Friction Classification L-2.**
    Use a combined aggregate such that:
    - **a)** At least 80% of the combined aggregate retained on the No. 4 sieve is Type 4 or better friction aggregate, and
    - **b)** At least 25% of the combined aggregate retained on the No. 4 sieve is Type 2 or better friction aggregate, and
    - **c)** For Interstates and all mixtures designed for Very High Traffic (VT), the fineness modulus of the combined Type 2 aggregate is at least 1.0. Calculations for fineness modulus are shown in Materials I.M. 501.
    - **d)** On Interstates and all mixtures designed for Very High Traffic (VT), if 40% or more of the total aggregate is a limestone as defined in Materials I.M. T203, at least 30% of the combined aggregate retained on the No. 4 sieve is Type 2 or better friction aggregate and at least 25% of combined aggregate passing No. 4 sieve is Type 2 or better friction aggregate.
  - **2) Friction Classification L-3.**
    Use a combined aggregate such that:
    - **a)** At least 80% of the combined aggregate retained on the No. 4 sieve is Type 4 or better friction aggregate, and
    - **b)** At least 45% of the combined aggregate retained on the No. 4 sieve is Type 3 or better friction aggregate, or if Type 2 is used in place of Type 3, at least 25% of the combined aggregate retained on the No. 4 sieve is Type 2.
  - **3) Friction Classification L-4.**
    Use a combined aggregate such that at least 50% of the combined aggregate retained on the No. 4 sieve is Type 4 or better friction aggregate.

2. Combined Aggregates.
- **a.** Use a combined aggregate meeting the requirements in Materials I.M. 510.
- **b.** When mixtures include RAM, use a combined aggregate gradation consisting of a mixture of RAM aggregate and virgin aggregate.

C. Recycled Asphalt Materials.

1. RAM includes RAP and RAS. The designations Classified and Unclassified are exclusively for the use of RAP in HMA.

2. Identify each RAP stockpile and document Classified and Unclassified RAP stockpiles as directed in Materials I.M. 505. Do not add material to a Classified RAP stockpile without the approval of the District Materials Engineer.

3. The Engineer may reject a RAP stockpile for non-uniformity based on visual inspection. Work the stockpiles in such a manner that the materials removed are representative of a cross section of the pile.

4. Place stockpiles of RAP as directed in Materials I.M. 505. Do not use RAP stockpiles containing concrete chunks, grass, dirt, wood, metal, coal tar, or other foreign or environmentally restricted materials. RAP stockpiles may include

PCC (not to exceed 10% of the stockpile) from patches or composite pavement that was milled as part of the asphalt pavement.

5. When RAP is taken from a project, or is furnished by the Contracting Authority, the contract documents will indicate quantity of RAP expected to be available and test information, if known. RAP not used in HMA becomes the property of the Contractor.

6. For mix design purposes, the Contracting Authority will test samples of the RAM. The aggregate gradation and amount of asphalt binder in the RAM will be based on the Contracting Authority's extraction tests. For mixtures containing RAM, adjust the contract binder grade as directed in Materials I.M. 510. No adjustments will be made to the contract unit price for required changes to the asphalt binder grade. RAP may be used in accordance with Materials I.M. 510 Appendix C. For surface mixtures, 70% of the total asphalt binder shall be virgin.

a. Classified RAP.

1) Classified RAP is one of the following
- RAP from a documented source.
- RAP from an undocumented source meeting quality control sampling, testing, and reporting requirements in Materials I.M. 505. Material shall be tested at a lab designated by the Engineer according to Iowa Test Method 222 at no additional cost to the Contracting Authority.

2) Classified RAP may be used in mixtures for which the RAP aggregate meets the quality requirements for the mixture design per Materials I.M. 510 Appendix A.

3) When from a documented source, credit will be given for frictional aggregate and crushed particles used in the original pavement to be reclaimed as determined in the paving history (or mix design when paving history is unavailable).

4) For all other Classified RAP, credit for crushed particles shall be the percent of aggregate retained on the No. 8 sieve from Engineer's extraction test. No friction credit will be given.

b. Unclassified RAP.

1) Any stockpiled RAP not meeting the requirements of Classified RAP shall be designated as Unclassified RAP. No frictional aggregate credit or aggregate crushed particles credit will be given for Unclassified RAP.

2) When an Unclassified RAP stockpile is characterized by sampling and testing for mix design, no material can be added to the stockpile until the project is completed.

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7. Pre-consumer or post-consumer shingles that have been processed, sized, and ready for incorporation into an asphalt mixture constitute RAS material.

8. Up to 5% RAS by weight of total aggregate may be used in the design and production of an asphalt mixture. The percentage of RAS used is considered part of the maximum allowable RAP percentage. Unless explicitly stated otherwise in this specification or Materials I.M. 505, use RAS according to the same requirements as prescribed for RAP material.

9. RAS shall be certified from an approved supplier designated in Materials I.M. 506. Material processed prior to Iowa DOT source approval will not be certified.

D. Flexible Paving Mixture.

1. The JMF is the percentage of each material, including the asphalt binder, to be used in the HMA mixture. Ensure the JMF gradation is within the control points specified for the particular mixture designated.

2. The basic asphalt binder content is the historical, nominal mixture asphalt binder content, expressed as percent by weight (mass) of the asphalt binder in the total mixture. Apply the values in Table 2303.02-1, based on mixture size and type.

3. If the asphalt binder demand for the combination of aggregates submitted for an acceptable mix design exceeds the basic asphalt binder content (see Table 2303.02-1) by more than 0.75%, include an economic evaluation with the mix design. For economic evaluation, provide an alternate mix design utilizing aggregates which results in an optimum binder content not exceeding basic asphalt binder content by more than 0.75% and documentation of costs associated with hauling both proposed aggregates and alternate aggregates to plant site. Alternate JMF shall meet requirements of Section 2303.

Table 2303.02-1: Basic Asphalt Binder Content (%)

Size	Aggregate Type	1 inch	3/4 inch	1/2 inch	3/8 inch
Intermediate and Surface	Type A	4.75	5.50	6.00	6.00

Size	Aggregate Type	1 inch	3/4 inch	1/2 inch	3/8 inch
Intermediate and Surface	Type B	5.25	5.75	6.00	6.25
Base	Type B	5.25	6.00	6.00	6.25

4. Use a mixture design meeting gyratory design and mixture criteria corresponding to the design level specified in the contract documents. The Engineer may approve mixtures substitutions meeting guidelines in Materials I.M. 511. When a commercial mix is specified, use 1/2 inch Standard Traffic (ST) or higher surface mixture, with PG 58-28S or PG 64-22S binder, for JMF approval.

5. For shoulders placed as a separate operation refer to Section 2122. When paving the shoulder with the mainline the Contractor has the option to substitute the mainline intermediate or surface mixture for a specified shoulder mixture at the Contractor's expense.

6. For base widening refer to Section 2213. When an adjoining surface is designed for Standard Traffic (ST) and is paved during the same project, use a base mixture at same traffic designation used in surface mixture.

7. WMA refers to asphalt concrete mixtures produced at temperatures approximately 50°F or more below those typically used in production of HMA but no higher than that shown in Article 2303.03, C, 3, d, 2, a. Temperature reductions may be achieved through additives or water injection systems (foamed asphalt).

8. Submit a mixture design complying with Materials I.M. 510. Propose both a production and a compaction temperature between 215ºF and 280ºF for WMA mixture designs.

9. Produce and place WMA mixtures meeting the same requirements established for HMA mixtures. Equivalent WMA mixtures may be substituted for HMA mixtures unless it is prohibited by the specifications.

E. Other Materials.

1. Tack Coat.
Tack coat may be SS-1, SS-1H, CSS-1, CSS-1H, CQS-1, or CQS-1H. Do not mix CQS, CSS, and SS grades. RC-70 and MC-70 may also be used prior to May 1 and after October 1, at the Contractor's option. The cement mixing test will be waived for tack coat emulsions.

2. Anti-strip Agent.

a. Perform a moisture sensitivity evaluation of the proposed asphalt mixture design in accordance with Materials I.M. 319 for the following mixtures when placed in travelled lanes:
   1) Mixtures for Interstate and Primary highways designed for Very High Traffic (VT), or
   2) Mixtures for Interstate and Primary highways containing quartzite, granite, or other siliceous (not a limestone or dolomite) aggregate obtained by crushing from ledge rock in at least 40% of the total aggregate (virgin and recycled) or at least 25% of the plus No. 4.

   For the purpose of evaluating moisture sensitivity of a proposed mix design, Contractor may test proposed JMF from plant produced material placed off-site at no additional cost to the Contracting Authority.

b. Sample and test plant produced mixture for moisture susceptibility in accordance with Materials I.M. 204 Appendix F and Materials I.M. 319 for bid item plan quantities of more than 1000 tons as follows:
   1) For mixtures satisfying Article 2303.02, E, 2, a.
   2) For conditions satisfied in Article 2303.02, E, 2, f.

c. Moisture susceptibility testing will not be required for base repair, patching, temporary pavement, or paved shoulders. Moisture susceptibility testing for mixture bid items of 1000 tons or less is only required on the mix design for mixtures satisfying Article 2303.02, E, 2, a.

d. Use the following minimum stripping inflection point (SIP) requirements for plant produced material based on traffic designation:

Table 2303.02-1: Minimum Stripping Inflection Point

Traffic Designation	SIP, Number of Passes[1, 2]
S	10,000
H, V	14,000

Note 1: If ratio between creep slope and stripping slope as defined in Materials I.M 319 is less than 2.00, the SIP is invalid.
Note 2: Minimum SIP for mixtures placed as base widening is 5000 passes.

When notified of non-compliant results, the Engineer may suspend paving operations until an approved “significant mix change” is implemented.

e. When the Contractor's mix design SIP results are below the minimum specified in Article 2303.02, E, 2, d, an anti-strip agent will be required. Plant produced material with anti-strip shall be tested to verify the minimum SIP is achieved.

f. The Engineer may require an evaluation of the test method in Materials I.M. 319 for plant produced mixture at any time.

g. ~~The following anti-strip agents may be used:~~

~~**1) Hydrated Lime.**~~

~~Meet the requirements of AASHTO M 303, Type I or ASTM C 1097, Type S. Hydrated lime will not be considered part of the aggregate when determining the job mix formula.~~

~~**2) Liquid Anti-strip Additives.**~~

Liquid anti-strip additives will be used as the anti-strip agent. For each JMF, obtain approval for liquid anti-strip additives blended into the binder. Approval will be based on the following conditions:

1) ~~**a)**~~ The asphalt binder supplier provides test results that the additive does not negatively impact the asphalt binder properties, including short term and long term aged properties.

2) ~~**b)**~~ The design is to establish the optimal additive rate that produces the maximum SIP value. See Materials I.M. 319 for additional information.

~~**3) Polymer-based Liquid Aggregate Treatments.**~~

~~For each JMF, obtain approval for polymer-based liquid aggregate treatments. Approval will be based on the design establishing the optimum additive rate that produces the maximum SIP value. See Materials I.M. 319 for additional information~~

3. Sand for Tack Coats.

Use sand meeting the requirements of Gradation No. 1 of the Aggregate Gradation Table in Article 4109.02.

4. WMA Technologies.

Chemical additives, organic additives, zeolites, or water injection systems (foamed asphalt) may be used at the rate established by the mixture design in the production of WMA. Once production of a bid item has begun with a WMA technology, continue its use throughout the remainder of the bid item's production unless otherwise approved by the District Materials Engineer.

2303.03 CONSTRUCTION.

A. General.

1. The Contractor is responsible for all aspects of the project.

2. Provide quality control management and testing, and maintain the quality characteristics specified.

a. ~~Apply Article 2303.03, D to asphalt mixture bid items when the plan quantity is greater than 1000 tons.~~ Asphalt mixture bid items that have a plan quantity of 1000 tons or less as well as patching, detours, and temporary pavement bid items will be considered small quantity HMA, apply Article 2303.03, E. For items bid in square yards, apply Article 2303.03, E when the plan quantity by weight (estimated with a unit weight of 145 pounds per cubic foot unless otherwise stated on the plans) does not exceed 1000 tons.

b. ~~Apply Article 2303.03, E, for asphalt mixture bid items that have a plan quantity of 1000 tons or less as well as patching, detours, and temporary pavement bid items. For items bid in square yards, apply Article 2303.03, E when the plan quantity by weight (estimated with a unit weight of 145 pounds per cubic foot unless otherwise stated on the plans) does not exceed 1000 tons.~~ For asphalt mixture bid items not considered small quantity HMA, apply Article 2303.03, D.

B. Equipment.

Use equipment meeting the requirements of Section 2001 with the following modifications:

1. Plant Calibration.

a. Calibrate each plant scale and metering system before work on a contract begins. Use calibration equipment meeting the manufacturer's guidelines and Materials I.M. 514.

b. The Engineer may waive calibration of permanent plant scales when a satisfactory operational history is available. The Engineer may require any scale or metering system to be recalibrated if operations indicate it is necessary.

c. Make calibration data available at the plant.

d. Calibrate each aggregate feed throughout an operating range wide enough to cover the proportion of that material required in the JMF. Make a new calibration each time there is a change in size or source of any aggregate being used.

e. For continuous and drum mixing plants, calibrate the asphalt metering pump at the operating temperature and with the outlet under pressure equal to that occurring in normal operations.

2. Paver.
Apply Article 2001.19. Spreaders described in Article 2001.13, D, may be used to place paved shoulders. Spreaders used to place the final lift of paved shoulders shall meet additional requirements of Article 2001.19.

3. Rollers.

a. For initial and intermediate rolling, use self-propelled, steel tired, pneumatic tired or vibratory rollers meeting the requirements of Article 2001.05, B, C, or F. Their weight (mass) or tire pressure may be adjusted when justified by conditions.

b. For finish rolling, use self-propelled, steel tired rollers or vibratory rollers in the static mode that meet the requirements of Article 2001.05, B, or F.

4. Scales.
Apply Article 2001.07, B, to paving operations regardless of the method of measurement.

C. Construction.

1. Maintenance of the Subgrade and Subbase.

a. Maintain completed subgrade and subbase to the required density, true cross section, and smooth condition, prior to and during subsequent construction activities.

b. If rutting or any other damage occurs to the subgrade or subbase as a result of hauling operations, immediately repair the subgrade and subbase. Such repair will include, if necessary, removal and replacement, at no additional cost to the Contracting Authority.

c. Should traffic by others authorized to do work on the project be specifically permitted by the Engineer to use loads which exceed the Contractor's established limit, the Contracting Authority will pay repair costs for repairs directed by the Engineer.

2. Preparation of Existing Surfaces.

a. Cleaning.
Clean and prepare existing surface according to Article 2212.03, B, 1.

b. Tack Coats.

1) Apply tack coats when the entire surface area on which the coat is to be applied is free of moisture. Do not apply them when the temperature on the surface being covered is less than 25°F.

2) Place a tack coat to form a continuous, uniform film on the area to be covered. Tack coat may be diluted with water at a 1:1 ratio to improve application. Unless directed otherwise, spread tack coat at the following undiluted rates:
- New HMA Surface: 0.03 to 0.05 gallon per square yard
- Milled HMA/CIR Surface: 0.05 to 0.07 gallon per square yard
- PCC/Existing HMA Surface: 0.04 to 0.06 gallon per square yard

3) Tack the vertical face of exposed, longitudinal joints as a separate operation at a rate from 0.10 to 0.15 gallon per square yard. Tack before the adjoining lift is placed. Lightly paint or spray vertical surfaces of all fixtures, curbs, bridges, or cold mixture with which the hot mixture will come in contact to facilitate a tight joint with the fresh mixture.

4) Limit tack coat application lengths to minimize inconvenience to the public. Keep applications within the hot mixture placing work area that is controlled by flaggers at each end. Plan applications so they will be covered with hot mixture when the work area is opened to traffic at the end of the days' work.

5) Allow tack coat to adequately cure prior to placement of HMA. If tack coat surface becomes dirty from weather or traffic, thoroughly clean and, if necessary, retack. A light application of sand cover may also be required for excessive application rates, breakdowns, and short sections remaining at the end of a day's run.

3. Handling, Production, and Delivery.
Ensure plant operation complies with the following requirements:

a. Handling Mineral Aggregate and RAM.
Apply Materials I.M. 505 and Materials I.M. 508.

b. Handling Asphalt Binder.
Maintain asphalt binder temperature between 260°F and 330°F. Heat modified asphalt binder according to the supplier's recommendations.

c. Handling Liquid Anti-Strip Agents.

~~**1) Hydrated Lime.**~~

~~**a) Added to a Drum Mixer.**~~

~~**(1)** Add hydrated lime at the rate of 0.75% by weight of the total aggregate (virgin and RAM) for Interstate and Primary projects. Add hydrated lime to a drum mixer using one of the following methods:~~

~~**(a)** Add to virgin aggregate on the primary feed belt, as a lime water slurry.~~

(b) Add to the outer drum of a double drum system away from heated gas flow and prior to the addition of the virgin asphalt binder.

(2) Alternative methods for mixing will be allowed only with the Engineer's approval. Do not introduce hydrated lime directly into a single drum mixer by blowing or by auger.

b) Added to a Batch Plant.

Add hydrated lime at the rate of 0.5% by weight of the total aggregate (virgin and RAM) for Interstate and Primary projects. Introduce it to a batch plant using one of the methods below. In any case, introduce the lime prior to the start of the dry mix cycle.

(1) Place on the recycle belt which leads directly into the weigh hopper.

(2) Add directly into the pugmill.

(3) Add directly into the hot aggregate elevator into the hot aggregate stream.

c) Added to the Aggregate Stockpile.

Add hydrated lime at a rate established by the optimization of the SIP as determined by Materials I.M. 319. Add it to the source aggregates defined in Article 2303.02, E, 2, thoroughly mixed with sufficient moisture to achieve aggregate coating, and then place in the stockpile.

2) Liquid.

1) **a)** When liquid anti-strip additives are used, eEmploy equipment complying with the anti-strip manufacturer's recommended practice to store, measure, and blend the additive with the binder.

2) **b)** The additive may be injected into the asphalt binder by the asphalt supplier or the Contractor. If the Contractor elects to add the liquid anti-strip agent, they assume the material certification responsibilities of the asphalt binder supplier. Ensure the shipping ticket reports the type and amount of additive and time of injection.

3) **c)** Ensure the asphalt supplier provides the Contactor and Engineer with the shelf life criteria defining when the anti-strip additive maintains its effectiveness. Do not use binder that has exceeded the shelf life criteria.

a) When using polymer-based aggregate treatment, comply with the manufacturer's recommended specifications and guidelines.

d. Production of Hot Mix Asphalt Mixtures.

1) Regulate the exact proportions of the various materials to be within the limits specified to produce a satisfactory asphalt coating and mixture.

2) Do not allow the temperature of the mixtures to fall outside the following parameters:

a) Keep the production temperature of WMA mixtures between 215ºF and 280ºF until placed on the grade. Maximum production temperature for WMA is 330ºF after October 1st.

b) Do not produce WMA mixtures more than 10ºF below the target temperature designated in the JMF without the approval of the Engineer.

c) Keep the production temperature of HMA mixtures between 225ºF and 330ºF until placed on the grade. Do not discharge HMA into the hopper when its temperature is less than:

(1) 245ºF for a nominal layer thickness of 1 1/2 inches or less, or

(2) 225ºF for a nominal layer thickness of more than 1 1/2 inches.

d) Flexible paving mixtures not meeting these requirements will be rejected.

e) Production temperature limits apply starting at point of discharge from mixer.

3) Minimize segregation to the extent that it cannot be visibly observed in the compacted surface.

4) Apply only approved release agents to trucks and equipment, as specified in Article 2001.01.

5) Except for an unavoidable delay or breakdown, provide continuous and uniform delivery of hot HMA to any individual spreading unit.

4. Placement.

a. Clean each lift according to Article 2212.03, B, 1. If necessary, re-tack.

b. Prior to placing the final lift, correct bumps or other significant irregularities that appear or are evident in the intermediate course or other lower course.

c. Do not place HMA mixtures under the following circumstances:

1) On a wet or damp surface.

2) When road surface temperature is less than that shown in Tables 2303.03-1 and 2303.03-2, unless allowed per Article 2303.03, F.

Table 2303.03-1: Base and Intermediate Course Lifts of Asphalt Mixtures

Nominal Thickness - inches	Road Surface Temperature, ºF
Less than 2	40
2 – 3	35
Over 3	35

Table 2303.03-2: Surface Course Lifts of Asphalt Mixtures

Nominal Thickness - inches	Road Surface Temperature, ºF
1	HMA: 50 / WMA: 40

Nominal Thickness - inches	Road Surface Temperature, ºF
1 1/2	HMA: 45 / WMA: 40
2 and greater	40

d. The Engineer may further limit placement if, in the Engineer's judgment, other conditions are detrimental to quality work.
e. Maintain a straight paving edge alignment. Correct edge alignment irregularities immediately.
f. Base the minimum layer thickness on Table 2303.03-3. Minimum layer thickness does not apply to leveling/scratch courses.

Table 2303.03-3: Minimum Lift Thickness

Design Mix Size - inches	Minimum Lift Thickness - inches
3/8	1
1/2	1 1/2
3/4	2
1	3

g. Complete each layer to full width before placing succeeding layers.
h. While operating on the road surface, do not use kerosene, distillate, other petroleum fractions, or other solvents, for cleaning hand tools or for spraying the paver hopper. Do not carry containers of cleaning solution on or near the paver. When a solvent is used, do not use the paver for at least 5 hours after cleaning.
i. After spreading, carefully smooth to remove all segregated aggregate and marks.
j. When placing two adjacent lanes, pave no more than 1 day of rated plant production before paving the adjacent lane(s). Place the adjacent lane to match the first lane during the next day of plant production.
k. At the close of each working day, clear all construction equipment from the roadbed.
l. Prior to opening a lane to traffic, place fillets, safety edge, or full width granular shoulders according to Article 2121.03, C, 4. Place the material adjacent to and equal in thickness to the resurfacing. Fillet removal is incidental to the HMA mixture.

5. Compaction.
a. General.
1) Promptly and thoroughly compact each layer. Use mechanical tampers for areas inaccessible to the rollers.
2) Use a rolling procedure and compactive effort that will produce a surface free of ridges, marks, or bumps.
3) The quality characteristic is in-place air void content and will be based on the theoretical maximum specific gravity (G_{mm}) for that day's mixture.
b. Class I Compaction.
1) Applications.
Use Class I compaction for all courses for the traffic lanes, ramps, and loops on all roadways.
2) Test Strip Construction for Class I Compaction.
a) For the purpose of evaluating properties of the asphalt mixtures and for evaluating an effective rolling pattern:
(1) Construct a test strip of the surface mixture prior to its placement on the surface course for Interstate highways, Primary highways, and ramps connecting Interstate and Primary highways.
(2) Construct a test strip of the intermediate mixture at the start of its placement on the intermediate course for Interstate highways, interstate-to-interstate ramps.
(3) Test strips for other mixtures may be constructed, but are not required.
b) Test strips are not required when the entire production of the mixture bid item is placed in a single day.
c) The quantity of mixture subject to the test strip production, will be pre-established with the Engineer and limited to a half day's production
d) When the contract documents specify both intermediate and surface courses and a test strip is required, place a surface course test strip in lieu of intermediate mixture in a section of the intermediate course prior to actual surface course placement. If surface course and intermediate course are not placed the same calendar year, then place test strip at beginning of surface mix production.
e) Only one test strip will be allowed for each mixture bid item and shall be declared to the Engineer prior to placement. The Engineer may require additional test strips if a complying HMA mixture or rolling pattern was not established.
f) Use test strip production control that meets the requirements of Article 2303.03, D, 3, b. The test strip will be an independent lot. Determine sublots in accordance with Table 2303.03-5.
c. Class II Compaction.
Intended for paved shoulders, temporary crossovers, onsite detours, base widening in a non-travel lane and other situations where Class I is not specified.
1) Establish a rolling pattern to verify adequate density.

2) At the Engineer's option, cores or gauge readings at the frequency designated in Materials I.M. 204 Appendix F for the first day of placement will be used. The Engineer may modify the sample size and frequency provided compaction is thorough and effective.
3) The Engineer will accept the rolling pattern based on the average test results. When the average field voids is less than or equal to 8.0%, the pattern is considered thorough and effective.
4) When the average field voids exceeds 8.0%, modify the rolling pattern. The Engineer may require additional testing until thorough and effective compaction is achieved.
5) For areas inaccessible to rollers, use mechanical tampers or other approved compaction methods.

6. Joints and Runouts.

a. Construct longitudinal joints for courses on resurfacing projects within 3 inches of the existing longitudinal joint. Construct longitudinal joints to secure complete joint closure and avoid bridging of the roller. When the joint is completed, the hot side shall be no more than 1/4 inch higher than the cold side.

b. Saw transverse construction joint to a straight line at right angles to the center line to provide a full thickness vertical edge before continuing paving.

c. Place temporary runouts according to road standards. Remove temporary runouts before commencing paving. Runout removal is incidental to the HMA mixture.

7. Miscellaneous Operations.

a. Leveling and Strengthening Courses.

1) Use the same mixture specified for the base or intermediate course.
2) Compact leveling courses and intermediate mixtures placed as leveling/scratch courses (less than or equal to 1 inch plan thickness) using pneumatic and vibratory rollers. This is considered Class II compaction.

b. b. Wedge Courses.

1) Use the base or intermediate mixture to construct wedge courses used to secure desired curve super-elevation. When possible, spread using a finishing machine.
2) Place wedge courses in compacted layers no thicker than 3 inches.
3) On super-elevated curves which require wedge course placement, stage the shoulder construction. After completing each day's wedge placement operations and prior to suspending that day's construction activities, construct a full width shoulder on the high side up to the completed wedge course elevation. Shoulder construction staging will be considered incidental to shoulder construction.
4) Use Class II compaction.

c. Fixtures in the Pavement Surface.

1) Adjust manholes, intakes, valve boxes, or other fixtures encountered within the area to be covered by HMA to conform to the final adjacent finished surface. Payment for adjustment of manholes or intakes will be per Section 2435. Payment for adjustment of valve boxes and other fixtures will be per Section 2554. Unless specified otherwise in the plans, adjust fixtures:
   - Between placing the surface course and the layer preceding the surface course, or
   - After placing the surface course using a composite patch or PCC patch.
2) Use PCC and HMA patch material complying with the requirements of Section 2529. Make patches large enough to accommodate the structure being adjusted.
3) Unless otherwise approved, construct patches to be square. Orient them diagonally to the direction of traffic flow. Ensure the elevation of the adjusted fixture and patch does not differ from the elevation of the surrounding pavement surface by more than 1/4 inch.
4) When shaping and compacting resurfacing near inlets to storm sewer intakes, shape to ensure maximum drainage into intakes.

d. Fillets for Intersecting Roads and Driveways.

1) Shape, remove loose material, and tack the surface adjacent to the pavement. On the tack coated surface, place and compact the hot mixture in layers equal to the adjacent layer. Extend from the edge of the pavement as shown on the plans.
2) Place and compact fillets at intersecting roads at the same time as the adjacent layer.
3) Entrance fillets that are 8 feet or wider may be placed as a separate operation. Pave fillets which are 8 feet or wider with a self-propelled finishing machine described in Article 2001.19.
4) The Engineer may approve other equipment for placement of fillets, based on a demonstration of satisfactory results.

e. Stop Sign Rumble Strips.

If the plans include the bid item Rumble Strip Panel (In Full Depth Patch), apply Section 2529. To meet the requirements of placing Stop Sign Rumble Strips before opening roadway sections to traffic, the Contractor may construct temporary rumble strip panels meeting the final pattern and location of the Stop Sign Rumble Strip indicated in the plans

f. Paved HMA Shoulders.

1) Compact paved HMA shoulders using one of the following methods:
   a) Class II compaction (Article 2303.03, C, 5, c),
   b) Same rolling pattern established for adjoining mainline or ramp driving lane, as determined by density coring.

2) Shoulder area will not be included in PWL calculations for field voids on adjoining mainline or ramp driving lane. A price adjustment may be applied to shoulder areas that do not adhere to the established roller pattern.

D. Quality Assurance Program.

1. General.

Except for small quantities as defined in Article 2303.03, A, 2, follow the procedures and meet the criteria established in Articles 2303.02 and 2303.03, B, Section 2521, and Materials I.M. 510 and 511.

2. Mix Design - Job Mix Formula.

a. The Contractor is responsible for the JMF for each mixture.
b. Submit a completed JMF, using the computer format of Form 956, for approval to the materials lab designated by the Contracting Authority. Submit supporting documentation demonstrating the design process was followed and how the recommended JMF was determined. Include an economic evaluation when required. Include trial and final proposed aggregate proportions (Form 955) and corresponding gyratory data. In addition, submit sufficient loose mixture and individual material samples for approval of the design.
c. Personnel preparing the JMF shall be Iowa DOT certified in HMA Level II.
d. An approved JMF will be required prior to beginning plant production.

3. Plant Production.

a. General.
All of the following qualify as a "significant mix change":

- A single occurrence of an aggregate interchange of greater than 5%.
- An aggregate interchange of greater than 5% from last approved JMF.
- A single occurrence of an asphalt content change greater than 0.2%.
- An asphalt content change greater than 0.2% from last approved JMF.
- A deletion or introduction of a new material into the mix.
- A change of additive dosage rate.
- A change of binder, aggregate, or additive source.

b. Production Control.

1) After the JMF is established, the combined aggregate gradation furnished for the project, asphalt binder content, asphalt film thickness, and lab voids should consistently comply with the JMF target values and design criteria in Materials I.M. 510 Appendix A. Control them within the production tolerances given in Table 2303.03-4.

Table 2303.03-4: Production Tolerances

Measured Characteristic	Target Value (%)	Specification Tolerance (%) [a]
Cold feed gradation No. 4 and larger sieves [a]	by JMF	± 7.0
Cold feed gradation No. 8 [a]	by JMF	± 5.0
Cold feed gradation No. 30 [a]	by JMF	± 4.0
Cold feed gradation No. 200 [a]	by JMF	± 2.0
Daily asphalt binder content [a]	by JMF	± 0.3
Lab voids ~~absolute deviation~~ AAD from target [b]	0.0	≤ 1.0
Lab voids PWL	by JMF	± 1.0
Field voids PWL	n/a	0-8.5% 91.5-100% of G_{mm}

(a) Based on single test unless noted otherwise.
~~(b) When lab voids acceptance is not based on PWL.~~

2) The gyratory mix design gradation control points for the size mixture designated in the project plans will not apply to plant production control tolerances.
3) Adjustments to the JMF target gradation and asphalt binder content values may be made.
a) The Contractor determines from quality control testing that adjustments are necessary to achieve the specified properties.
b) Consult with the Engineer regarding adjustments to the JMF.
c) Notify the Engineer if the average daily gradation for a mixture bid item is outside the production tolerances. If other production tolerances and mixture requirements of Materials I.M. 510 Appendix A are acceptable, a change in gradation target can be requested.

- **d)** The Contractor's adjustment recommendations prevail provided all specifications and established mix criteria are being met for plant production.

4) Calculate estimated film thickness every day of production according to Materials I.M. 501. Compliance is based on limits in Materials I.M. 510 Appendix A.

5) Calculate absolute deviation from target lab voids according to Materials I.M. 501. To determine the moving average absolute deviation from target laboratory voids, use the average of the last four individual sample absolute deviations from target laboratory voids.

6) Notify the Engineer whenever the process approaches a specification tolerance limit. When acceptance for lab voids is not based on PWL, cease operations when the moving average point for absolute deviation from target lab voids is outside the specification tolerance limit. Assume responsibility to cease operations, including not incorporating material which has not been placed. Do not start the production process again until notifying the Engineer of the corrective action proposed. The moving AAD may restart only in the event of a mandatory plant shutdown for failure to maintain the average within the production tolerance.

7) After the second occurrence of the moving AAD falling outside the specification tolerance limit, the Engineer may declare the lot or portions of the lot defective.

4. Sampling and Testing.

a. General.

1) Perform sampling and testing to provide the quality control of the mixture during plant production. Certified Plant Inspection according to Section 2521 is required.

2) Personnel involved in sampling and testing on both verification and quality control shall be Iowa DOT certified for the duties performed per Materials I.M. 213.

3) Provide easy and safe access for Iowa DOT staff to the location in the plant where samples are taken.

4) Maintain and calibrate the quality control testing equipment using prescribed procedures. Sample and test according to the specified procedures as listed in the applicable Materials I.M. and Specifications. When the results from a Contractor's quality control lab are used as part of product acceptance, the Contractor's quality control lab is required to be qualified.

5) Identify, store, and retain all quality control samples and field lab gyratory specimens used for acceptance until the lot is accepted.

6) Obtain verification samples at random times as directed and witnessed by the Engineer according to Materials I.M. 204 Appendix F. Secure all verification samples according to Materials I.M. 205 Appendix A. Store verification samples for the Contracting Authority until delivery to the Contracting Authority's lab.

7) Deliver the Plant Report to the Engineer and the designated district materials laboratory daily. At project completion, provide the Engineer a copy of the reports, charts, and other electronic file(s) containing project information generated during the progress of the work.

b. Asphalt Binder.

Sample and test asphalt binder to verify the quality of the binder grade. Do not sample when daily production is less than 100 tons of mixture.

c. Tack Material.

Sample and test asphalt emulsions to verify residual asphalt content.

d. Aggregate Gradation.

1) Use cold feed or ignition oven gradation for aggregate gradation control to assure materials are being proportioned according to the specifications.

2) Take a minimum of one aggregate gradation for each day's production that exceeds 100 tons of mixture. When more than one sample in a day's production is tested, use the average gradation to determine compliance of the daily lot.

3) Engineer will verify Contractor gradation with an ignition oven or a split cold feed sample. For ignition oven validation, split a cold feed sample with the Engineer to determine the need for a correction factor according to Materials I.M. 511. The Engineer may require additional cold feed split samples.

e. Uncompacted Asphalt Mixture.

1) Sample the loose mixture according to Materials I.M. 322.

2) Modify sampling location to include placement with mix stored from a previous day's production.

3) The number of daily samples is defined in Table 2303.03-5 based on the day's estimated production. See Materials I.M. 511 for determining sample locations.

Table 2303.03-5: Uncompacted Mixture Sampling

Estimated Daily Production, Tons	Number of Samples
101-500	1
501-1250	2
1251-2000	3
2001-4500	4
Over 4500	5

4) Do not take samples from the first 100 tons of mix produced each day or the first 100 tons of mix following a significant mix change. When paving operations are staged so each day of placement is less than 100 tons for the entire production of the bid item, establish a sampling plan with the Engineer that includes a minimum of one sample per 2500 tons.

5) Split samples for specimen preparation according to Materials I.M. 357.

6) Paired sampling may also be accomplished by taking a bulk sample and immediately splitting the sample according to Materials I.M. 322 on the grade.

7) Test the quality control sample of each production paired sample as follows:

a) Prepare and compact two gyratory specimens according to Materials I.M. 325G.

b) Determine the bulk specific gravity of compacted mixture (G_{mb}) at N_{design} for each specimen according to Materials I.M. 321. Average the results.

c) Determine the Theoretical Maximum Specific Gravity (G_{mm}) of the uncompacted mixture according to Materials I.M. 350.

d) Determine laboratory air voids for each sample according to Materials I.M. 501.Use the target laboratory voids listed in Materials I.M. 510 Appendix A unless otherwise specified in the contract documents.

f. Compacted Pavement Cores.

1) The Engineer will determine the core locations. The length laid in each lot will be divided into approximately equal sublots. Obtain one sample at a random location in each sublot. Determine a new random location for the sublot when the designated core location falls on a runout taper at an existing pavement, bridge, or bridge approach section where the thickness is less than the design thickness.

2) Take samples from the compacted mixture and test no later than the next working day following placement and compaction.

3) Restore the surfaces the same day. Dry, fill with the same material, and properly compact core holes.

4) Pavement core samples will be identified, taken possession of by the Engineer, and delivered to the Contractor's quality control field laboratory.

5) The Engineer may either:

- Transport the cores directly to the lab, or
- Secure the cores and allow the Contractor to transport the cores to the lab.

6) Prepare and test the cores according to Materials I.M. 320, 321, and 337.

7) Cut and trim samples under the direction of and witnessed by the Engineer for tests of G_{mb}, thickness, or composition by using a power driven masonry saw.

8) The compacted HMA pavement will be tested in a timely manner by the Engineer's personnel. The Engineer will test each lot of cores at the Contractor's field quality control laboratory. Cores may also be tested by the Contractor; however, the Contractor's test results will not be used for material acceptance.

5. Verification and Independent Assurance Testing.

a. The Contractor's quality control test results will be validated by the Engineer's verification test results on a regular basis using guidelines and tolerances set forth in Materials I.M. 216 and 511.

b. If the Engineer's verification test results validate the Contractor's test results, the Contractor's results will be used for material acceptance. Disputes between the Contractor's and Engineer's test results will be resolved according to Materials I.M. 511.

c. The Engineer will randomly select one or more of the daily production verification samples. Some or all of the samples selected will be tested in the materials laboratory designated by the Engineer. The Engineer will use the verification test results to determine if the Contractor's test results can be used for acceptance.

d. Personnel and laboratory equipment performing tests used in the acceptance of material are required to have participated in the statewide Independent Assurance Program according to Materials I.M. 207.

6. Acceptance of Asphalt Mixtures.

a. Lab Voids.

1) Use the following methods of acceptance for laboratory voids:

a) For base widening, ramps and loops, shoulders, recreational trails, and other mixture bid items not placed in travel lanes of a permanent pavement, acceptance for laboratory voids will be based on a moving average absolute deviation (AAD) from target as defined in Materials I.M. 501. Use the production tolerance in Table 2303.03-4. During a day's production, if more than 100 tons of the bid item is placed in an area not listed above, apply Article 2303.03, D, 6, b, for entire production of bid item.

b) Determine PWL for each lot as defined in Materials I.M. 501. The PWL limits shall be +/- 1.0% from the target air voids. Each mixture bid item will constitute a lot. Lot size is defined as follows:

(1) No less than eight and no more than 15 sequential tests will constitute a lot (exceptions stated below).

(2) After the eighth test, all subsequent samples collected will also be included in the lot up to a maximum of 15.

(3) Once a lot has been established with at least eight tests, a new lot will begin the day following the fifteenth sample. Lots shall not contain partial days. When the fifteenth sample is reached, include all samples taken that day in the lot.

(4) If the bid item's production has ended and fewer than eight tests are available, those tests may be combined with the previous lot provided the maximum lot size has not already been reached. When combining results, if the day to be combined contains the fifteenth sample, include all samples for that day. Do not combine partial day's results.

(5) If samples cannot be combined with the previous lot due to maximum lot size restrictions or if fewer than eight tests are available for the entire production of a bid item, combine those tests into a single lot and use the AAD analysis in Materials I.M. 501.

(6) Test strips will be considered a separate lot.

(7) When the same mix type is produced for multiple bid items in one day from a single plant and the production going to each item exceeds 500 tons, assign all box samples to each bid item's existing lot for lab voids. In addition, assign the quantity of each bid item produced to its respective lot.

(8) When the same mix type is placed in both PWL and AAD areas in a single day, include all samples for that day in the PWL lot as well as the quantity of the mixture bid item produced and placed in the PWL area.

2) Determine the pay factor using the AAD procedure described in Materials I.M. 501 for mix in a PWL lot which is produced at irregular intervals and placed in irregular areas. The following items qualify as such and shall be combined into a single lot:

- Asphalt mixture produced and placed on gores, detours, cross-overs, temporary pavements, turning lanes, and fillets,
- Asphalt mixture produced and placed on ramps
- Asphalt mixture produced and placed on shoulders.

To be considered irregular, the production rate for mixture bid items described above is not to exceed 1000 tons in a single day.

b. Field Voids.

1) Class I.

a) A lot is considered to be one layer of one mixture bid item placed during a day's operation. The Engineer may approve classifying multiple layers of construction placed during a single day as a lot provided only one mixture was used.

b) For the following situations sampling for field voids may be waived by the Engineer provided compaction has been thorough and effective, or sampling may be modified by mutual agreement to include more than one day's production provided samples are taken prior to trafficking:

- When the day's operation is not more than 2500 square yards excluding areas deducted from the field voids lot,
- When the day's operation is not more than 500 tons excluding quantities deducted from the field voids lot,
- When the mixture is being placed in irregular areas, or
- When placing strengthening courses.

c) If a sample is damaged or measures less than 70% or more than 150% of the intended thickness, an alternate sampling location will be determined and used. Take samples from no less than 1 foot from the unconfined edge of a given pass of the placing equipment, from run-outs, or from day's work joints or structures.

d) Use the following methods of acceptance for field voids:

(1) For mixture bid items placed in the following areas:

- Base widening placed in a travel lane,
- Ramps,
- Bridge approaches placed as a separate operation,
- Non-interstate travel lanes intended to be in service for fewer than 12 months,
- State Park and Institutional roadways,
- Recreational trails, and
- Irregular areas identified by the Engineer that may include areas not suitable for continuous paving,

The Engineer will accept the field voids lot based on the average test results or an established effective rolling pattern when approved by the Engineer. Do not exceed 8.0% average field voids. The Engineer may modify the sample size and frequency provided compaction is thorough and effective. The Engineer may apply the pay schedule in Article 2303.05, A, 3, b, 3, to areas where thorough and effective compaction is not achieved.

(2) For all other areas of Class I compaction, determine PWL as defined in Materials I.M. 501. The PWL limit shall be between 91.5% of G_{mm} (8.5% voids) and -100% of G_{mm} (0% voids). Use maximum specific gravity (G_{mm}) results in field voids calculations as follows:

(a) When cores represent one day's production and more than one G_{mm} test result is available, use the average G_{mm} in the field voids calculation for all cores.

(b) When cores represent one day's production and only one G_{mm} test result is available, use the single G_{mm} test result in the field voids calculation for all cores.

(c) When the cores represent more than one day's production, use the average of all G_{mm} test results from all days corresponding with the cores.

e) When the PWL falls below 90.0, use the procedure outlined in Materials I.M. 501 to identify outliers with 1.80 as the quality index criterion. Only one core may be considered an outlier in a single lot. If an outlier is identified, recalculate the PWL with the results of the remaining cores and determine whether the PWL is improved. Use the larger of the original and recalculated PWL to determine the pay factor.

2) For Class II apply Article 2303.03, C, 5, c.

c. Asphalt Film Thickness.
A lot is considered one day's production of one mixture. When film thickness falls outside the limits in Materials I.M. 510 Appendix A, see Article 2303.05, A, 3, c, for payment adjustment.

d. Thickness.

1) The Engineer will measure cores, exclusive of thin surface treatments, according to Materials I.M. 337. Sampling frequency and lot definitions are as follows:

a) Class I Compaction.
The Engineer will obtain and test samples for each lot according to Materials I.M. 204 Appendix F. Density cores sampled as part of a field voids lot will be combined into daily lots based on cores' intended thickness. Samples for thickness not tested for G_{mb}, because they are less than 70% or greater than 150% of the intended thickness, are included for thickness. In these particular instances, do not measure the thickness of additional sufficiently thick samples used to determine field voids. Measure core thickness prior to any trimming that may be needed for density testing.

b) Class II Compaction.
The Engineer will obtain and test samples full depth once the final lift is placed. The lot shall be defined as the length of a day's production of the final lift. Take a minimum eight cores from each lot. The Engineer may approve classifying multiple days of construction as a lot.

2) Provided there is reasonable assurance that the pavement complies with the required thickness, the Engineer may waive sampling for thickness for the following situations:

a) When an alternate method is deployed by the Engineer

b) When the day's operation is 2500 square yards or less.

c) When the mixture is being placed in irregular areas.

d) When the mixture is being placed next to structures.

3) Establish the intended thickness daily with consideration given to field conditions and tie-in features.

4) When the quality index falls below 0.00, the Engineer may declare the lot or parts of the lot defective. If the final lift has not been placed, the Engineer may approve additional thickness to be placed on succeeding lifts to ensure a final grade as intended. The unit price of the defective lot will be used for payment of the additional material.

e. Smoothness.

1) Apply Section 2317 to HMA surface mixture bid items of a Primary project or when specifically required for other projects.

2) On all projects, the Engineer may determine and identify irregularities of 1/2 inch or more in 25 feet longitudinally. Correct the irregularities identified by the Engineer in accordance with Section 2317.

E. Quality Control for Small HMA Paving Quantities.

1. General.

~~For small quantities, a~~A lot will be the entire quantity of each HMA mixture bid item.

2. Mix Design.

a. Prepare the JMF. Prior to production, obtain the Engineer's approval for the JMF. Comply with Article 2303.02 and Materials I.M. 510.

b. For mixtures meeting the criteria in Article 2303.02, E, 2, a:

1) An anti-stripping agent is required when the optimum dosage is greater than 0%.

2) Use Materials I.M. 319 to optimize the design dosage rate.

3) When prior-approved designs have demonstrated acceptable field SIP values, the anti-stripping agent and dosage from the JMF may be used in lieu of optimization testing.

3. Plant Production.

a. Ensure production plant calibration for the JMF is current and no more than 12 months old.

b. Use certified asphalt binder and approved aggregate sources meeting the JMF. Ensure the plant maintains an asphalt binder log to track the date and time of binder delivery. Ensure delivery tickets identify the JMF.

c. Monitor the quality control test results and make adjustments to keep the mixture near the target JMF values.

4. Sampling and Testing.

a. Field Voids.

1) Take compacted mixture G_{mb} measurements, except when Class II compaction is specified, no later than the next working day following placement and compaction.

2) The Engineer may accept the void content of the compacted layer based on cores or calculations from density gauge measurements. The Engineer may waive field void sampling provided the compaction has been thorough and effective.

3) PWL for field voids will not apply to small quantities.

b. **Lab Voids.**
   1) Material sampling and testing is for production quality control. Acceptance of mixture is based on Contractor certification. Sampling and testing of uncompacted mixture is only required for mechanically placed mixture. Sample and test a minimum of one uncompacted mixture sample according to the Standard Specifications and Materials I.M.s using certified technicians and qualified testing equipment.
   2) The Engineer may approve alternative sampling procedures or may waive sampling of uncompacted mix and gradation if Contractor can provide plant reports from other recent project(s) demonstrating the JMF has been produced within specification. Take the sample between the first 100 to 200 tons of production. No split samples for agency verification testing are required.
   3) PWL for lab voids will not apply to small quantities.

c. **Binder.**
   No binder sampling or testing is required.

d. **Moisture Sensitivity.**
   Moisture susceptibility testing on plant produced mixture is not required.

e. **Gradation.**
   Perform a minimum of one aggregate gradation.

5. **Certification.**
   a. When the production tolerances in Table 2303.03-4 are not met, payment may be adjusted according to Article 1105.04.
   b. When the production tolerances are met, provide a certification for the production of any mixture in which the requirements in this article are applied. Place the test results and the following certification statement on the Daily Plant Report.
      "The mixture contains certified asphalt binder and approved aggregate as specified in the approved mix design and was produced in compliance with the provisions of Article 2303.03, E."
   c. The Daily Plant Report may be submitted at the end of the project for all certified quantities, or submitted at intervals for portions of the certified quantity.

F. **Cold Weather Paving.**

1. When road surface temperature is below requirements shown in Tables 2303.03-1 and 2303.03-2, or when air temperature approximately 3 feet above grade, in shade, and away from artificial heat sources is less than 40°F, cold-weather paving may be considered by the Engineer.

2. **Cold Weather Paving Plan.**
   a. Submit a written cold weather paving plan to the Engineer. Document material, operational, and equipment changes for paving when air temperature approximately 3 feet above grade, in shade, and away from artificial heat sources is less than 40°F.
   b. Include the following:
      1) Use an approved mix design that incorporates a warm mix additive. Do not use water injection (foamed asphalt).
      2) Identify warm mix additive and dosage rate.
      3) Identify modifications to compaction process and when modifications apply.
   c. If the National Weather Service forecast for the construction area predicts ambient air temperature less than 40°F at the projected time of paving within the next 24 hours, confirm or submit revisions to the cold weather paving plan for Engineer validation. Update plan as required to accommodate conditions anticipated for the next day's operations. Upon validation of the plan, the Engineer will allow paving for the next day. Once in effect, pave conforming to the Engineer-accepted cold weather paving plan for balance of that workday or shift regardless of the temperature at time of paving.
   d. Engineer's written acceptance will be required for the cold weather paving plan. Engineer's acceptance of the plan does not relieve Contractor of responsibility for the quality of HMA pavement placed in cold weather.

3. Do not place flexible paving mixtures over frozen subgrade or base, or where roadbed is unstable.

4. Engineer may further limit placement if, in the Engineer's judgment, other conditions are detrimental to quality work.

2303.04 METHOD OF MEASUREMENT.

A. **Hot Mix Asphalt Mixture.**

1. **General.**
   a. Removal of fillets is incidental to the contract unit price for the mixture.
   b. If the Contractor chooses to place intermediate or surface mixture in lieu of base for the outside shoulders, the quantity will be calculated from the pavement and shoulder template. If placed as a separate operation, the quantity will be calculated from scale tickets. If the substitute mixture placed on the shoulder is for an

intermediate course fillet only, include the quantity in the fillet for payment in the quantity placed in the adjacent intermediate course.

c. Payment for the quality control requirements for small quantities will not be measured separately.

2. Measurement by Weight.

a. The quantity of the type specified, expressed in tons, will be determined from the weight of individual loads, including fillets, measured to the nearest 0.01 tons.

b. Loads may be weighed in trucks, weigh hoppers, or from the weight from batch plants computed by count of batches in each truck and batch weight. Article 2001.07 applies. Segregate the weights of various loads into the quantities for each pay item.

3. Measurement by Area.

a. The quantity of the type specified, expressed in square yards, will be shown in the contract documents to the nearest 0.1 square yard. The area of manholes, intakes, or other fixtures will not be deducted from the measured pavement area.

b. When constructing shoulders on a basis of payment of square yards, inspection of the profile and elevation will be based on the completed work relative to the pavement edge. The Contractor is responsible for the profile and elevation of the subgrade and for thickness.

B. Asphalt Binder.

1. Measure the amount of asphalt binder by in-line flow meter reading, according to Article 2001.07, B.

2. Compute the asphalt binder quantity added to the storage tank using a supplier certified transport ticket accompanying each load.

3. The quantity of asphalt binder not used in the work will be deducted.

4. When the quantity of asphalt binder in a batch is measured by weight and is separately identified by automatic or semi-automatic printout, the Engineer may compute the quantity of asphalt binder used from this printout. By mutual agreement, this method may be modified when small quantities or intermittent operations are involved.

5. The Engineer will calculate and exclude the quantity of asphalt binder used in mixtures in excess of the tolerance specified in Article 2303.03, D, 3, b.

6. When payment for-HMA is based on area, the quantity of asphalt binder used will not be measured separately for payment.

C. Recycled Asphalt Pavement.

1. A completed Daily HMA Plant Report with the certification statement is required for measurement and payment for Contractor Certified HMA. The quantity of asphalt binder will be based on the approved JMF and any plant production quality control adjustments.

2. The quantity of asphalt binder in RAP incorporated into the mixture will be calculated in tons. This quantity shall be based on the actual asphalt binder content determined for the mix design from the results of the Engineer’s extraction tests.

3. The quantity of asphalt binder in RAP, which is incorporated into the mix, will be included in the quantity of asphalt binder used.

D. Anti-strip Agent.
Will not be measured separately. The quantity will be based on tons of HMA mixture with anti-strip agent added.

E. Tack Coat.
Will not be measured separately.

F. Hot Mix Asphalt Pavement Samples.
Will not be individually counted for payment if furnished according to Article 2303.03, D, 4, or required elsewhere in the contract documents,

G. Recycled Asphalt Shingles.
67% of the asphalt binder from RAS which is incorporated into the mixture will be included in the quantity of asphalt binder used.

H. Cold Weather Paving.

Will not be measured separately. The quantity will be based on tons of flexible paving mixture placed with warm mix additive.

2303.05 BASIS OF PAYMENT.

The costs of designing, producing, placing, and testing bituminous mixtures and the cost of furnishing and equipping the QM-A field laboratory will not be paid for separately, but are included in the contract unit price for the HMA mixes used. The application of tack coat and sand cover aggregate are incidental and will not be paid for separately. Pollution testing is at the Contractor's expense. The installation of temporary Stop Sign Rumble Strips will not be paid for separately, but is incidental to the price bid for the HMA course for which it is applied.

The quality control requirements for small quantities are incidental to the items of HMA mixtures in the contract.

A. Flexible Paving Mixture.

1. Payment will be the contract unit price for Asphalt Mixture of the type specified per ton or square yard.

2. Payment for test strips will be the contract unit price for the test strip mixture bid item per ton regardless of lift placement.

3. Payment will be adjusted by the following Pay Factor for field voids, laboratory voids, and film thickness determined for the lot.

Multiply the unit price for the HMA bid item by the Pay Factor rounded to three decimal places.

a. Laboratory Voids.

1) Payment when PWL is used for acceptance:

Table 2303.05-1: Lab Voids Payment (PWL)

PWL	Pay Factor
100.0	1.060
90.1 – 99.9	0.006000*PWL + 0.4600
90.0	1.000
50.0 – 89.9	0.00625*PWL + 0.4375
Less than 50.0	0.750 maximum

When PWL is less than 50.0, the Engineer may declare the lot or parts of the lot deficient or unacceptable.

2) When PWL applies, the minimum pay factor for lab voids shall be 1.0 when the following changes are made via plan note or special provision:

a) Decreasing the target lab voids from the limits published in Materials I.M. 510.

b) Increasing the minimum asphalt film thickness from the limits published in Materials I.M. 510.

3) Payment when PWL lots are incomplete:

Table 2303.05-2: Lab Voids Payment (AAD)

AAD from Target Air Void	Pay Factor
0.0 to 1.0	1.000
1.1 to 1.5	0.900
1.6 to 2.0	0.750
Over 2.0	0.500 maximum

When the AAD is more than 2.0, the Engineer may declare the lot or parts of the lot deficient or unacceptable.

4) Use the following payment schedule when a test strip is constructed:

Table 2303.05-3: Lab Voids Payment (Test Strip)

AAD from Target Air Void	Pay Factor
0.0 to 1.5	1.000
1.6 to 2.0	2.5 - AAD
Over 2.0	0.500 maximum

When the AAD is more than 2.0, the Engineer may declare the lot or parts of the lot deficient or unacceptable.

b. Field Voids.

1) Payment when PWL is used for acceptance:

Table 2303.05-4: Field Voids Payment (PWL)

PWL	Pay Factor
100.0	1.060
90.1 - 99.9	0.00600*PWL + 0.4600

PWL	Pay Factor
90.0	1.000
50.0 –89.9	0.00625*PWL + 0.4375
Less than 50.0	0.750 maximum

When PWL is less than 50.0, the Engineer may declare the lot or parts of the lot deficient or unacceptable.

2) Payment when a test strip is constructed:

Table 2303.05-5: Field Voids Payment (Test Strip)

Average Field Voids (Pa), %	Pay Factor
0.0 to 9.0	1.000
9.1 to 9.5	10 - Pa
Over 9.5	0.500 maximum

When the average air void content from a test strip exceeds 9.5%, the Engineer may declare the lot or parts of the lot deficient or unacceptable.

3) Payment when PWL is not used for acceptance:

Table 2303.05-6: Field Voids Payment (Non-PWL)

Average Field Voids (Pa), %	Pay Factor
0.0 to 8.0	1.000
8.1 to 9.5	(11-Pa)/3
Over 9.5	0.500 maximum

When the average air void content exceeds 9.5%, the Engineer may declare the lot or parts of the lot deficient or unacceptable.

c. Film Thickness.

When film thickness (FT) is outside the limits in Materials I.M. 510 Appendix A, apply the following pay factor:

Table 2303.05-7: Film Thickness Payment

Placement	Pay Factor Low Film (FT < LL)	Pay Factor High Film (FT > UL)
Base/Shoulders	1 - (0.15 (LL - FT))	1 - (0.15 (FT-UL))
Intermediate	1 - (0.20 (LL - FT))	1 - (0.20 (FT-UL))
Surface	1 - (0.25 (LL - FT))	1 - (0.25 (FT-UL))

Where

LL = Lower Limit (Materials I.M. 510, Appendix A)

UL = Upper Limit (Materials I.M. 510, Appendix A)

1. When basis of payment is by area, add 1.0 to the pay factor (computed above) and divide by 2.0.
2. For FT < 7.0 or FT > 16.0, the Engineer may consider the lot defective. This applies to all lots (days) of production.
3. No film thickness price adjustment for the test strip (first day of production, if no test strip performed) for each job mix formula.
4. No film thickness price adjustment on temporary pavement.

d. Pavement Thickness

1) Payment will be further adjusted by the appropriate percentage in Table 2303.05-8 below according to the quality index for thickness determined for that lot:

$$QI_{Thickness} = \frac{\text{Average Thickness}_{Measured} - (\text{Thickness}_{Intended} - 0.5)}{\text{Maximum Thickness}_{Measured} - \text{Minimum Thickness}_{Measured}}$$

Table 2303.05-8: Payment Adjustment for Thickness

Quality Index (Thickness) 8 Samples	Percent of Payment
Greater than 0.34	100
0.14 to 0.34	95
0.00 to 0.13	85
Less than 0.00	75 maximum

2) Do not apply the quality index adjustment to a layer with a designated thickness of “variable” or “nominal”, or to a layer designated as scratch course or leveling course. Do not apply the quality index adjustment to pavement layers designated in the contract documents as grade correction or cross slope correction. Place grade correction or cross slope correction layers as specified in the contract documents or as directed by the Engineer.

4. Payment for courses for which quality index (thickness) is not determined because of size or shape, and courses which are found to be deficient in average width, will be according to Article 1105.04.

B. Asphalt Binder.

1. Payment will be the contract unit price per ton for the number of tons of asphalt binder used in the work.

2. Payment for asphalt binder will be for new asphalt binder, the asphalt binder in the RAP which is incorporated in the mixture, and 67% of the asphalt binder from RAS which is incorporated into the mixture. The quantity of asphalt binder in RAM, which is incorporated into the mix, will be calculated in tons of asphalt binder in the RAM. This will be based on the actual asphalt binder content determined for the mix design from the results of the Engineer's extraction test.

3. When the basis of payment for HMA is in square yards, compensation for asphalt binder will be included in the contract unit price per square yard.

C. Recycled Asphalt Pavement.
RAP owned by the Contracting Authority will be made available to the Contractor for the recycled mixture at no cost to the Contractor other than loading, hauling, and processing as required for incorporation into the mix.

D. Anti-strip Agent.

1. When anti-strip agent is required, payment will be made at the rate of $3.00 per ton of asphalt mixture in which the anti-strip agent is incorporated, if the Contracting Authority's test results from the field produced mixture meet or exceed the minimum requirement established in Article 2303.02, E, 2, d.

2. Payment will be full compensation for designing, adding, and testing for anti-strip agent.

E. Tack Coat.
Incidental to HMA.

F. Hot Mix Asphalt Pavement Samples.

1. Payment will be the lump sum contract price.

2. Payment is full compensation for furnishing all samples for all courses or items of work, and for delivery of samples as specified in Article 2303.03, D, 4.

G. Cold Weather Paving.

1. When cold weather paving is permitted by the Engineer, payment will be made at the rate of $3.00 per ton of flexible paving mixture in which the warm mix additive is incorporated.

2. Contracting Authority will not pay for compaction additive when:
   a. Pay factor for Field Voids is less than 1.0 for Class I compaction.
   b. Compaction is not thorough and effective for Class II compaction.

3. If because of an excusable compensable delay, the Engineer directs Contractor to pave when temperatures meet cold weather definition, the Contracting Authority will relieve Contractor of responsibility for damage and defects the Engineer attributes to cold weather paving.

SS-23009

SUPPLEMENTAL SPECIFICATIONS
FOR
HOT MIX ASPHALT INTERLAYER

Effective Date
September 16, 2025

THE STANDARD SPECIFICATIONS, SERIES 2023, ARE AMENDED BY THE FOLLOWING MODIFICATIONS AND ADDITIONS. THESE ARE SUPPLEMENTAL SPECIFICATIONS AND THEY PREVAIL OVER THOSE PUBLISHED IN THE STANDARD SPECIFICATIONS.

23009.01 DESCRIPTION.
These specifications describe requirements for a highly polymer modified asphalt interlayer. Apply Section 2303 of the Standard Specifications unless otherwise directed in these specifications.

23009.02 MATERIALS.

A. Asphalt Binder.
Use a PG 58-34E.

B. Mix Design.

1. See Materials I.M. 510 Appendix A.

2. Mix approval is based on Performance Testing Requirements per Materials I.M. 510 Appendix A.

3. Do not use RAP.

23009.03 CONSTRUCTION.

A. Apply tack coat prior to placement of HMA interlayer according to Section 2303 of the Standard Specifications.

B. Compact with static steel wheeled roller.

C. Do not open to traffic until the entire mat has cooled below 150°F.

D. Quality Assurance/Quality Control.

1. **Field Voids Acceptance.**
Acceptance for field voids shall be based on visual field observations. Should problems be

observed, the Engineer may require density gauge readings to verify field voids are less than or equal to 2%.

2. **Lab Voids Acceptance.**
Sample from windrow or hopper. Apply ~~Article 2303.05, A, 3, a, 2~~ Article 2303.05, A, 3, a, 3, of the Standard Specifications for AAD acceptance. Air void target is based on approved JMF.

3. Take at least one cold feed for gradation control each day of production.

23009.04 METHOD OF MEASUREMENT.
Hot Mix Asphalt Interlayer, of the size specified, will be measured according to Article 2303.04 of the Standard Specifications.

23009.05 BASIS OF PAYMENT.
Hot Mix Asphalt Interlayer, of the size specified, will be paid for according to Article 2303.05 of the Standard Specifications.

DS-23016

DS-23016
(New)

DEVELOPMENTAL SPECIFICATIONS
FOR
EVALUATION OF LONGITUDINAL JOINT QUALITY FOR
FLEXIBLE PAVING MIXTURES WITH INCENTIVE/DISINCENTIVE

Effective Date
October 17, 2023

THE STANDARD SPECIFICATIONS, SERIES 2023, ARE AMENDED BY THE FOLLOWING MODIFICATIONS AND ADDITIONS. THESE ARE SUPPLEMENTAL SPECIFICATIONS AND THEY SHALL PREVAIL OVER THOSE PUBLISHED IN THE STANDARD SPECIFICATIONS.

23016.01 DESCRIPTION.
This work is evaluating in-place quality of centerline longitudinal joints on surface wearing courses for flexible paving and replaces Article 2303.03, D, 4, c, of the Standard Specifications.

23016.02 EVALUATION.

A. General Requirements.
For Class I compaction areas on the surface, longitudinal joint density lots independent from the mat will be established for mainline paving as specified in Article DS-23016.02, B, for acceptance. Class I compaction is defined in Article 2303.03, C, 5, of the Standard Specifications. Mainline shall be considered through lanes within the traveled way including middle turn lanes.

B. Sampling.

1. When surface paving abuts a previously placed surface course, forming a completed longitudinal joint eligible for evaluation, Engineer will obtain and test samples according to Materials I.M. 320 and 321. Using random core locations determined for daily field voids lot (mat), Engineer will randomly select three of these locations to be sampled for joint density. When length of longitudinal joint is less than 3 mat sublots, Engineer will select two sublot locations. When length of longitudinal joint(s) is less than 2 mat sublots, joint cores will be waived.

2. When sampling for mat field voids is modified to include multiple days due to low production, sampling from the joint may also be modified by the Engineer.

3. Joints constructed with tandem pavers will be included, unless otherwise indicated in the contract documents.

4. For vertical joints, center joint cores on the visible seam between to the two adjacent lanes as shown in Appendix A of these specifications.

5. For notched wedge joints, center joint cores 4 inches away from the visible seam in the direction of the wedge as shown in Appendix A of these specifications.

6. Under direction and witnessing of the Engineer, drill one 6 inch diameter core at each sample location as soon as possible, but no later than the day following the completion of the longitudinal joint.

7. Do not compress, bend, or distort samples during cutting, handling, transporting, and storing. If samples are damaged, immediately obtain replacement samples, as directed by the Engineer, longitudinally from within 12 inches of the original sample location.

8. Apply Article 2303.03, D, 5, c, of the Standard Specifications for post drilling operations.

9. Report sample locations and test results on the daily plant report corresponding with the JMF used in production of the sublot(s).

C. Lot Size.
Lot size shall be the length of field voids lot where longitudinal joint(s) exist.

D. Excluded Areas.

1. Engineer will not obtain samples from the following excluded areas to determine lot acceptance:
   - Joints where one side of the joint is formed by existing pavement not constructed under this contract
   - Joints where one side of the joint is not on the mainline surface.
   - Areas within 1 foot longitudinally of an obstruction during construction of surface course (manholes, inlet grates, utilities, bridge structures, runout, etc.). Should a random sample location fall within 1 foot of such an area, Engineer will select an alternate nearby location away from obstruction.
   - Small areas, such as intersections, gore areas or transitions, or anywhere Engineer determines paving and phasing methods do not allow for consistent longitudinal joint construction.

2. Prior to paving, submit requests in writing to the Engineer for consideration of areas to be excluded on this basis. Engineer will make the final determination.

E. Joint Density.
Determine average joint density as a percent of average mat density per Appendix A. Mat cores and joint cores shall be collected on the same day of production for density determination. Mat cores identified as outliers for field voids acceptance will not be used in average mat density calculation.

23016.04 METHOD OF MEASUREMENT.
The Engineer will measure the length of each longitudinal joint density lot in feet.

23016.05 BASIS OF PAYMENT.
Use Table DS-23016-01 to determine the lot payment adjustment.

Table DS-23016-01: Payment for Longitudinal Joint Density

Avg Joint Density (%)	Payment Adjustment ($/ft)
< 95.0[1]	0.16*Avg Joint Density -15.2
95.0 – 97.0	$0.00
> 97.0[2]	0.1333*Avg Joint Density – 12.93

1. Disincentive is not to exceed $0.80/ft.
2. Incentive is not to exceed $0.40/ft.

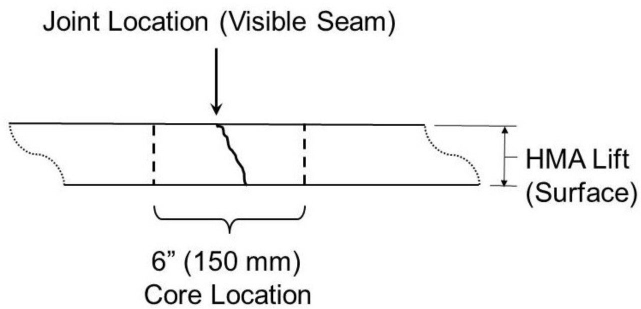
APPENDIX A

A. Joint Density

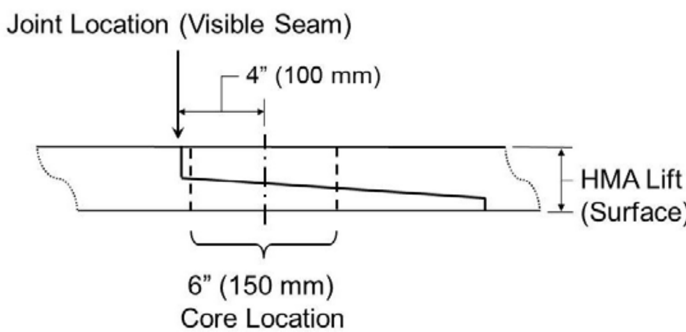
$$Avg\ Joint\ Density = 100 \times \frac{Avg\ Joint\ G_{mb}}{Avg\ Mat\ G_{mb}}$$

B. Coring Diagram

(a) Vertical Edge/Conventional (Butt) Joint



(b) Notched Wedge Joint



DS-23078

DS- 23078
(Replace DS-23075)

DEVELOPMENTAL SPECIFICATIONS
FOR
HIGH PERFORMANCE THIN LIFT OVERLAY

Effective Date
September 16, 2025

THE STANDARD SPECIFICATIONS, SERIES 2023, ARE AMENDED BY THE FOLLOWING MODIFICATIONS AND ADDITIONS. THESE ARE DEVELOPMENTAL SPECIFICATIONS AND THEY PREVAIL OVER THOSE PUBLISHED IN THE STANDARD SPECIFICATIONS.

23078.01 DESCRIPTION.

These specifications describe requirements for a highly polymer modified asphalt thin lift surface course. Apply Section 2303 of the Standard Specifications unless otherwise directed in these specifications.

23078.02 MATERIALS.

A. Asphalt Binder.

Use PG 64-34E+ with a minimum percent recovery of 90% when tested at 64°C per AASHTO T 350 at 3.2 kPa.

B. Mix Design.

1. General.

Table DS-23078.02-1: Mix Design

Test or Quality	Value
Design Gyrations	50
Design Voids Target (Based on %Gmm)	≤2.0
Film Thickness	8.0 – 15.0
Aggregate Quality	A
Crushed Content (minimum)	50%
FAA (minimum)	40
Sand Equivalency (minimum)	50

2. Friction Aggregate.

- Interstates: minimum 30% of Total Aggregate shall be Type 2 or better
- Non-Interstates: minimum 50% of Total Aggregate shall be Type 4 or better

3. Hamburg Testing (AASHTO T324).

Required only for Interstate paving mixes. Compact to 3.5% air voids. No more than ~~4 mm~~ 6.00 mm rutting in the first 8000 passes.

4. Do not use more than 15.0% binder replacement. Do not use RAS.

5. **Gradation.**

Table DS-23078.02-2: Thin Lift Overlay Gradation

Sieve Size	Min % Passing	Max % Passing
1½ inch		
1 inch		
3/8 inch	91	100
#4		90
#8	27	63
#16		
#30		
#50		
#100		
#200	2	10

23078.03 CONSTRUCTION.

A. Apply tack coat prior to placement of thin lift overlay according to Section 2303 of the Standard Specifications.

B. Keep the production temperature of HMA mixtures between 225ºF and 335ºF until placed on the grade.

C. Compact with static steel wheeled roller.

D. Do not open to traffic until the entire mat has cooled below 150°F.

E. Quality Assurance/Quality Control.

1. **Field Voids Acceptance.**
   Acceptance for field voids shall be based on visual field observations. Should problems be observed, the Engineer may require density gauge readings to verify field voids are less than or equal to 2%.

2. **Lab Voids Acceptance.**
   Sample from windrow or hopper. Apply ~~Article 2303.05, A, 3, a, 2~~ Article 2303.05, A, 3, a, 3, of the Standard Specifications for AAD acceptance. Air void target is based on approved JMF.

3. Take at least one cold feed for gradation control each day of production.

23078.04 METHOD OF MEASUREMENT.
Hot Mix Asphalt Thin Lift Overlay will be measured according to Article 2303.04 of the Standard Specifications.

23078.05 BASIS OF PAYMENT.
Hot Mix Asphalt Thin Lift Overlay will be paid for according to Article 2303.05 of the Standard Specifications.

CALCULATIONS

EXAMPLE CALCULATIONS FOR ASPHALT MIX DESIGN

The following pages contain examples of the common calculations used in the testing and analysis of an asphalt mix design. The formulas needed to solve the examples can be found in Materials IM 501. Although the computer programs will do most of these calculations, it is essential that the certified technician understands the mathematical relationships of the test results and the specification values. For that reason, the certification exam for HMA Level II contains several questions requiring the calculation of test values and volumetric properties.

Solutions to the example problems are included in the pages following the examples, so the students may check their own work and see the proper calculations.

SPECIFIC GRAVITY DETERMINATION

Given the following weights obtained during a test for aggregate specific gravity:

Weight of sample (W)	= 2025.0 grams
Weight of pyc. & water (W_1)	= 7445.0 grams
Weight of pyc. & water & sample (W_2)	= 8705.0 grams
Test Temperature	= 77°F
Weight of SSD +2.36 mm portion	= 909.0 grams
Weight of SSD -2.36 mm portion	= 1107.0 grams
Weight of DRY +2.36 mm portion	= 900.0 grams
Weight of DRY -2.36 mm portion	= 1079.0 grams

Using the procedure in I.M. 380 determine:

(a) Apparent Specific Gravity (G_{sa}): __________ (3 decimal places)
(b) % Water Absorption (% Abs): ___________ (2 decimal places)
(c) Bulk Dry Specific Gravity (G_{sb}): __________ (3 decimal places)

COMBINED GRADATION EXAMPLE:

Assume the proportions of the individual aggregates are as follows: 60% ¾" Minus, 15% ⅜" Chips, and 25% Nat. Sand. Then using the following gradations for the individual aggregates, determine the combined gradation.

% Passing

Sieve Size	3/4 in	1/2 in	3/8 in	#4	#8	#16	#30	#50	#100	#200
3/4" Minus	100	86	69	38	20	16	14	11	8.9	6.8
3/8" Chip	100	100	66	33	12	2.8	2.4	2.1	1.5	1.1
Nat. Sand	100	100	100	100	84	61	43	12	2.8	0.6
Combined										

COMBINED GRADATION EXAMPLE:

Assume the proportions of the individual aggregates are as follows: 10% ¾" Clean, 35% ½" Crushed, and 55% Nat. Gravel. Then using the following gradations for the individual aggregates, determine the combined gradation.

% Passing

Sieve Size	3/4 in	1/2 in	3/8 in	#4	#8	#16	#30	#50	#100	#200
3/4" Clean	100	65	21	11	6.5	4.2	3.1	2.5	2.1	1.1
1/2" Crush	100	100	69	40	31	22	16	12	9.5	7.3
Gravel	100	100	100	60	48	40	30	17	10.0	4.5
Combined										

FINENESS MODULUS CALCULATION EXAMPLE

Determine the fineness modulus of the Type 2 aggregate given the following information:

The Type 2 aggregate is 40% of the combined aggregate blend.

The gradation of the Type 2 aggregate is:

Percent passing:	**3/4**	**1/2**	**3/8**	**#4**	**#8**	**#16**	**#30**	**#50**	**#100**	**#200**
	100	**89**	**74**	**66**	**45**	**33**	**22**	**16**	**11**	**5.5**

COMBINED AGGREGATE PROPERTIES

Assuming the following information:

		% Passing							
% in Mix	**Sieve Size**	**3/4 in**	**1/2 in**	**3/8 in**	**#4**	**#8**	**#200**	**% Abs**	**G_{sb}**
60.0%	1/2" Stone	100	95	80	42	22	7.0	1.76	2.657
40.0%	Sand	100	100	100	96	83	1.0	0.57	2.635

Compute the following combined material properties:

a. Gradation

b. Specific Gravity

c. Absorption

BATCHING EXAMPLE #1:

You have been directed to prepare a 14,000 gram batch of aggregate composed of the following aggregates. The ¾" Minus has been split into four size fractions by sieving on the 1/2 in, 3/8 in and #4 sieves. The ⅜" Chip has been split into three size fractions by sieving on the 3/8 in and #4 sieves. The Nat. Sand is one size fraction passing the #4 sieve. Complete the following batching sheet by determining the mass of each aggregate needed, the percentage of each size fraction and the weight of each size fraction.

Weight ¾" Minus @ 60% =_______ grams

Sieve	% Passing	Size Fraction	% In Size Fraction	Weight Needed Each Fraction	Cumulative Weight
3/4 in	100				
1/2 in	86	-3/4 + 1/2	_________	_________	_________
3/8 in	69	-1/2 + 3/8	_________	_________	_________
#4	38	-3/8 + #4	_________	_________	_________
		-#4	_________	_________	_________
			_________		

Weight ⅜" Chip @ 15% =_______ grams

Sieve	% Passing	Size Fraction	% In Size Fraction	Weight Needed Each Fraction	Cumulative Weight
1/2 in	100				
3/8 in	66	-1/2 + 3/8	_________	_________	_________
#4	33	-3/8 + #4	_________	_________	_________
		-#4	_________	_________	_________
			_________		

Weight Nat. Sand @ 25% =_______ grams

Sieve	% Passing	Size Fraction	% In Size Fraction	Weight Needed Each Fraction	Cumulative Weight
#4	100	-#4	_________	_________	_________
			________		

BATCHING EXAMPLE #2:

You have been directed to prepare a 15,000 gram batch of aggregate composed of the following aggregates. The ¾" Clean has been split into four size fractions by sieving on the 1/2 in, 3/8 in and #4 sieves. The ½" Crushed has been split into three size fractions by sieving on the 3/8 in and #4 sieves. The Nat. Gravel has been split into two size fractions by sieving on the #4 sieve. Complete the following batching sheet by determining the mass of each aggregate needed, the percentage of each size fraction and the weight of each size fraction.

Weight ¾" Clean @ 10% =_______ grams

Sieve	% Passing	Size Fraction	% In Size Fraction	Weight Needed Each Fraction	Cumulative Weight
3/4 in	100				
1/2 in	65	-3/4 + 1/2	________	________	________
3/8 in	21	-1/2 + 3/8	________	________	________
#4	11	-3/8 + #4	________	________	________
		-#4	________	________	________
			________		

Weight ½" Crushed @ 35% =________ grams

Sieve	% Passing	Size Fraction	% In Size Fraction	Weight Needed Each Fraction	Cumulative Weight
1/2 in	100				
3/8 in	69	-1/2 + 3/8	________	________	________
#4	40	-3/8 + #4	________	________	________
		-#4	________	________	________
			________		

Weight Nat. Gravel @ 55% =________ grams

Sieve	% Passing	Size Fraction	% In Size Fraction	Weight Needed Each Fraction	Cumulative Weight
3/8 in	100				
#4	60	-3/8 + #4	________	________	________
		-#4	________	________	________
			________		

BATCH WEIGHT OF BINDER EXAMPLE

You have a 14,000g batch of aggregate with no RAM. You want to make a mix batch with an intended total P_b of 5.0%. Calculate the weight of binder to add W_b :

PERCENT BINDER TO ADD TO A BATCH WITH RAM AND BATCH WEIGHT EXAMPLE

You have a 14,000g batch of aggregate that includes 10% RAP. The percent binder in the RAP ($P_{b(RAP)}$) is 5.2%. You want to make a mix batch with an intended total P_b of 6.0%. Calculate the percent of virgin binder to add ($P_{b(add)}$) and the weight of binder to add W_b :

Film Thickness Calculation

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Sieve Analysis % Passing												
Sieve	1 1/2"	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200
Gradation	100	100	100	91	80	45	35	20	16	8.2	5.8	4.2

	#4	#8	#16	#30	#50	#100	#200	Total
Surface Area Coefficient	0.0041	0.0082	0.0164	0.0287	0.0614	0.1229	0.3277	Total
Surface Area m^2/kg + 0.41								
								SA

Where:			
P_b	= asphalt binder content, % , mixture basis	.00	Decimal Places
P_s	= aggregate, % , mixture basis	.00	Decimal Places
P_{be}	= effective asphalt content, % , mixture basis	.00	Decimal Places
P_{ba}	= absorbed asphalt %, aggr. basis	.00	Decimal Places
FT	= film thickness	.0	Decimal Places
SA	= surface area	.00	Decimal Places
G_{sb}	= bulk specific gravity of the combined aggregate	.000	Decimal Places
G_{se}	= effective specific gravity of the combined aggregate	.000	Decimal Places
G_b	= specific gravity of the asphalt binder @ 25 degrees C	.000	Decimal Places
G_{mm}	= maximum specific gravity of the mix	.000	Decimal Places

Refer to IM 501 for example calculation of Effective Binder %, (P_{be}), using aggregate effective specific gravity, (G_{se}).

Given: The combined gradation shown above and:

P_b = 5.80 % ← From Tank Stick

G_b = 1.030 ← From Asphalt Supplier

G_{sb} = 2.575 ← From Mix Design Information

G_{mm} = 2.430 ← From Daily Test Data

Aggregate Effective Sp. Gr. (G_{se}) = ______________________ = ______ **G_{se}**

$$\frac{100 - (P_b)}{(100 / G_{mm}) - (P_b / G_b)} = G_{se}$$

Percent Absorbed Asphalt (P_{ba}) = ______________________ = ______ **P_{ba}**

$$\frac{100 \times (G_{se} - G_{sb}) \times (G_b)}{(G_{se}) \times (G_{sb})} = P_{ba}$$

Effective Asphalt Content (P_{be}) = ______ – ______________________ = ______ **P_{be}**

$$P_b - \frac{(P_{ba}) \times (P_s)}{100} = P_{be}$$

Film Thickness = ______________________ = ______ **microns**

$$\frac{(P_{be}) \times 10}{(SA)} = FT \text{ microns}$$

MIX DESIGN ANALYSIS PROBLEM #1

Given the following information for a gyratory mix design:

	G_{sa}	%Abs	%-200	% Of Blend
Aggregate #1	2.705	1.26	7.3	55%
Aggregate #2	2.769	2.07	1.5	10%
Aggregate #3	2.689	1.03	3.0	10%
Aggregate #4	2.725	1.69	0.9	25%

Aggregate #4 is a Type 2 Frictional Class Aggregate that has 88% retained on the #4 sieve. The combined blend has 52% retained on the #4 sieve.

P_b = 5.4
G_b = 1.026

Surface Area of Combined Blend
4.79 m^2/kg

G_{mb} = 2.357
G_{mm} = 2.461

For the aggregates, calculate:
The G_{sb} of each aggregate.
The combined G_{sb} and combined absorption of the total blend.
The percent of +#4 Type 2 Frictional Class Aggregate in the total blend.
The G_{se} of the total blend.

For the mixture, calculate:
P_a, VMA, VFA, Filler/Bitumen Ratio and Film Thickness.

Aggregate #1 G_{sb} =

Aggregate #2 G_{sb} =

Aggregate #3 G_{sb} =

Aggregate #4 G_{sb} =

Combined G_{sb} =

Combined %Abs =

% +#4 Type 2 Frictional Aggr. in the Total Blend =

G_{se} =

P_a =

VMA =

VFA =

Filler/Bitumen Ratio =

Film Thickness =

MIX DESIGN ANALYSIS PROBLEM #2

Given the following information for a gyratory mix design:

	G_{sa}	%Abs	%-200	% Of Blend
Aggregate #1	2.709	2.21	6.8	35%
Aggregate #2	2.679	1.18	4.5	20%
Aggregate #3	2.739	3.05	1.1	15%
Aggregate #4	2.715	1.58	0.5	30%

Aggregate #3 is a Type 2 Frictional Class Aggregate that has 98% retained on the #4 sieve. The combined blend has 49% retained on the #4 sieve.

P_b = 5.9
G_b = 1.031

Surface Area of Combined Blend
5.19 m^2/kg

G_{mb} = 2.389
G_{mm} = 2.475

For the aggregates, calculate:
The G_{sb} of each aggregate.
The combined G_{sb} and combined absorption of the total blend.
The percent of +#4 Type 2 Frictional Class Aggregate in the total blend.
The G_{se} of the total blend.

For the mixture, calculate:
P_a, VMA, VFA, Filler/Bitumen Ratio and Film Thickness.

Aggregate #1 G_{sb} =

Aggregate #2 G_{sb} =

Aggregate #3 G_{sb} =

Aggregate #4 G_{sb} =

Combined G_{sb} =

Combined %Abs =

% +#4 Type 2 Frictional
Aggr. in the Total Blend =

G_{se} =

P_a =

VMA =

VFA =

Filler/Bitumen Ratio =

Film Thickness =

SPECIFIC GRAVITY DETERMINATION SOLUTIONS

Given the following weights obtained during a test for aggregate specific gravity:

Weight of sample (W)	= 2025.0 grams
Weight of pyc. & water (W_1)	= 7445.0 grams
Weight of pyc. & water & sample (W_2)	= 8705.0 grams
Test Temperature	= 77°F
Weight of SSD +2.36 mm portion	= 909.0 grams
Weight of SSD -2.36 mm portion	= 1107.0 grams
Weight of DRY +2.36 mm portion	= 900.0 grams
Weight of DRY -2.36 mm portion	= 1079.0 grams

Using the procedure in I.M. 380 determine:

(a) Apparent Specific Gravity (G_{sa}): 2.647 (3 decimal places)
(b) % Water Absorption (% Abs): 1.87 (2 decimal places)
(c) Bulk Dry Specific Gravity (G_{sb}): 2.522 (3 decimal places)

$$\frac{2025 \times 1.00}{2025 + 7445 - 8705} = 2.647$$

$$\frac{(909 + 1107) - (900 + 1079)}{(900 + 1079)} \times 100 = 1.87$$

$$\frac{2.647}{1 + (0.0187 \times 2.647)} = 2.522$$

COMBINED GRADATION EXAMPLE SOLUTION:

Assume the proportions of the individual aggregates are as follows: 60% ¾” Minus, 15% ⅜” Chips, and 25% Nat. Sand. Then using the following gradations for the individual aggregates, determine the combined gradation.

% Passing

Sieve Size	3/4 in	1/2 in	3/8 in	#4	#8	#16	#30	#50	#100	#200
3/4" Minus	100	86	69	38	20	16	14	11	8.9	6.8
3/8" Chip	100	100	66	33	12	2.8	2.4	2.1	1.5	1.1
Nat. Sand	100	100	100	100	84	61	43	12	2.8	0.6
Combined	100	91.6	76.3	52.8	34.8	25.3	19.5	9.9	6.3	4.4

COMBINED GRADATION EXAMPLE SOLUTION:

Assume the proportions of the individual aggregates are as follows: 10% ¾” Clean, 35% ½” Crushed, and 55% Nat. Gravel. Then using the following gradations for the individual aggregates, determine the combined gradation.

% Passing

Sieve Size	3/4 in	1/2 in	3/8 in	#4	#8	#16	#30	#50	#100	#200
3/4" Clean	100	65	21	11	6.5	4.2	3.1	2.5	2.1	1.1
1/2" Crush	100	100	69	40	31	22	16	12	9.5	7.3
Gravel	100	100	100	60	48	40	30	17	10.0	4.5
Combined	100.0	96.5	81.3	48.1	37.9	30.1	22.4	13.8	9.0	5.1

FINENESS MODULUS CALCULATION EXAMPLE SOLUTION

Determine the fineness modulus of the Type 2 aggregate given the following information:

The Type 2 aggregate is 40% of the combined aggregate blend.

The gradation of the Type 2 aggregate is:

Percent passing:	**3/4**	**1/2**	**3/8**	**#4**	**#8**	**#16**	**#30**	**#50**	**#100**	**#200**
	100	**89**	**74**	**66**	**45**	**33**	**22**	**16**	**11**	**5.5**

$$\frac{600-(66+45+33+22+16+11)}{100}\times 0.40=1.6$$

COMBINED AGGREGATE PROPERTIES SOLUTIONS

Assuming the following information:

% Passing

% in Mix	**Sieve Size**	**3/4 in**	**1/2 in**	**3/8 in**	**#4**	**#8**	**#200**	**% Abs**	**G_{sb}**
60.0%	1/2" Stone	100	95	80	42	22	7.0	1.76	2.657
40.0%	Sand	100	100	100	96	83	1.0	0.57	2.635

Compute the following <u>combined</u> material properties:

a. Gradation

% Passing

Sieve Size	**3/4 in**	**1/2 in**	**3/8 in**	**#4**	**#8**	**#200**
1/2" Stone	60.0	57.0	48.0	25.2	13.2	4.2
Sand	40.0	40.0	40.0	38.4	33.2	0.4
Combined	100.0	97.0	88.0	63.6	46.4	4.6

b. Specific Gravity

$$G_{sb} = \frac{100}{\frac{60}{2.657} + \frac{40}{2.635}} = 2.648$$

c. Absorption

% Abs = (1.76) x (0.60) + (0.57) x (0.40) = 1.28

BATCHING EXAMPLE #1 SOLUTION:

You have been directed to prepare a 14,000 gram batch of aggregate composed of the following aggregates. The ¾" Minus has been split into four size fractions by sieving on the 1/2 in, 3/8 in and #4 sieves. The ⅜" Chip has been split into three size fractions by sieving on the 3/8 in and #4 sieves. The Nat. Sand is one size fraction passing the #4 sieve. Complete the following batching sheet by determining the mass of each aggregate needed, the percentage of each size fraction and the weight of each size fraction.

Weight ¾" Minus @ 60% = 8400.0 grams

Sieve	% Passing	Size Fraction	% In Size Fraction	Weight Needed Each Fraction	Cumulative Weight
3/4 in	100				
1/2 in	86	-3/4 + 1/2	14.0	1176.0	1176.0
3/8 in	69	-1/2 + 3/8	17.0	1428.0	2604.0
#4	38	-3/8 + #4	31.0	2604.0	5208.0
		-#4	38.0	3192.0	8400.0
			100.0		

Weight ⅜" Chip @ 15% = 2100.0 grams

Sieve	% Passing	Size Fraction	% In Size Fraction	Weight Needed Each Fraction	Cumulative Weight
1/2 in	100				
3/8 in	66	-1/2 + 3/8	34.0	714.0	9114.0
#4	33	-3/8 + #4	33.0	693.0	9807.0
		-#4	33.0	693.0	10500.0
			100.0		

Weight Nat. Sand @ 25% = 3500.0 grams

Sieve	% Passing	Size Fraction	% In Size Fraction	Weight Needed Each Fraction	Cumulative Weight
#4	100	-#4	100.0	3500.0	14000.0

BATCHING EXAMPLE #2 SOLUTION:

You have been directed to prepare a 15,000 gram batch of aggregate composed of the following aggregates. The ¾" Clean has been split into four size fractions by sieving on the 1/2 in, 3/8 in and #4 sieves. The ½" Crushed has been split into three size fractions by sieving on the 3/8 in and #4 sieves. The Nat. Gravel has been split into two size fractions by sieving on the #4 sieve. Complete the following batching sheet by determining the mass of each aggregate needed, the percentage of each size fraction and the weight of each size fraction.

Weight ¾" Clean @ 10% = 1500.0 grams

Sieve	% Passing	Size Fraction	% In Size Fraction	Weight Needed Each Fraction	Cumulative Weight
3/4 in	100				
1/2 in	65	-3/4 + 1/2	35.0	525.0	525.0
3/8 in	21	-1/2 + 3/8	44.0	660.0	1185.0
#4	11	-3/8 + #4	10.0	150.0	1335.0
		-#4	11.0	165.0	1500.0
			100.0		

Weight ½" Crushed @ 35% = 5250.0 grams

Sieve	% Passing	Size Fraction	% In Size Fraction	Weight Needed Each Fraction	Cumulative Weight
1/2 in	100				
3/8 in	69	-1/2 + 3/8	31.0	1627.5	3127.5
#4	40	-3/8 + #4	29.0	1522.5	4650.0
		-#4	40.0	2100.0	6750.0
			100.0		

Weight Nat. Gravel @ 55% = 8250.0 grams

Sieve	% Passing	Size Fraction	% In Size Fraction	Weight Needed Each Fraction	Cumulative Weight
3/8 in	100				
#4	60	-3/8 + #4	40.0	3300.0	10050.0
		-#4	60.0	4950.0	15000.0
			100.0		

BATCH WEIGHT OF BINDER EXAMPLE SOLUTION

You have a 14,000g batch of aggregate with no RAM. You want to make a mix batch with an intended total P_b of 5.0%. Calculate the weight of binder to add W_b :

$$Wb = \frac{5.0 \ \times 14{,}000}{100 - 5.0} = 736.8g$$

PERCENT BINDER TO ADD TO A BATCH WITH RAM AND BATCH WEIGHT EXAMPLE SOLUTION

You have a 14,000g batch of aggregate that includes 10% RAP. The percent binder in the RAP ($P_{b(RAP)}$) is 5.2%. You want to make a mix batch with an intended total P_b of 6.0%. Calculate the percent of virgin binder to add ($P_{b(add)}$) and the weight of binder to add W_b :

$$Pb(add) = \frac{(100 \times 6.0) - (10 \times 5.2)}{100 - (10 \times 5.2 \times 0.01)} = 5.51\%$$

$$Wb = \frac{14{,}000 \times 5.51}{100 - 5.51} = 816.4g$$

Film Thickness Calculation Solution

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Sieve Analysis % Passing													
Sieve	1 1/2"	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200	
Gradation	100	100	100	91	80	45	35	20	16	8.2	5.8	4.2	
Surface Area Coefficient						0.0041	0.0082	0.0164	0.0287	0.0614	0.1229	0.3277	Total
Surface Area m^2/kg					+ 0.41	0.18	0.29	0.33	0.46	0.50	0.71	1.38	4.26
													SA

Where:

P_b	= asphalt binder content, % , mixture basis	.00 Decimal Places
P_s	= aggregate, % , mixture basis	.00 Decimal Places
P_{be}	= effective asphalt content, % , mixture basis	.00 Decimal Places
P_{ba}	= absorbed asphalt %, aggr. basis	.00 Decimal Places
FT	= film thickness	.0 Decimal Places
SA	= surface area	.00 Decimal Places
G_{sb}	= bulk specific gravity of the combined aggregate	.000 Decimal Places
G_{se}	= effective specific gravity of the combined aggregate	.000 Decimal Places
G_b	= specific gravity of the asphalt binder @ 25 degrees C	.000 Decimal Places
G_{mm}	= maximum specific gravity of the mix	.000 Decimal Places

Refer to IM 501 for example calculation of Effective Binder %, (P_{be}), using aggregate effective specific gravity, (G_{se}).

Given: The combined gradation shown above and:

P_b = 5.80 % ← From Tank Stick

G_b = 1.030 ← From Asphalt Supplier

G_{sb} = 2.575 ← From Mix Design Information

G_{mm} = 2.430 ← From Daily Test Data

Aggregate Effective Sp. Gr. (G_{se}) =

$$\frac{100 - 5.80}{100 / 2.430 - 5.80 / 1.030} = 2.652 \quad G_{se}$$

$$\frac{100 - (P_b)}{(100 / G_{mm}) - (P_b / G_b)} = G_{se}$$

Percent Absorbed Asphalt (P_{ba}) =

$$\frac{100 \times (2.652 - 2.575) \times 1.030}{2.652 \times 2.575} = 1.16 \quad P_{ba}$$

$$\frac{100 \times (G_{se} - G_{sb}) \times (G_b)}{(G_{se}) \times (G_{sb})} = P_{ba}$$

Effective Asphalt Content (P_{be}) =

$$5.80 - \frac{1.16 \times 94.20}{100} = 4.71 \quad P_{be}$$

$$P_b - \frac{(P_{ba}) \times (P_s)}{100} = P_{be}$$

Film Thickness =

$$\frac{4.71 \times 10}{4.26} = 11.1 \text{ microns}$$

$$\frac{(P_{be}) \times 10}{(SA)} = FT \text{ microns}$$

MIX DESIGN ANALYSIS PROBLEM #1 SOLUTION

Given the following information for a gyratory mix design:

	G_{sa}	%Abs	%-200	% Of Blend
Aggregate #1	2.705	1.26	7.3	55%
Aggregate #2	2.769	2.07	1.5	10%
Aggregate #3	2.689	1.03	3.0	10%
Aggregate #4	2.725	1.69	0.9	25%

Aggregate #4 is a Type 2 Frictional Class Aggregate that has 88% retained on the #4 sieve. The combined blend has 52% retained on the #4 sieve.

$P_b = 5.4$

$G_b = 1.026$

Surface Area of Combined Blend 4.79 m^2/kg

$G_{mb} = 2.357$

$G_{mm} = 2.461$

For the aggregates, calculate:
The G_{sb} of each aggregate.
The combined G_{sb} and combined absorption of the total blend.
The percent of +#4 Type 2 Frictional Class Aggregate in the total blend.
The G_{se} of the total blend.

For the mixture, calculate:
P_a, VMA, VFA, Filler/Bitumen Ratio and Film Thickness.

Aggregate #1 G_{sb} = $\frac{2.705}{1+(2.705x0.0126)} = \frac{2.705}{1.034083} = 2.616$

Aggregate #2 G_{sb} = $\frac{2.769}{1+(2.769x0.0207)} = \frac{2.769}{1.0573183} = 2.619$

Aggregate #3 G_{sb} = $\frac{2.689}{1+(2.689x0.0103)} = \frac{2.689}{1.0276967} = 2.617$

Aggregate #4 G_{sb} = $\frac{2.725}{1+(2.725x0.0169)} = \frac{2.725}{1.0460525} = 2.605$

Combined G_{sb} = $\dfrac{100}{\dfrac{55}{2.616}+\dfrac{10}{2.619}+\dfrac{10}{2.617}+\dfrac{25}{2.605}}$ = 2.614

Combined %Abs = (1.26 x 55%) + (2.07 x 10%) + (1.03 x 10%) + (1.69 x 25%) = 1.43

% +#4 Type 2 Frictional
Aggr. in the Total Blend = $\dfrac{88x25}{52}$ = 42.3

G_{se} = $\dfrac{100-5.4}{\dfrac{100}{2.461}-\dfrac{5.4}{1.026}}$ = 2.675

P_a = $\left[1-\dfrac{2.357}{2.461}\right]x100$ = 4.2

VMA = $100-\dfrac{2.357x94.6}{2.614}$ = 14.7

VFA = $\dfrac{14.7-4.2}{14.7}x100$ = 71.4

Filler/Bitumen Ratio =

Combined % - #200 = (7.3 x 55%) + (1.5 x 10%) + (3.0 x 10%) + (0.9 x 25%) = 4.7

$P_{ba} = \dfrac{2.675-2.614}{2.675x2.614}x1.026x100$ = 0.90

$P_{be} = 5.4-\dfrac{0.90x94.6}{100}$ = 4.55

$F/B = \dfrac{4.7}{4.55}$ = 1.03

Film Thickness = $\dfrac{4.55}{4.79}x10$ = 9.5

MIX DESIGN ANALYSIS PROBLEM #2 SOLUTION

Given the following information for a gyratory mix design:

	G_{sa}	%Abs	%-200	% Of Blend
Aggregate #1	2.709	2.21	6.8	35%
Aggregate #2	2.679	1.18	4.5	20%
Aggregate #3	2.739	3.05	1.1	15%
Aggregate #4	2.715	1.58	0.5	30%

Aggregate #3 is a Type 2 Frictional Class Aggregate that has 98% retained on the #4 sieve. The combined blend has 49% retained on the #4 sieve.

P_b = 5.9
G_b = 1.031

Surface Area of Combined Blend
5.19 m^2/kg

G_{mb} = 2.389
G_{mm} = 2.475

For the aggregates, calculate:
The G_{sb} of each aggregate.
The combined G_{sb} and combined absorption of the total blend.
The percent of +#4 Type 2 Frictional Class Aggregate in the total blend.
The G_{se} of the total blend.

For the mixture, calculate:
P_a, VMA, VFA, Filler/Bitumen Ratio and Film Thickness.

Aggregate #1 G_{sb} = $\dfrac{2.709}{1+(2.709x0.0221)} = \dfrac{2.709}{1.0598689} = 2.556$

Aggregate #2 G_{sb} = $\dfrac{2.679}{1+(2.679x0.0118)} = \dfrac{2.679}{1.0316122} = 2.597$

Aggregate #3 G_{sb} = $\dfrac{2.739}{1+(2.739x0.0305)} = \dfrac{2.739}{1.0835395} = 2.528$

Aggregate #4 G_{sb} = $\dfrac{2.715}{1+(2.715x0.0158)} = \dfrac{2.715}{1.042897} = 2.603$

Combined G_{sb} = $\dfrac{100}{\dfrac{35}{2.556}+\dfrac{20}{2.597}+\dfrac{15}{2.528}+\dfrac{30}{2.603}}$ = 2.574

Combined %Abs = (2.21 x 35%) + (1.18 x 20%) + (3.05 x 15%) + (1.58 x 30%) = 1.94

% +#4 Type 2 Frictional
Aggr. in the Total Blend = $\dfrac{98x15}{49}$ = 30.0

G_{se} = $\dfrac{100-5.9}{\dfrac{100}{2.475}-\dfrac{5.9}{1.031}}$ = 2.713

P_a = $\left[1-\dfrac{2.389}{2.475}\right]x100$ = 3.5

VMA = $100-\dfrac{2.389x94.1}{2.574}$ = 12.7

VFA = $\dfrac{12.7-3.5}{12.7}$ = 72.4

Filler/Bitumen Ratio =

Combined % - #200 = (6.8 x 35%) + (4.5 x 20%) + (1.1 x 15%) + (0.5 x 30%) = 3.6

P_{ba} = $\dfrac{2.713-2.574}{2.713x2.574}x1.031x100$ = 2.05

P_{be} = $5.9-\dfrac{2.05x94.1}{100}$ = 3.97

F/B = $\dfrac{3.6}{3.97}$ = 0.91

Film Thickness = $\dfrac{3.97}{5.19}x10$ = 7.6