HR-141

# EFFECT OF CEMENT ON MOISTURE MIGRATION IN CONCRETE

PHASE A

LABORATORY STUDY OF MOISTURE
MIGRATION IN HARDENED CEMENT PASTE

to

POLICY COMMITTEE

POOLED FUND RESEARCH
on
D-CRACKING OF CONCRETE PAVEMENT

IOWA STATE HIGHWAY COMMISSION
STATE HIGHWAY COMMISSION OF KANSAS
MISSOURI STATE HIGHWAY DEPARTMENT

In Cooperation With

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FEDERAL HIGHWAY ADMINISTRATION

by

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# EFFECT OF CEMENT ON MOISTURE MIGRATION IN CONCRETE

## PHASE A

## LABORATORY STUDY OF MOISTURE MIGRATION IN HARDENED CEMENT PASTE

by

David R. Lankard and Alvin J. Walker

The Columbus Laboratories of Battelle Memorial Institute is currently conducting a study of the effect of cement on moisture migration in concrete as related to the problem of D-cracking of portland cement concrete pavements. The study began on December 31, 1970, and is planned as a 3-year program. The work plan, approved by the policy committee of the members of the Iowa, Kansas, and Missouri highway departments and the Federal Highway Administration, is composed of four parts:

(A) Laboratory Study of Moisture Migration in Hardened Cement Paste

(B) Laboratory Study of Moisture Migration in Simulated Concrete in Relation to Freeze-Thaw Behavior

(C) Cement Characterization Studies

(D) Correlation of the Properties of the Cements with Their Performance in Concrete.

The first phase (A) of the investigation concerned the movement of moisture into and from hardened cement pastes and the dimensional changes accompanying the moisture changes. Small slab specimens of hardened neat cement pastes were prepared from 32 different cements which were prepared at the same water/cement ratio and hydrated to the same maturity factor.

For each cement the following data were obtained:

(1) Maturity factor at time of testing

(2) Total evaporable water content of the saturated specimens at time of testing (2 specimens each cement)

(3) The total evaporable water list in isothermally (74 F) drying from initial saturation to equilibrium at each of two conditions of lower relative humidity, viz. (2 specimens each cement):

75 percent relative humidity
25 percent relative humidity

(4) The rate of moisture loss under conditions of Item (3)

(5) The total evaporable water gained when the partially dried specimens of Item (3) were reexposed (at 74 F) to 100 percent relative humidity.

(6) The rate of moisture absorption under conditions of Item (5)

(7) Data as in Item (3) for second cycle of drying at 74 F

(8) Data as in Item (4) for second cycle of drying

(9) The total evaporable water lost in isothermally (100 F) drying from initial saturation to equilibrium at 75 percent relative humidity (2 specimens each cement)

(10) The rate of moisture loss under the conditions of Item (9)

(11) After equilibrium was attained in Item (9) the specimen temperature was decreased to 74 F and Steps (5) through (8) were carried out.

Statistical techniques were used to identify significant differences in the moisture migration behavior of the cement pastes.

## MATERIAL ACQUISITION AND SAMPLING

### Cements

A total of 32 cements (approximately one barrel each) were provided for the program by the states involved and by Battelle. The code number, type, and source of the cements are shown in Table 1. Ten cements were received from Missouri, twelve cements from Kansas, and seven cements from Iowa. Seventeen

Type I cements were obtained; seven Type II cements; three Type III cements; two Type IV cements; two Type V cements; and one oil well cement. Included among the cements were a 20-year-old Type I (No. 9), a Type I cement with total alkali content below 0.20 percent (No. 71), a Type I with a total alkali content above 1.00 (No. 27), two Type III cements with a Blaine fineness in excess of 5500 (Nos. 25 and 26); and one cement with a zero $C_3A$ content (No. 74).

## Cement Sampling

All handling of the cements at Battelle was done inside a 12 x 12 x 12-foot enclosure built from 2 x 2-inch wood framing and covered on all sides with polyethylene sheet. A dehumidifier inside the enclosure maintained the relative humidity below 30 percent.

The entire lot of a given cement (approximately 400 pounds) was placed in one pile on a clean sheet of polyethylene film. The material in the pile was thoroughly blended by hand using recommended procedures. The pile was then quartered into four lots having roughly the same amount of material (approximately 100 pounds each).

Three of the 100-pound quartered lots were doubly bagged in polyethylene and placed in small fiber drums which were subsequently sealed with polyethylene sheet and taped shut. A packet of drying agent was placed in each drum.

The remaining 100 pounds of material was passed through a Gilson large capacity sample splitter and then through a smaller splitter to provide 3- to 35-pound representative samples for various phases of the experimental program. All of the split cement samples were doubly bagged in polyethylene in the presence of the drying agent.

## SPECIMEN PREPARATION

Cement paste specimens for use in Phase A of the study were prepared as thin slabs about 5 inches long by 1 inch wide by 0.1 inch thick. The following procedure was used in the fabrication and curing of the slabs:

(1) A nominally air-free cement-water mixture was prepared in a Waring blender using 300 grams of cement and 136.5 grams of distilled water precooled to 50 F. These mixtures were prepared in the same manner as that used by Powers et al.* Inasmuch as about 1.5 grams of water is lost through evaporation during mixing, the final water/cement ratio is 135/300 or 0.45.

(2) Upon completion of mixing the fresh paste was transferred to a porcelain pan. Slab-shaped specimens were prepared from the paste by casting into individual molds and using light external vibration (Syntron-Jogger Model J-1A) at 60 cps. The casting operation is shown in Figure 1. The break-apart molds were constructed from rigid plexiglas plates and machined brass spacers. A total of 12 slab specimens (6-1/2 x 1 x 0.1 inch) were prepared from each cement.

(3) After casting, the open end of each mold was covered with a polyethylene bonnet, and the mold placed in a fog room at about 73 F.

(4) After 24 hours mold curing the slabs were removed from the molds and were saw-cut to a length of 5 inches.** The upper (with respect to the casting direction) 1-1/2 inches of the slab were cut off.

(5) After cutting, the slabs were weighed and measured before placing in lime water for curing. All slabs of a given cement were stored in a single wide-mouth quart jar that was filled with saturated lime water. The jars were then stored in a water bath in a room maintained at 74 F.

The average weights of the slab specimens prepared with the 32 cements are shown in Table 2.

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* Journal American Concrete Institute, Vol. 26, No. 3, pp 286-287 (1954).

** Due to their low early strengths, Type II and IV cement pastes were allowed to cure for longer periods prior to cutting.

# EXPERIMENTAL PROCEDURE

## Measurement of Nonevaporable Water Contents of Cement Pastes

It was desired to begin the investigation of moisture migration in the hardened cement pastes after they had developed a maturity factor of about 80 percent; specifically when the nonevaporable water content ($w_{n/c}$) of the water-cured paste as 80±2 percent that of the fully hydrated cement. In practice the maturity factors varied from 75 to 90 percent. The nonevaporable water content of the hardened cement pastes was determined as a function of elapsed curing time using the method of Copeland and Hayes (ASTM Bull. 194, pp 70-74, 1953, commonly referred to as D-drying).

Complete hydration of the cements was achieved using an intermittent ball milling procedure. High water content (w/c = 9.0) cement slurries were ball milled over a 12-day period during which time the mills rotated for 10 minutes out of each hour (every other day), thereby giving a water-cement content time of 12 days and a total milling time of 24 hours. The milled cements were checked using X-ray diffraction techniques to detect any unhydrated cement. No anhydrous cement phases were detected in any of the cements subjected to the wet milling operation.

## Measurement of Evaporable Water Contents of Cement Pastes

The evaporable water content of the water-cured cement pastes was measured at the time they were subjected to the moisture migration study, i.e., when the cement was 80 percent hydrated. This measurement was obtained in duplicate on granulated pastes (-30, +80 mesh) using a procedure outlined by Powers and described below:

> "About 5 grams of the sample to be saturated are placed in a 50-ml Erlenmeyer flash fitted with a special stopper that permits either the introduction of water from a burette or a stream of dried air free from $CO_2$. At the start, water is slowly dropped onto the sample from the burette until the sample, upon being shaken, gathers into a lump and clings to the flask. Dry air is then passed over the sample while it

is vigorously shaken by hand. After 2 minutes of this treatment, the flow of air is topped and the shaking of the flask is continued. If the sample persists in gathering into a lump, the drying is continued for 2 more minutes. This procedure is continued until the particles just fail to cling to each other and to the flask."

The samples were then D-dried to determine $w_e$.

## Measurement of Moisture Migration in the Hardened Cement Pastes

The weight and dimensional changes accompanying the loss and gain of moisture in the slab specimens of hardened cement paste was determined under the following conditions:

(1) After the appropriate curing period, the specimens were removed from the lime water and placed in a $CO_2$-free controlled temperature and humidity environmental chamber. The relative humidity in the test chambers was controlled using saturated salt solutions and controlled density sulfuric acid solutions. The rate and amount of moisture lost from the specimen as it equilibrated from 100 percent relative humidity to lower relative humidities was measured. Measurements were made simultaneously of the contraction of the specimens as they lost moisture.

(2) Once equilibrium was attained in the partially dry specimen at the newer relative humidity, the relative humidity in the test chamber was increased to 100 percent by replacing the salt or acid solution with pure water. The rate and amount of moisture absorbed by the specimen as it equilibrated with the 100 percent relative humidity was measured until equilibrium was again attained. Specimen dilation was monitored during this time.

(3) Once equilibrium was attained at 100 percent relative humidity, the relative humidity was lowered to its original low value (for any given specimen). The rate and amount of moisture loss of the specimen, as well as their deformation, was measured until equilibrium was again reached. Once equilibrium was reachieved at the lower chamber relative, the test was terminated.

(4) One additional experiment was performed in addition to the above to study the effect of the temperature of drying on subsequent moisture movement characteristics of cement pastes. This was accomplished by initially drying pastes at 100 F before subjecting them to the other conditions just outlined.

A photograph of the experimental equipment is shown in Figure 2 which shows the 8-inch-square glass environmental chambers, the optical extensometer for measuring dimensional changes, the balance for measuring weight changes, the ovens used to achieve 100 F in the environmental chambers, and other pertinent items. The entire setup was contained in a controlled temperature room that was maintained at 74±1 F.

A schematic of the test method is shown in Figure 3. $CO_2$-free air (at the desired relative humidity and 74 F) was slowly bubbled into the humidity chambers so as to maintain a slight overpressure. This assured that no atmospheric $CO_2$-contamination could occur. The opening for the humidity sensor served as the overpressure discharge opening when the sensor was not in position. Specimen weight changes were measured directly using a bottom-loading Mettler P120 balance (with milligram readout capability). The brief period (~5 seconds) that the specimen was suspended for weighing did not affect the relative humidity of the chamber. Specimen deformation was measured remotely using a Gaertner double telescope estensometer.

For the tests conducted at 75 percent relative humidity at 74 F a saturated NaCl solution was used to control the relative humidity in the environmental chamber. For the tests conducted at 25 percent relative humidity at 74 F an aqueous sulfuric acid solution (density = 1.450 at 74 F) was used to control R.H. Measurements made at 100 F/75 percent R.H. were made in environmental chambers containing saturated NaCl solutions in which both the air and solution temperature was maintained at 100 F.

In practice, data were obtained concurrently on three cements. The total testing time for each cement was three weeks. The equilibration time for each of the two desorption periods and the one adsorption period was one week each. Preliminary work indicated that for the specimen size used, most (probably 90 percent or more) of the weight and dimensional changes on desorption occur in the first 72 hours at low R.H. (25 percent) and the first 120 hours at 75 percent R.H. Helmuth and Turk* reported that almost all the shrinkage in cement paste slabs (0.5 to 3.0 mm thick, w/c = 0.6) occurred in one day of drying. It is felt, therefore, that the one week equilibration

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* Helmuth, R. A. and Turk, D., Jour. of the PCA Research and Development Labs, 9(2), pp 8-21 (1967).

periods for adsorption and desorption was satisfactory for establishing rates in the present program.

Two slab specimens of each cement were subjected to one of the three environmental situations described below:

| | |
|---|---|
| Environment I: | Initial Desorption at 75 RH/100 F (170 hours)<br>Adsorption at 100 RH/74 F (170 hours)<br>Final Desorption at 75 RH/74 F (170 hours) |
| Environment II: | Initial Desorption at 75 RH/74 F (170 hours)<br>Adsorption at 100 RH/74 F (170 hours)<br>Final Desorption at 75 RH/74 F (170 hours) |
| Environment III: | Initial Desorption at 25 RH/74 F (170 hours)<br>Adsorption at 100 RH/74 F (170 hours)<br>Final Desorption at 25 RH/74 F (170 hours). |

On the first day of the desorption or adsorption period, data were taken one-half hour after the start of the measurements, then at hourly intervals for the remainder of the work day. Following the first 24-hour period after start, data were taken twice daily until the final four days when one reading was taken.

The temperature and relative humidity of each environmental chamber was measured periodically. $CO_2$-free air at the same temperature and relative humidity as the environmental chambers was bubbled into the chambers at the rate of 25-30 cc/min, resulting in a complete change of air about every 4 hours. Electric timers are used to record elapsed time.

All of the data were transferred to a standard computer form for computer processing. The computer program was designed to provide:

(1) Tabular data showing elapsed time, weight change, and dimensional change

(2) Graphical data showing

  (a) Weight change (gram water lost or gained per gram of initial evaporable water) versus elapsed time

  (b) Dimensional change (strain) versus elapsed time

  (c) Weight change versus dimensional change.

## Statistical Procedures

The total weight change, total dimensional change, and rate of weight change data were subjected to statistical analyses using the method of simultaneous comparisons (Tukey) to determine significant differences in performance of the 32 cements. A description of the statistical procedure and the verification of the validity of the chosen procedure is presented in Appendix A.

## EXPERIMENTAL RESULTS

Property data obtained on the 32 cement pastes at the time of testing are presented in Table 3. A complete summary of the dimensional and weight change data is presented in Tables 4 through 12. The rate of weight change was calculated as a linear function between the time periods of 0-5, 5-10, 10-25, and 25-50 hours.

The ordered mean values of the total weight change, total dimensional change and rate of weight change (during the first 5 hours of adsorption or desorption) for the cement pastes subjected to the three environmental situations are presented in Tables 13 through 39. The calculated critical comparison differences (see Appendix A) for each situation are shown in the tables. The vertical lines in the tables connect cements for which no claim can be made as to any difference in their behavior.

For convenience in interpreting the data in Tables 13 through 39, Tables 40 through 44 were constructed to identify the cements within a given type which exhibited no statistically different behavior for the various conditions of exposure. Figures 4 through 35 show graphically the total weight change, total dimensional change, and rate of weight change of the 32 cements during the initial desorption, adsorption, and final desorption periods. Similar data obtained as the average values for the 6 different types of cements investigated are shown in Figures 36 through 40. The overall behavioral trends exhibited by the 6 types of cements are indicated in Table 45. Values of total weight and dimensional change and rate of initial weight change have been qualitatively rated as high, intermediate, and low for this purpose.

A primary objective of the Phase A investigation was to identify statistically significant differences in the moisture migration behavior of cement pastes whose only intended difference was in the source of the raw cement. The 32 pastes were, in most cases, cured to a maturity factor of 80±2 percent; had evaporable water contents ranging from 21.2 to 25.0 percent; total porosities ranging from 34.4 to 39.8 percent and bulk densities ranging from 1.93 to 2.09 gms/cc. The achievement of the stated objective presupposes that intrinsic features of the 32 cement pastes (e.g., pore-size distribution, morphology of hydration products, etc.) control to some degree the movement of evaporable water within the hardened paste.

It is evident from the data that the source of cement does influence the moisture migration behavior of hardened cement pastes including the total weight change, total dimensional change, and the rate of weight change exhibited by the hardened pastes during moisture adsorption and desorption periods.

## Type I Cements

Relative to the other cement types investigated, the Type I cements generally exhibited intermediate to low values of total weight change, intermediate to high values of total dimensional change, and intermediate to low values of the initial rate of weight change.

The seventeen Type I cements were further rated relative to each other to establish relative behavior of the Type I cements within the Type I classification. Rating values were again set at high, intermediate, and low. Thus, for a given set of environmental conditions (nine total), the first six highest values were classed as high, the next five as intermediate, and the last six as low. A cement showing a majority of values in the intermediate classification was given an intermediate rating and so on. The results of this analysis are shown below for the Type I cements.

## TYPE I CEMENTS
## RELATIVE BEHAVIOR

### TOTAL WEIGHT CHANGE

| | |
|---|---|
| High Values | Cements 2-7-9-18-22-71 |
| Intermediate Values | Cements 1-3-5-16-27 |
| Low Values | Cements 4-8-11-14-23-24 |

### TOTAL DIMENSIONAL CHANGE

| | |
|---|---|
| High Values | Cements 1-2-8-14-16-23-27 |
| Intermediate Values | Cements 3-5-7-22-24-71 |
| Low Values | Cements 4-9-11-18 |

### INITIAL RATE OF WEIGHT CHANGE

| | |
|---|---|
| High Values | Cements 1-2-3-5-9-18-22-71 |
| Intermediate Values | Cements 7-16-24-27 |
| Low Values | Cements 4-8-11-14-23 |

These results make it possible to identify the Type I cements which exhibited unique or similar behavior as shown below:

| | |
|---|---|
| High Total Weight Change<br>High Total Dimensional Change<br>High Initial Rate of Weight Change | Cement 2 |
| High Total Weight Change<br>Low Total Dimensional Change<br>High Initial Rate of Weight Change | Cements 9-18 |
| Low Total Weight Change<br>Low Total Dimensional Change<br>Low Initial Rate of Weight Change | Cements 4-11 |
| Low Total Weight Change<br>High Total Dimensional Change<br>Low Initial Rate of Weight Change | Cements 8-14-23 |
| Intermediate to High Total Weight Change<br>Intermediate to High Total Dimensional Change<br>Intermediate to High Initial Rate of Weight Change | Cements 1-3-5-7-16-22-27-71 |

| | |
|---|---|
| Intermediate to Low Total Weight Change<br>Intermediate to Low Total Dimensional Change<br>Intermediate to Low Initial Rate of Weight Change | Cement 24 |

Type II Cements

Relative to the other cement types investigated, the Type II cements generally exhibited intermediate to high values of total weight change, intermediate to low values of total dimensional change, and intermediate to high values of the initial rate of weight change.

The seven Type II cements were further rated relative only to each other to establish relative behavior of the Type II cements within the Type II classification. The rating system was the same as was described previously for the Type I cements (i.e., high, intermediate, and low values) and the results are shown below:

TYPE II CEMENTS
RELATIVE BEHAVIOR

TOTAL WEIGHT CHANGE

| | |
|---|---|
| High Values | Cement 12 |
| Intermediate Values | Cements 13-15-17-19 |
| Low Values | Cements 6-10 |

TOTAL DIMENSIONAL CHANGE

| | |
|---|---|
| High Values | Cements 10-19 |
| Intermediate Values | Cements 6-13-15-17 |
| Low Values | Cement 12 |

INITIAL RATE OF WEIGHT CHANGE

| | |
|---|---|
| High Values | Cements 12-17 |
| Intermediate Values | Cements 6-15-19 |
| Low Values | Cements 10-13 |

These results again make it possible to identify the Type II cements which exhibited singularly or collectively unique behavior as shown below:

| | |
|---|---|
| High Total Weight Change<br>High Total Dimensional Change<br>High Initial Rate of Weight Change | None |
| High Total Weight Change<br>Low Total Dimensional Change<br>High Initial Rate of Weight Change | Cement 12 |
| Low Total Weight Change<br>Low Total Dimensional Change<br>Low Initial Rate of Weight Change | None |
| Low Total Weight Change<br>High Total Dimensional Change<br>Low Initial Rate of Weight Change | Cement 10 |
| Intermediate to High Total Weight Change<br>Intermediate to High Total Dimensional Change<br>Intermediate to High Initial Rate of Weight Change | Cements 15-17-19 |
| Intermediate to Low Total Weight Change<br>Intermediate to Low Total Dimensional Change<br>Intermediate to High Initial Rate of Weight Change | Cements 6-13 |

Type III Cements

Relative to the other cement types, the three Type III cements investigated generally exhibited low values of total weight change, intermediate to high values of total dimensional change, and intermediate to low values of the initial rate of weight change.

The three Type III cements exhibited no significant difference in behavior over 50 percent of the time. However, Cement No. 25 generally had higher values of total weight change and lower values of total dimensional change relative to the other two Type III cements. Cement No. 26 had low values of total weight change and high values of total dimensional change relative to the other two Type III cements.

Type IV Cements

Relative to the other cement types, the two Type IV cements investigated generally exhibited intermediate values of total weight change, low values of dimensional change, and intermediate to low values of the initial rate of weight change.

The two Type IV cements exhibited no significant difference in behavior about 60 percent of the time.

The behavior of the two Type IV cements and the oil well cement (No. 74) was quite similar. The oil well cement (No. 74) and Type IV cement No. 70 exhibited no significant difference in behavior over 90 percent of the time.

Type V Cements

Relative to the other cement types investigated, the Type V cements generally exhibited high values of total weight change, low values of total dimensional change and high values of the initial rate of weight change.

The two Type V cements (Nos. 73 and 21) showed no significant difference in behavior relative to each other over 80 percent of the time. Cement No. 73, however, generally showed a higher total weight change and rate of initial weight change and a lower total dimensional change than Cement No. 21.

The graphical representation of the data in Figures 4 through 35 reveals an interesting behavioral characteristic exhibited by a number of the cements of all six types. This feature, illustrated by Cement No. 3 (I), Figure 6, is that the dimensional changes exhibited by the paste during exposure to Environment I are not much different from those associated with Environment II. That is, exposure to elevated temperatures (100 F) at 75 RH did not significantly increase the shrinkage of the paste relative to that occurring at 74 F and 75 RH. Cements which exhibited this behavioral pattern included six Type I's (Nos. 3, 4, 5, 9, 11, 14), three Type II's (Nos. 12, 13, 17), one Type III (No. 26), one Type IV (No. 70), one Type V (No. 73), and the oil well cement (No. 74).

## Selection of Cements for the Phase B Study

The data presented in this report establish that significant differences exist in the overall weight and dimensional change behavior of the six types of cements which was exhibited during the imposed adsorption-desorption periods. During a meeting between a Battelle representative and the Policy Committee sixteen cements were selected for further study in Phase B of the program.

(1) Cement No. 9(I) - This 20-year-old Type I behaved more like the Type II cements studied and is representative of the group of Type I cements exhibiting high values of total weight change and initial rate of weight change and low values of total dimensional change (Cements 9 and 18).

(2) Cement No. 14(I) - This cement is representative of the Type I cements exhibiting low values of total weight change and initial rate of weight change and high values of total dimensional change (Cements 8-23-14).

(3) Cement No. 2(I) - This cement is the only Type I cement which exhibited high values for total weight and dimensional change and initial rate of weight change.

(4) Cement No. 4(I) - This cement is representative of the Type I cements exhibiting low values of total weight and dimensional change and initial rate of weight change (Cements Nos. 4 and 11).

(5) Cement No. 27(I) - This Type I cement showed consistently high values of total dimensional change (relative to all cements investigated). The total weight loss on initial desorption was among the highest of all the Type I cements, yet the total weight loss on final desorption was among the lowest of all the Type I cements.

(6) Cement No. 23(I) - This cement exhibited about the same behavior as Cement No. 14(I) and was selected for comparative purposes.

(7) Cement No. 71(I) - This cement is representative of the Type I cements exhibiting intermediate to high values in all three property categories (Cements Nos. 1, 3, 5, 7, 16, 22, 27 and 71).

(8) Cement No. 24(I) - This cement was the only Type I falling into the intermediate to low value range in all three property categories.

(9) Cement No. 12(II) - This cement was the only Type II which exhibited high values of total weight change and initial rate of weight change and low values of total dimensional change.

(10) Cement No. 10(II) - This cement was the only Type II which exhibited low values of total weight change and initial rate of weight change and high values of total dimensional change.

(11) Cement No. 13(II) - This cement was chosen to represent the two Type II cements which exhibited intermediate to low values of total dimensional and weight change and intermediate to high values of initial rate of weight change (Cements Nos. 6 and 13).

(12) Cement No. 17(II) - This cement was chosen to represent the Type II cements which exhibited intermediate to high values in all three property categories (Cements Nos. 15, 17 and 19).

(13) Cement No. 25(III) - This cement was arbitrarily chosen to represent the three Type III cements investigated (Cements Nos. 20, 25, and 26).

(14) Cement No. 70(IV) - This cement was arbitrarily chosen to represent the two Type IV cements investigated (Nos. 70 and 72).

(15) Cement No. 21(V) - This cement was arbitrarily chosen to represent the two Type V cements investigated (Nos. 21 and 73).

(16) Cement No. 74(Oil Well) - This cement was chosen because of its unique chemical composition (zero $C_3A$ content).

The sixteen cements recommended for further investigation cover the the range of exhibited behavior of the thirty-two cements subjected to adsorption-desorption exposure periods. The moisture migration and freeze-thaw behavior of concretes made with these cements will be evaluated in Phase B of the research program as outlined in the work plan.

DRL:dlm
August, 1972

TABLE 1. IDENTIFICATION OF CEMENTS

| Cement Code No. | Type | Source | Cement Code No. | Type | Source |
|---|---|---|---|---|---|
| 1 | I | Iowa | 16 | I | Missouri |
| 2 | I | " | 17 | II | " |
| 3 | I | " | 18 | I | " |
| 4 | I-L | " | 19 | II | " |
| 5 | I | " | 20 | III | " |
| 6 | II | " | 21 | V | " |
| 7 | I | " | 22 | I | " |
| 8 | I | Kansas | 23 | I | " |
| 9 | I | Kansas | 24 | I | " |
| 10R | II | Missouri | 25 | III | BCL |
| 11 | I | Kansas | 26 | III | BCL |
| 12 | II | " | 27 | I | BCL |
| 13 | II | " | 70 | IV | Kansas |
| 14 | I | " | 71 | I | " |
| 15 | II | " | 72 | IV | " |
| | | | 73 | V | " |
| | | | 74 | Oil Well | " |

Type I Cements: 17
Type II Cements: 7
Type III Cements: 3
Type IV Cements: 2
Type V Cements: 2
Oil Well Cement: 1

TABLE 2. MEAN WEIGHT OF CEMENT PASTE SLAB SPECIMENS (1.0 x 5.0 x 0.1 INCH) AFTER DEMOLDING AND CUTTING (W/C = 0.45)

| Cement Code Number | Cement Type | Average Slab Weight[a], g | Standard Deviation, g |
|---|---|---|---|
| 16 | I | 17.16 | 0.12 |
| 17 | II | 17.08 | 0.12 |
| 20 | III | 16.98 | 0.11 |
| 25 | III | 17.20 | 0.15 |
| 21 | V | 16.59 | 0.23 |
| 10R | II | 17.16 | 0.14 |
| 9 | I | 16.54 | 0.19 |
| 74 | Oil Well | 17.34 | 0.13 |
| 70 | IV | 16.54 | 0.09 |
| 6 | II | 17.26 | 0.15 |
| 73 | V | 16.80 | 0.13 |
| 26 | III | 16.96 | 0.12 |
| 4 | II | 17.11 | 0.09 |
| 11 | I | 17.24 | 0.15 |
| 12 | II | 17.07 | 0.14 |
| 13 | II | 17.08 | 0.11 |
| 14 | I | 17.15 | 0.14 |
| 1 | I | 17.09 | 0.12 |
| 2 | I | 17.12 | 0.18 |
| 3 | I | 17.07 | 0.16 |
| 5 | I | 17.23 | 0.32 |
| 7 | I | 17.07 | 0.17 |
| 8 | I | 17.15 | 0.13 |
| 15 | II | 17.18 | 0.19 |
| 18 | I | 17.03 | 0.12 |
| 19 | II | 16.81 | 0.22 |
| 22 | I | 17.21 | 0.39 |
| 23 | I | 17.01 | 0.14 |
| 24 | I | 17.06 | 0.20 |
| 27 | I | 16.99 | 0.15 |
| 71 | I | 17.10 | 0.15 |
| 72 | IV | 17.40 | 0.16 |

(a) SSD weight obtained after demolding and cutting. Most of the Type II and Type IV cement slabs were allowed to cure in lime water for 2-3 weeks prior to cutting, hence the reported mean weight includes moisture gain during this curing period.

TABLE 3. CHARACTERIZATION OF CEMENT PASTES USED IN THE STUDY OF MOISTURE MIGRATION IN HARDENEDED CEMENT PASTES (PHASE A)

| Cement Code No. | Cement Type | Data Obtained at Time of Test | | | | | |
|---|---|---|---|---|---|---|---|
| | | Age, days | $w_{n/c}$, g/g | Maturity Factor percent | Bulk Density, g/cc | Total Porosity, percent | Total Evaporable $H_2O$, percent |
| 74 | O.W. | 98 | 0.168 | 81 | 1.97 | 0.380 | 22.8 |
| 21 | V | 128 | 0.167 | 78 | 2.00 | 0.386 | 21.3 |
| 73 | V | 146 | 0.152 | 80 | -- | -- | 23.5 |
| 6 | II | 98 | 0.160 | 75 | 1.95 | 0.387 | 23.1 |
| 12 | II | 105 | 0.162 | 80 | 2.00 | 0.393 | 24.4 |
| 13 | II | 108 | 0.167 | 81 | 1.97 | 0.380 | 23.7 |
| 4 | I | 87 | 0.179 | 85 | 1.96 | 0.361 | 23.3 |
| 11 | I | 92 | 0.192 | 90 | 1.95 | 0.344 | 22.5 |
| 14 | I | 80 | 0.170 | 82 | 1.95 | 0.373 | 23.1 |
| 26 | III | 84 | 0.180 | 82 | 1.95 | 0.360 | 23.7 |
| 17 | II | 119 | 0.168 | 81 | 1.96 | 0.382 | 24.0 |
| 3 | I | 62 | 0.184 | 83 | 1.95 | 0.358 | 22.6 |
| 70 | IV | 204 | 0.156 | 82 | 1.94 | 0.392 | 24.4 |
| 9 | I | 71 | 0.170 | 78 | 1.93 | 0.372 | 25.0 |
| 5 | I | 56 | 0.190 | 82 | 1.95 | 0.350 | 21.5 |
| 25 | III | 41 | 0.177 | 80 | 1.96 | 0.369 | 22.7 |
| 1 | I | 69 | 0.180 | 80 | 1.93 | 0.356 | 23.5 |
| 7 | I | 190 | 0.190 | 82 | 1.96 | 0.348 | 22.4 |
| 72 | IV | 190 | 0.154 | 79 | 1.97 | 0.398 | 24.1 |
| 8 | I | 91 | 0.187 | 81 | 2.00 | 0.359 | 22.4 |
| 2 | I | 119 | 0.176 | 78 | 2.09 | 0.391 | 24.1 |
| 15 | II | 125 | 0.164 | 82 | 2.02 | 0.394 | 24.0 |
| 22 | I | 93 | 0.182 | 80 | 1.96 | 0.350 | 23.6 |
| 18 | I | 109 | 0.172 | 78 | 1.96 | 0.372 | 23.9 |
| 23 | I | 110 | 0.177 | 80 | 1.99 | 0.371 | 23.6 |
| 27 | I | 30 | 0.180 | 82 | 1.95 | 0.363 | 22.9 |
| 19 | II | 201 | 0.175 | 80 | 1.99 | 0.374 | 23.9 |
| 20 | III | 38 | 0.185 | 82 | 1.97 | 0.356 | 23.1 |
| 24 | I | 40 | 0.176 | 78 | 1.99 | 0.372 | 23.9 |
| 71 | I | 40 | 0.187 | 85 | 1.95 | 0.350 | 23.5 |
| 16 | I | 40 | 0.182 | 83 | 1.94 | 0.356 | 24.0 |
| 10R | II | 104 | 0.177 | 85 | 1.96 | 0.365 | 24.4 |

AFTER 170 HOUR INITIAL DESORPTION PERIOD AT 75 RH/100 F

ENVIRONMENT I

| ement No. | | Total Weight Loss[a], $\Delta w/w_e$, g/g | Total Shrinkage Strain[a] ($\Delta L/L$) x $10^2$ | Ratio of Shrinkage to Weight Loss | Rate of Weight Loss for Indicated Period[a], g/g/hr | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | 0-5 hr | 5-10 hr | 10-25 hr | 25-50 h |
| I) | 1 | 0.262 | 0.429 | 1.64 | 0.028 | 0.007 | 0.002 | 0.001 |
| | 2 | 0.278 | 0.389 | 1.40 | 0.029 | 0.011 | 0.002 | 0.001 |
| | 3 | 0.259 | 0.248 | 0.96 | 0.028 | 0.009 | 0.002 | 0.001 |
| | 4 | 0.238 | 0.222 | 0.93 | 0.025 | 0.008 | 0.002 | 0.001 |
| | 5 | 0.280 | 0.271 | 0.97 | 0.027 | 0.007 | 0.003 | 0.001 |
| | 7 | 0.302 | 0.363 | 1.20 | 0.029 | 0.010 | 0.003 | 0.001 |
| | 8 | 0.241 | 0.355 | 1.47 | 0.024 | 0.008 | 0.003 | 0.001 |
| | 9 | 0.387 | 0.212 | 0.55 | 0.039 | 0.016 | 0.004 | 0.001 |
| | 11 | 0.191 | 0.226 | 1.18 | 0.016 | 0.007 | 0.002 | 0.001 |
| | 14 | 0.260 | 0.226 | 0.87 | 0.024 | 0.008 | 0.003 | 0.001 |
| | 16 | 0.288 | 0.432 | 1.50 | 0.032 | 0.009 | 0.002 | 0.007 |
| | 18 | 0.309 | 0.377 | 1.22 | 0.035 | 0.019 | 0.007 | 0.002 |
| | 22 | 0.294 | 0.367 | 1.25 | 0.028 | 0.012 | 0.003 | 0.001 |
| | 23 | 0.252 | 0.436 | 1.73 | 0.026 | 0.004 | 0.003 | 0.001 |
| | 24 | 0.279 | 0.383 | 1.37 | 0.028 | 0.009 | 0.003 | 0.001 |
| | 27 | 0.313 | 0.439 | 1.40 | 0.033 | 0.010 | 0.002 | 0.001 |
| | 71 | 0.320 | 0.500 | 1.56 | 0.035 | 0.006 | 0.003 | 0.001 |
| II) | 6 | 0.351 | 0.346 | 0.99 | 0.035 | 0.007 | 0.003 | 0.001 |
| | 10 | 0.244 | 0.492 | 2.02 | 0.024 | 0.008 | 0.003 | 0.001 |
| | 12 | 0.350 | 0.192 | 0.53 | 0.037 | 0.019 | 0.002 | 0.001 |
| | 13 | 0.308 | 0.189 | 0.61 | 0.027 | 0.011 | 0.003 | 0.001 |
| | 15 | 0.350 | 0.382 | 1.09 | 0.042 | 0.004 | 0.004 | 0.001 |
| | 17 | 0.324 | 0.207 | 0.64 | 0.042 | 0.004 | 0.003 | 0.001 |
| | 19 | 0.304 | 0.474 | 1.56 | 0.033 | 0.009 | 0.003 | 0.001 |
| III) | 20 | 0.237 | 0.482 | 2.03 | 0.025 | 0.007 | 0.002 | 0.001 |
| | 25 | 0.297 | 0.414 | 1.39 | 0.027 | 0.011 | 0.003 | 0.001 |
| | 26 | 0.194 | 0.300 | 1.55 | 0.021 | 0.008 | 0.002 | 0.001 |
| IV) | 70 | 0.323 | 0.194 | 0.60 | 0.025 | 0.014 | 0.004 | 0.001 |
| | 72 | 0.306 | 0.349 | 1.14 | 0.026 | 0.011 | 0.004 | 0.001 |
| V) | 21 | 0.355 | 0.402 | 1.13 | 0.039 | 0.008 | 0.003 | 0.001 |
| | 73 | 0.428 | 0.159 | 0.37 | 0.047 | 0.015 | 0.004 | 0.001 |
| O.W.) | 74 | 0.305 | 0.215 | 0.70 | 0.033 | 0.010 | 0.002 | 0.001 |

a) Average value (2 specimens for each cement).

HOUR ADSORPTION PERIOD AT 100 RH/74 F (INITIAL DESORPTION 75 RH/100 F)

ENVIRONMENT I

| ement No. | | Total Weight Gain[a], $\Delta w/w_e$, g/g | Total Expansion Strain[a], $(\Delta L/L) \times 10^2$ | Ratio of Expansion to Weight Gain | Rate of Weight Gain for Indicated Period[a], g/g/hr | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | 0-5 hr | 5-10 hr | 10-25 hr | 25-50 h |
| ype I | 1 | 0.208 | 0.314 | 1.51 | 0.012 | 0.006 | 0.003 | 0.002 |
| | 2 | 0.249 | 0.280 | 1.12 | 0.013 | 0.007 | 0.004 | 0.002 |
| | 3 | 0.213 | 0.070 | 0.33 | 0.013 | 0.004 | 0.003 | 0.002 |
| | 4 | 0.190 | 0.087 | 0.46 | 0.010 | 0.005 | 0.003 | 0.001 |
| | 5 | 0.219 | 0.137 | 0.63 | 0.013 | 0.003 | 0.004 | 0.002 |
| | 7 | 0.237 | 0.267 | 1.13 | 0.013 | 0.007 | 0.005 | 0.002 |
| | 8 | 0.201 | 0.298 | 1.48 | 0.011 | 0.005 | 0.003 | 0.001 |
| | 9 | 0.269 | 0.074 | 0.28 | 0.012 | 0.006 | 0.004 | 0.002 |
| | 11 | 0.212 | 0.146 | 0.69 | 0.011 | 0.005 | 0.003 | 0.002 |
| | 14 | 0.190 | 0.128 | 0.67 | 0.012 | 0.005 | 0.003 | 0.002 |
| | 16 | 0.201 | 0.306 | 0.52 | 0.011 | 0.005 | 0.003 | 0.001 |
| | 18 | 0.273 | 0.312 | 1.14 | 0.012 | 0.006 | 0.004 | 0.002 |
| | 22 | 0.260 | 0.272 | 1.04 | 0.014 | 0.007 | 0.004 | 0.002 |
| | 23 | 0.220 | 0.303 | 1.37 | 0.012 | 0.005 | 0.003 | 0.001 |
| | 24 | 0.232 | 0.281 | 1.21 | 0.012 | 0.007 | 0.005 | 0.002 |
| | 27 | 0.214 | 0.313 | 1.46 | 0.012 | 0.005 | 0.003 | 0.001 |
| | 71 | 0.256 | 0.283 | 1.11 | 0.012 | 0.005 | 0.004 | 0.002 |
| ype II | 6 | 0.232 | 0.216 | 0.93 | 0.013 | 0.005 | 0.004 | 0.002 |
| | 10 | 0.176 | 0.363 | 2.06 | 0.011 | 0.004 | 0.002 | 0.001 |
| | 12 | 0.306 | 0.070 | 0.23 | 0.014 | 0.008 | 0.005 | 0.002 |
| | 13 | 0.272 | 0.114 | 0.42 | 0.013 | 0.006 | 0.004 | 0.002 |
| | 15 | 0.286 | 0.316 | 1.10 | 0.013 | 0.006 | 0.004 | 0.002 |
| | 17 | 0.285 | 0.096 | 0.34 | 0.012 | 0.006 | 0.005 | 0.002 |
| | 19 | 0.242 | 0.289 | 1.19 | 0.013 | 0.006 | 0.004 | 0.002 |
| ype III | 20 | 0.199 | 0.294 | 1.48 | 0.011 | 0.004 | 0.002 | 0.002 |
| | 25 | 0.209 | 0.303 | 1.45 | 0.011 | 0.005 | 0.003 | 0.002 |
| | 26 | 0.177 | 0.137 | 0.77 | 0.012 | 0.005 | 0.002 | 0.001 |
| ype IV | 70 | 0.249 | 0.099 | 0.40 | 0.012 | 0.005 | 0.004 | 0.002 |
| | 72 | 0.270 | 0.273 | 1.01 | 0.012 | 0.007 | 0.004 | 0.002 |
| ype V | 21 | 0.290 | 0.253 | 0.87 | 0.010 | 0.010 | 0.004 | 0.001 |
| | 73 | 0.296 | 0.052 | 0.18 | 0.011 | 0.006 | 0.004 | 0.002 |
| ).W. | 74 | 0.249 | 0.113 | 0.45 | 0.012 | 0.003 | 0.005 | 0.002 |

(a) Average value (2 specimens for each cement).

FINAL DESORPTION PERIOD AT 75 RH/74 F (INITIAL DESORPTION AT 75 RH/100 F)

ENVIRONMENT I

| ement No. | | Total Weight Loss[a], $\Delta w/w_e$, g/g | Total Shrinkage Strain[a] $(\Delta L/L) \times 10^2$ | Ratio of Shrinkage to Weight Loss | Rate of Weight Loss for Indicated Period[a], g/g/hr | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | 0-5 hr | 5-10 hr | 10-25 hr | 25-50 h |
| ype I | 1 | 0.154 | -- | -- | 0.025 | 0.004 | 0.001 | 0.000 |
| | 2 | 0.194 | 0.121 | 0.62 | 0.024 | 0.008 | 0.002 | 0.000 |
| | 3 | 0.156 | 0.105 | 0.67 | 0.024 | 0.003 | 0.001 | 0.000 |
| | 4 | 0.136 | 0.093 | 0.68 | 0.021 | 0.003 | 0.001 | 0.000 |
| | 5 | 0.151 | 0.102 | 0.68 | 0.025 | 0.003 | 0.001 | 0.000 |
| | 7 | 0.182 | 0.085 | 0.47 | 0.024 | 0.006 | 0.001 | 0.000 |
| | 8 | 0.160 | 0.113 | 0.71 | 0.019 | 0.006 | 0.001 | 0.000 |
| | 9 | 0.207 | 0.100 | 0.48 | 0.030 | 0.008 | 0.001 | 0.000 |
| | 11 | 0.157 | 0.088 | 0.56 | 0.022 | 0.005 | 0.001 | 0.000 |
| | 14 | 0.160 | 0.119 | 0.74 | 0.025 | 0.004 | 0.000 | 0.000 |
| | 16 | 0.152 | 0.113 | 0.74 | 0.023 | 0.003 | 0.001 | 0.000 |
| | 18 | 0.221 | 0.102 | 0.46 | 0.029 | 0.009 | 0.001 | 0.000 |
| | 22 | 0.196 | 0.097 | 0.49 | 0.028 | 0.007 | 0.001 | 0.000 |
| | 23 | 0.161 | 0.109 | 0.68 | 0.024 | 0.005 | 0.001 | 0.000 |
| | 24 | 0.155 | 0.119 | 0.77 | 0.024 | 0.005 | 0.001 | 0.000 |
| | 27 | 0.140 | 0.111 | 0.79 | 0.024 | 0.002 | 0.001 | 0.000 |
| | 71 | 0.179 | 0.105 | 0.59 | 0.029 | 0.005 | 0.001 | 0.000 |
| ype II | 6 | 0.166 | 0.111 | 0.67 | 0.024 | 0.005 | 0.001 | 0.000 |
| | 10 | 0.139 | 0.125 | 0.90 | 0.023 | 0.002 | 0.000 | 0.000 |
| | 12 | 0.232 | 0.084 | 0.36 | 0.027 | 0.010 | 0.002 | 0.000 |
| | 13 | 0.221 | 0.102 | 0.46 | 0.020 | 0.014 | 0.002 | 0.000 |
| | 15 | 0.233 | 0.095 | 0.41 | 0.031 | 0.009 | 0.001 | 0.000 |
| | 17 | 0.222 | 0.089 | 0.40 | 0.029 | 0.009 | 0.002 | 0.000 |
| | 19 | 0.187 | 0.123 | 0.66 | 0.026 | 0.007 | 0.001 | 0.000 |
| ype III | 20 | 0.148 | 0.123 | 0.83 | 0.023 | 0.004 | 0.000 | 0.000 |
| | 25 | 0.150 | 0.103 | 0.69 | 0.023 | 0.003 | 0.001 | 0.000 |
| | 26 | 0.127 | 0.155 | 1.22 | 0.019 | 0.003 | 0.001 | 0.000 |
| ype IV | 70 | 0.208 | 0.123 | 0.59 | 0.026 | 0.008 | 0.001 | 0.000 |
| | 72 | 0.227 | 0.073 | 0.32 | 0.026 | 0.011 | 0.002 | 0.000 |
| ype V | 21 | 0.223 | 0.068 | 0.30 | 0.023 | 0.010 | 0.002 | 0.001 |
| | 73 | 0.240 | 0.066 | 0.28 | 0.030 | 0.011 | 0.002 | 0.000 |
| ).W. | 74 | 0.178 | 0.137 | 0.77 | 0.023 | 0.005 | 0.001 | 0.001 |

(a) Average value (2 specimens for each cement).

AFTER 170 HOUR INITIAL DESORPTION PERIOD AT 75 RH/74 F

ENVIRONMENT II

| ement No. | | Total Weight Loss[a], $\Delta w/w_e$, g/g | Total Shrinkage Strain[a] $(\Delta L/L) \times 10^2$ | Ratio of Shrinkage to Weight Loss | Rate of Weight Loss for Indicated Period[a], g/g/hr | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | 0-5 hr | 5-10 hr | 10-25 hr | 25-50 h |
| ype I | 1 | 0.175 | 0.198 | 1.13 | 0.019 | 0.006 | 0.002 | 0.001 |
| | 2 | 0.199 | 0.161 | 0.87 | 0.019 | 0.009 | 0.002 | 0.001 |
| | 3 | 0.175 | 0.194 | 1.11 | 0.017 | 0.005 | 0.002 | 0.001 |
| | 4 | 0.159 | 0.174 | 1.09 | 0.014 | 0.004 | 0.002 | 0.001 |
| | 5 | 0.159 | 0.195 | 1.23 | 0.014 | 0.003 | 0.002 | 0.001 |
| | 7 | 0.199 | 0.181 | 0.91 | 0.017 | 0.006 | 0.003 | 0.001 |
| | 8 | 0.146 | 0.105 | 0.72 | 0.013 | 0.005 | 0.002 | 0.001 |
| | 9 | 0.293 | 0.197 | 0.67 | 0.025 | 0.010 | 0.005 | 0.001 |
| | 11 | 0.127 | 0.182 | 1.43 | 0.011 | 0.004 | 0.002 | 0.001 |
| | 14 | 0.156 | 0.177 | 1.13 | 0.013 | 0.005 | 0.002 | 0.001 |
| | 16 | 0.180 | 0.203 | 1.12 | 0.016 | 0.006 | 0.003 | 0.001 |
| | 18 | 0.223 | 0.153 | 0.69 | | | | |
| | 22 | 0.187 | 0.163 | 0.87 | 0.019 | 0.007 | 0.002 | 0.001 |
| | 23 | 0.146 | 0.198 | 1.36 | 0.015 | 0.007 | 0.001 | 0.001 |
| | 24 | 0.193 | 0.191 | 0.99 | 0.018 | 0.007 | 0.002 | 0.001 |
| | 27 | 0.197 | 0.242 | 1.23 | 0.017 | 0.006 | 0.003 | 0.001 |
| | 71 | 0.199 | 0.217 | 1.09 | 0.018 | 0.007 | 0.002 | 0.000 |
| 'ype II | 6 | 0.242 | 0.143 | 0.59 | 0.027 | 0.012 | 0.001 | 0.000 |
| | 10 | 0.146 | 0.250 | 1.71 | 0.013 | 0.004 | 0.002 | 0.001 |
| | 12 | 0.273 | 0.154 | 0.56 | 0.022 | 0.010 | 0.004 | 0.001 |
| | 13 | 0.218 | 0.158 | 0.72 | 0.019 | 0.005 | 0.003 | 0.001 |
| | 15 | 0.238 | 0.154 | 0.65 | 0.021 | 0.007 | 0.004 | 0.001 |
| | 17 | 0.211 | 0.169 | 0.80 | 0.018 | 0.007 | 0.003 | 0.001 |
| | 19 | 0.197 | 0.139 | 0.71 | 0.024 | 0.006 | 0.002 | 0.000 |
| 'ype III | 20 | 0.150 | 0.200 | 1.33 | 0.015 | 0.005 | 0.002 | 0.000 |
| | 25 | 0.203 | 0.195 | 0.96 | 0.015 | 0.007 | 0.003 | 0.001 |
| | 26 | 0.102 | 0.264 | 2.59 | 0.011 | 0.002 | 0.001 | 0.000 |
| 'ype IV | 70 | 0.190 | 0.179 | 0.94 | 0.012 | 0.004 | 0.003 | 0.001 |
| | 72 | 0.210 | 0.148 | 0.70 | 0.016 | 0.007 | 0.003 | 0.001 |
| 'ype V | 21 | 0.255 | 0.182 | 0.71 | 0.025 | 0.009 | 0.003 | 0.001 |
| | 73 | 0.342 | 0.163 | 0.48 | 0.032 | 0.014 | 0.005 | 0.001 |
| ).W. | 74 | 0.197 | 0.184 | 0.93 | 0.023 | 0.005 | 0.001 | 0.001 |

(a) Average value (2 specimens for each cement).

ADSORPTION PERIOD AT 100 RH/74 F (INITIAL DESORPTION AT 75 RH/74 F)

ENVIRONMENT II

| nent No. | | Total Weight Gain[a], $\Delta w/w_e$, g/g | Total Expansion Strain[a] ($\Delta L/L$) x $10^2$ | Ratio of Expansion to Weight Gain | Rate of Weight Gain for Indicated Period[a], g/g/hr | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | 0-5 hr | 5-10 hr | 10-25 hr | 25-50 hr |
| pe I | 1 | 0.143 | 0.337 | 0.96 | 0.011 | 0.005 | 0.002 | 0.001 |
| | 2 | 0.180 | 0.110 | 0.61 | 0.011 | 0.005 | 0.003 | 0.001 |
| | 3 | 0.139 | 0.130 | 0.94 | 0.010 | 0.003 | 0.002 | 0.001 |
| | 4 | 0.135 | 0.096 | 0.71 | 0.009 | 0.003 | 0.002 | 0.001 |
| | 5 | 0.123 | 0.121 | 0.98 | 0.010 | 0.003 | 0.002 | 0.001 |
| | 7 | 0.172 | 0.138 | 0.80 | 0.010 | 0.005 | 0.003 | 0.002 |
| | 8 | 0.126 | 0.131 | 1.04 | 0.010 | 0.004 | 0.002 | 0.001 |
| | 9 | 0.197 | 0.104 | 0.53 | 0.010 | 0.004 | 0.003 | 0.001 |
| | 11 | 0.128 | 0.151 | 1.18 | 0.009 | 0.004 | 0.002 | 0.001 |
| | 14 | 0.118 | 0.159 | 1.35 | 0.008 | 0.004 | 0.002 | 0.001 |
| | 16 | 0.138 | 0.109 | 0.79 | 0.010 | 0.004 | 0.002 | 0.001 |
| | 18 | 0.206 | 0.115 | 0.56 | 0.011 | 0.005 | 0.004 | 0.001 |
| | 22 | 0.178 | 0.135 | 0.76 | 0.012 | 0.005 | 0.003 | 0.001 |
| | 23 | 0.127 | 0.114 | 0.90 | 0.010 | 0.004 | 0.002 | 0.001 |
| | 24 | 0.168 | 0.104 | 0.62 | 0.011 | 0.006 | 0.003 | 0.001 |
| | 27 | 0.143 | 0.156 | 1.09 | 0.009 | 0.004 | 0.002 | 0.001 |
| | 71 | 0.164 | 0.128 | 0.78 | 0.010 | 0.004 | 0.003 | 0.001 |
| pe II | 6 | 0.159 | 0.078 | 0.49 | 0.009 | 0.004 | 0.003 | 0.001 |
| | 10 | 0.114 | 0.171 | 1.50 | 0.009 | 0.003 | 0.002 | 0.001 |
| | 12 | 0.250 | 0.076 | 0.30 | 0.012 | 0.007 | 0.004 | 0.002 |
| | 13 | 0.199 | 0.130 | 0.65 | 0.010 | 0.005 | 0.003 | 0.001 |
| | 15 | 0.202 | 0.131 | 0.65 | 0.011 | 0.005 | 0.003 | 0.001 |
| | 17 | 0.191 | 0.130 | 0.68 | 0.011 | 0.005 | 0.004 | 0.001 |
| | 19 | 0.160 | 0.092 | 0.58 | 0.011 | 0.003 | 0.002 | 0.001 |
| pe III | 20 | 0.135 | 0.108 | 0.80 | 0.010 | 0.004 | 0.002 | 0.001 |
| | 25 | 0.142 | 0.139 | 0.98 | 0.009 | 0.003 | 0.002 | 0.001 |
| | 26 | 0.127 | 0.176 | 1.39 | 0.009 | 0.003 | 0.001 | 0.000 |
| pe IV | 70 | 0.151 | 0.140 | 0.93 | 0.009 | 0.004 | 0.002 | 0.001 |
| | 72 | 0.192 | 0.123 | 0.64 | 0.010 | 0.005 | 0.003 | 0.002 |
| pe V | 21 | 0.216 | 0.091 | 0.42 | 0.007 | 0.008 | 0.004 | 0.001 |
| | 73 | 0.233 | 0.085 | 0.36 | 0.011 | 0.010 | 0.002 | 0.001 |
| W. | 74 | 0.171 | 0.127 | 0.74 | 0.009 | 0.004 | 0.004 | 0.001 |

) Average value (2 specimens for each cement).

FINAL DESORPTION PERIOD AT 75 RH/74 F (INITIAL DESORPTION AT 74 RH/74 F)

ENVIRONMENT II

| ement No. | | Total Weight Loss[a], $\Delta w/w_e$, g/g | Total Shrinkage Strain[a] ($\Delta L/L$) x $10^2$ | Ratio of Shrinkage to Weight Loss | Rate of Weight Loss for Indicated Period[a], g/g/hr | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | 0-5 hr | 5-10 hr | 10-25 hr | 25-50 h |
| ype I | 1 | 0.132 | -- | -- | 0.019 | 0.003 | 0.001 | 0.000 |
| | 2 | 0.173 | 0.139 | 0.80 | 0.020 | 0.006 | 0.002 | 0.000 |
| | 3 | 0.133 | 0.141 | 1.06 | 0.020 | 0.003 | 0.000 | 0.000 |
| | 4 | 0.128 | 0.100 | 0.78 | 0.018 | 0.002 | 0.001 | 0.000 |
| | 5 | 0.109 | 0.119 | 1.09 | 0.015 | 0.003 | 0.000 | 0.000 |
| | 7 | 0.162 | 0.126 | 0.78 | 0.018 | 0.006 | 0.002 | 0.000 |
| | 8 | 0.122 | 0.142 | 1.16 | 0.015 | 0.003 | 0.001 | 0.000 |
| | 9 | 0.180 | 0.135 | 0.75 | 0.024 | 0.008 | 0.001 | 0.000 |
| | 11 | 0.120 | 0.111 | 0.93 | 0.017 | 0.003 | 0.001 | 0.000 |
| | 14 | 0.118 | 0.144 | 1.22 | 0.018 | 0.002 | 0.000 | 0.000 |
| | 16 | 0.132 | 0.132 | 1.00 | 0.019 | 0.002 | 0.001 | 0.000 |
| | 18 | 0.199 | 0.107 | 0.54 | 0.024 | 0.007 | 0.002 | 0.000 |
| | 22 | 0.164 | 0.127 | 0.77 | 0.021 | 0.005 | 0.001 | 0.000 |
| | 23 | 0.116 | 0.119 | 1.03 | 0.016 | 0.003 | 0.001 | 0.000 |
| | 24 | 0.142 | 0.129 | 0.91 | 0.020 | 0.004 | 0.001 | 0.000 |
| | 27 | 0.124 | 0.151 | 1.21 | 0.019 | 0.002 | 0.001 | 0.000 |
| | 71 | 0.150 | 0.142 | 0.94 | 0.022 | 0.003 | 0.001 | 0.000 |
| ype II | 6 | 0.140 | 0.128 | 0.91 | 0.020 | 0.003 | 0.001 | 0.000 |
| | 10 | 0.109 | 0.167 | 1.53 | 0.017 | 0.002 | 0.000 | 0.000 |
| | 12 | 0.244 | 0.101 | 0.41 | 0.026 | 0.009 | 0.003 | 0.000 |
| | 13 | 0.194 | 0.122 | 0.63 | 0.020 | 0.008 | 0.002 | 0.000 |
| | 15 | 0.195 | 0.093 | 0.48 | 0.018 | 0.007 | 0.003 | 0.001 |
| | 17 | 0.186 | 0.119 | 0.64 | 0.021 | 0.007 | 0.002 | 0.000 |
| | 19 | 0.153 | 0.141 | 0.92 | 0.022 | 0.004 | 0.001 | 0.000 |
| ype III | 20 | 0.126 | 0.136 | 1.08 | 0.018 | 0.005 | 0.000 | 0.000 |
| | 25 | 0.132 | 0.112 | 0.85 | 0.018 | 0.003 | 0.001 | 0.000 |
| | 26 | 0.091 | 0.201 | 2.21 | 0.012 | 0.002 | 0.001 | 0.000 |
| ype IV | 70 | 0.156 | 0.162 | 1.04 | 0.021 | 0.005 | 0.001 | 0.000 |
| | 72 | 0.198 | 0.115 | 0.58 | 0.020 | 0.008 | 0.002 | 0.001 |
| ype V | 21 | 0.195 | 1.104 | 0.53 | 0.017 | 0.008 | 0.003 | 0.001 |
| | 73 | 0.225 | 0.099 | 0.69 | 0.025 | 0.010 | 0.003 | 0.000 |
| .W. | 74 | 0.143 | 0.154 | 1.08 | 0.017 | 0.004 | 0.001 | 0.001 |

a) Average value (2 specimens for each cement).

AFTER 170 HOUR INITIAL DESORPTION PERIOD AT 25 RH/74 F

ENVIRONMENT III

| ement No. | | Total Weight Loss[a], $\Delta w/w_e$, g/g | Total Shrinkage Strain[a] ($\Delta L/L$) x $10^2$ | Ratio of Shrinkage to Weight Loss | Rate of Weight Loss for Indicated Percent[a], g/g/hr | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | 0-5 hr | 5-10 hr | 10-25 hr | 25-50 h |
| ype I | 1 | 0.645 | 0.615 | 0.95 | 0.072 | 0.018 | 0.007 | 0.002 |
| | 2 | 0.628 | 0.553 | 0.88 | 0.070 | 0.017 | 0.007 | 0.002 |
| | 3 | 0.640 | 0.728 | 1.14 | 0.075 | 0.011 | 0.006 | 0.003 |
| | 4 | 0.589 | 0.522 | 0.89 | 0.057 | 0.014 | 0.005 | 0.003 |
| | 5 | 0.648 | 0.586 | 0.90 | 0.065 | 0.015 | 0.007 | 0.003 |
| | 7 | 0.650 | 0.485 | 0.75 | 0.069 | 0.017 | 0.007 | 0.003 |
| | 8 | 0.639 | 0.542 | 0.85 | 0.070 | 0.017 | 0.008 | 0.002 |
| | 9 | 0.703 | 0.521 | 0.74 | 0.081 | 0.022 | 0.007 | 0.002 |
| | 11 | 0.545 | 0.543 | 1.00 | 0.046 | 0.016 | 0.006 | 0.002 |
| | 16 | 0.652 | 0.654 | 1.00 | 0.069 | 0.016 | 0.007 | 0.003 |
| | 18 | 0.640 | 0.455 | 0.71 | 0.071 | 0.017 | 0.007 | 0.002 |
| | 22 | 0.630 | 0.518 | 0.82 | 0.069 | 0.017 | 0.006 | 0.002 |
| | 23 | 0.613 | 0.643 | 1.05 | 0.080 | 0.020 | 0.003 | 0.001 |
| | 24 | 0.623 | 0.480 | 0.77 | 0.065 | 0.018 | 0.006 | 0.003 |
| | 27 | 0.670 | 0.654 | 0.98 | 0.070 | 0.019 | 0.007 | 0.003 |
| | 71 | 0.637 | 0.526 | 0.83 | 0.071 | 0.017 | 0.006 | 0.002 |
| ype II | 6 | 0.647 | 0.331 | 0.51 | 0.068 | 0.019 | 0.006 | 0.003 |
| | 10 | 0.643 | 0.726 | 1.13 | 0.065 | 0.017 | 0.008 | 0.003 |
| | 12 | 0.673 | 0.442 | 0.66 | 0.069 | 0.018 | 0.006 | 0.003 |
| | 13 | 0.633 | 0.526 | 0.83 | 0.065 | 0.015 | 0.007 | 0.003 |
| | 15 | 0.645 | 0.474 | 0.73 | 0.070 | 0.019 | 0.007 | 0.002 |
| | 17 | 0.626 | 0.516 | 0.82 | 0.065 | 0.018 | 0.006 | 0.003 |
| | 19 | 0.700 | 0.659 | 0.94 | 0.082 | 0.019 | 0.007 | 0.002 |
| ype III | 20 | 0.617 | 0.586 | 0.95 | 0.059 | 0.014 | 0.007 | 0.003 |
| | 25 | 0.636 | 0.517 | 0.81 | 0.072 | 0.013 | 0.007 | 0.003 |
| | 26 | 0.611 | 0.684 | 1.12 | 0.057 | 0.019 | 0.007 | 0.003 |
| ype IV | 70 | 0.670 | 0.512 | 0.76 | 0.066 | 0.021 | 0.008 | 0.003 |
| | 72 | | | | 0.056 | 0.018 | 0.007 | 0.003 |
| ype V | 21 | 0.679 | 0.491 | 0.72 | 0.073 | 0.019 | 0.006 | 0.003 |
| | 73 | 0.723 | 0.410 | 0.57 | 0.086 | 0.022 | 0.006 | 0.002 |
| .W. | 74 | 0.638 | 0.531 | 0.83 | 0.066 | 0.016 | 0.006 | 0.003 |

a) Average value (2 specimens for each cement).

ADSORPTION PERIOD AT 100 RH/74 F (INITIAL DESORPTION AT 25 RH/74 F)

ENVIRONMENT III

| ement No. | | Total Weight Gain[a], $\Delta w/w_e$, g/g | Total Expansion Strain[a] ($\Delta L/L$) x $10^2$ | Ratio of Expansion to Weight Gain | Rate of Weight Gain for Indicated Period[a], g/g/hr | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | 0-5 hr | 5-10 hr | 10-25 hr | 25-50 h |
| ype I | 1 | 0.584 | 0.373 | 0.64 | 0.027 | 0.019 | 0.011 | 0.005 |
| | 2 | 0.571 | 0.376 | 0.66 | 0.021 | 0.013 | 0.011 | 0.006 |
| | 3 | 0.569 | 0.354 | 0.62 | 0.026 | 0.015 | 0.013 | 0.004 |
| | 4 | 0.537 | 0.360 | 0.67 | 0.018 | 0.014 | 0.012 | 0.005 |
| | 5 | 0.600 | 0.367 | 0.61 | 0.029 | 0.017 | 0.013 | 0.004 |
| | 7 | 0.586 | 0.326 | 0.56 | 0.024 | 0.014 | 0.012 | 0.005 |
| | 8 | 0.587 | 0.372 | 0.63 | 0.025 | 0.015 | 0.013 | 0.005 |
| | 9 | 0.616 | 0.254 | 0.41 | 0.033 | 0.015 | 0.010 | 0.004 |
| | 11 | 0.582 | 0.380 | 0.65 | 0.020 | 0.014 | 0.010 | 0.007 |
| | 14 | 0.541 | 0.390 | 0.72 | 0.028 | 0.017 | 0.011 | 0.004 |
| | 16 | 0.566 | 0.340 | 0.60 | 0.023 | 0.013 | 0.012 | 0.004 |
| | 18 | 0.591 | 0.306 | 0.52 | 0.024 | 0.012 | 0.010 | 0.006 |
| | 22 | 0.591 | 0.320 | 0.54 | 0.023 | 0.013 | 0.011 | 0.006 |
| | 23 | 0.572 | 0.377 | 0.66 | 0.023 | 0.012 | 0.010 | 0.007 |
| | 24 | 0.567 | 0.303 | 0.53 | 0.020 | 0.012 | 0.010 | 0.008 |
| | 27 | 0.577 | 0.330 | 0.57 | 0.024 | 0.014 | 0.012 | 0.005 |
| | 71 | 0.560 | 0.322 | 0.58 | 0.022 | 0.012 | 0.011 | 0.005 |
| ype II | 6 | 0.547 | 0.163 | 0.30 | 0.020 | 0.014 | 0.012 | 0.005 |
| | 10 | 0.574 | 0.413 | 0.72 | 0.024 | 0.013 | 0.012 | 0.005 |
| | 12 | 0.621 | 0.288 | 0.46 | 0.021 | 0.014 | 0.011 | 0.006 |
| | 13 | 0.596 | 0.342 | 0.57 | 0.020 | 0.014 | 0.011 | 0.005 |
| | 15 | 0.586 | 0.307 | 0.52 | 0.021 | 0.013 | 0.011 | 0.005 |
| | 17 | 0.598 | 0.365 | 0.61 | 0.021 | 0.014 | 0.012 | 0.005 |
| | 19 | 0.611 | 0.329 | 0.54 | 0.023 | 0.013 | 0.002 | 0.006 |
| ype III | 20 | 0.580 | 0.329 | 0.57 | 0.018 | 0.011 | 0.011 | 0.007 |
| | 25 | 0.564 | 0.345 | 0.61 | 0.020 | 0.014 | 0.012 | 0.005 |
| | 26 | 0.590 | 0.438 | 0.74 | 0.022 | 0.015 | 0.013 | 0.005 |
| ype IV | 70 | 0.600 | 0.355 | 0.59 | 0.030 | 0.016 | 0.012 | 0.004 |
| | 72 | 0.578 | 0.318 | 0.55 | 0.017 | 0.013 | 0.010 | 0.006 |
| ype V | 21 | 0.620 | 0.318 | 0.51 | 0.017 | 0.017 | 0.013 | 0.006 |
| | 73 | 0.579 | 0.262 | 0.45 | 0.021 | 0.014 | 0.010 | 0.005 |
| .W. | 74 | 0.580 | 0.344 | 0.59 | 0.021 | 0.015 | 0.012 | 0.005 |

(a) Average value (2 specimens for each cement).

FINAL DESORPTION PERIOD AT 25 RH/74 F (INITIAL DESORPTION AT 25 RH/74 F)

ENVIRONMENT III

| ement No. | | Total Weight Loss[a], $\Delta w/w_e$, g/g | Total Shrinkage Strain[a] ($\Delta L/L$) x $10^2$ | Ratio of Shrinkage to Weight Loss | Rate of Weight Loss for Indicated Period[a], g/g/hr | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | 0-5 hr | 5-10 hr | 10-25 hr | 10-25 h |
| ype I | 1 | 0.562 | -- | -- | 0.068 | 0.014 | 0.005 | 0.002 |
| | 2 | 0.537 | 0.332 | 0.62 | 0.058 | 0.012 | 0.005 | 0.002 |
| | 3 | 0.552 | 0.370 | 0.67 | 0.064 | 0.012 | 0.006 | 0.002 |
| | 4 | 0.521 | 0.350 | 0.67 | 0.056 | 0.011 | 0.004 | 0.002 |
| | 5 | 0.562 | 0.340 | 0.60 | 0.064 | 0.013 | 0.005 | 0.002 |
| | 7 | 0.543 | 0.283 | 0.52 | 0.063 | 0.013 | 0.004 | 0.002 |
| | 8 | 0.524 | 0.293 | 0.56 | 0.049 | 0.013 | 0.005 | 0.002 |
| | 9 | 0.560 | 0.264 | 0.47 | 0.072 | 0.013 | 0.005 | 0.002 |
| | 11 | 0.547 | 0.314 | 0.57 | 0.065 | 0.014 | 0.004 | 0.002 |
| | 14 | 0.502 | 0.389 | 0.78 | 0.057 | 0.014 | 0.003 | 0.002 |
| | 16 | 0.539 | 0.361 | 0.67 | 0.063 | 0.012 | 0.005 | 0.003 |
| | 18 | 0.555 | 0.310 | 0.56 | 0.067 | 0.013 | 0.005 | 0.002 |
| | 22 | 0.554 | 0.332 | 0.60 | 0.064 | 0.013 | 0.005 | 0.002 |
| | 23 | 0.532 | 0.398 | 0.75 | 0.060 | 0.013 | 0.005 | 0.002 |
| | 24 | 0.513 | 0.359 | 0.70 | 0.062 | 0.012 | 0.005 | 0.002 |
| | 27 | 0.526 | 0.354 | 0.67 | 0.060 | 0.012 | 0.006 | 0.002 |
| | 71 | 0.528 | 0.302 | 0.57 | 0.067 | 0.012 | 0.005 | 0.002 |
| ype II | 6 | 0.513 | 0.252 | 0.49 | 0.057 | 0.012 | 0.005 | 0.002 |
| | 10 | 0.532 | 0.432 | 0.81 | 0.060 | 0.012 | 0.005 | 0.002 |
| | 12 | 0.569 | 0.259 | 0.46 | 0.062 | 0.014 | 0.005 | 0.002 |
| | 13 | 0.535 | 0.296 | 0.55 | 0.053 | 0.014 | 0.005 | 0.002 |
| | 15 | 0.554 | 0.289 | 0.52 | 0.065 | 0.012 | 0.004 | 0.002 |
| | 17 | 0.571 | 0.338 | 0.59 | 0.067 | 0.013 | 0.004 | 0.002 |
| | 19 | 0.586 | 0.354 | 0.60 | 0.077 | 0.014 | 0.005 | 0.002 |
| ype III | 20 | 0.537 | 0.419 | 0.78 | 0.060 | 0.016 | 0.005 | 0.002 |
| | 25 | 0.521 | 0.300 | 0.58 | 0.052 | 0.011 | 0.005 | 0.002 |
| | 26 | 0.546 | 0.456 | 0.84 | 0.056 | 0.015 | 0.005 | 0.002 |
| ype IV | 70 | 0.487 | 0.303 | 0.62 | 0.041 | 0.011 | 0.005 | 0.002 |
| | 72 | 0.542 | -- | -- | 0.058 | 0.015 | 0.005 | 0.002 |
| ype V | 21 | 0.549 | 0.297 | 0.54 | 0.055 | 0.016 | 0.005 | 0.002 |
| | 73 | 0.549 | 0.217 | 0.40 | 0.068 | 0.014 | 0.004 | 0.002 |
| .W. | 74 | 0.496 | 0.339 | 0.69 | 0.051 | 0.011 | 0.004 | 0.002 |

a) Average value (2 specimens for each cement).

TABLE 13. IDENTIFICATION OF SIGNIFICANT DIFFERENCES IN CEMENT BEHAVIOR BASED ON THE METHOD OF SIMULTANEOUS COMPARISONS[a]

ORDERED MEANS TOT WGT LOSS[b] ENV I. INITIAL DES

| CEMENT NO | MEAN | SPECS |
|---|---|---|
| 11(I) | 0.191 | |
| 26(III) | 0.194 | |
| 20(III) | 0.237 | |
| 4(I) | 0.238 | |
| 8(I) | 0.241 | |
| 10(II) | 0.244 | |
| 23(I) | 0.252 | |
| 3(I) | 0.259 | |
| 14(I) | 0.260 | |
| 1(I) | 0.262 | |
| 2(I) | 0.278 | |
| 24(I) | 0.279 | |
| 5(I) | 0.280 | |
| 16(I) | 0.288 | |
| 22(I) | 0.296 | |
| 25(III) | 0.296 | |
| 7(I) | 0.302 | |
| 19(II) | 0.304 | |
| 72(IV) | 0.305 | |
| 74(OW) | 0.306 | |
| 13(II) | 0.308 | |
| 18(I) | 0.309 | |
| 27(I) | 0.313 | |
| 71(I) | 0.320 | |
| 70(IV) | 0.323 | |
| 17(II) | 0.324 | |
| 15(II) | 0.350 | |
| 6(II) | 0.351 | |
| 21(V) | 0.355 | |
| 12(II) | 0.360 | |
| 9(I) | 0.387 | |
| 73(V) | 0.428 | |

| | |
|---|---|
| SUM = | 18.8880000000 |
| SUM2 = | 5.7511940000 |
| A4 = | 5.7400370000 |
| A5 = | 5.5743210000 |
| SS3 = | 0.1657160000 |
| SS = | 0.1768730000 |
| SS2 = | 0.0111570000 |
| SS3* = | 0.0053456774 |
| SS2* = | 0.0003486562 |
| SS* = | 0.0028075079 |
| FRATIO= | 15.3322268630 |
| CRITICAL DIFF = | 0.0785598590 |

(a) Vertical lines connect cements for which no claim can be made as to any difference in their behavior.

TABLE 14. IDENTIFICATION OF SIGNIFICANT DIFFERENCES IN CEMENT BEHAVIOR BASED ON THE METHOD OF SIMULTANEOUS COMPARISONS[a]

ORDERED MEANS TOT WGT LOSS[b] ENV II. INITIAL DES

| CEMENT NO | MEAN | SPECS |
|---|---|---|
| 26(III) | 0.103 | |
| 11(I) | 0.127 | |
| 8(I) | 0.145 | |
| 10(II) | 0.146 | |
| 23(I) | 0.146 | |
| 20(III) | 0.151 | |
| 14(I) | 0.157 | |
| 5(I) | 0.159 | |
| 4(I) | 0.159 | |
| 3(I) | 0.175 | |
| 1(I) | 0.175 | |
| 16(I) | 0.181 | |
| 22(I) | 0.188 | |
| 70(IV) | 0.189 | |
| 24(I) | 0.194 | |
| 27(I) | 0.197 | |
| 74(OW) | 0.197 | |
| 19(II) | 0.197 | |
| 2(I) | 0.199 | |
| 7(I) | 0.199 | |
| 71(I) | 0.199 | |
| 25(III) | 0.203 | |
| 72(IV) | 0.210 | |
| 17(II) | 0.211 | |
| 13(II) | 0.218 | |
| 18(I) | 0.223 | |
| 15(II) | 0.239 | |
| 6(II) | 0.242 | |
| 21(V) | 0.255 | |
| 12(II) | 0.273 | |
| 9(I) | 0.293 | |
| 73(V) | 0.342 | |

SUM = 12.5880000000
SUM2 = 2.6287500000
A4 = 2.6247490000
A5 = 2.4759022500
SS3 = 0.1488467500
SS = 0.1528477500
SS2 = 0.0040010000
SS3* = 0.0048015081
SS2* = 0.0001250312
SS* = 0.0024261548
FRAT10= 38.4024639012
CRITICAL DIFF = 0.0470447597

(a) Vertical lines connect cements for which no claim can be made as to any difference in their behavior.

(b) GM/GM.

TABLE 15. IDENTIFICATION OF SIGNIFICANT DIFFERENCES IN CEMENT BEHAVIOR BASED ON THE METHOD OF SIMULTANEOUS COMPARISONS[a]

ORDERED MEANS TOTAL WEIGHT LOSS[b] ENVIR. III. INITIAL DESORPTION

| CEMENT NO | MEAN |
|---|---|
| 11(I) | 0.540 |
| 4(I) | 0.589 |
| 72(IV) | 0.609 |
| 26(III) | 0.611 |
| 23(I) | 0.613 |
| 14(I) | 0.615 |
| 20(III) | 0.617 |
| 24(I) | 0.625 |
| 17(II) | 0.626 |
| 2(I) | 0.628 |
| 22(I) | 0.630 |
| 13(II) | 0.633 |
| 25(III) | 0.636 |
| 71(I) | 0.637 |
| 74(OW) | 0.638 |
| 8(I) | 0.639 |
| 18(I) | 0.640 |
| 3(I) | 0.640 |
| 1(II) | 0.643 |
| 1(I) | 0.645 |
| 15(II) | 0.645 |
| 6(II) | 0.647 |
| 5(I) | 0.648 |
| 7(I) | 0.65[illegible] |
| 16(I) | 0.652 |
| 70(IV) | 0.670 |
| 27(I) | 0.671 |
| 12(II) | 0.673 |
| 21(V) | 0.68[illegible] |
| 19(II) | 0.700 |
| 9(I) | 0.703 |
| 73(V) | 0.723 |

SUM = 41.0500000000
SUM2 = 26.419632[illegible]
A4 = 26.4066[illegible]2 000
A5 = 26.337424 000
SS3 = 0.07[illegible]573 000
SS = 0.0822[illegible] 000
SS2 = 0.011[illegible] 000
SS3* = 0.0[illegible]27[illegible]97
SS2* = 0.0[illegible]3034375
SS* = 0.013 [illegible]
FRATIO= 6.2643774454
CRITICAL DIFF = 0.0802278428

(a) Vertical lines connect cements for which no claim can be made as to any difference in their behavior.

(b) GM/GM.

TABLE 16. IDENTIFICATION OF SIGNIFICANT DIFFERENCES IN CEMENT BEHAVIOR BASED ON THE METHOD OF SIMULTANEOUS COMPARISONS[a]

ORDERED MEANS TOT WGT GAIN[b] ENVIR I. ADSORPTION

| CEMENT NO | MEAN | SPECS |
|---|---|---|
| 10(II) | 0.176 | |
| 26(III) | 0.177 | |
| 14(I) | 0.190 | |
| 4(I) | 0.191 | |
| 20(III) | 0.199 | |
| 16(I) | 0.201 | |
| 8(I) | 0.202 | |
| 1(I) | 0.208 | |
| 25(III) | 0.209 | |
| 11(I) | 0.212 | |
| 3(I) | 0.213 | |
| 27(I) | 0.215 | |
| 5(I) | 0.219 | |
| 23(I) | 0.229 | |
| 6(II) | 0.232 | |
| 24(I) | 0.232 | |
| 7(I) | 0.237 | |
| 19(II) | 0.242 | |
| 2(I) | 0.249 | |
| 70(IV) | 0.249 | |
| 74(OW) | 0.250 | |
| 71(I) | 0.256 | |
| 22(I) | 0.260 | |
| 9(I) | 0.269 | |
| 72(IV) | 0.270 | |
| 13(II) | 0.272 | |
| 18(I) | 0.273 | |
| 17(II) | 0.285 | |
| 15(II) | 0.286 | |
| 21(V) | 0.290 | |
| 73(V) | 0.296 | |
| 12(II) | 0.306 | |

SUM = 15.1780000000
SUM2 = 3.6883085000
A4 = 3.6826910000
A5 = 3.5995575625
SS3 = 0.0831334375
SS = 0.0887504375
SS2 = 0.0056170000
SS3* = 0.0026817238
SS2* = 0.0001755312
SS* = 0.0014087371
FRATIO= 15.2777577399
CRITICAL DIFF = 0.0557415692

(a) Vertical lines connect cements for which no claim can be made as to any difference in their behavior.

(b) GM/GM.

TABLE 17. IDENTIFICATION OF SIGNIFICANT DIFFERENCES IN CEMENT BEHAVIOR BASED ON THE METHOD OF SIMULTANEOUS COMPARISONS[a]

ORDERED MEANS TOT WGT GAIN[b] ENVIR II. ADSORP.

| CEMENT NO | MEAN | SPECS |
|---|---|---|
| 10(II) | 0.115 | |
| 14(I) | 0.118 | |
| 5(I) | 0.123 | |
| 8(I) | 0.126 | |
| 26(III) | 0.127 | |
| 23(I) | 0.127 | |
| 11(I) | 0.128 | |
| 4(I) | 0.135 | |
| 20(III) | 0.135 | |
| 16(I) | 0.137 | |
| 3(I) | 0.139 | |
| 25(III) | 0.142 | |
| 1(I) | 0.143 | |
| 27(I) | 0.143 | |
| 70(IV) | 0.151 | |
| 6(II) | 0.159 | |
| 19(II) | 0.160 | |
| 71(I) | 0.163 | |
| 24(I) | 0.168 | |
| 74(OW) | 0.171 | |
| 7(I) | 0.172 | |
| 22(I) | 0.178 | |
| 2(I) | 0.180 | |
| 17(II) | 0.191 | |
| 72(IV) | 0.192 | |
| 9(I) | 0.197 | |
| 13(II) | 0.199 | |
| 15(II) | 0.202 | |
| 18(I) | 0.206 | |
| 21(V) | 0.216 | |
| 73(V) | 0.234 | |
| 12(II) | 0.250 | |

SUM = 10.4630000000
SUM2 = 1.7910915000
A4 = 1.7882535000
A5 = 1.7105370156
SS3 = 0.0777164844
SS = 0.0805539844
SS2 = 0.0028375000
SS3* = 0.0025069834
SS2* = 0.0000886719
SS* = 0.0012786347
FRAT10= 28.2725877512
CRITICAL DIFF = 0.0396782159

(a) Vertical lines connect cements for which no claim can be made as to any difference in their behavior.

(b) GM/GM.

TABLE 18. IDENTIFICATION OF SIGNIFICANT DIFFERENCES IN CEMENT BEHAVIOR BASED ON THE METHOD OF SIMULTANEOUS COMPARISONS[a]

ORDERED MEANS TOT WGT GAIN[b] ENV III. ADSORP

| CEMENT NO | MEAN | SPECS |
|---|---|---|
| 4(I) | 0.538 | |
| 14(I) | 0.541 | |
| 6(II) | 0.547 | |
| 71(I) | 0.560 | |
| 25(III) | 0.564 | |
| 16(I) | 0.566 | |
| 24(I) | 0.567 | |
| 3(I) | 0.569 | |
| 23(I) | 0.572 | |
| 10(II) | 0.574 | |
| 27(I) | 0.577 | |
| 72(IV) | 0.578 | |
| 73(V) | 0.578 | |
| 2(I) | 0.578 | |
| 20(III) | 0.580 | |
| 74(OW) | 0.580 | |
| 11(I) | 0.582 | |
| 1(I) | 0.583 | |
| 7(I) | 0.587 | |
| 15(II) | 0.587 | |
| 8(I) | 0.587 | |
| 26(III) | 0.590 | |
| 18(I) | 0.591 | |
| 22(I) | 0.591 | |
| 13(II) | 0.596 | |
| 17(II) | 0.598 | |
| 70(IV) | 0.600 | |
| 5(I) | 0.600 | |
| 19(II) | 0.611 | |
| 9(I) | 0.617 | |
| 21(V) | 0.620 | |
| 12(II) | 0.621 | |

SUM = 37.2690005000
SUM2 = 21.7382835000
A4 = 21.7288235000
A5 = 21.7027868906
SS3 = 0.0260166094
SS = 0.0354961694
SS2 = 0.0094795000
SS3* = 0.0008392455
SS2* = 0.0002962344
SS* = 0.0005634303
FRATIO= 2.8330455027
CRITICAL DIFF = 0.0724135259

(a) Vertical lines connect cements for which no claim can be made as to any difference in their behavior.

(b) GM/GM.

TABLE 19. IDENTIFICATION OF SIGNIFICANT DIFFERENCES IN CEMENT BEHAVIOR BASED ON THE METHOD OF SIMULTANEOUS COMPARISONS[a]

ORDERED MEANS TOT WGT LOSS[b] ENV I FINAL DESORP

| CEMENT NO | MEAN | SPECS |
|---|---|---|
| 26(III) | 0.127 | |
| 4(I) | 0.136 | |
| 10(II) | 0.139 | |
| 27(I) | 0.140 | |
| 20(III) | 0.148 | |
| 25(III) | 0.150 | |
| 5(I) | 0.151 | |
| 16(I) | 0.152 | |
| 1(I) | 0.154 | |
| 24(I) | 0.155 | |
| 3(I) | 0.156 | |
| 11(I) | 0.157 | |
| 8(I) | 0.160 | |
| 14(I) | 0.160 | |
| 23(I) | 0.162 | |
| 6(II) | 0.166 | |
| 74(OW) | 0.178 | |
| 71(I) | 0.179 | |
| 7(I) | 0.182 | |
| 19(II) | 0.187 | |
| 2(I) | 0.194 | |
| 22(I) | 0.196 | |
| 9(I) | 0.207 | |
| 70(IV) | 0.208 | |
| 18(I) | 0.221 | |
| 13(II) | 0.221 | |
| 17(II) | 0.222 | |
| 21(V) | 0.223 | |
| 72(IV) | 0.227 | |
| 12(II) | 0.232 | |
| 15(II) | 0.233 | |
| 73(V) | 0.240 | |

SUM = 11.5350000000
SUM2 = 2.1525330000
A4 = 2.1500085000
A5 = 2.0790035156
SS3 = 0.0710049844
SS = 0.0735294844
SS2 = 0.0025245000
SS3* = 0.0022904834
SS2* = 0.0000788906
SS* = 0.0011671347
FRAT10= 29.0336572567
CRITICAL DIFF = 0.0373692745

(a) Vertical lines connect cements for which no claim can be made as to any difference in their behavior.

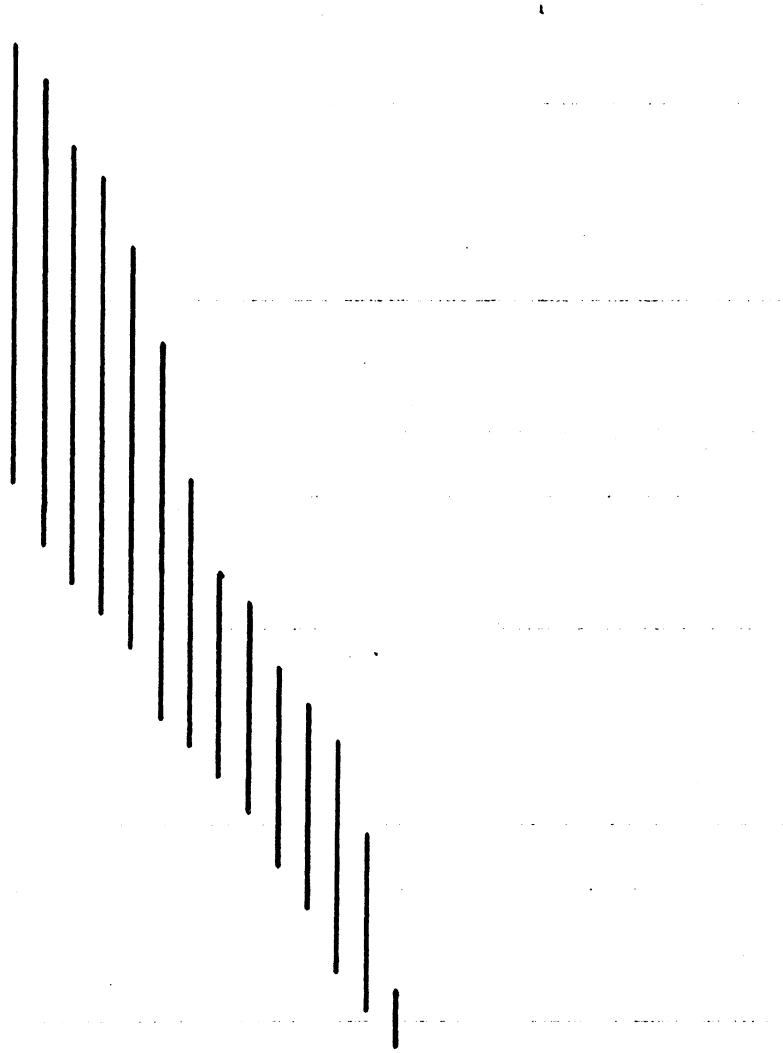
(b) GM/GM.

TABLE 20. [illegible]
ON THE METHOD OF SIMULTANEOUS COMPARISONS[a]

ORDERED MEANS TOT WGT LOSS[b] ENV II FINAL DESOR

| CEMENT NO | MEAN |
|---|---|
| 26(III) | 0.091 |
| 5(I) | 0.109 |
| 10(II) | 0.110 |
| 23(I) | 0.116 |
| 14(I) | 0.119 |
| 11(I) | 0.120 |
| 8(I) | 0.121 |
| 27(I) | 0.123 |
| 20(III) | 0.126 |
| 4(I) | 0.128 |
| 16(I) | 0.132 |
| 25(III) | 0.132 |
| 1(I) | 0.132 |
| 3(I) | 0.133 |
| 6(II) | 0.140 |
| 24(I) | 0.143 |
| 74(OW) | 0.143 |
| 71(I) | 0.151 |
| 19(II) | 0.153 |
| 70(IV) | 0.156 |
| 7(I) | 0.162 |
| 22(I) | 0.164 |
| 2(I) | 0.173 |
| 9(I) | 0.180 |
| 17(II) | 0.186 |
| 13(II) | 0.194 |
| 15(II) | 0.195 |
| 21(V) | 0.196 |
| 72(IV) | 0.198 |
| 18(I) | 0.199 |
| 73(V) | 0.225 |
| 12(II) | 0.244 |

SPECS



SUM = 9.7910000000
SUM2 = 1.5836630000
A4 = 1.5816385000
A5 = 1.4978700156
SS3 = 0.0837684844
SS = 0.0857929844
SS2 = 0.0020245000
SS3* = 0.0027022092
SS2* = 0.0000632656
SS* = 0.0013617934
FRAT10= 42.7121232654
CRITICAL DIFF = 0.0334646178

---

(a) Vertical lines connect cements for which no claim can be made as to any difference in their behavior.

(b) GM/GM.

TABLE 21. IDENTIFICATION OF SIGNIFICANT DIFFERENCES IN CEMENT BEHAVIOR BASED ON THE METHOD OF SIMULTANEOUS COMPARISONS[a]

ORDERED MEANS TOTAL WGT LOSS[b] ENV III FINAL DES

| CEMENT NO | MEAN | SPECS |
|---|---|---|
| 70(IV) | 0.487 | |
| 74(OW) | 0.496 | |
| 14(I) | 0.502 | |
| 24(I) | 0.513 | |
| 6(II) | 0.514 | |
| 25(III) | 0.521 | |
| 4(I) | 0.521 | |
| 8(I) | 0.524 | |
| 27(I) | 0.526 | |
| 71(I) | 0.529 | |
| 10(II) | 0.532 | |
| 23(I) | 0.532 | |
| 13(II) | 0.535 | |
| 20(III) | 0.536 | |
| 2(I) | 0.537 | |
| 16(I) | 0.538 | |
| 72(IV) | 0.543 | |
| 7(I) | 0.543 | |
| 26(III) | 0.546 | |
| 11(I) | 0.547 | |
| 73(V) | 0.549 | |
| 21(V) | 0.549 | |
| 3(I) | 0.552 | |
| 15(II) | 0.554 | |
| 22(I) | 0.554 | |
| 18(I) | 0.555 | |
| 9(I) | 0.560 | |
| 1(I) | 0.562 | |
| 5(I) | 0.563 | |
| 12(II) | 0.569 | |
| 17(II) | 0.570 | |
| 19(II) | 0.586 | |

SUM = 34.4960000000
SUM2 = 18.6299260000
A4 = 18.6240110000
A5 = 18.5933440000
SS3 = 0.0306670000
SS = 0.0365820000
SS2 = 0.0059150000
SS3* = 0.0009892581
SS2* = 0.0001848437
SS* = 0.0005806667
FRATIO= 5.3518610433
CRITICAL DIFF = 0.0572010964

(a) Vertical lines connect cements for which no claim can be made as to any difference in their behavior.

(b) GM/GM.

TABLE 22. IDENTIFICATION OF SIGNIFICANT DIFFERENCES IN CEMENT BEHAVIOR BASED ON THE METHOD OF SIMULTANEOUS COMPARISONS[a]

ORDERED MEANS TOT SHRINKAGE[b] EN I INITIAL DES.

| CEMENT NO | MEAN | SPECS |
|---|---|---|
| 73(V) | 0.159 | |
| 13(II) | 0.188 | |
| 12(II) | 0.192 | |
| 70(IV) | 0.194 | |
| 17(II) | 0.207 | |
| 9(I) | 0.212 | |
| 74(OW) | 0.215 | |
| 4(I) | 0.222 | |
| 14(I) | 0.225 | |
| 11(I) | 0.226 | |
| 3(I) | 0.248 | |
| 5(I) | 0.271 | |
| 26(III) | 0.300 | |
| 6(II) | 0.346 | |
| 72(IV) | 0.350 | |
| 8(I) | 0.355 | |
| 7(I) | 0.363 | |
| 22(I) | 0.367 | |
| 18(I) | 0.377 | |
| 15(II) | 0.382 | |
| 24(I) | 0.383 | |
| 2(I) | 0.389 | |
| 21(V) | 0.402 | |
| 25(III) | 0.414 | |
| 1(I) | 0.429 | |
| 16(I) | 0.432 | |
| 23(I) | 0.436 | |
| 27(I) | 0.439 | |
| 19(II) | 0.474 | |
| 20(III) | 0.482 | |
| 10(II) | 0.492 | |
| 71(I) | 0.500 | |

SUM = 21.3560000000
SUM2 = 7.8233640000
A4 = 7.8118720000
A5 = 7.1262302500
SS3 = 0.6856417500
SS = 0.6971337500
SS2 = 0.0114920000
SS3* = 0.0221174758
SS2* = 0.0003591250
SS* = 0.0110656151
FRATIO= 61.5871237227
CRITICAL DIFF = 0.0797305550

a) Vertical lines connect cements for which no claim can be made as to any difference in their behavior.

b) Strain x $10^2$.

TABLE 23. IDENTIFICATION OF SIGNIFICANT DIFFERENCES IN CEMENT BEHAVIOR BASED ON THE METHOD OF SIMULTANEOUS COMPARISONS[a]

ORDERED MEANS TOT SHRINKAGE[b] ENV II INITIAL DES

| CEMENT NO | MEAN | SPECS |
|---|---|---|
| 19(II) | 0.139 | |
| 8(I) | 0.143 | |
| 72(IV) | 0.148 | |
| 18(I) | 0.154 | |
| 15(II) | 0.154 | |
| 12(II) | 0.154 | |
| 13(II) | 0.158 | |
| 2(I) | 0.162 | |
| 22(I) | 0.163 | |
| 73(V) | 0.163 | |
| 17(II) | 0.169 | |
| 4(I) | 0.175 | |
| 14(I) | 0.177 | |
| 70(IV) | 0.179 | |
| 7(I) | 0.181 | |
| 6(II) | 0.181 | |
| 21(V) | 0.182 | |
| 11(I) | 0.182 | |
| 74(OW) | 0.184 | |
| 24(I) | 0.191 | |
| 5(I) | 0.195 | |
| 25(III) | 0.195 | |
| 3(I) | 0.195 | |
| 9(I) | 0.197 | |
| 23(I) | 0.198 | |
| 1(I) | 0.198 | |
| 20(III) | 0.200 | |
| 16(I) | 0.204 | |
| 71(I) | 0.218 | |
| 27(I) | 0.242 | |
| 10(II) | 0.250 | |
| 26(III) | 0.264 | |

SUM = 11.7920000000
SUM2 = 2.2363900000
A4 = 2.2268720000
A5 = 2.1726760000
SS3 = 0.0541960000
SS = 0.0637140000
SS2 = 0.0095180000
SS3* = 0.0017482581
SS2* = 0.0002974375
SS* = 0.0010113333
FRAT10= 5.8777325137
CRITICAL DIFF = 0.0725604269

(a) Vertical lines connect cements for which no claim can be made as to any difference in their behavior.

(b) Strain x $10^2$.

TABLE 24. IDENTIFICATION OF SIGNIFICANT DIFFERENCES IN CEMENT BEHAVIOR BASED ON THE METHOD OF SIMULTANEOUS COMPARISONS[a]

ORDERED MEANS TOT SHRINKAGE[b] ENV III INITIAL D

| CEMENT NO | MEAN | SPECS |
|---|---|---|
| 6(II) | 0.331 | |
| 72(IV) | 0.386 | |
| 73(V) | 0.410 | |
| 12(II) | 0.422 | |
| 18(I) | 0.456 | |
| 15(II) | 0.474 | |
| 24(I) | 0.481 | |
| 7(I) | 0.485 | |
| 21(V) | 0.492 | |
| 70(IV) | 0.512 | |
| 14(I) | 0.515 | |
| 17(II) | 0.516 | |
| 25(III) | 0.517 | |
| 22(I) | 0.518 | |
| 9(I) | 0.521 | |
| 4(I) | 0.522 | |
| 71(I) | 0.526 | |
| 13(II) | 0.526 | |
| 74(OW) | 0.531 | |
| 8(I) | 0.542 | |
| 11(I) | 0.543 | |
| 2(I) | 0.553 | |
| 5(I) | 0.586 | |
| 20(III) | 0.587 | |
| 1(I) | 0.615 | |
| 23(I) | 0.643 | |
| 27(I) | 0.654 | |
| 16(I) | 0.654 | |
| 19(II) | 0.659 | |
| 26(III) | 0.684 | |
| 10(II) | 0.726 | |
| 3(I) | 0.738 | |

SUM = 34.6550000000
SUM2 = 19.3547750000
A4 = 19.3211555000
A5 = 18.7651410156
SS3 = 0.5560144844
SS = 0.5896339844
SS2 = 0.0336195000
SS3* = 0.0179359511
SS2* = 0.0010506094
SS* = 0.0093592696
FRATIO= 17.0719503712
CRITICAL DIFF = 0.1363711817

(a) Vertical lines connect cements for which no claim can be made as to any difference in their behavior.

(b) Strain x $10^2$.

TABLE 25. IDENTIFICATION OF SIGNIFICANT DIFFERENCES IN CEMENT BEHAVIOR BASED ON THE METHOD OF SIMULTANEOUS COMPARISONS[a]

ORDERED MEANS TOT EXPANSION[b] ENV I ADSORPTION

| CEMENT NO | MEAN | SPECS |
|---|---|---|
| 73(V) | 0.052 | |
| 3(I) | 0.070 | |
| 12(II) | 0.070 | |
| 9(I) | 0.075 | |
| 4(I) | 0.087 | |
| 17(II) | 0.096 | |
| 70(IV) | 0.099 | |
| 74(OW) | 0.113 | |
| 13(II) | 0.114 | |
| 14(I) | 0.128 | |
| 26(III) | 0.137 | |
| 5(I) | 0.137 | |
| 11(I) | 0.146 | |
| 6(II) | 0.216 | |
| 21(V) | 0.253 | |
| 7(I) | 0.267 | |
| 22(I) | 0.272 | |
| 72(IV) | 0.274 | |
| 2(I) | 0.280 | |
| 24(I) | 0.281 | |
| 71(I) | 0.284 | |
| 19(II) | 0.290 | |
| 20(III) | 0.294 | |
| 8(I) | 0.298 | |
| 23(I) | 0.303 | |
| 25(III) | 0.303 | |
| 16(I) | 0.306 | |
| 18(I) | 0.312 | |
| 27(I) | 0.313 | |
| 1(I) | 0.314 | |
| 15(II) | 0.316 | |
| 10(II) | 0.364 | |

SUM = 13.7310000000
SUM2 = 3.5703350000
A4 = 3.5559205000
A5 = 2.9459431406
SS3 = 0.6099773594
SS = 0.6243918594
SS2 = 0.0144145000
SS3* = 0.0196766890
SS2* = 0.0004504531
SS* = 0.0099109819
FRAT10= 43.6819902455
CRITICAL DIFF = 0.0892949236

(a) Vertical lines connect cements for which no claim can be made as to any difference in their behavior.

(b) Strain x $10^2$.

TABLE 26. IDENTIFICATION OF SIGNIFICANT DIFFERENCES IN CEMENT BEHAVIOR BASED ON THE METHOD OF SIMULTANEOUS COMPARISONS[a]

ORDERED MEANS TOT EXPANSION[b] ENV II ADSORPTION

| CEMENT NO | MEAN | SPECS |
|---|---|---|
| 12(II) | 0.075 | |
| 6(II) | 0.077 | |
| 73(V) | 0.085 | |
| 21(V) | 0.091 | |
| 19(II) | 0.092 | |
| 4(I) | 0.099 | |
| 24(I) | 0.104 | |
| 9(I) | 0.104 | |
| 20(III) | 0.108 | |
| 16(I) | 0.109 | |
| 2(I) | 0.111 | |
| 23(I) | 0.114 | |
| 5(I) | 0.121 | |
| 72(IV) | 0.123 | |
| 74(OW) | 0.127 | |
| 71(I) | 0.128 | |
| 13(II) | 0.130 | |
| 15(II) | 0.130 | |
| 17(II) | 0.130 | |
| 3(I) | 0.130 | |
| 8(I) | 0.131 | |
| 22(I) | 0.135 | |
| 18(I) | 0.135 | |
| 1(I) | 0.137 | |
| 7(I) | 0.138 | |
| 25(III) | 0.139 | |
| 70(IV) | 0.140 | |
| 11(I) | 0.151 | |
| 27(I) | 0.156 | |
| 14(I) | 0.159 | |
| 10(II) | 0.171 | |
| 26(III) | 0.176 | |

SUM = 7.9260000000
SUM2 = 1.0279620000
A4 = 1.0208160000
A5 = 0.9815855625
SS3 = 0.0392304375
SS = 0.0463764375
SS2 = 0.0071460000
SS3* = 0.0012654980
SS2* = 0.0002233125
SS* = 0.0007361339
FRATIO= 5.6669375153
CRITICAL DIFF = 0.0628721750

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(a) Vertical lines connect cements for which no claim can be made as to any difference in their behavior.

(b) Strain x $10^2$.

TABLE 27. IDENTIFICATION OF SIGNIFICANT DIFFERENCES IN CEMENT BEHAVIOR BASED ON THE METHOD OF SIMULTANEOUS COMPARISONS[a]

ORDERED MEANS TOT EXPANSION[b] ENV III ADSORPTION

| CEMENT NO | MEAN | SPECS |
|---|---|---|
| 6(II) | 0.163 | |
| 9(I) | 0.254 | |
| 73(V) | 0.262 | |
| 12(II) | 0.288 | |
| 24(I) | 0.303 | |
| 18(I) | 0.306 | |
| 15(II) | 0.307 | |
| 21(V) | 0.318 | |
| 72(IV) | 0.318 | |
| 22(I) | 0.320 | |
| 71(I) | 0.322 | |
| 7(I) | 0.326 | |
| 19(II) | 0.329 | |
| 20(III) | 0.329 | |
| 27(I) | 0.330 | |
| 16(I) | 0.341 | |
| 13(II) | 0.342 | |
| 74(OW) | 0.345 | |
| 25(III) | 0.345 | |
| 3(I) | 0.354 | |
| 70(IV) | 0.355 | |
| 4(I) | 0.360 | |
| 17(II) | 0.365 | |
| 5(I) | 0.367 | |
| 8(I) | 0.372 | |
| 1(I) | 0.373 | |
| 2(I) | 0.375 | |
| 23(I) | 0.377 | |
| 11(I) | 0.380 | |
| 14(I) | 0.390 | |
| 10(II) | 0.413 | |
| 26(III) | 0.438 | |

SUM = 21.5470000000
SUM2 = 7.4201390000
A4 = 7.4119955000
A5 = 7.2542688906
SS3 = 0.1577266094
SS = 0.1658701094
SS2 = 0.0081435000
SS3* = 0.0050879551
SS2* = 0.0002544844
SS* = 0.0026328589
FRAT10= 19.9931926721
CRITICAL DIFF = 0.0671169989

(a) Vertical lines connect cements for which no claim can be made as to any difference in their behavior.

(b) Strain x $10^2$.

TABLE 28. IDENTIFICATION OF SIGNIFICANT DIFFERENCES IN CEMENT BEHAVIOR BASED ON THE METHOD OF SIMULTANEOUS COMPARISONS[a]

ORDERED MEANS TOT SHRINK[b] ENV I FINAL DESORP.

| CEMENT NO | MEAN | SPECS |
|---|---|---|
| 73(V) | 0.066 | |
| 21(V) | 0.068 | |
| 72(IV) | 0.073 | |
| 12(II) | 0.084 | |
| 7(I) | 0.085 | |
| 11(I) | 0.088 | |
| 17(II) | 0.089 | |
| 4(I) | 0.094 | |
| 15(II) | 0.095 | |
| 22(I) | 0.098 | |
| 9(I) | 0.100 | |
| 13(II) | 0.101 | |
| 5(I) | 0.102 | |
| 18(I) | 0.103 | |
| 25(III) | 0.103 | |
| 3(I) | 0.105 | |
| 71(I) | 0.106 | |
| 23(I) | 0.109 | |
| 1(I) | 0.110 | |
| 6(II) | 0.111 | |
| 27(I) | 0.111 | |
| 8(I) | 0.113 | |
| 16(I) | 0.114 | |
| 14(I) | 0.119 | |
| 24(I) | 0.119 | |
| 2(I) | 0.122 | |
| 19(II) | 0.123 | |
| 20(III) | 0.123 | |
| 70(IV) | 0.123 | |
| 10(II) | 0.124 | |
| 74(OW) | 0.138 | |
| 26(III) | 0.155 | |

SUM = 6.7510000000
SUM2 = 0.7414890000
A4 = 0.7350725000
A5 = 0.7121250156
SS3 = 0.0229474844
SS = 0.0293639844
SS2 = 0.0064165000
SS3* = 0.0007402414
SS2* = 0.0002005156
SS* = 0.0004660950
FRAT10= 3.6916895202
CRITICAL DIFF = 0.0595766498

(a) Vertical lines connect cements for which no claim can be made as to any difference in their behavior.

(b) Strain x $10^2$.

TABLE 29. IDENTIFICATION OF SIGNIFICANT DIFFERENCES IN CEMENT BEHAVIOR BASED ON THE METHOD OF SIMULTANEOUS COMPARISONS[a]

ORDERED MEANS TOT SHRINK[b] ENV II FINAL DESORP.

| CEMENT NO | MEAN | SPECS |
|---|---|---|
| 15(II) | 0.094 | |
| 73(V) | 0.099 | |
| 4(I) | 0.100 | |
| 12(II) | 0.101 | |
| 21(V) | 0.103 | |
| 18(I) | 0.107 | |
| 11(I) | 0.111 | |
| 25(III) | 0.112 | |
| 72(IV) | 0.115 | |
| 5(I) | 0.119 | |
| 17(II) | 0.119 | |
| 23(I) | 0.119 | |
| 1(I) | 0.120 | |
| 13(II) | 0.122 | |
| 7(I) | 0.127 | |
| 22(I) | 0.127 | |
| 6(II) | 0.128 | |
| 24(I) | 0.129 | |
| 16(I) | 0.132 | |
| 9(I) | 0.135 | |
| 20(III) | 0.136 | |
| 2(I) | 0.138 | |
| 19(II) | 0.141 | |
| 3(I) | 0.141 | |
| 71(I) | 0.143 | |
| 8(I) | 0.143 | |
| 14(I) | 0.144 | |
| 27(I) | 0.151 | |
| 74(OW) | 0.154 | |
| 70(IV) | 0.161 | |
| 10(II) | 0.167 | |
| 26(III) | 0.202 | |

SUM = 8.2880000000
SUM2 = 1.1099740000
A4 = 1.1054990000
A5 = 1.0732960000
SS3 = 0.0322030000
SS = 0.0366780000
SS2 = 0.0044750000
SS3* = 0.0010388065
SS2* = 0.0001398437
SS* = 0.0005821905
FRATIO= 7.4283366373
CRITICAL DIFF = 0.0497534841

a) Vertical lines connect cements for which no claim can be made as to any difference in their behavior.

b) Strain x $10^2$.

TABLE 30. IDENTIFICATION OF SIGNIFICANT DIFFERENCES IN CEMENT BEHAVIOR BASED ON THE METHOD OF SIMULTANEOUS COMPARISONS[a]

ORDERED MEANS TOT SHRINK[b] ENV III FINAL DESORP.

| CEMENT NO | MEAN | SPECS |
|---|---|---|
| 1(I) | 0.000 | |
| 73(V) | 0.217 | |
| 6(II) | 0.252 | |
| 12(II) | 0.259 | |
| 9(I) | 0.264 | |
| 7(I) | 0.283 | |
| 72(IV) | 0.284 | |
| 15(II) | 0.290 | |
| 8(I) | 0.293 | |
| 13(II) | 0.296 | |
| 21(V) | 0.297 | |
| 25(III) | 0.300 | |
| 71(I) | 0.302 | |
| 70(IV) | 0.303 | |
| 18(I) | 0.310 | |
| 11(I) | 0.314 | |
| 22(I) | 0.332 | |
| 2(I) | 0.332 | |
| 17(II) | 0.338 | |
| 74(OW) | 0.339 | |
| 5(I) | 0.341 | |
| 4(I) | 0.351 | |
| 19(II) | 0.354 | |
| 27(I) | 0.354 | |
| 24(I) | 0.358 | |
| 16(I) | 0.361 | |
| 3(I) | 0.370 | |
| 14(I) | 0.389 | |
| 23(I) | 0.398 | |
| 20(III) | 0.419 | |
| 10(II) | 0.432 | |
| 26(III) | 0.447 | |

SUM = 20.3630000000
SUM2 = 6.8712630000
A4 = 6.8605045000
A5 = 6.4789338906
SS3 = 0.3815706094
SS = 0.3923291094
SS2 = 0.0107585000
SS3* = 0.0123087293
SS2* = 0.0003362031
SS* = 0.0062274462
FRAT10= 36.6109902609
CRITICAL DIFF = 0.0771441220

(a) Vertical lines connect cements for which no claim can be made as to any difference in their behavior.

(b) Strain x $10^2$.

TABLE 31. IDENTIFICATION OF SIGNIFICANT DIFFERENCES IN CEMENT BEHAVIOR BASED ON THE METHOD OF SIMULTANEOUS COMPARISONS[a]

ORDERED MEANS RATE[b] WGT LOSS ENV I INITIAL DES.

| CEMENT NO | MEAN | SPECS |
|---|---|---|
| 11(I) | 0.016 | |
| 26(III) | 0.020 | |
| 10(II) | 0.023 | |
| 14(I) | 0.024 | |
| 8(I) | 0.024 | |
| 20(III) | 0.024 | |
| 70(IV) | 0.024 | |
| 4(I) | 0.025 | |
| 72(IV) | 0.026 | |
| 23(I) | 0.026 | |
| 5(I) | 0.026 | |
| 25(III) | 0.027 | |
| 13(II) | 0.027 | |
| 22(I) | 0.028 | |
| 1(I) | 0.028 | |
| 3(I) | 0.028 | |
| 2(I) | 0.028 | |
| 24(I) | 0.028 | |
| 7(I) | 0.028 | |
| 16(I) | 0.031 | |
| 19(II) | 0.032 | |
| 27(I) | 0.033 | |
| 74(OW) | 0.033 | |
| 18(I) | 0.035 | |
| 71(I) | 0.035 | |
| 6(II) | 0.035 | |
| 12(II) | 0.037 | |
| 9(I) | 0.039 | |
| 21(V) | 0.039 | |
| 17(II) | 0.042 | |
| 15(II) | 0.042 | |
| 73(V) | 0.047 | |

SUM = 1.9360000000
SUM2 = 0.0617360000
A4 = 0.0615560000
A5 = 0.0585640000
SS3 = 0.0029920000
SS = 0.0031720000
SS2 = 0.0001800000
SS3* = 0.0000965161
SS2* = 0.0000056250
SS* = 0.0000503492
FRAT10= 17.1584229392
CRITICAL DIFF = 0.0099784533

(a) Vertical lines connect cements for which no claim can be made as to any difference in their behavior.

(b) Strain x $10^2$.

TABLE 32. IDENTIFICATION OF SIGNIFICANT DIFFERENCES IN CEMENT BEHAVIOR BASED ON THE METHOD OF SIMULTANEOUS COMPARISONS[a]

ORDERED MEANS RATE[b] WGT LOSS EN II INITIAL DES.

| CEMENT NO | MEAN | SPECS |
|---|---|---|
| 18(I) | 0.000 | |
| 26(III) | 0.011 | |
| 11(I) | 0.011 | |
| 70(IV) | 0.012 | |
| 10(II) | 0.013 | |
| 8(I) | 0.013 | |
| 14(I) | 0.013 | |
| 4(I) | 0.014 | |
| 5(I) | 0.015 | |
| 20(III) | 0.015 | |
| 23(I) | 0.015 | |
| 25(III) | 0.015 | |
| 16(I) | 0.016 | |
| 72(IV) | 0.016 | |
| 3(I) | 0.016 | |
| 7(I) | 0.017 | |
| 27(I) | 0.017 | |
| 24(I) | 0.018 | |
| 17(II) | 0.018 | |
| 71(I) | 0.018 | |
| 22(I) | 0.018 | |
| 1(I) | 0.019 | |
| 13(II) | 0.019 | |
| 2(I) | 0.019 | |
| 15(II) | 0.021 | |
| 12(II) | 0.022 | |
| 74(OW) | 0.023 | |
| 19(II) | 0.023 | |
| 9(I) | 0.025 | |
| 21(V) | 0.025 | |
| 6(II) | 0.027 | |
| 73(V) | 0.032 | |

SUM = 1.1130000000
SUM2 = 0.0216250000
A4 = 0.0215455000
A5 = 0.0193557656
SS3 = 0.0021897344
SS = 0.0022692344
SS2 = 0.0000795000
SS3* = 0.0000706366
SS2* = 0.0000024844
SS* = 0.0000360196
FRATIO= 28.4323392173
CRITICAL DIFF = 0.0066314812

(a) Vertical lines connect cements for which no claim can be made as to any difference in their behavior.

(b) GM/GM/HR.

TABLE 33. IDENTIFICATION OF SIGNIFICANT DIFFERENCES IN CEMENT BEHAVIOR BASED ON THE METHOD OF SIMULTANEOUS COMPARISONS[a]

ORDERED MEANS RATE[b] WGT LOSS EN III INITIAL DES

| CEMENT NO | MEAN | SPECS |
|---|---|---|
| 11(I) | 0.046 | |
| 72(IV) | 0.056 | |
| 4(I) | 0.056 | |
| 26(III) | 0.056 | |
| 20(III) | 0.059 | |
| 14(I) | 0.063 | |
| 24(I) | 0.064 | |
| 10(II) | 0.065 | |
| 13(II) | 0.065 | |
| 17(II) | 0.065 | |
| 74(OW) | 0.065 | |
| 5(I) | 0.066 | |
| 6(II) | 0.068 | |
| 22(I) | 0.068 | |
| 16(I) | 0.069 | |
| 7(I) | 0.069 | |
| 12(II) | 0.069 | |
| 2(I) | 0.070 | |
| 71(I) | 0.071 | |
| 27(I) | 0.071 | |
| 15(II) | 0.071 | |
| 8(I) | 0.071 | |
| 18(I) | 0.071 | |
| 70(IV) | 0.071 | |
| 1(I) | 0.071 | |
| 25(III) | 0.072 | |
| 21(V) | 0.073 | |
| 3(I) | 0.075 | |
| 23(I) | 0.079 | |
| 9(I) | 0.080 | |
| 19(II) | 0.083 | |
| 73(V) | 0.085 | |

SUM = 4.3720000000
SUM2 = 0.3028640000
A4 = 0.3026140000
A5 = 0.2986622500
SS3 = 0.0039517500
SS = 0.0042017500
SS2 = 0.0002500000
SS3* = 0.0001274758
SS2* = 0.0000078125
SS* = 0.0000666944
FRAT10= 16.3169032268
CRITICAL DIFF = 0.0117597200

(a) Vertical lines connect cements for which no claim can be made as to any difference in their behavior.

(b) GM/GM/HR.

TABLE 34. IDENTIFICATION OF SIGNIFICANT DIFFERENCES IN CEMENT BEHAVIOR BASED ON THE METHOD OF SIMULTANEOUS COMPARISONS[a]

ORDERED MEANS RATE[b] WGT GAIN ENV I ADSORPTION

| CEMENT NO | MEAN | SPECS |
|---|---|---|
| 4(I) | 0.010 | |
| 21(V) | 0.010 | |
| 73(V) | 0.011 | |
| 10(II) | 0.011 | |
| 25(III) | 0.011 | |
| 20(III) | 0.011 | |
| 11(I) | 0.011 | |
| 8(I) | 0.011 | |
| 16(I) | 0.011 | |
| 26(III) | 0.012 | |
| 27(I) | 0.012 | |
| 72(IV) | 0.012 | |
| 1(I) | 0.012 | |
| 74(OW) | 0.012 | |
| 71(I) | 0.012 | |
| 70(IV) | 0.012 | |
| 24(I) | 0.012 | |
| 14(I) | 0.012 | |
| 9(I) | 0.012 | |
| 23(I) | 0.012 | |
| 18(I) | 0.012 | |
| 17(II) | 0.012 | |
| 7(I) | 0.013 | |
| 3(I) | 0.013 | |
| 13(II) | 0.013 | |
| 19(II) | 0.013 | |
| 2(I) | 0.013 | |
| 5(I) | 0.013 | |
| 15(II) | 0.013 | |
| 6(II) | 0.014 | |
| 22(I) | 0.014 | |
| 12(II) | 0.014 | |

SUM = 0.7590000000
SUM2 = 0.0090970000
A4 = 0.0090665000
A5 = 0.0090012656
SS3 = 0.0000652344
SS = 0.0000957344
SS2 = 0.0000305000
SS3* = 0.0000021043
SS2* = 0.0000009531
SS* = 0.0000015196
FRAT10= 2.2078265469
CRITICAL DIFF = 0.0041074936

(a) Vertical lines connect cements for which no claim can be made as to any difference in their behavior.

(b) GM/GM/HR.

TABLE 35. IDENTIFICATION OF SIGNIFICANT DIFFERENCES IN CEMENT BEHAVIOR BASED ON THE METHOD OF SIMULTANEOUS COMPARISONS[a]

ORDERED MEANS RATE[b] WGT GAIN ENV II ADSORPTION

| CEMENT NO | MEAN | SPECS |
|---|---|---|
| 21(V) | 0.007 | |
| 14(I) | 0.008 | |
| 74(OW) | 0.009 | |
| 70(IV) | 0.009 | |
| 11(I) | 0.009 | |
| 10(II) | 0.009 | |
| 25(III) | 0.009 | |
| 26(III) | 0.009 | |
| 6(II) | 0.009 | |
| 27(I) | 0.009 | |
| 4(I) | 0.009 | |
| 23(I) | 0.010 | |
| 20(III) | 0.010 | |
| 72(IV) | 0.010 | |
| 16(I) | 0.010 | |
| 3(I) | 0.010 | |
| 5(I) | 0.010 | |
| 9(I) | 0.010 | |
| 8(I) | 0.010 | |
| 71(I) | 0.010 | |
| 13(II) | 0.010 | |
| 7(I) | 0.010 | |
| 15(II) | 0.011 | |
| 73(V) | 0.011 | |
| 1(I) | 0.011 | |
| 19(II) | 0.011 | |
| 17(II) | 0.011 | |
| 18(I) | 0.011 | |
| 2(I) | 0.011 | |
| 24(I) | 0.011 | |
| 22(I) | 0.012 | |
| 12(II) | 0.012 | |

SUM = 0.6190000000
SUM2 = 0.0060830000
A4 = 0.0060505000
A5 = 0.0059868906
SS3 = 0.0000636094
SS = 0.0000961094
SS2 = 0.0000325000
SS3* = 0.0000020519
SS2* = 0.0000010156
SS* = 0.0000015255
FRAT10= 2.0203473946
CRITICAL DIFF = 0.0042400274

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(a) Vertical lines connect cements for which no claim can be made as to any difference in their behavior.

(b) GM/GM/HR.

ABLE 36. IDENTIFICATION OF SIGNIFICANT DIFFERENCES IN CEMENT BEHAVIOR BASED ON THE METHOD OF SIMULTANEOUS COMPARISONS[a]

ORDERED MEANS RATE[b] WGT GAIN ENV III ADSORPTION

| CEMENT NO | MEAN | SPECS |
|---|---|---|
| 72(IV) | 0.017 | |
| 21(V) | 0.017 | |
| 4(I) | 0.017 | |
| 20(III) | 0.017 | |
| 25(III) | 0.019 | |
| 6(II) | 0.020 | |
| 24(I) | 0.020 | |
| 11(I) | 0.020 | |
| 13(II) | 0.020 | |
| 2(I) | 0.021 | |
| 15(II) | 0.021 | |
| 12(II) | 0.021 | |
| 73(V) | 0.021 | |
| 74(OW) | 0.021 | |
| 26(III) | 0.021 | |
| 71(I) | 0.021 | |
| 17(II) | 0.021 | |
| 23(I) | 0.022 | |
| 19(II) | 0.022 | |
| 16(I) | 0.022 | |
| 22(I) | 0.023 | |
| 18(I) | 0.024 | |
| 7(I) | 0.024 | |
| 10(II) | 0.024 | |
| 27(I) | 0.024 | |
| 8(I) | 0.025 | |
| 3(I) | 0.026 | |
| 1(I) | 0.026 | |
| 14(I) | 0.028 | |
| 5(I) | 0.029 | |
| 70(IV) | 0.030 | |
| 9(I) | 0.033 | |

SUM = 1.4470000000
SUM2 = 0.0336670000
A4 = 0.0336145000
A5 = 0.0327157656
SS3 = 0.0008987344
SS = 0.0009512344
SS2 = 0.0000525000
SS3* = 0.0000289914
SS2* = 0.0000016406
SS* = 0.0000150990
FRAT10= 17.6709677425
CRITICAL DIFF = 0.0053889807

(a) Vertical lines connect cements for which no claim can be made as to any difference in their behavior.

(b) GM/GM/HR.

TABLE 37. IDENTIFICATION OF SIGNIFICANT DIFFERENCES IN CEMENT BEHAVIOR BASED ON THE METHOD OF SIMULTANEOUS COMPARISONS[a]

ORDERED MEANS RATE[b] WEIGHT LOSS ENV I FINAL DES

| CEMENT NO | MEAN | SPECS |
|---|---|---|
| 26(III) | 0.019 | |
| 13(II) | 0.019 | |
| 4(I) | 0.021 | |
| 11(I) | 0.022 | |
| 20(III) | 0.022 | |
| 74(OW) | 0.023 | |
| 25(III) | 0.023 | |
| 16(I) | 0.023 | |
| 27(I) | 0.023 | |
| 6(II) | 0.023 | |
| 21(V) | 0.023 | |
| 10(II) | 0.023 | |
| 7(I) | 0.024 | |
| 2(I) | 0.024 | |
| 3(I) | 0.024 | |
| 24(I) | 0.024 | |
| 23(I) | 0.024 | |
| 1(I) | 0.024 | |
| 14(I) | 0.025 | |
| 70(IV) | 0.025 | |
| 72(IV) | 0.025 | |
| 5(I) | 0.025 | |
| 19(II) | 0.026 | |
| 8(I) | 0.026 | |
| 12(II) | 0.027 | |
| 22(I) | 0.027 | |
| 18(I) | 0.028 | |
| 17(II) | 0.028 | |
| 71(I) | 0.029 | |
| 73(V) | 0.029 | |
| 9(I) | 0.029 | |
| 15(II) | 0.030 | |

SUM = 1.5900000000
SUM2 = 0.0400820000
A4 = 0.0399960000
A5 = 0.0395015625
SS3 = 0.0004944375
SS = 0.0005804375
SS2 = 0.0000860000
SS3* = 0.0000159496
SS2* = 0.0000026875
SS* = 0.0000092133
FRATIO= 5.9347336836
CRITICAL DIFF = 0.0068972538

(a) Vertical lines connect cements for which no claim can be made as to any difference in their behavior.

(b) GM/GM/HR.

TABLE 38. IDENTIFICATION OF SIGNIFICANT DIFFERENCES IN CEMENT BEHAVIOR BASED ON THE METHOD OF SIMULTANEOUS COMPARISONS[a]

ORDERED MEANS RATE[b] WGT LOSS ENV II FINAL DES.

| CEMENT NO | MEAN | SPECS |
|---|---|---|
| 26(III) | 0.012 | |
| 5(I) | 0.015 | |
| 8(I) | 0.015 | |
| 23(I) | 0.016 | |
| 10(II) | 0.017 | |
| 11(I) | 0.017 | |
| 74(OW) | 0.017 | |
| 25(III) | 0.017 | |
| 21(V) | 0.017 | |
| 20(III) | 0.017 | |
| 14(I) | 0.017 | |
| 7(I) | 0.018 | |
| 4(I) | 0.018 | |
| 27(I) | 0.018 | |
| 15(II) | 0.018 | |
| 1(I) | 0.019 | |
| 16(I) | 0.019 | |
| 72(IV) | 0.019 | |
| 3(I) | 0.019 | |
| 6(II) | 0.019 | |
| 24(I) | 0.019 | |
| 13(II) | 0.019 | |
| 2(I) | 0.020 | |
| 70(IV) | 0.020 | |
| 17(II) | 0.020 | |
| 22(I) | 0.021 | |
| 19(II) | 0.021 | |
| 71(I) | 0.022 | |
| 9(I) | 0.023 | |
| 18(I) | 0.024 | |
| 73(V) | 0.024 | |
| 12(II) | 0.025 | |

SUM = 1.2210000000
SUM2 = 0.0238590000
A4 = 0.0238115000
A5 = 0.0232943906
SS3 = 0.0005171094
SS = 0.0005646094
SS2 = 0.0000475000
SS3* = 0.0000166809
SS2* = 0.0000014844
SS* = 0.0000089621
FRATIO= 11.2376910019
CRITICAL DIFF = 0.0051259431

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(a) Vertical lines connect cements for which no claim can be made as to any difference in their behavior.

(b) GM/GM/HR.

TABLE 39. IDENTIFICATION OF SIGNIFICANT DIFFERENCES IN CEMENT BEHAVIOR BASED ON THE METHOD OF SIMULTANEOUS COMPARISONS[a]

ORDERED MEANS RATE[b] WGT LOSS EN III FINAL DES.

| CEMENT NO | MEAN | SPECS |
|---|---|---|
| 70(IV) | 0.041 | |
| 8(I) | 0.049 | |
| 74(OW) | 0.051 | |
| 25(III) | 0.051 | |
| 13(II) | 0.052 | |
| 21(V) | 0.055 | |
| 26(III) | 0.056 | |
| 4(I) | 0.056 | |
| 6(II) | 0.057 | |
| 14(I) | 0.057 | |
| 72(IV) | 0.058 | |
| 2(I) | 0.058 | |
| 27(I) | 0.059 | |
| 10(II) | 0.060 | |
| 23(I) | 0.060 | |
| 20(III) | 0.060 | |
| 12(II) | 0.062 | |
| 24(I) | 0.062 | |
| 16(I) | 0.063 | |
| 7(I) | 0.063 | |
| 22(I) | 0.063 | |
| 5(I) | 0.063 | |
| 3(I) | 0.064 | |
| 11(I) | 0.065 | |
| 15(II) | 0.065 | |
| 71(I) | 0.067 | |
| 17(II) | 0.067 | |
| 18(I) | 0.067 | |
| 73(V) | 0.068 | |
| 1(I) | 0.068 | |
| 9(I) | 0.072 | |
| 19(II) | 0.077 | |

SUM = 3.8820000000
SUM2 = 0.2388480000
A4 = 0.2386390000
A5 = 0.2354675625
SS3 = 0.0031714375
SS = 0.0033804375
SS2 = 0.0002090000
SS3* = 0.0001023044
SS2* = 0.0000065312
SS* = 0.0000536577
FRATIO= 15.6638370125
CRITICAL DIFF = 0.0107522690

(a) Vertical lines connect cements for which no claim can be made as to any difference in their behavior.

(b) GM/GM/HR.

TABLE 40. IDENTIFICATION OF TYPE I CEMENTS EXHIBITING THE SAME PERFORMANCE CHARACTERISTICS DURING ADSORPTION AND DESORPTION PERIODS[a]
CEMENTS 1-2-3-4-5-7-8-9-11-14-16-18-22-23-24-27-71

| Environmental and Test Conditions | Total Weight Change | Total Dimensional Change | Initial Rate of Weight Change |
|---|---|---|---|
| Initial Desorption Environment I | 9-71-27-18<br>71-27-18-7-22-16-5-24-2-1-14-3-23-8<br>27-18-7-22-16-5-24-2-1-14-3-23-8-4<br>1-14-3-23-8-4-11 | 71-27-23-16-1<br>27-23-16-1-2-24-18-22-7<br>16-1-2-24-18-22-7-8<br>5-3-11-14-4-9 | 9-71-18-27-16<br>71-18-27-16-7-24-2-3-1-22-5-23-4<br>27-16-7-24-2-3-1-22-5-23-4-8-14<br>5-23-4-8-14-11 |
| Initial Desorption Environment II | 9<br>18-71-7-2-27-24-22-16<br>71-7-2-27-24-22-16-1-3-4-5-14<br>22-16-1-3-4-5-14-23-8<br>23-8-11 | 27-71-16-1-23-9-3-5-24-11-7-14-4<br>71-16-1-23-9-3-5-24-11-7-14-4-22-2-18<br>16-1-23-9-3-5-24-11-7-14-4-22-2-18-8 | 9-2-1-22-71-24<br>2-1-22-71-24-27-7-3-16-23-5-4-14-8<br>22-71-24-27-7-3-16-23-5-4-14-8-11 |
| Initial Desorption Environment III | 9-27-16-7-5-1-3-18-8-71-22-2-24<br>27-16-17-5-1-3-18-8-71-22-2-24-14-23<br>24-14-23-4-11 | 3-16-27-23-1<br>16-27-23-1-5-2-11-8-71<br>27-23-1-5-2-11-8-71-4-9-22<br>23-1-5-2-11-8-71-4-9-22-14<br>1-5-2-11-8-71-4-9-22-14-7-24<br>5-2-11-8-71-4-9-22-14-7-24-18 | 9-23-3-1-18-8-27-71-2-7-16-22-5-24-14<br>22-5-24-14-4<br>4-11 |
| Adsorption Environment I | 18-9-22-71-2-7-23-5<br>9-22-71-2-7-23-5-27-3<br>22-71-2-7-23-5-27-3-11-1<br>71-2-7-23-5-27-3-11-1-8-16<br>7-23-5-27-3-11-1-8-16-4-14 | 1-27-18-16-23-8-71-24-2-21-7<br>11-5-14<br>11-5-14-4-9-3 | 22-5-2-3-7-18-23-9-14-24-71-1-27-16-8-11-4 |
| Adsorption Environment II | 18-9-2-22-7-24<br>9-2-22-7-24-71<br>2-22-7-24-71-27-1<br>7-24-71-27-1-3-16-4<br>24-71-27-1-3-16-4-11<br>71-27-1-3-16-4-11-23-8-5<br>27-1-3-16-4-11-23-8-5-14 | 14-27-11-7-1-18-22-8-3-71-5-23-2-16-9-24-4 | 22-24-2-18-1-7-71-8-9-5-3-16-23-4-27-11-14 |

TABLE 40. (CONTINUED)

| Environmental and Test Conditions | Total Weight Change | Total Dimensional Change | Initial Rate of Weight Change |
|---|---|---|---|
| Adsorption Environment III | 9-5-22-18-8-7-1-11-2-27-23-3-24-16-71<br>5-22-18-8-7-1-11-2-27-23-3-24-16-71-14-4 | 14-11-23-2-1-8-5-4-3-16-27-7<br>11-23-2-1-8-5-4-3-16-27-7-71-22<br>1-8-5-4-3-16-27-7-71-22-18<br>5-4-3-16-27-7-71-22-18-24<br>22-18-24-9 | 9-5-14<br>5-14-1-3-8-27-7-18<br>14-1-3-8-27-7-18-22<br>1-3-8-27-7-18-22-16-23-71-2<br>8-27-7-18-22-16-23-71-2-11-24<br>16-23-71-2-11-24-4 |
| Final Desorption Environment I | 18-9-22-2<br>9-22-2-7-71<br>22-2-7-71-23-14-8<br>2-7-71-23-14-8-11<br>7-71-23-14-8-11-3-24-1-16-5<br>23-14-8-11-3-24-1-16-5-27-4 | 2-24-14-16-8-27-1-23-71-3-18-5-9-22-4-11-7 | 9-71-18-22-8-5-14-1-23-24-3-2-7-27-16-11<br>18-22-8-5-14-1-23-24-3-2-7-27-16-11-4 |
| Final Desorption Environment II | 18-9-2<br>9-2-22-7-71<br>2-22-7-71-24<br>22-7-71-24-3-1-16<br>71-24-3-1-16-4-27-8-11-14<br>24-3-1-16-4-27-8-11-14-23<br>27-8-11-14-23-5 | 27-14-8-71-3-2-9-16-24-22-7-1-23-5-11-18<br>14-8-71-3-2-9-16-24-22-7-1-23-5-11-18-4 | 9-71-22-2-24-3-16-1-27-4-7<br>71-22-2-24-3-16-1-27-4-7-14-11-23<br>2-24-3-16-1-27-4-7-14-11-23-8-5 |
| Final Desorption Environment II | 5-1-9-18-22-3-11-7-16-2-23-71-27-8-4-24<br>3-11-7-16-2-23-71-27-8-4-24-14 | 23-14-3-16-24-27-4-5-2-22-11<br>3-16-24-27-4-5-2-22-11-18-71-8<br>24-27-4-5-2-22-11-18-71-8-7<br>5-2-22-11-18-71-8-7-9 | 9-1-18-71-11-3-5-22-7-16-24<br>1-18-71-11-3-5-22-7-16-24-23-27-2-14<br>18-71-11-3-5-22-7-16-24-23-27-2-14-4<br>23-27-2-14-4-8 |

(a) Cements exhibiting no significant differences in behavior are linked horizontally. Values of the respective changes decrease from left to right for the rows. Values of the rows also decrease from top to bottom; i.e., top row → middle row(s) → bottom row.

TABLE 41. IDENTIFICATION OF TYPE II CEMENTS EXHIBITING THE SAME PERFORMANCE CHARACTERISTICS DURING ADSORPTION AND DESORPTION PERIODS[a]
CEMENTS 6-10-12-13-15-17-19

| nvironmental and Test Conditions | Total Weight Change | Total Dimensional Change | Initial Rate of Weight Change |
|---|---|---|---|
| nitial Desorption nvironment I | 12-6-15-17-13-19<br>13-19-10 | 10-19<br>15-6<br>17-12-13 | 15-17-12-6-19<br>12-6-19-13<br>19-13-10 |
| nitial Desorption nvironment II | 12-6-15<br>6-15-13-17-19<br>10 | 10-6<br>6-17-13-12-15-19 | 6-19-12-15<br>19-12-15-13-17<br>13-17-10 |
| nitial Desorption nvironment III | 19-12-6-15-10-13-17 | 10-19<br>19-13<br>13-17-15-12<br>12-6 | 19-15<br>15-12-6-17-13-10 |
| lsorption nvironment I | 12-15-17-13<br>15-17-13-19<br>13-19-6<br>6-10 | 10-15-19<br>19-6<br>13-17-12 | 12-6-15-19-13-17-10 |
| lsorption nvironment II | 12<br>15-13-17<br>13-17-19-6<br>10 | 10-17-15-13<br>17-15-13-19-6-12 | 12-17-19-15-13-6-10 |
| lsorption nvironment III | 12-19-17-13-15-10<br>19-17-13-15-10-6 | 10-17<br>17-13-19-15<br>13-19-15-12<br>6 | 10-19-17-12-15-13-6 |
| nal Desorption vironment I | 15-12-17-13<br>17-13-19<br>19-6<br>6-10 | 10-19-6-13-15-17-12 | 15-17-12-19-10-6<br>19-10-6-13 |
| nal Desorption vironment II | 12<br>15-13-17<br>17-19<br>19-6<br>6-10 | 10-19-6-13-17<br>19-6-13-17-12-15 | 12-19-17<br>19-17-13-6-15-10 |
| nal Desorption vironment III | 19-17-12-15-13-10-6 | 10<br>19-17-13-15<br>13-15-12-6 | 19-17<br>17-15-12-10-6<br>12-10-16-13 |

) Cements exhibiting no significant differences in behavior are linked horizontally. Values of the respective changes decrease from left to right for the rows. Values of the rows also decrease from top to bottom; i.e., top row > middle row(s) > bottom row.

TABLE 42. IDENTIFICATION OF TYPE III CEMENTS EXHIBITING THE SAME PERFORMANCE CHARACTERISTICS DURING ADSORPTION AND DESORPTION PERIODS[a]
CEMENTS 25-26

| ıvironmental and ɜst Conditions | Total Weight Change | Total Dimensional Change | Initial Rate of Weight Change |
|---|---|---|---|
| ıitial Desorption ıvironment I | 25-20<br>20-26 | 20-25<br>26 | 25-20-26 |
| ıitial Desorption ıvironment II | 25<br>20-26 | 26-20-25 | 25-20-26 |
| ıitial Desorption ıvironment III | 25-20-26 | 26-20<br>20-25 | 25-20<br>20-26 |
| lsorption ıvironment I | 25-20-26 | 25-20<br>26 | 26-20-25 |
| lsorption ıvironment II | 25-20-26 | 26-25<br>25-20 | 20-26-25 |
| lsorption ıvironment III | 26-20-25 | 26<br>25-20 | 26-25-20 |
| .nal Desorption ıvironment I | 25-20-26 | 26-20-25 | 25-20-26 |
| .nal Desorption ıvironment II | 25-20<br>26 | 26<br>20-25 | 20-25-26 |
| .nal Desorption ıvironment III | 26-20-25 | 26-20<br>25 | 20-26-25 |

.) Cements exhibiting no significant differences in behavior are linked horizontally. Values of the respective changes decrease from left to right for the rows. Values of the rows also decrease from top to bottom; i.e., top row > middle row(s) > bottom row.

TABLE 43. IDENTIFICATION OF TYPE IV AND OIL WELL CEMENTS EXHIBITING THE SAME PERFORMANCE CHARACTERISTICS DURING ADSORPTION AND DESORPTION PERIODS[a] CEMENTS 70-72-74

| ıvironmental and ɜst Conditions | Total Weight Change | Total Dimensional Change | Initial Rate of Weight Change |
|---|---|---|---|
| ıitial Desorption ıvironment I | 70-74-72 | 72<br>74-70 | 74-72-70 |
| ıitial Desorption ıvironment II | 72-74-70 | 74-70-72 | 74-72<br>72-70 |
| ıitial Desorption ıvironment III | 70-74-72 | 74-70<br>70-72 | 70-74<br>74-72 |
| isorption ıvironment I | 72-74-70 | 72<br>74-70 | 70-74-72 |
| isorption ıvironment II | 72-74<br>74-70 | 70-74-72 | 72-70-74 |
| isorption ıvironment III | 70-74-72 | 70-74-72 | 70<br>74-72 |
| inal Desorption ıvironment I | 72-70<br>70-74 | 74-70<br>70-72 | 72-70-74 |
| inal Desorption ıvironment II | 72<br>70-74 | 70-74-72 | 70-72-74 |
| inal Desorption ıvironment III | 72-74-70 | 74-70-72 | 72-74<br>74-70 |

a) Cements exhibiting no significant differences in behavior are linked horizontally. Values of the respective changes decrease from left to right for the rows. Values of the rows also decrease from top to bottom; i.e., top row > middle row(s) > bottom row.

TABLE 44. IDENTIFICATION OF TYPE V CEMENTS EXHIBITING THE SAME PERFORMANCE CHARACTERISTICS DURING ADSORPTION AND DESORPTION PERIODS[a]
CEMENTS 21-73

| Environmental and Test Conditions | Total Weight Change | Total Dimensional Change | Initial Rate of Weight Change |
|---|---|---|---|
| Initial Desorption Environment I | 73-21 | 21<br>73 | 73-21 |
| Initial Desorption Environment II | 73<br>21 | 21-73 | 73-21 |
| Initial Desorption Environment III | 73-21 | 21-73 | 73-21 |
| Adsorption Environment I | 73-21 | 21<br>73 | 73-21 |
| Adsorption Environment II | 73-21 | 21-73 | 73-21 |
| Adsorption Environment III | 21-73 | 21-73 | 73-21 |
| Final Desorption Environment I | 73-21 | 21-73 | 73-21 |
| Final Desorption Environment II | 73-21 | 21-73 | 73<br>21 |
| Final Desorption Environment III | 73-21 | 21-73 | 73<br>21 |

(a) Cements exhibiting no significant differences in behavior are linked horizontally. Values of the respective changes decrease from left to right for the rows. Values of the rows also decrease from top to bottom; i.e., top row > middle row(s) > bottom row.

TABLE 45. BEHAVIORAL TRENDS OF THIRTY-TWO CEMENTS INVESTIGATED IN PHASE A ADSORPTION-DESORPTION STUDIES (I.D.)

| Cement Type (No. Investigated) | Values[a] of Total Weight Change | Values[a] of Total Dimensional Change | Values[a] of Rate of Initial Weight Change |
|---|---|---|---|
| Type I (17) | Low | Intermediate to high | Intermediate to low |
| Type II (7) | Intermediate to high | Intermediate to low | Intermediate to high |
| Type III (3) | Low | Intermediate to high | Intermediate to low |
| Type IV (2) | Intermediate | Low | Intermediate to low |
| Type V (2) | High | Low | High |
| Oil Well (1) | Intermediate | Intermediate | Intermediate |

(a) Values are relative to all thirty-two cements.

FIGURE 1. PREPARATION OF CEMENT PASTE SLAB SPECIMENS

FIGURE 2. EXPERIMENTAL APPARATUS USED IN THE MEASUREMENT OF MOISTURE MIGRATION IN HARDENED CEMENT PASTES SHOWING (1) ANALYTICAL BALANCE ON MOVABLE PLATFORM, (2) OPTICAL EXTENSOMETER ON MOVABLE PLATFORM, (3) ENVIRONMENTAL CHAMBERS CONTAINING SPECIMENS, (4) OVENS FOR MAINTAINING CHAMBERS AT 100 F, (5) ELECTRICAL TIMERS, (6) PURGE GAS TRAIN, (7) MONFORE RELATIVE HUMIDITY INDICATOR

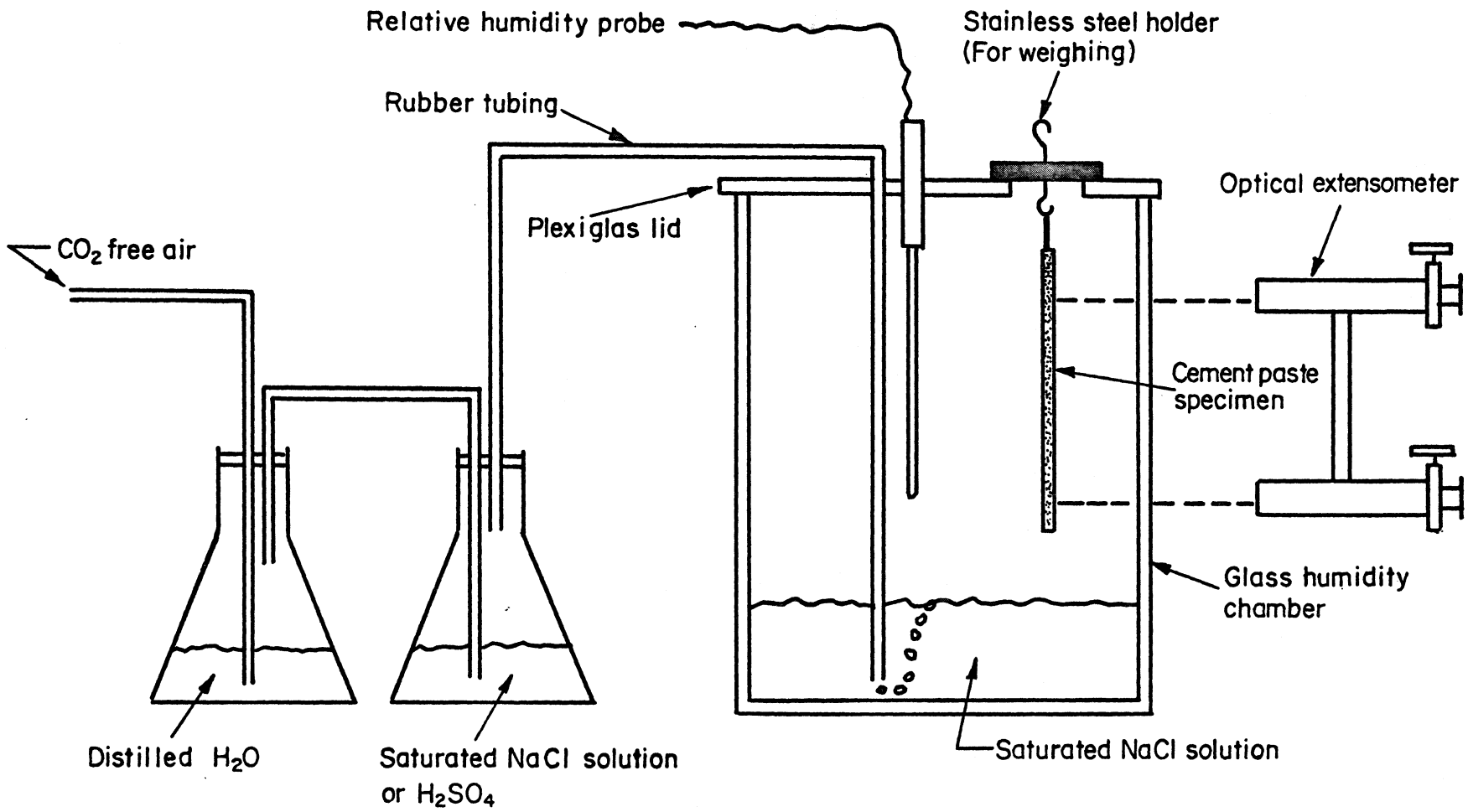


FIGURE 3. APPARATUS FOR MEASURING THE DEFORMATION AND WEIGHT CHANGE OF HARDENED CEMENT PASTES

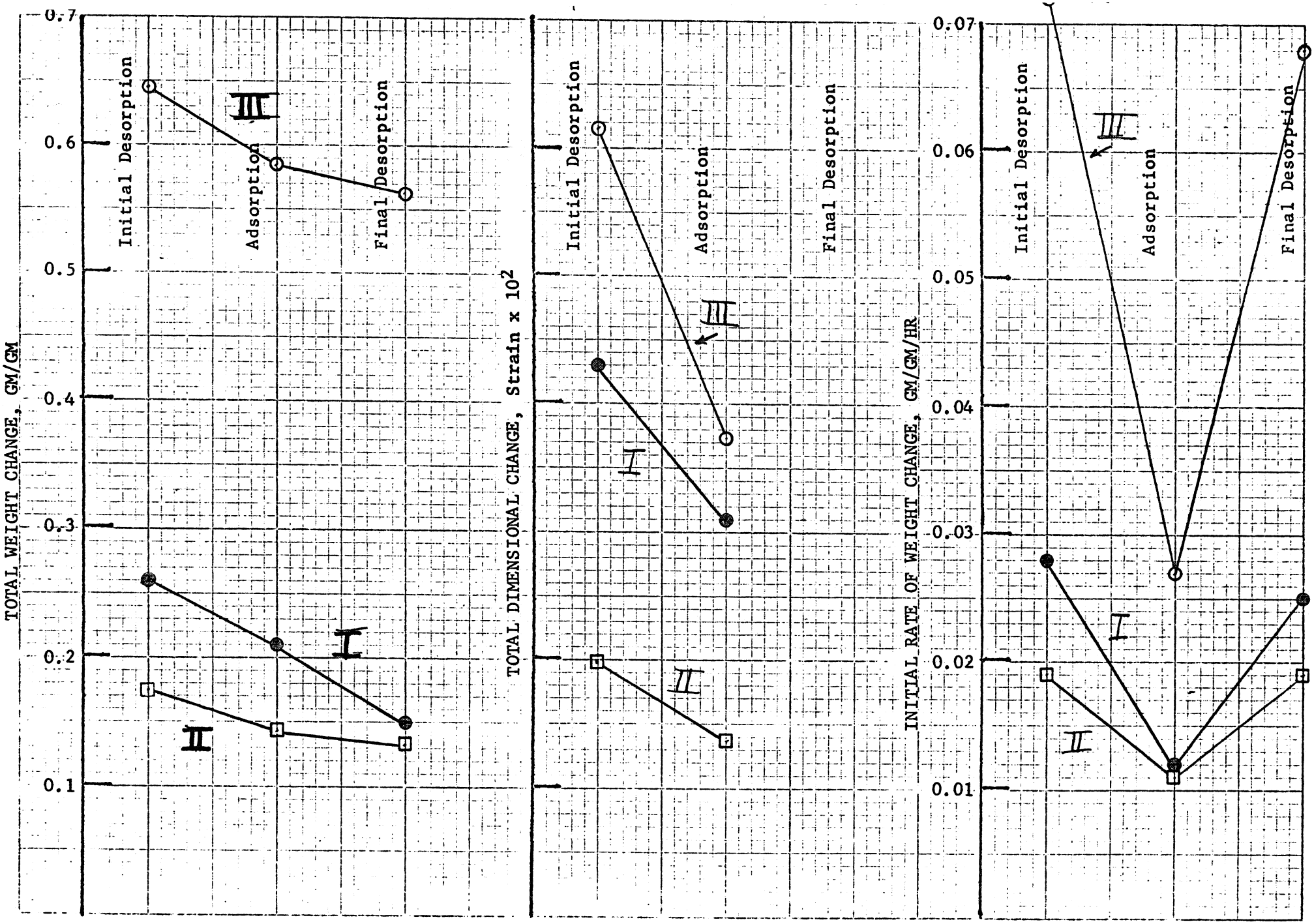


FIGURE 4. CEMENT #1, TYPE I. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

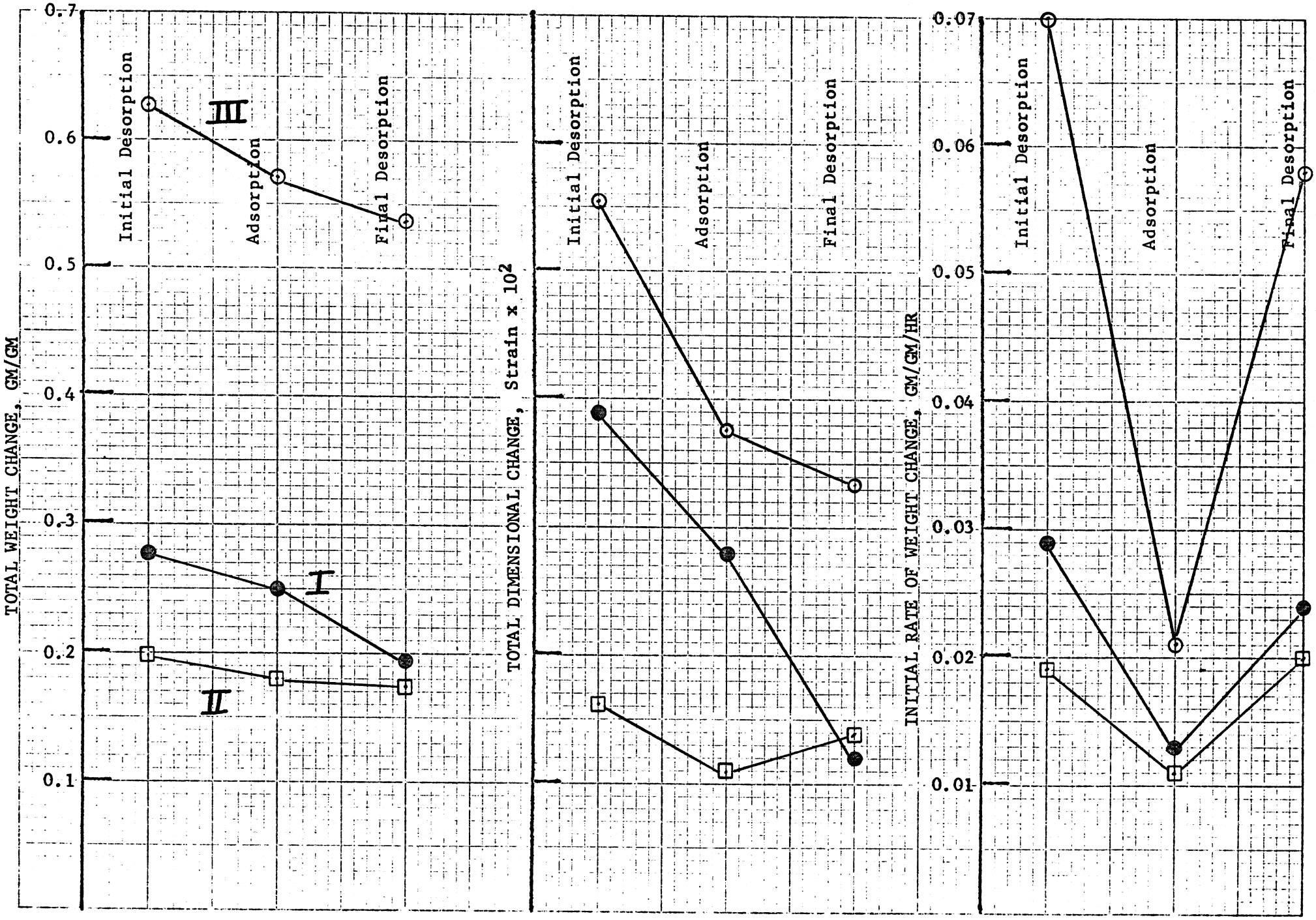


FIGURE 5. CEMENT #2, TYPE I. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

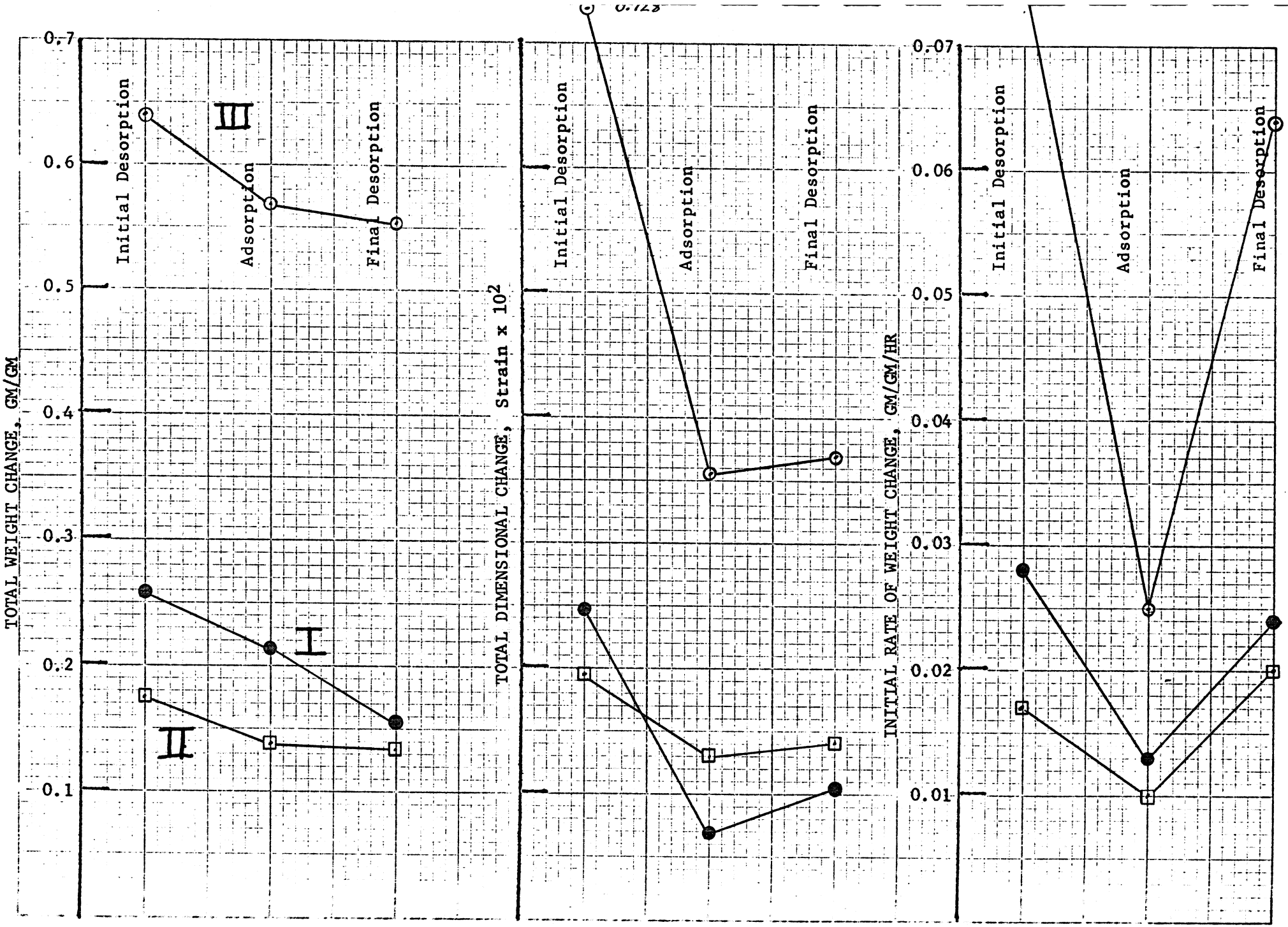


FIGURE 6. CEMENT #3, TYPE I. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

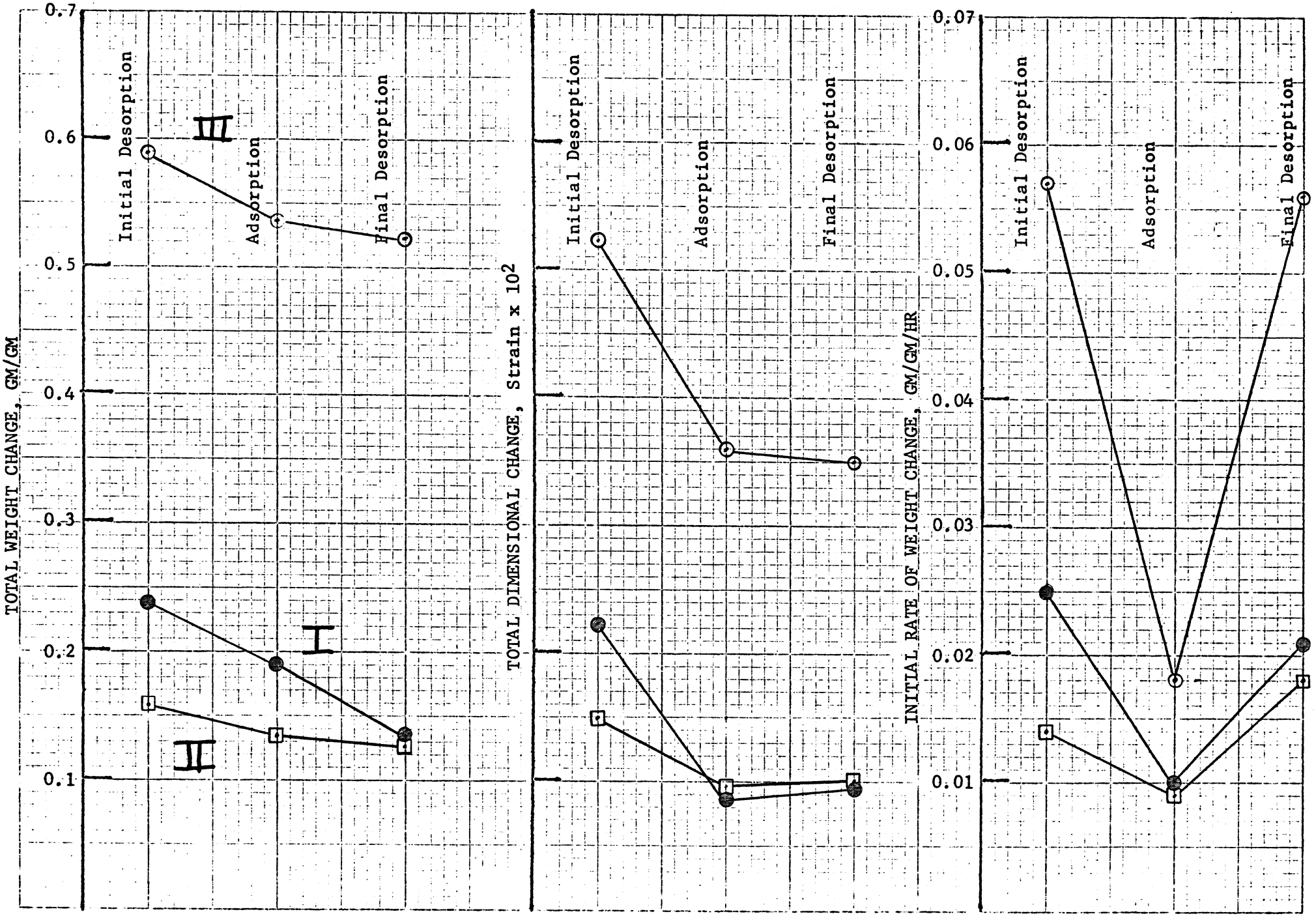


FIGURE 7. CEMENT #4. TYPE I. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

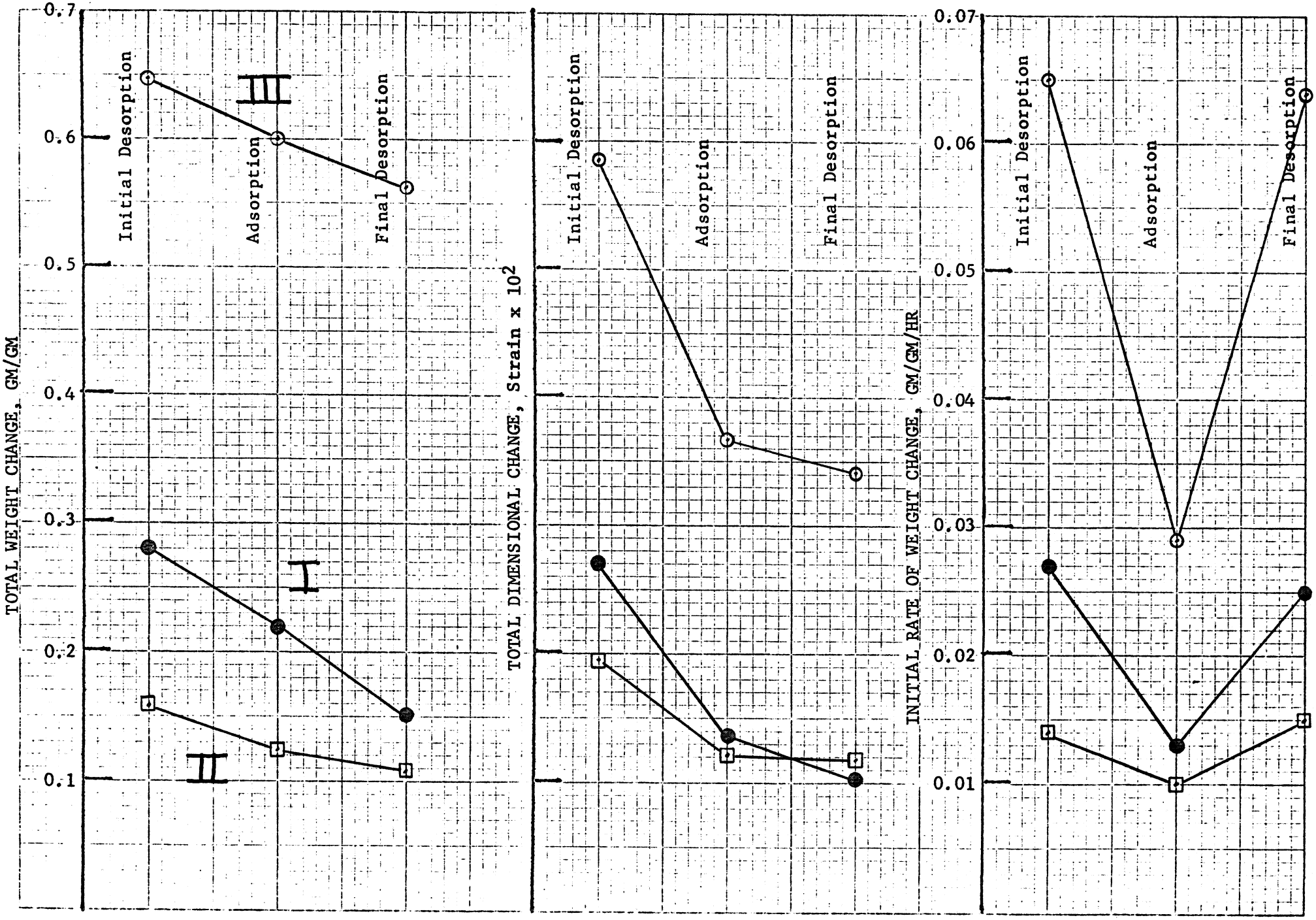


FIGURE 8. CEMENT #5. TYPE I. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

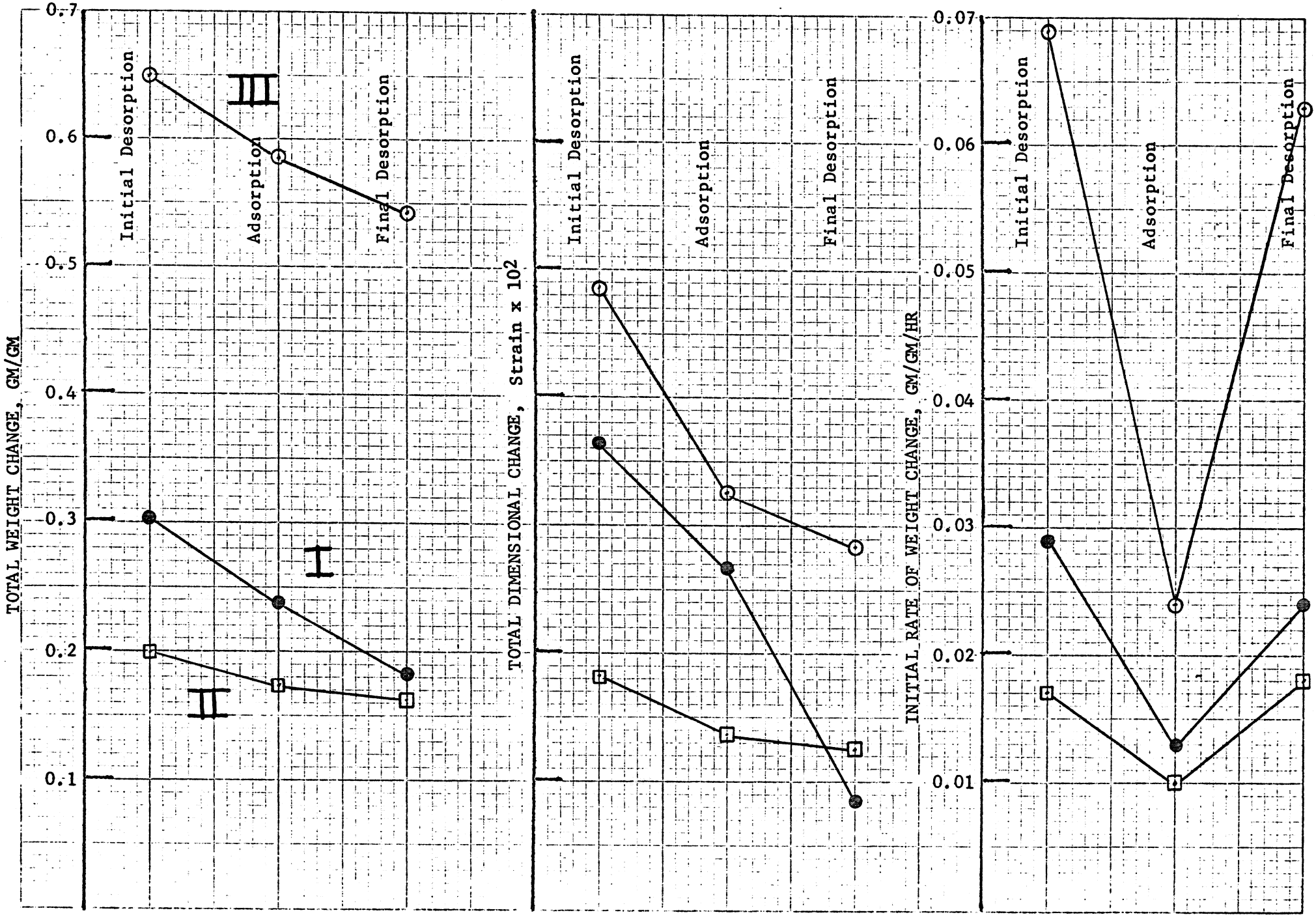


FIGURE 9. CEMENT #7, TYPE I. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

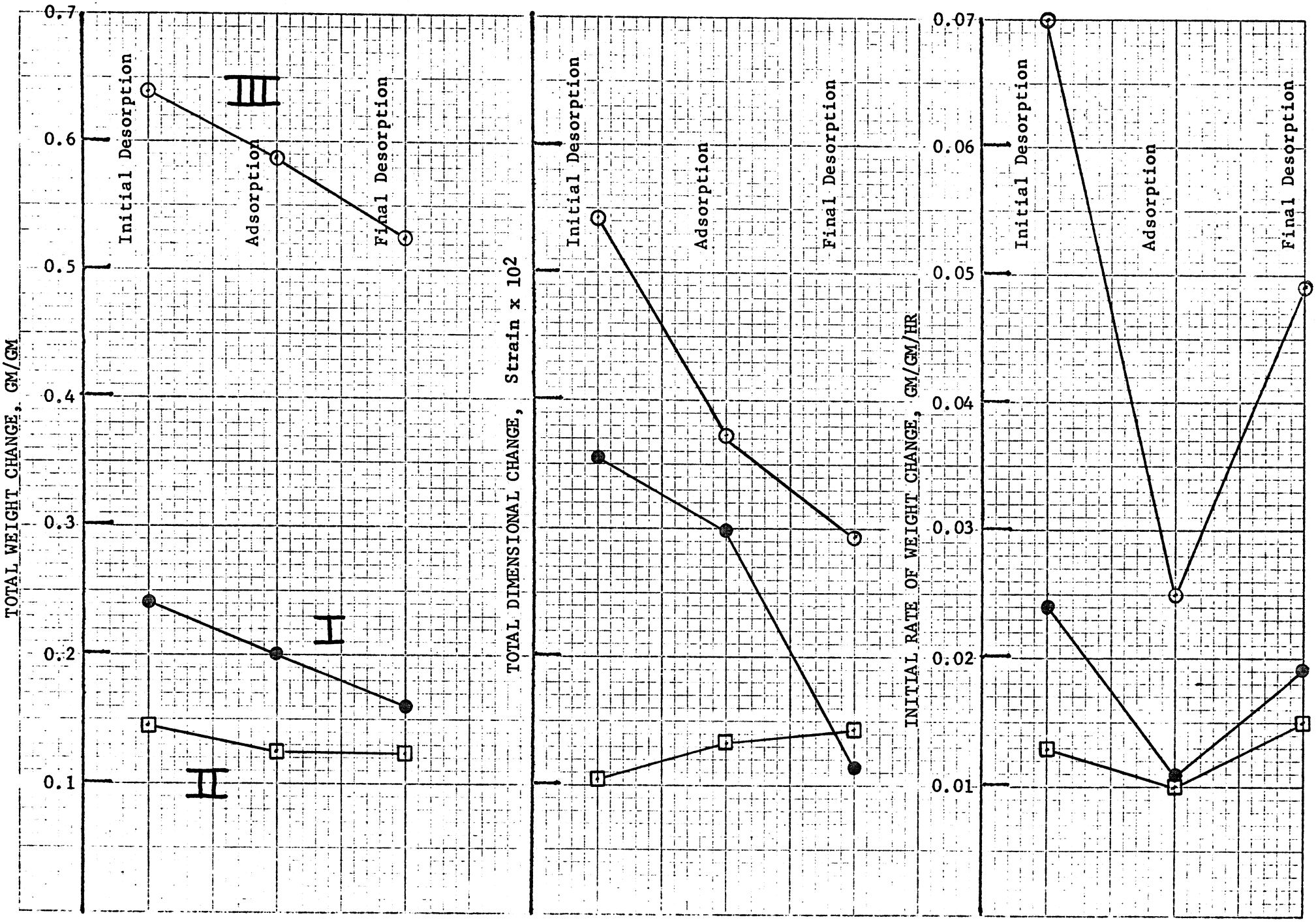


FIGURE 10. CEMENT #8. TYPE I. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

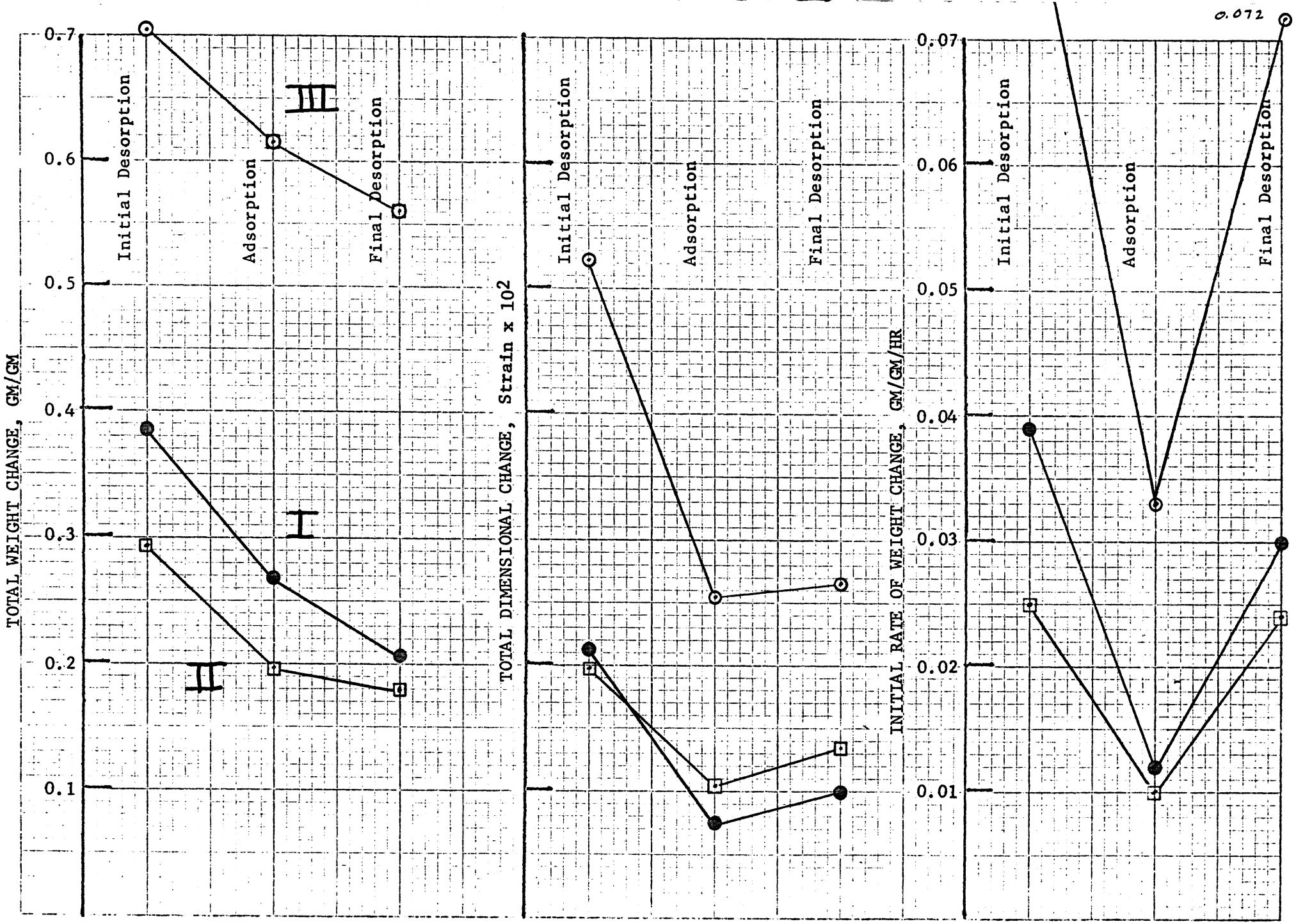


FIGURE 11. CEMENT #9. TYPE I. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0.5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION

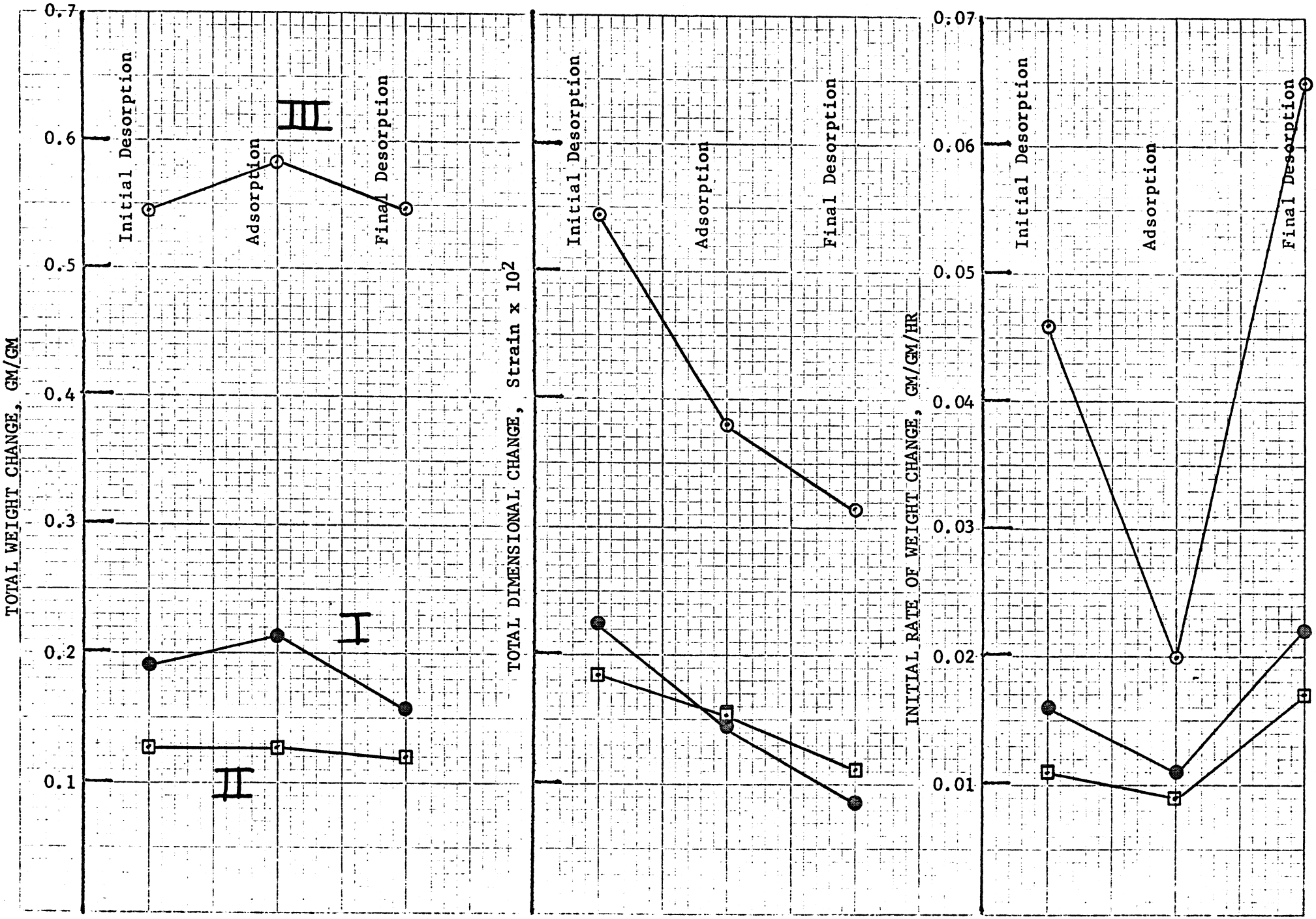


FIGURE 12. CEMENT #11.TYPE I. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

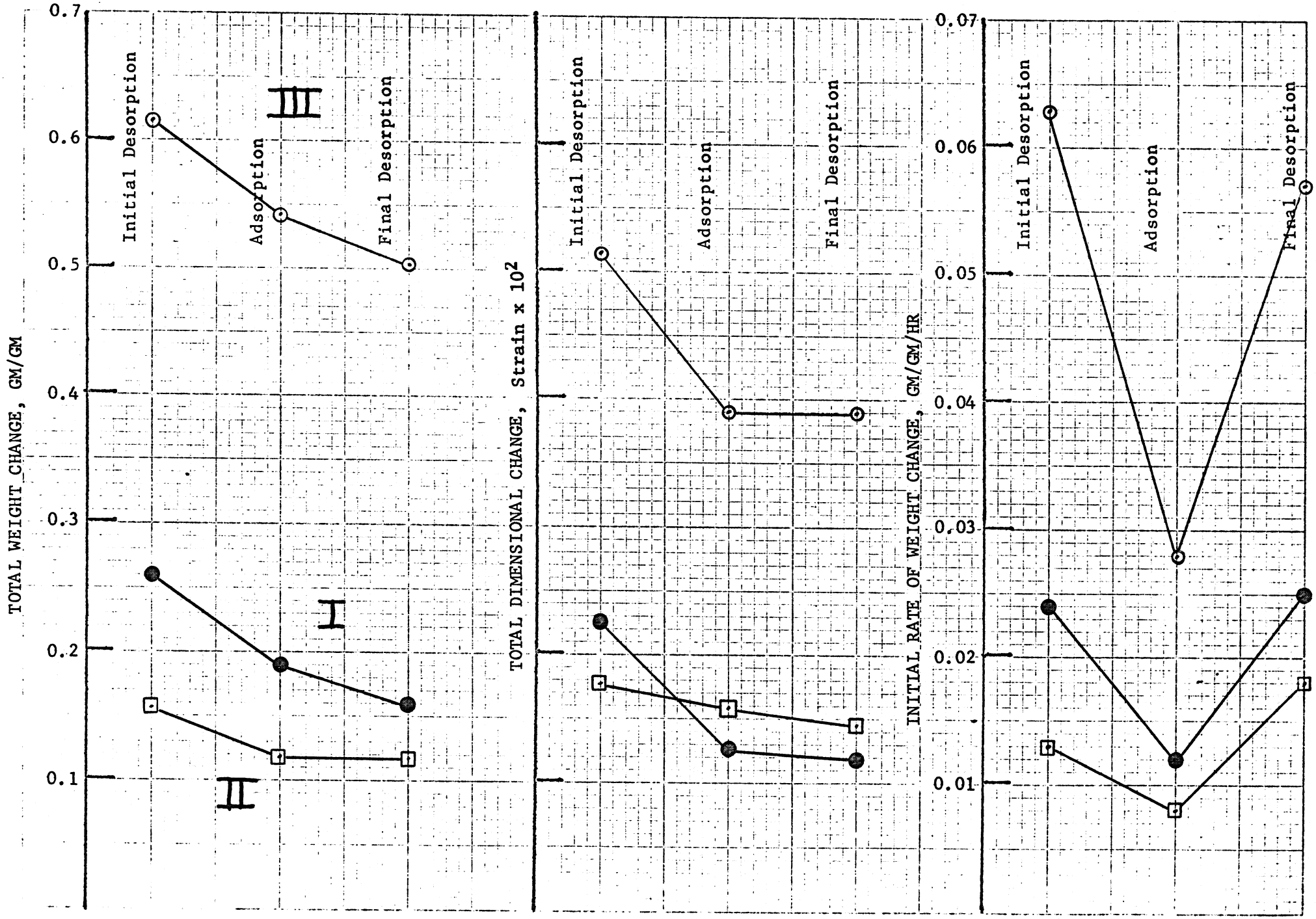


FIGURE 13. CEMENT #14.TYPE I. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

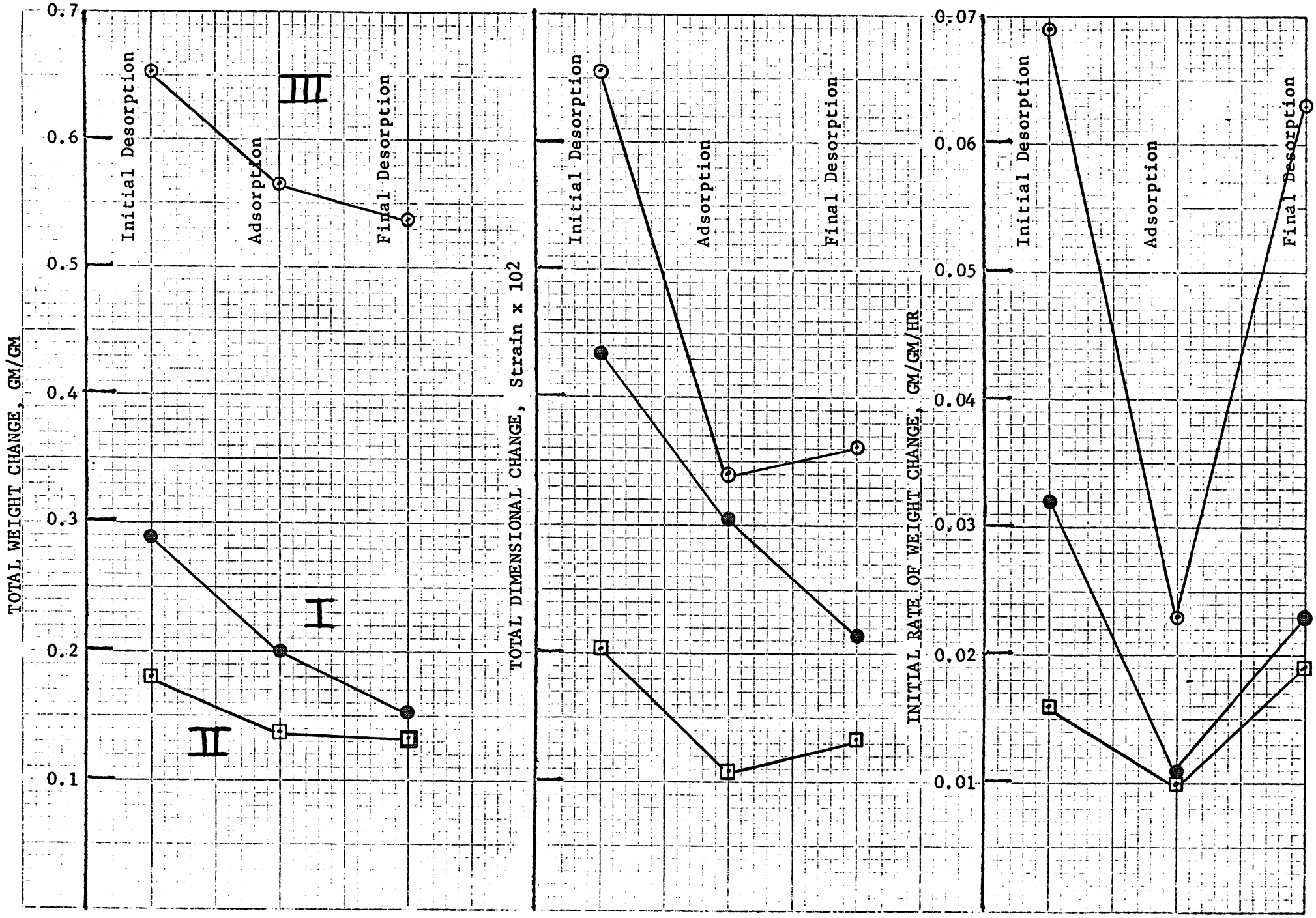


FIGURE 14. CEMENT #16.TYPE I. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

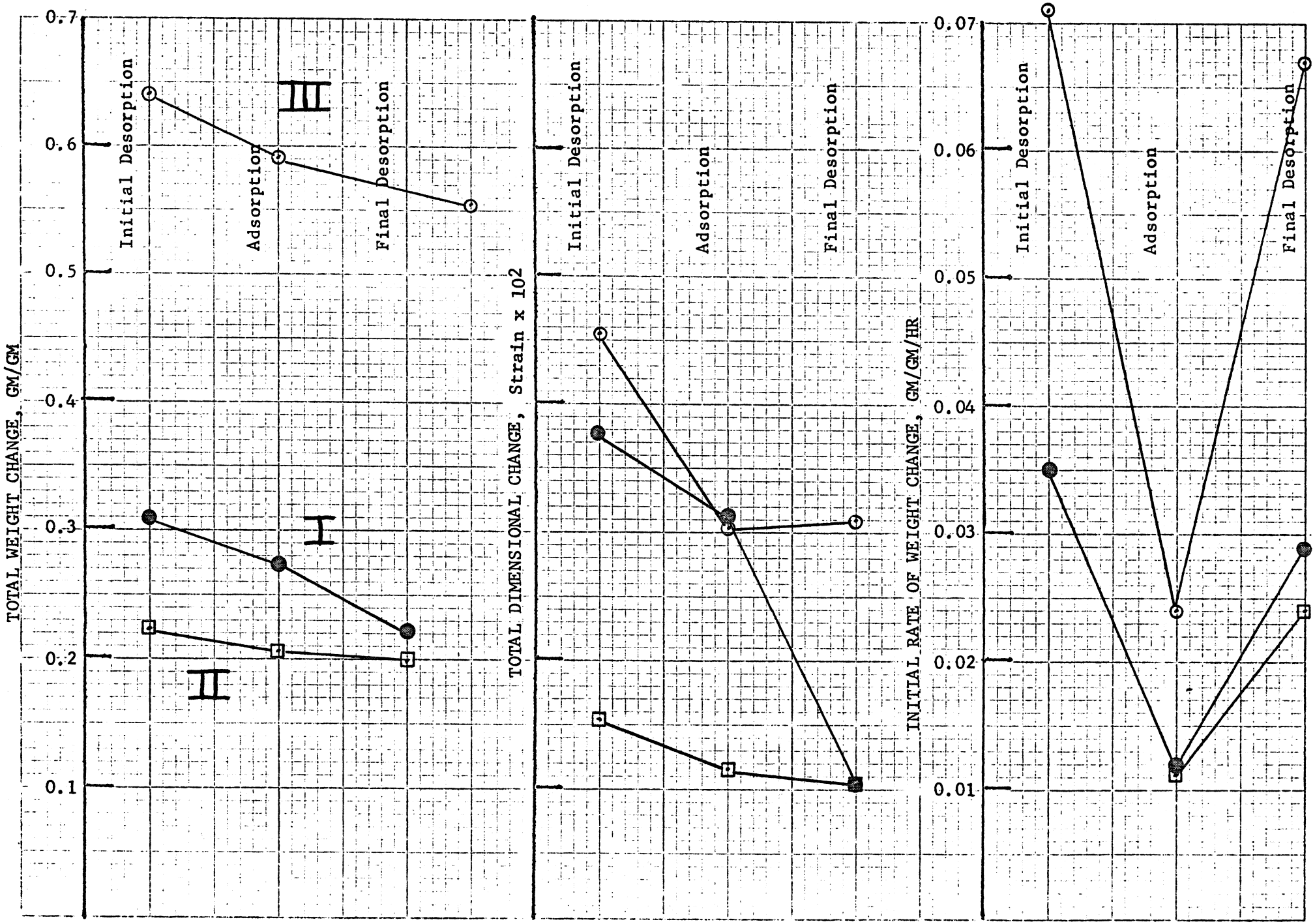


FIGURE 15. CEMENT #18.TYPE I. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

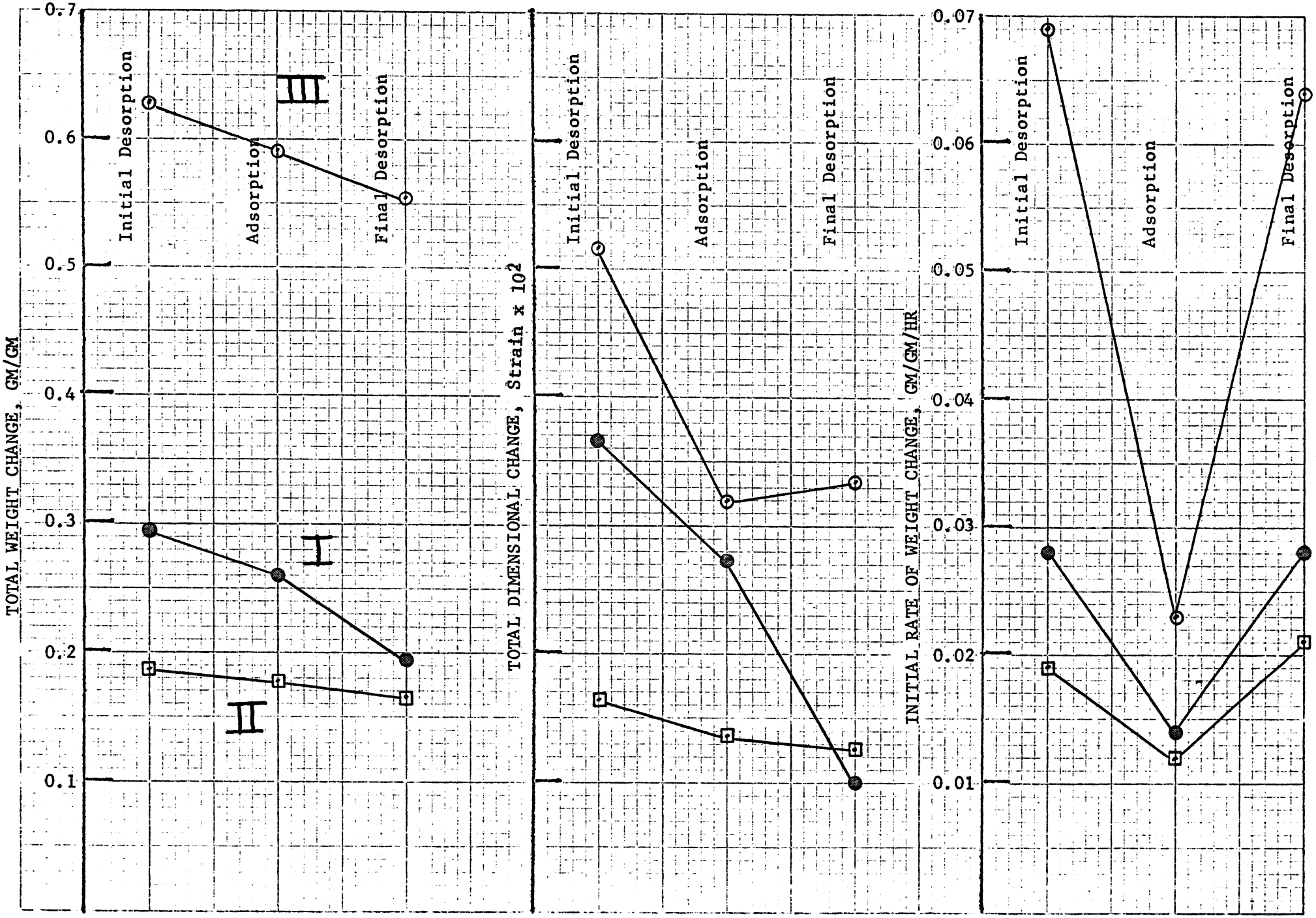


FIGURE 16. CEMENT #22 TYPE I. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

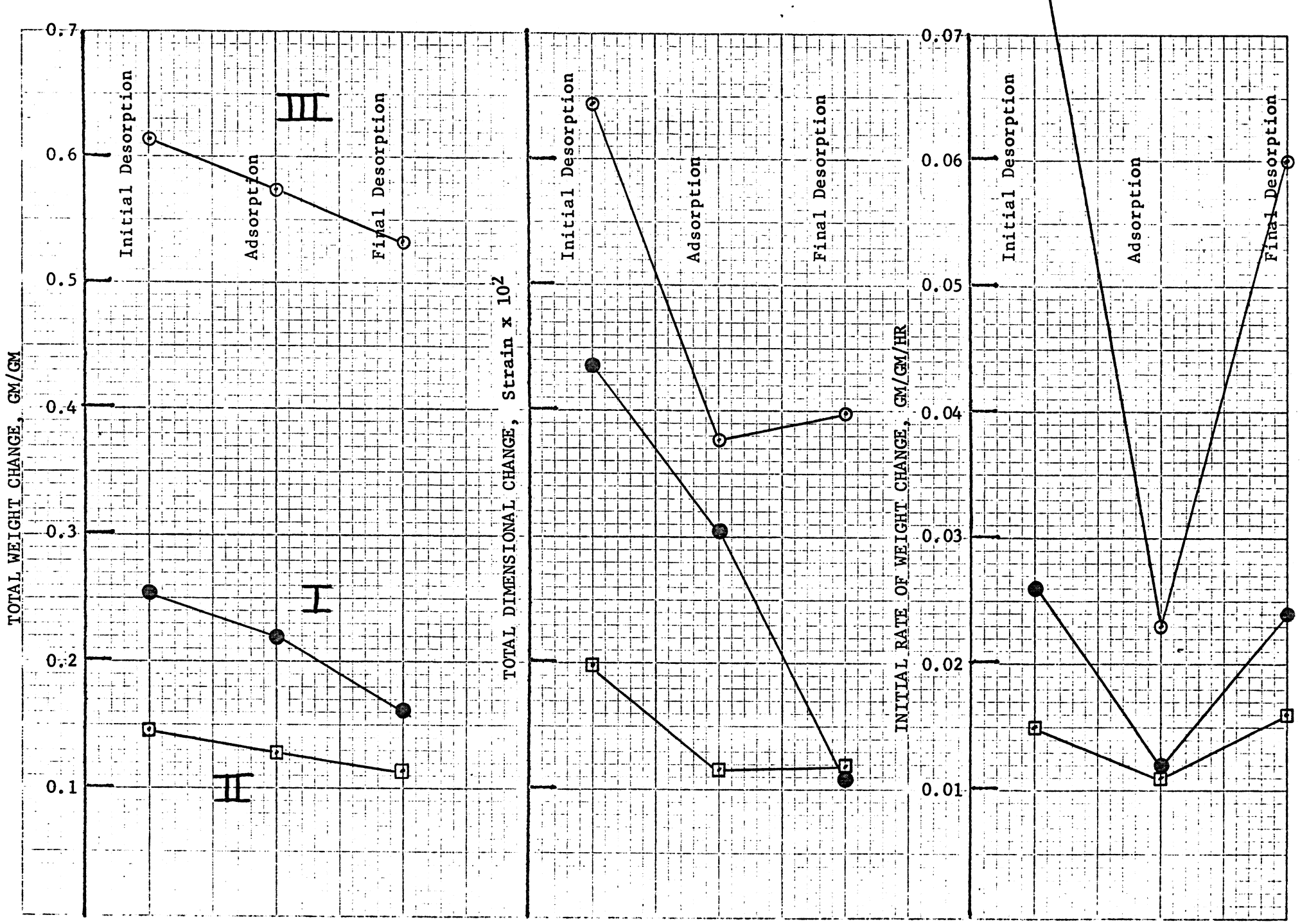


FIGURE 17. CEMENT #23.TYPE I. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION

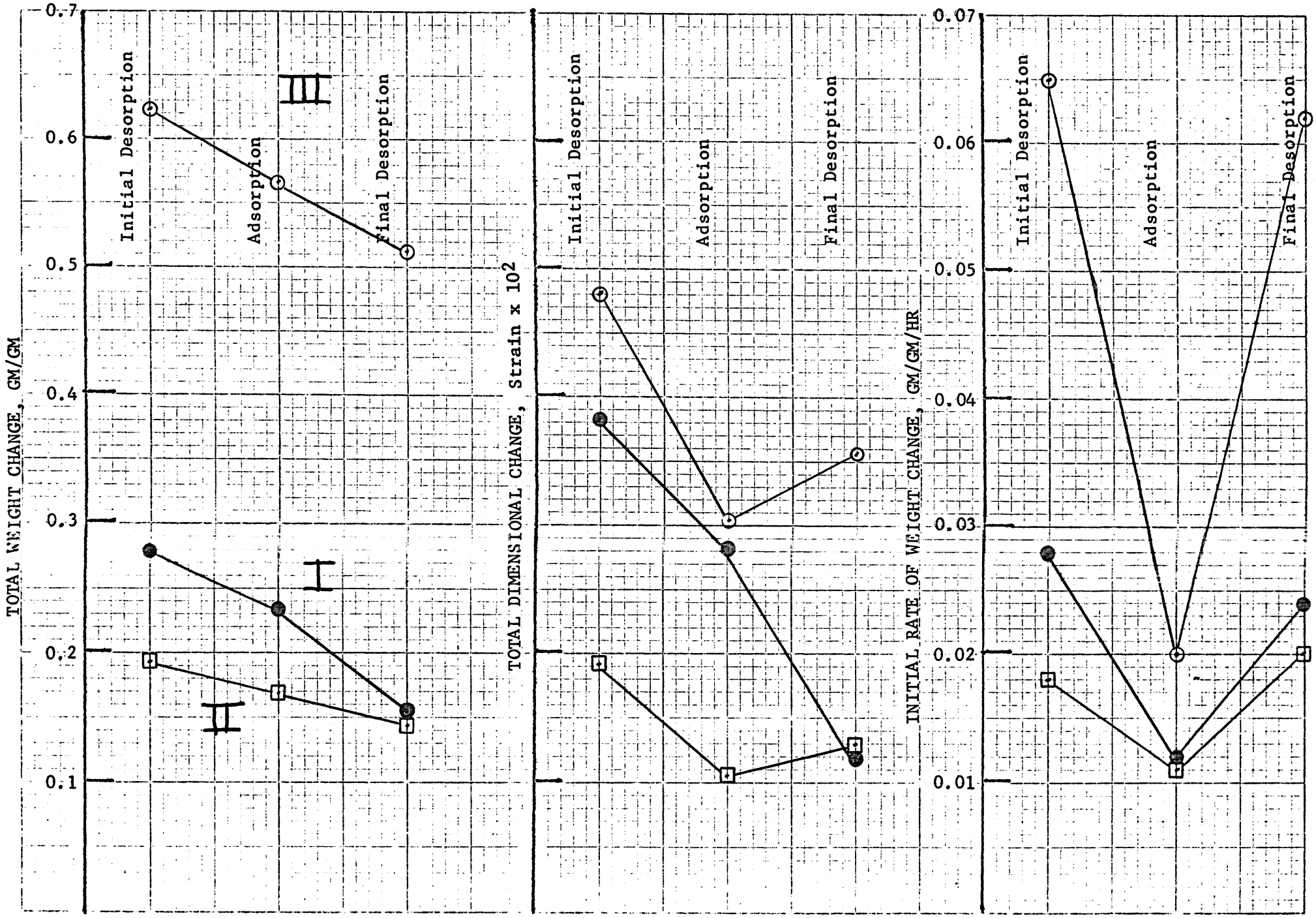


FIGURE 18. CEMENT #24, TYPE I. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

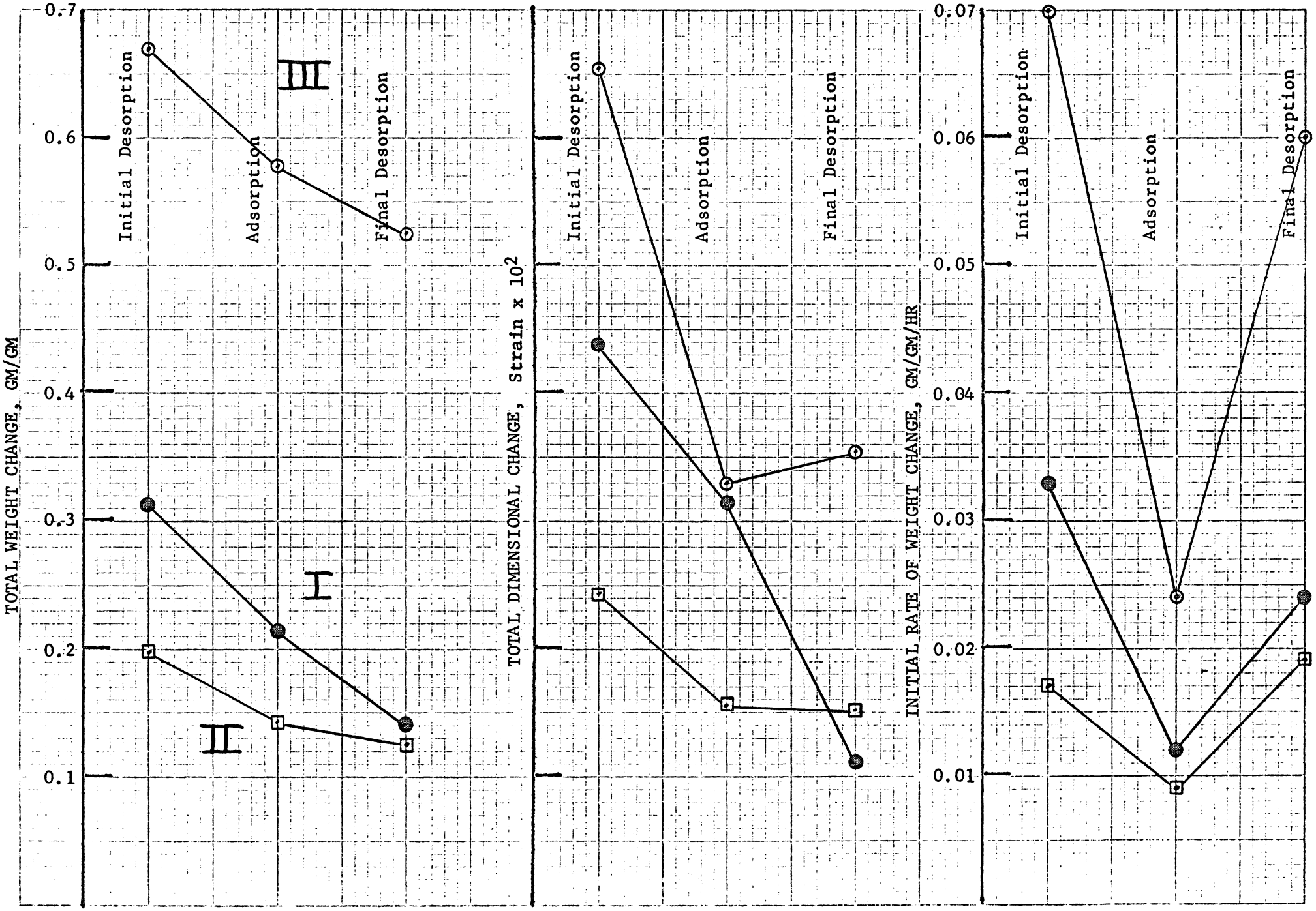


FIGURE 19. CEMENT #27.TYPE I. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

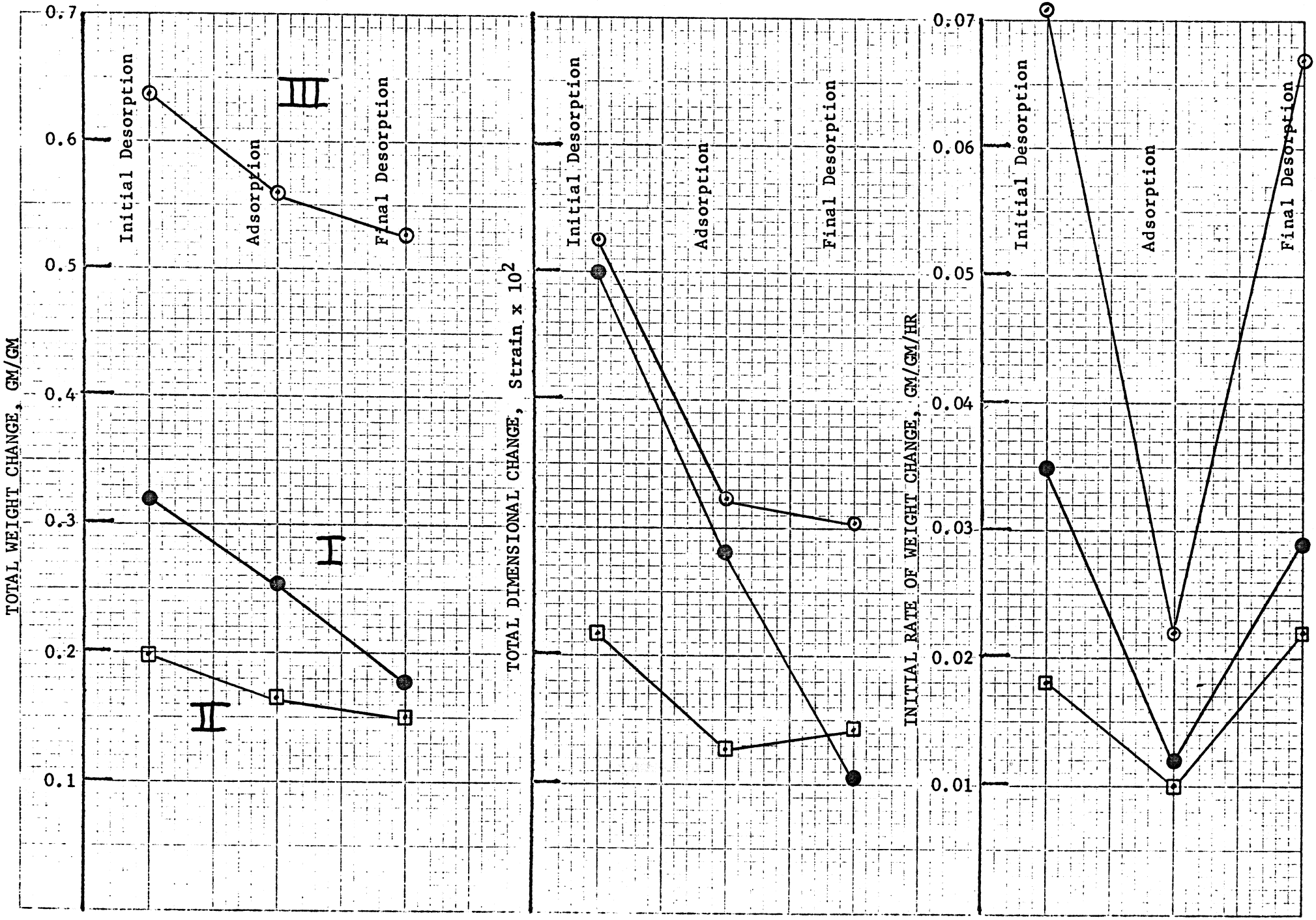


FIGURE 20. CEMENT #71.TYPE I. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

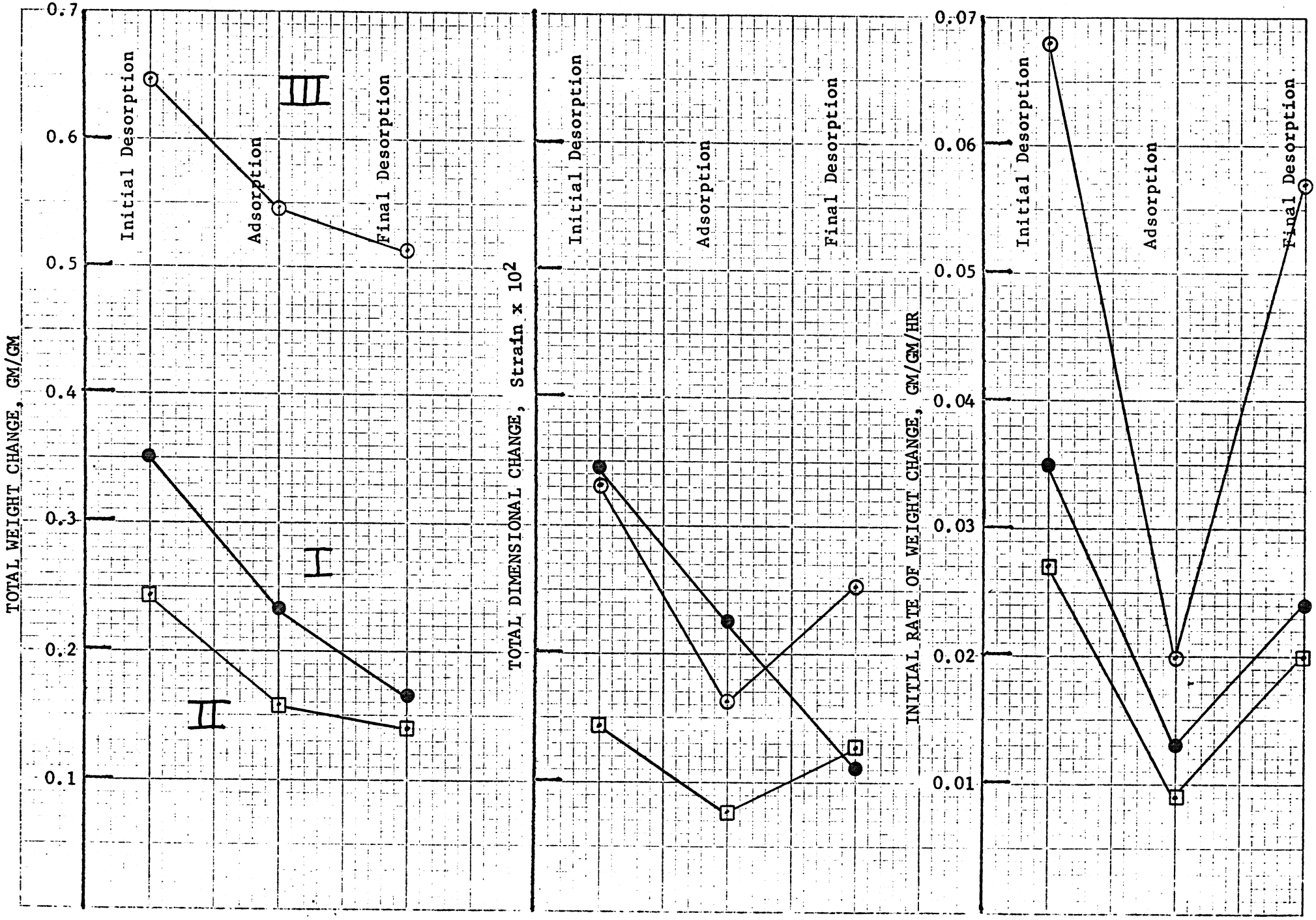


FIGURE 21. CEMENT #6. TYPE II. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

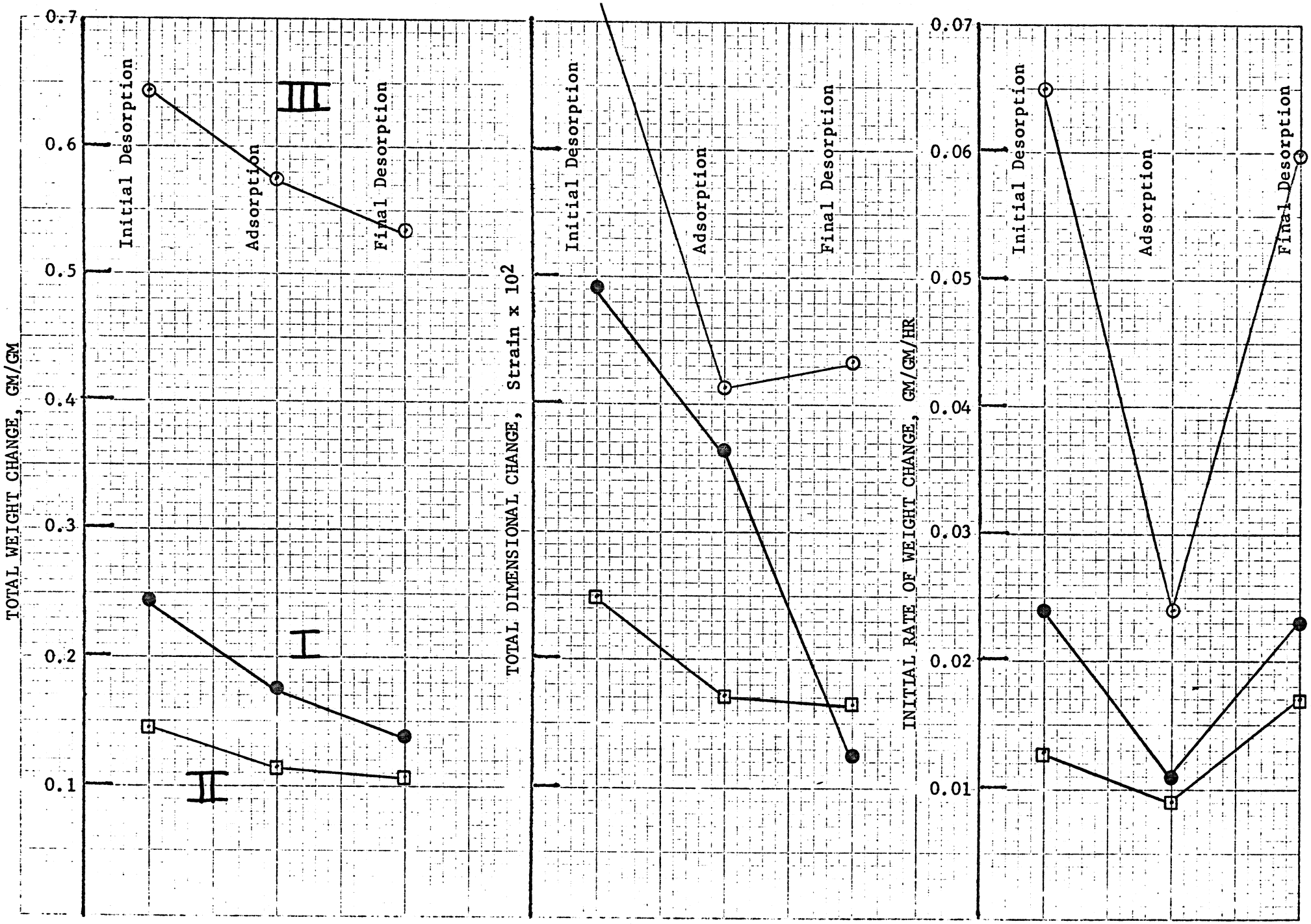


FIGURE 22. CEMENT #10.TYPE II. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

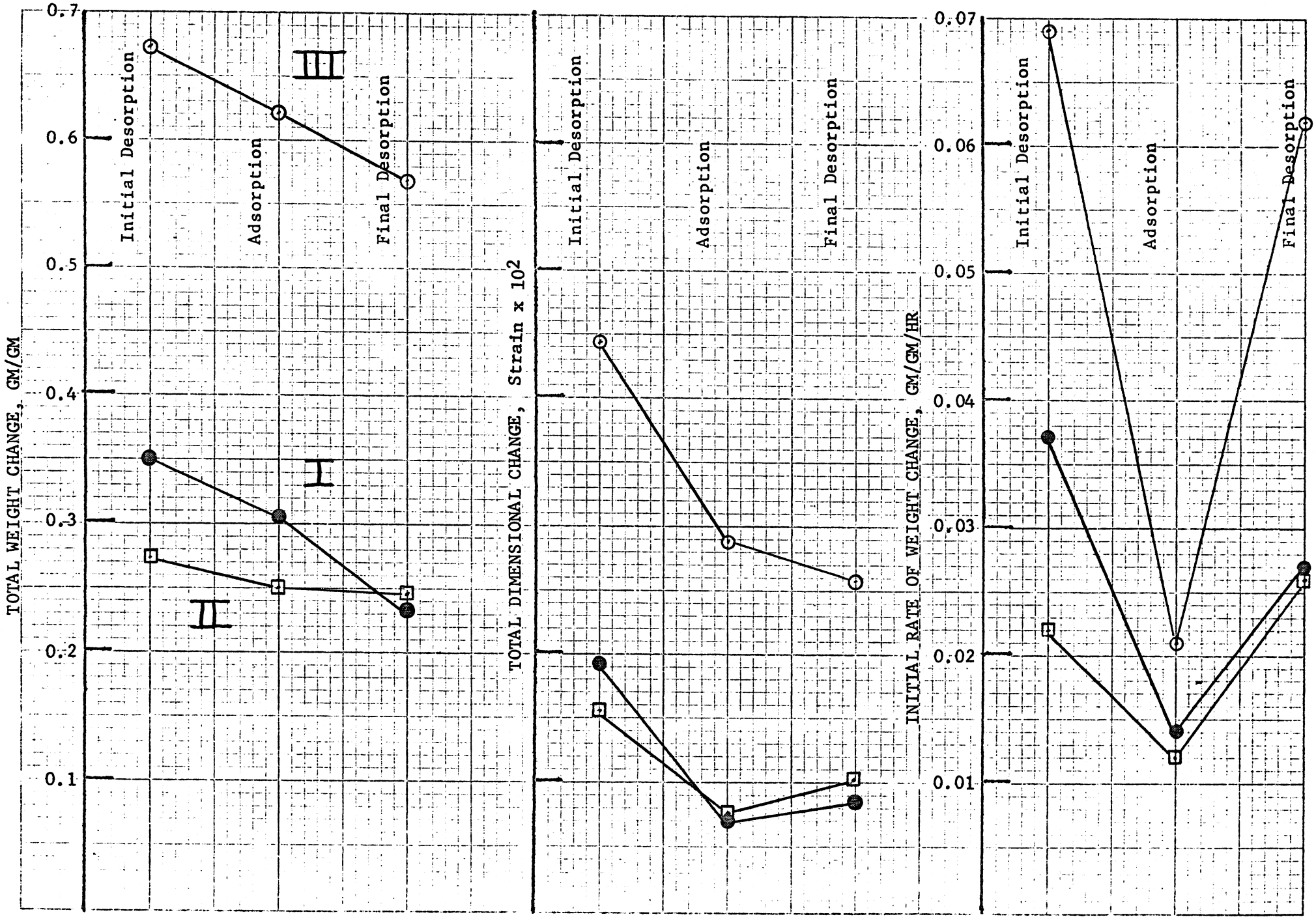


FIGURE 23. CEMENT #12.TYPE II. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

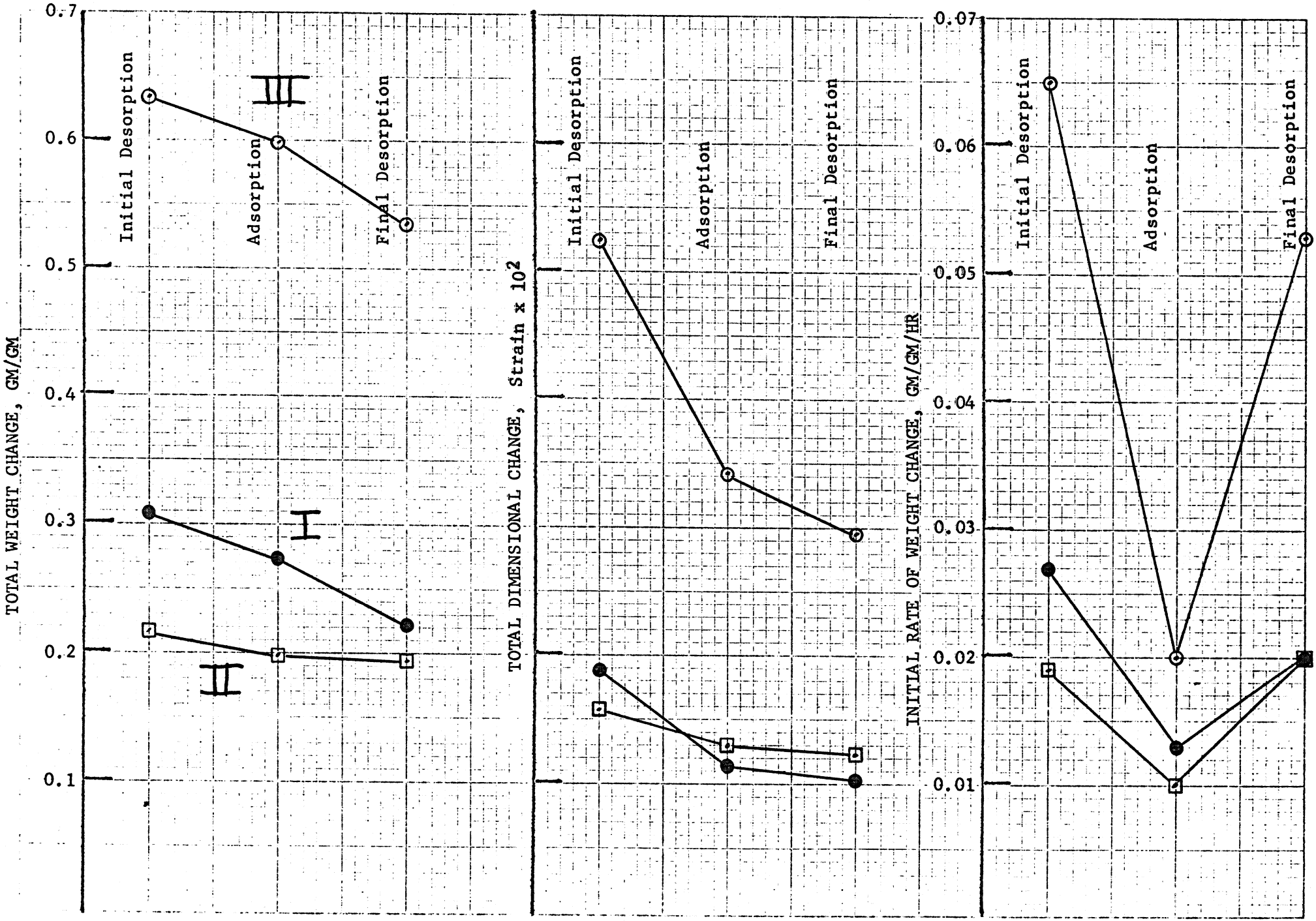


FIGURE 24. CEMENT #13.TYPE II. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

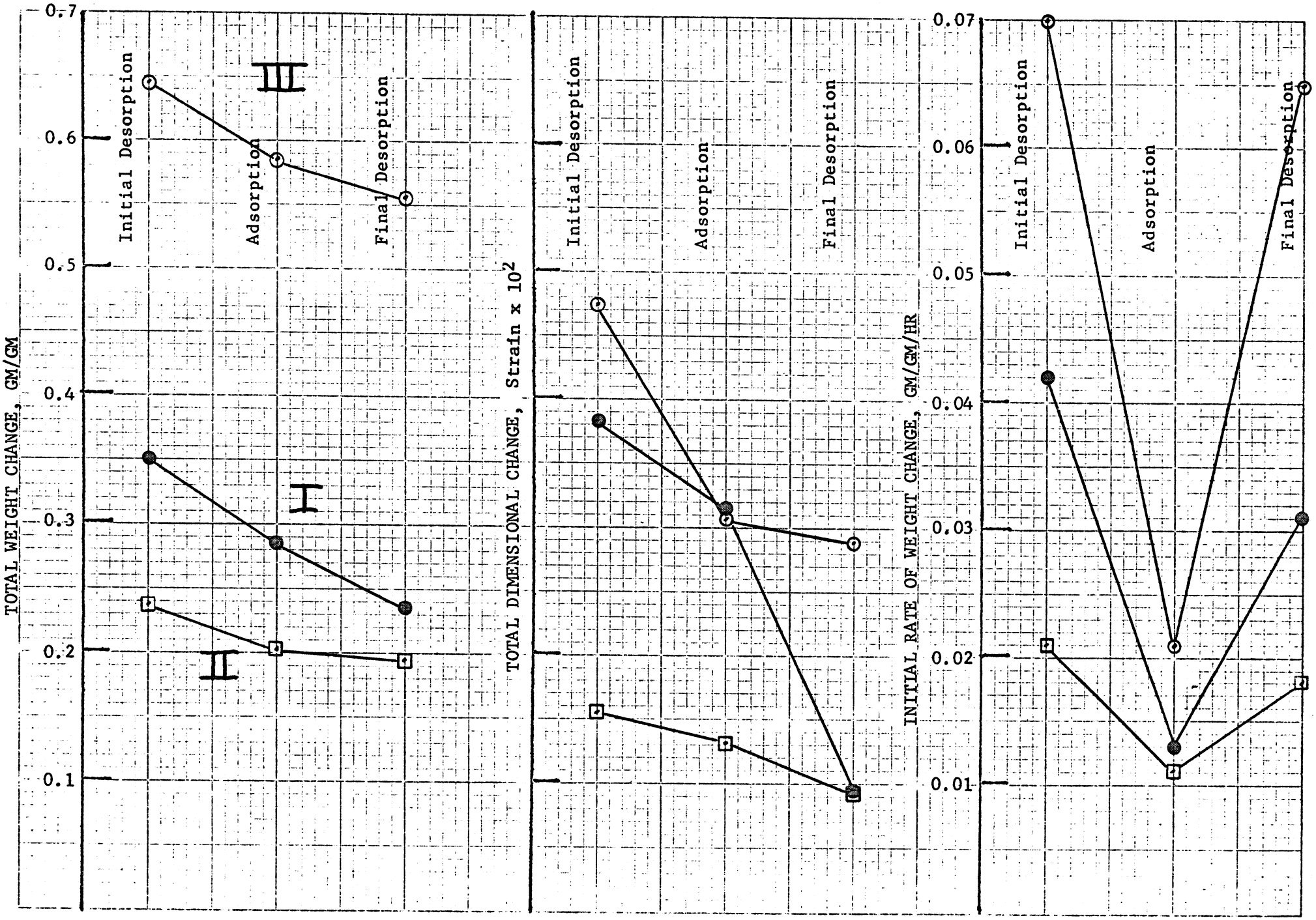


FIGURE 25. CEMENT #15.TYPE II. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

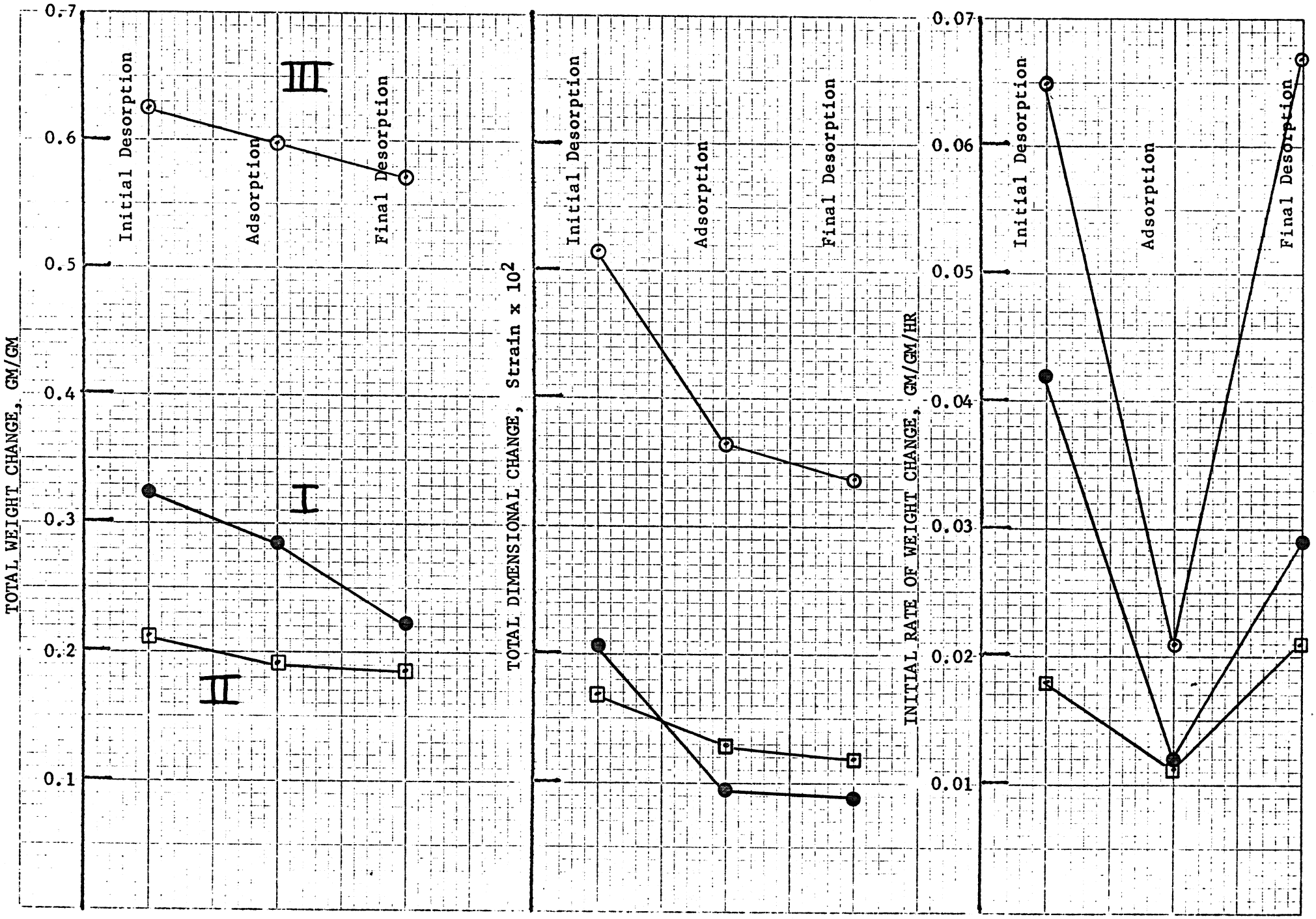


FIGURE 26. CEMENT #17.TYPE II. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

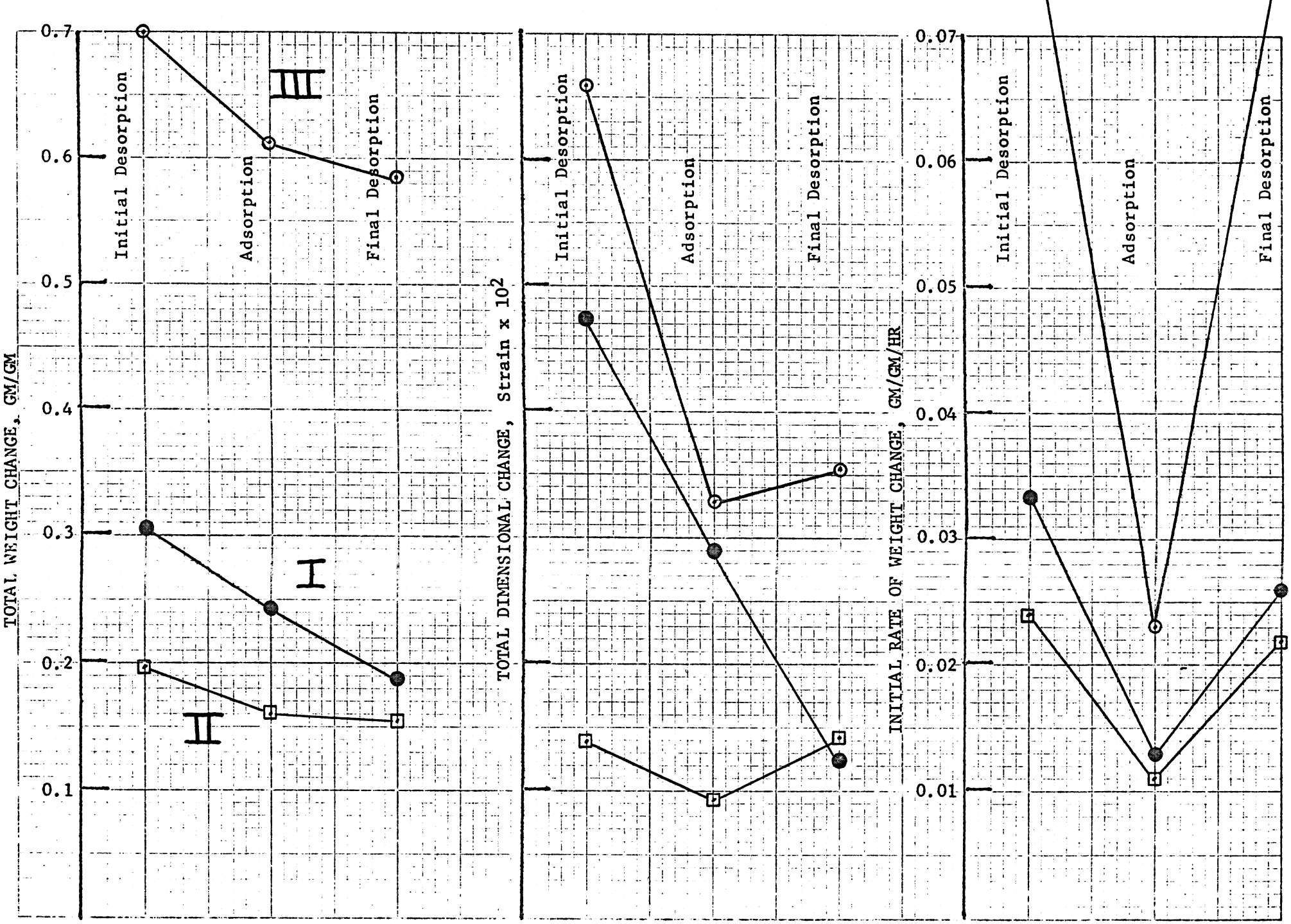


FIGURE 27. CEMENT #19.TYPE II. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION

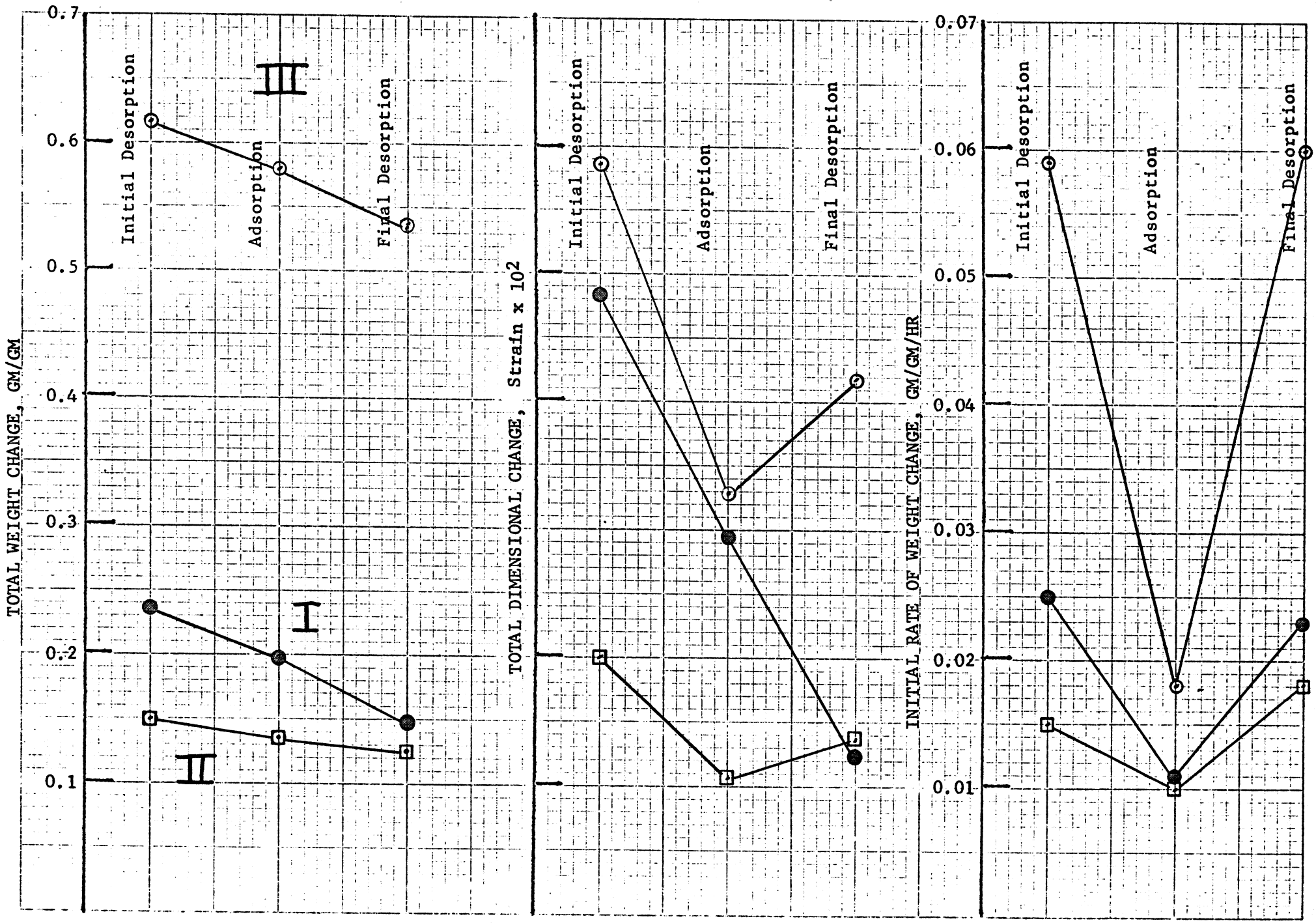


FIGURE 28. CEMENT #20. TYPE III. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

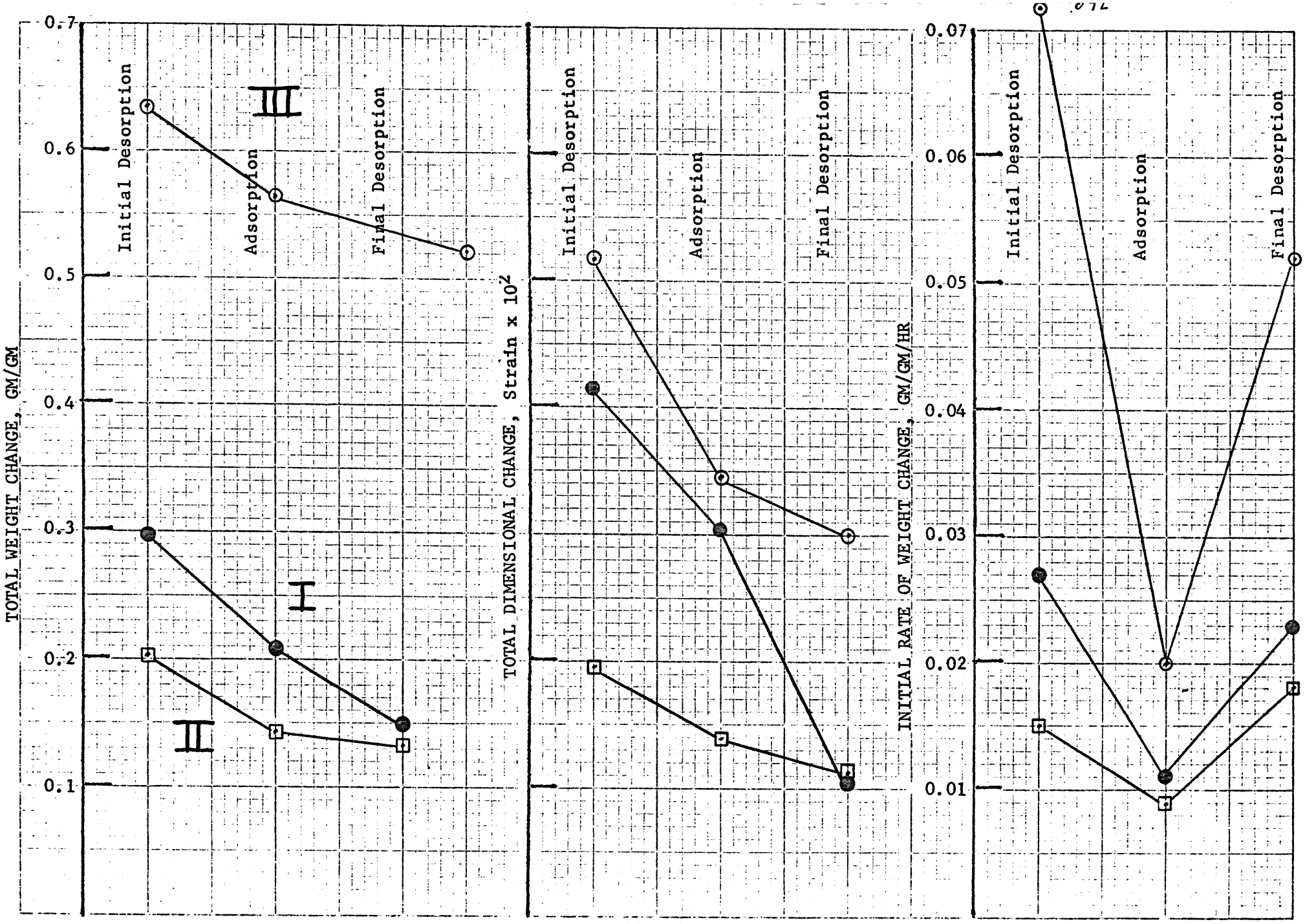


FIGURE 29. CEMENT #25.TYPE III.TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

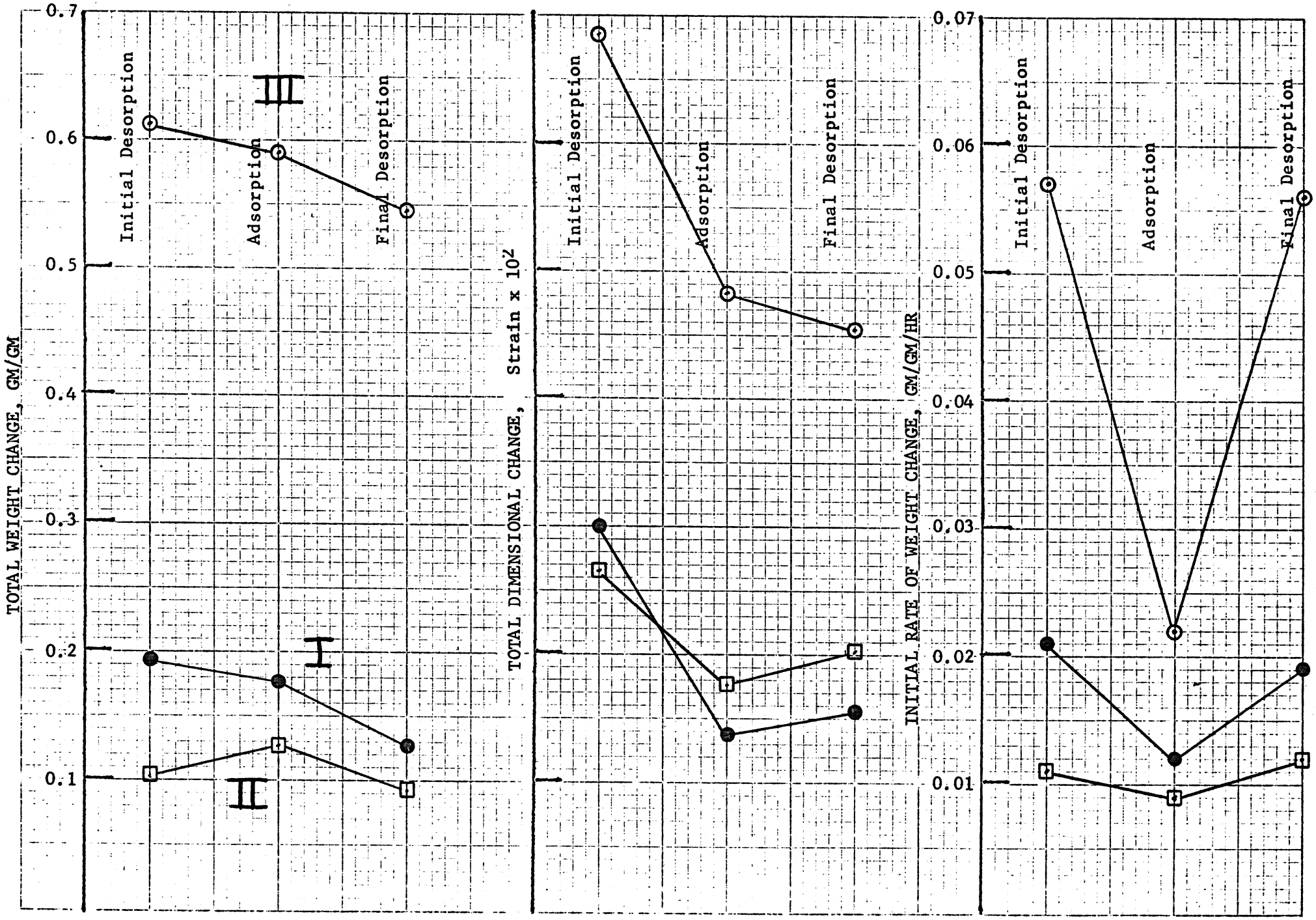


FIGURE 30. CEMENT #26. TYPE III. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

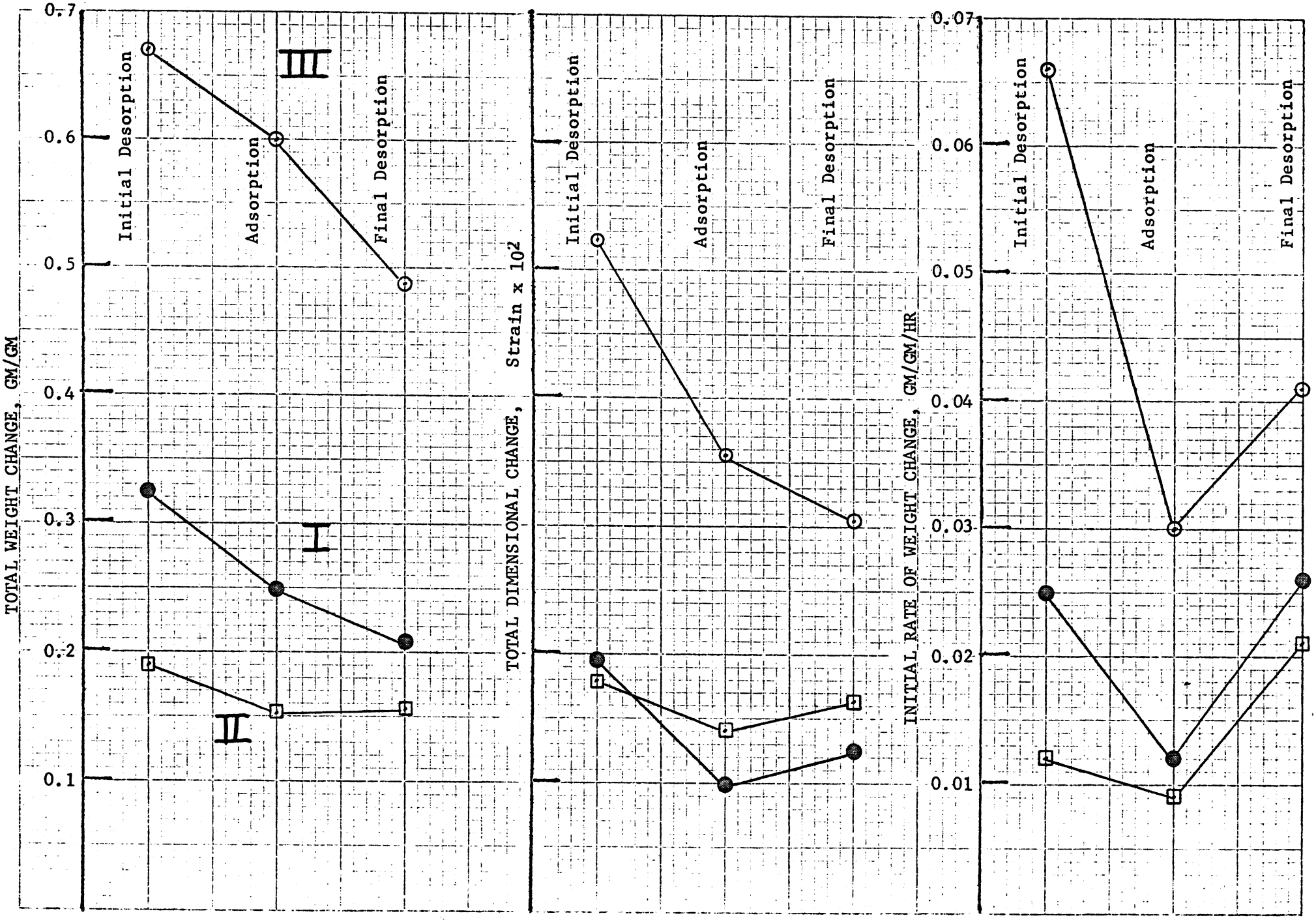


FIGURE 31. CEMENT #70.TYPE IV. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

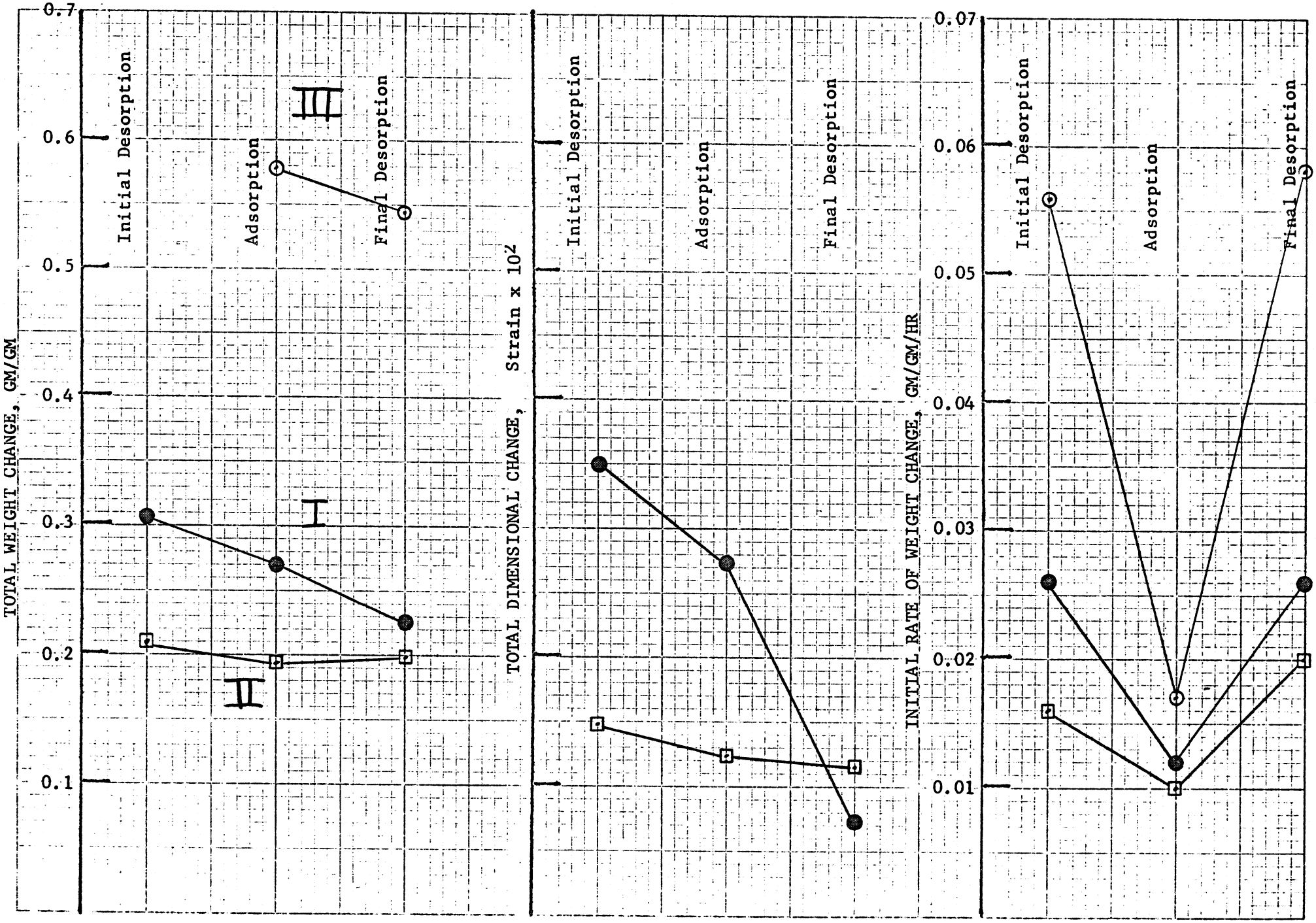


FIGURE 32. CEMENT #72.TYPE IV. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

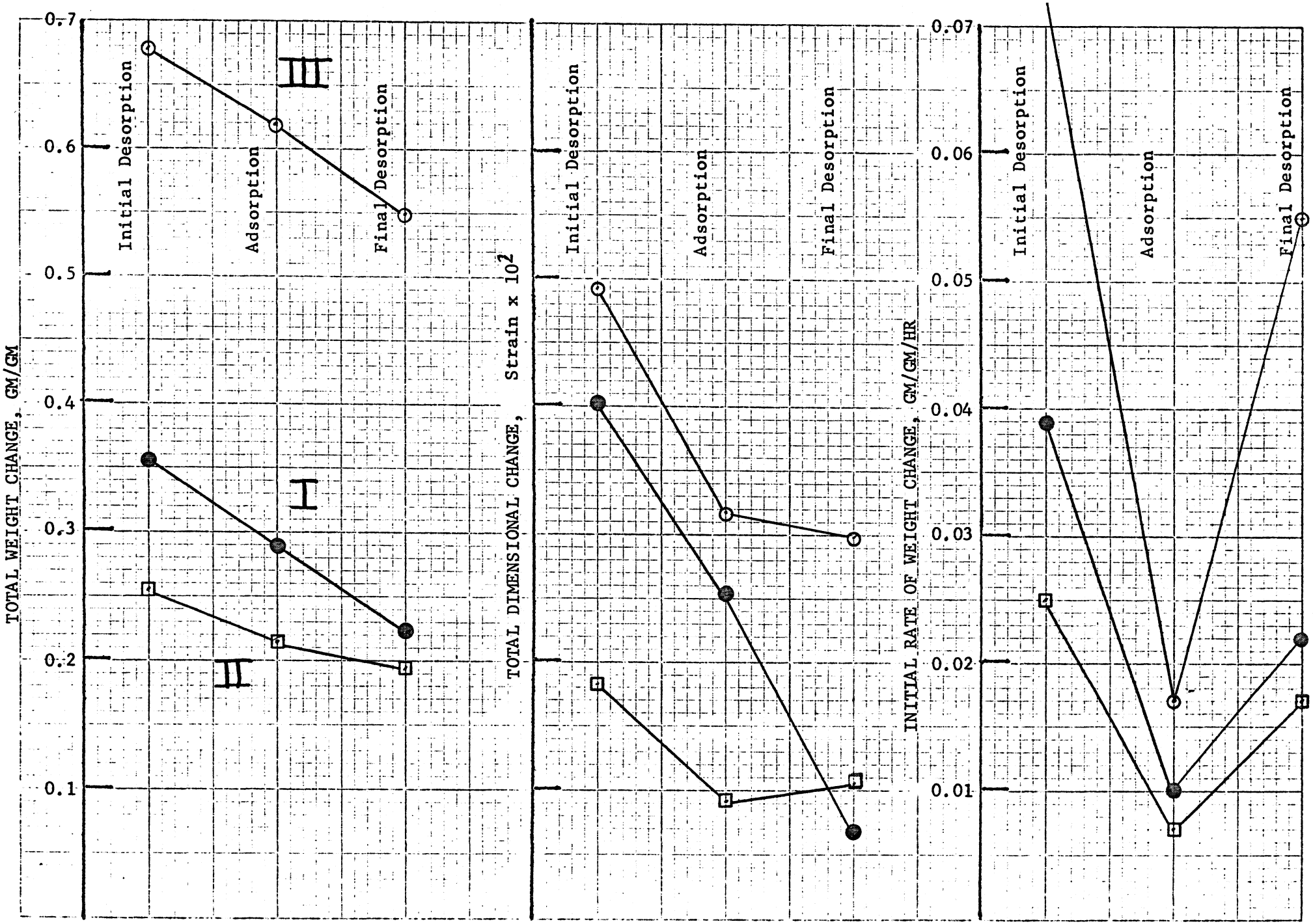


FIGURE 33. CEMENT #21.TYPE V. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

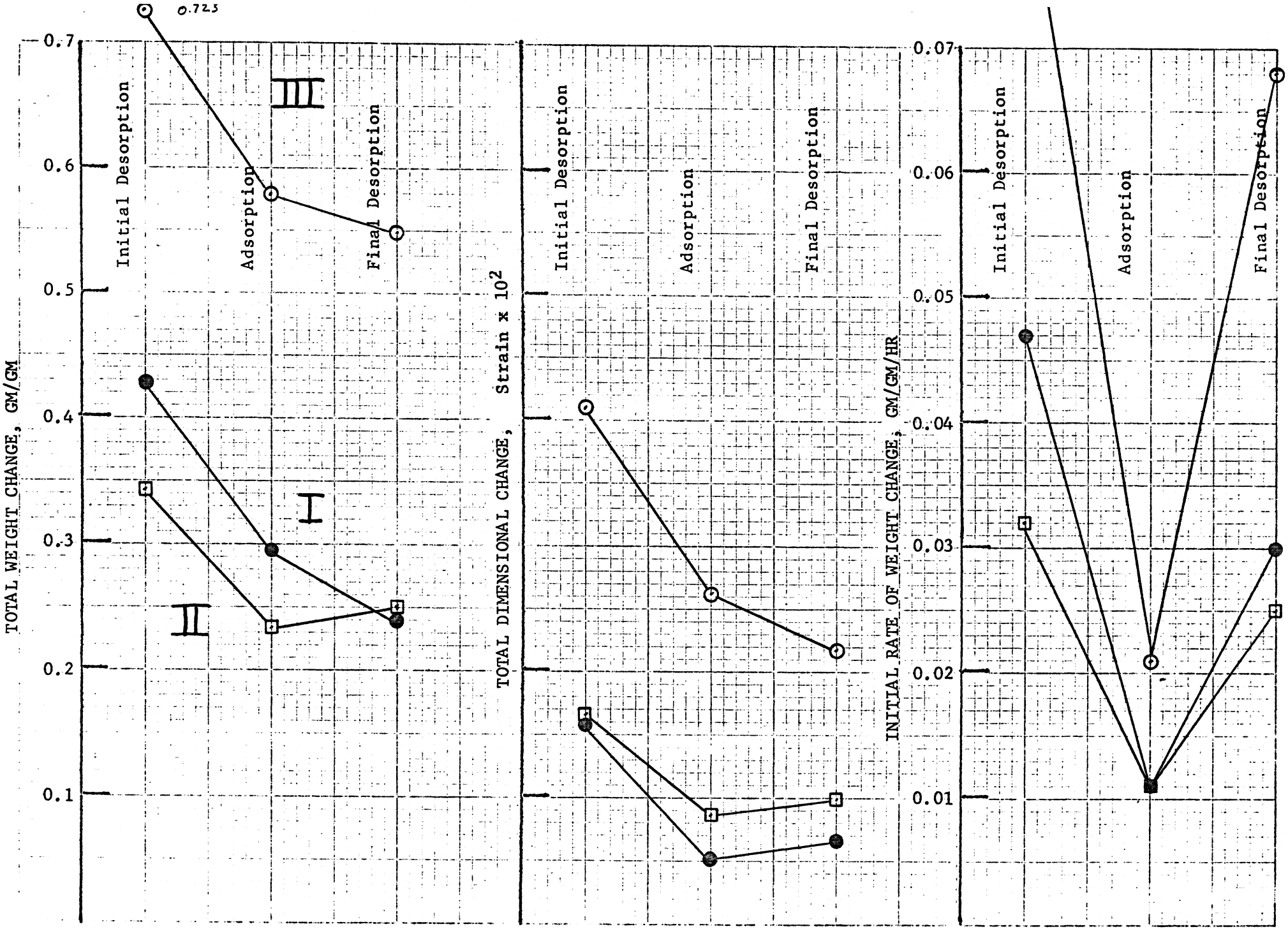


FIGURE 34. CEMENT #73.TYPE V. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION

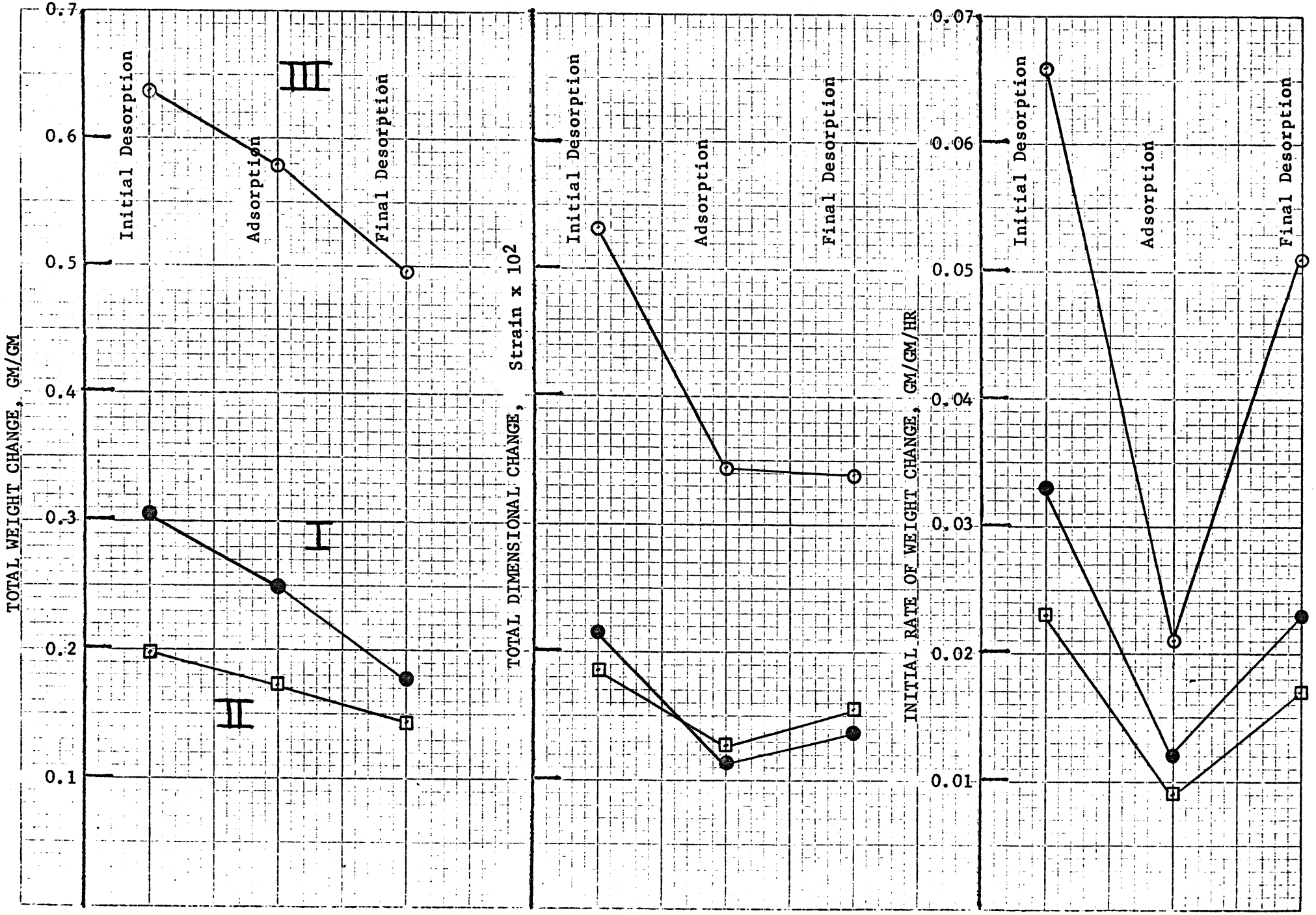


FIGURE 35. CEMENT #74. TYPE O.W.TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

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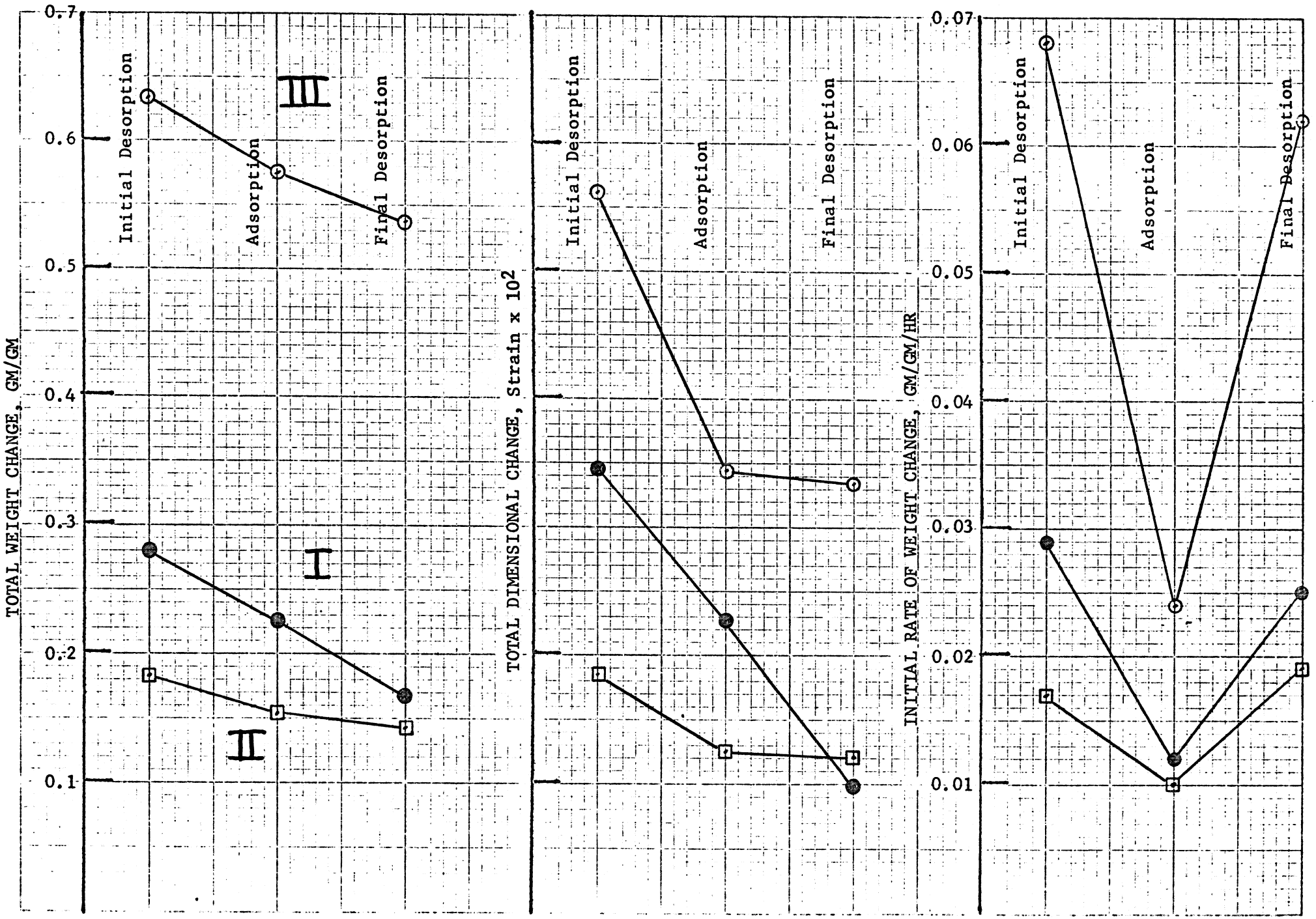


FIGURE 36. TYPE I CEMENTS (AVERAGE)

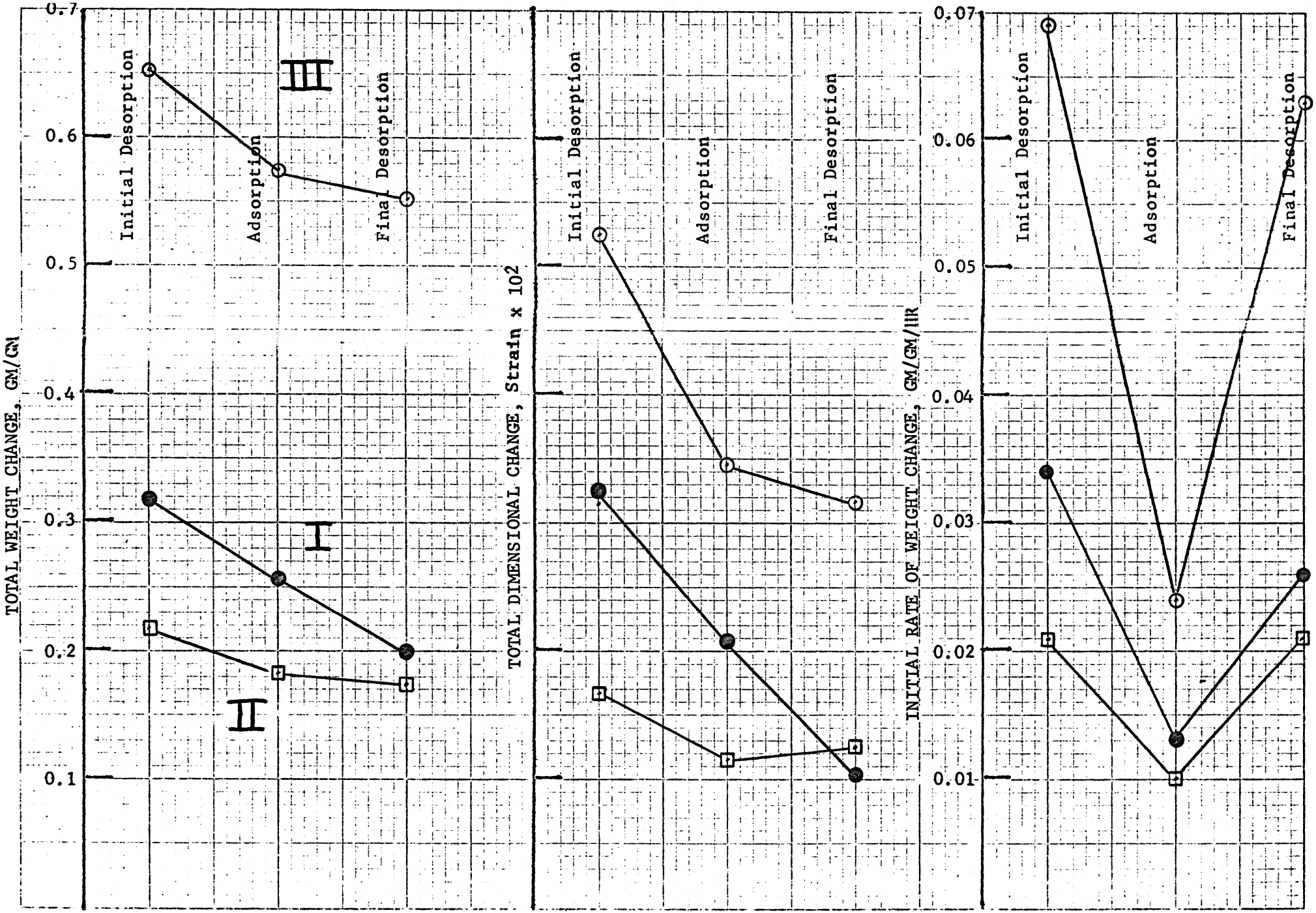


FIGURE 37. TYPE II CEMENTS (AVERAGE)

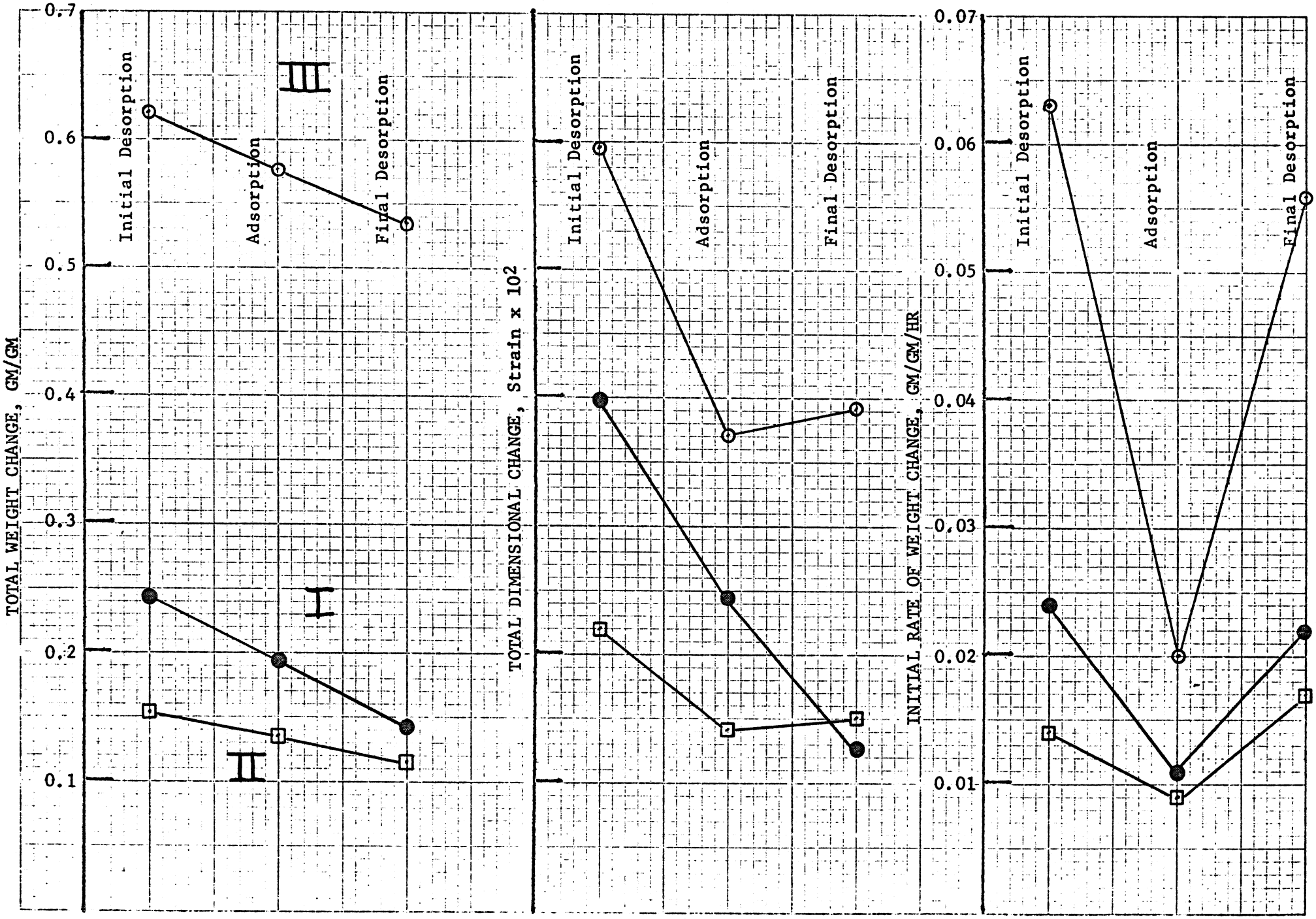


FIGURE 38. TYPE III CEMENTS (AVERAGE)

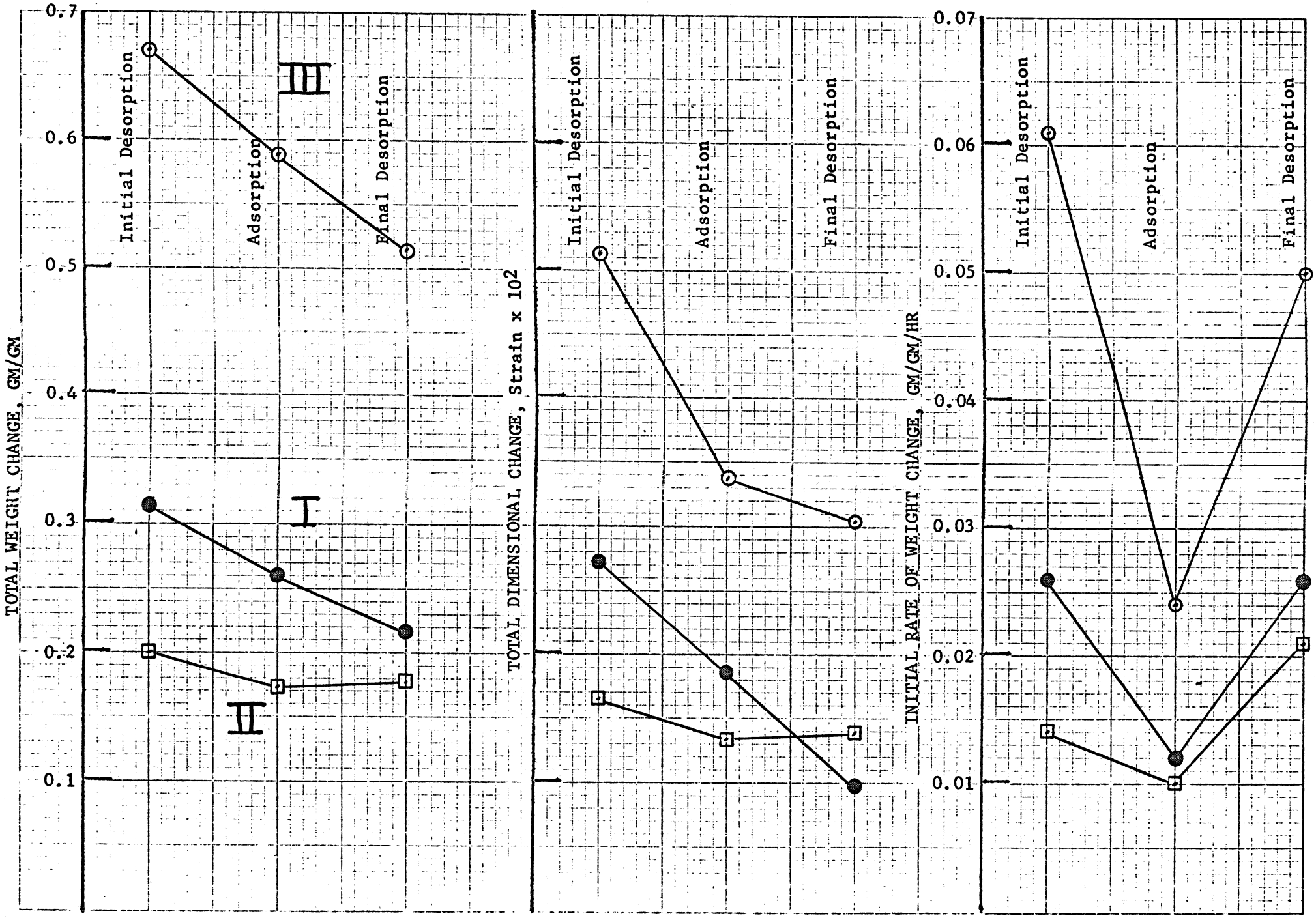


FIGURE 39. TYPE IV CEMENTS (AVERAGE)

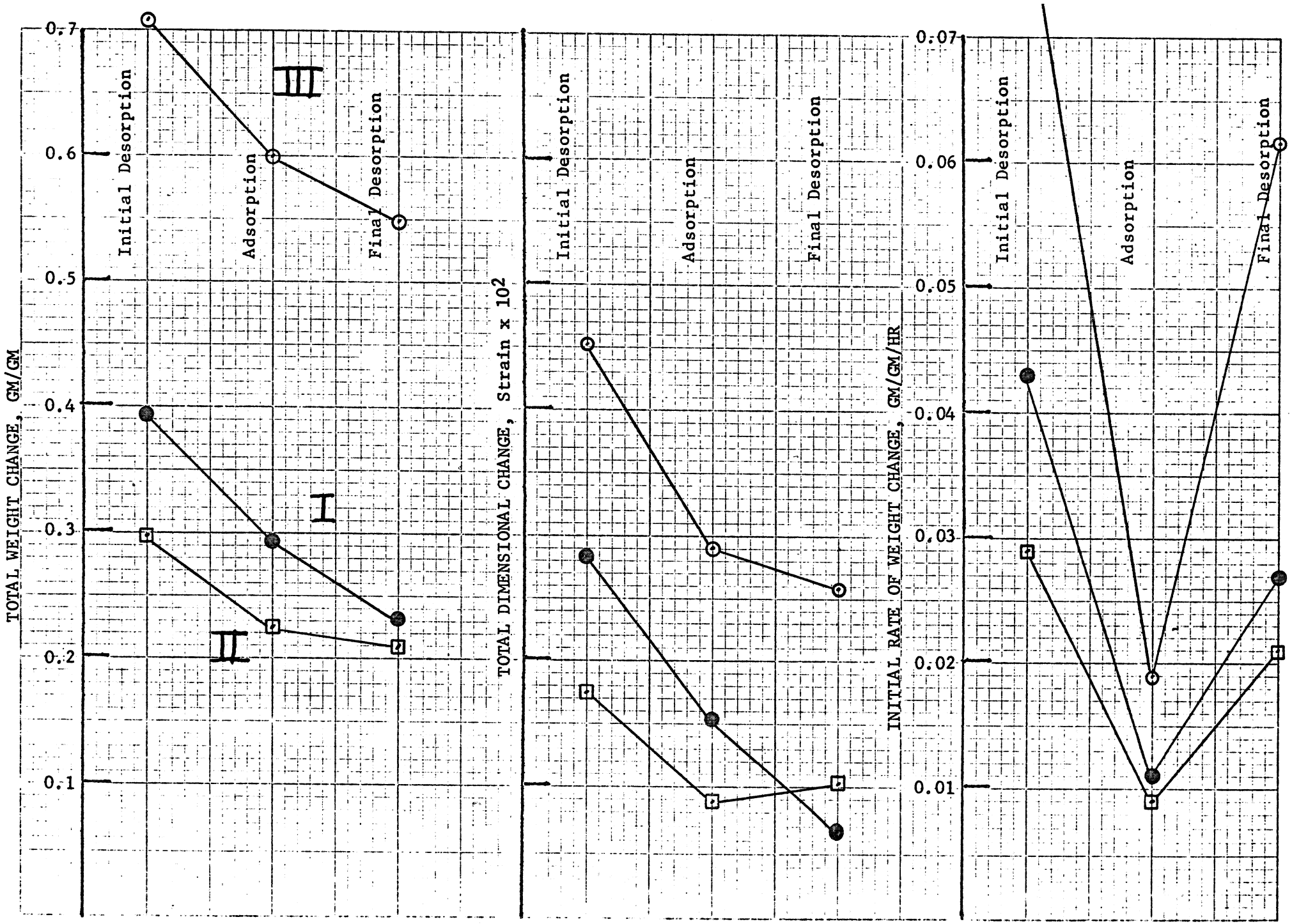


FIGURE 40. TYPE V CEMENTS (AVERAGE)

# APPENDIX A

## STATISTICAL ANALYSIS OF PHASE A DATA

## APPENDIX A

### STATISTICAL ANALYSIS* OF PHASE A DATA

Data description: One measurement on each of two specimens of 16 different types of cement was taken in each of two environments. (see Table A-1). The assumption is made that the two measurements on each cement for a given environment are statistically independent. The data are given in Table 1 in the form of the mean and difference of the two measurements on each cement.

Analysis: A one-way analysis of variance was performed for each environment to determine if there were significant differences in the cement mean. See Table A-2. For both environments, the effect of different cements was clearly significant with F values of 19.1 and 47.6 respectively for the two environments. (For significance at the 1 percent level, the F value must exceed 3.41).

To determine which cements were significantly different from which, the method of simultaneous comparisons (Tukey) was used. In Table A-3 lists of the ordered means are given. Along the right of the means, lines are drawn to connect those means which cannot be declared significantly different. That is, means not flanked by a common line are significantly different at 5 percent level.

A good description of Tukey's method is given in Chapter 9 of Contribution to Order Statistics by Sarhan and Greenberg (Wiley, 1962). The application of this method to Environment I means follows.

First we need a definition of the studentized range. Suppose $y_1$, --, $y_k$ is a random sample of size k from a $N(\mu, \sigma_y^2)$. Tukey's method is based on the studentized range statistic

---

* This exercise was performed when complete data from 16 cements were available.

TABLE A-1. TOTAL WEIGHT LOSS ON INITIAL DESORPTION OF SIXTEEN CEMENTS EXPOSED TO ENVIRONMENTS I & II

| Cement No. | ENVIRONMENT I Total Weight Loss | | ENVIRONMENT II Total Weight Loss | |
|---|---|---|---|---|
| | Average | Difference[a] | Average | Difference[a] |
| 9 | 0.387 | 0.002 | 0.293 | 0.035 |
| 5 | 0.280 | 0.024 | 0.159 | 0.026 |
| 14 | 0.260 | 0.004 | 0.156 | 0.003 |
| 3 | 0.259 | 0.059 | 0.175 | 0.028 |
| 4 | 0.238 | 0.002 | 0.159 | 0.006 |
| 11 | 0.191 | 0.044 | 0.127 | 0.013 |
| 12 | 0.360 | 0.018 | 0.273 | 0.014 |
| 6 | 0.351 | 0.022 | 0.242 | 0.004 |
| 17 | 0.324 | 0.008 | 0.211 | 0.014 |
| 13 | 0.308 | 0.013 | 0.218 | 0.022 |
| 26 | 0.194 | 0.013 | 0.102 | 0.003 |
| 25 | 0.297 | 0.001 | 0.203 | 0.004 |
| 70 | 0.323 | 0.004 | 0.190 | 0.018 |
| 21 | 0.355 | 0.015 | 0.255 | 0.004 |
| 73 | 0.428 | 0.081 | 0.342 | 0.032 |
| 74 | 0.305 | 0.021 | 0.197 | 0.013 |

(a) Difference between two specimens.

TABLE A-2a. ANALYSIS OF VARIANCE TABLE: ENVIRONMENT I

| Source | Sum of Squares | d.f. | Mean Square | F |
|---|---|---|---|---|
| Total | 0.137835 | 31 | | |
| Due to cements | 0.129600 | 15 | 0.00864 | 19.1 |
| Error | 0.007235 | 16 | 0.000452 | |

TABLE A-2b. ANALYSIS OF VARIANCE TABLE: ENVIRONMENT II

| Source | Sum of Squares | d.f. | Mean Square | F |
|---|---|---|---|---|
| Total | 0.122075 | 31 | | |
| Due to cements | 0.119400 | 15 | 0.00796 | 47.6 |
| Error | 0.002675 | 16 | 0.000167 | |

TABLE A-3. SIGNIFICANT DIFFERENCES OF ORDERED MEANS BY TUKEY'S METHOD

| (a) ENVIRONMENT I | | (b) ENVIRONMENT II | |
|---|---|---|---|
| Cement No. | Mean | Cement No. | Mean |
| 11 | 0.191 | 26 | 0.102 |
| 26 | 0.194 | 11 | 0.127 |
| 4 | 0.238 | 14 | 0.156 |
| 3 | 0.259 | 5 | 0.159 |
| 14 | 0.260 | 4 | 0.159 |
| 5 | 0.280 | 3 | 0.175 |
| 25 | 0.297 | 70 | 0.190 |
| 74 | 0.305 | 74 | 0.197 |
| 13 | 0.308 | 25 | 0.203 |
| 70 | 0.323 | 17 | 0.211 |
| 17 | 0.324 | 13 | 0.218 |
| 6 | 0.351 | 6 | 0.242 |
| 21 | 0.355 | 21 | 0.255 |
| 12 | 0.360 | 12 | 0.273 |
| 9 | 0.387 | 9 | 0.293 |
| 73 | 0.428 | 73 | 0.342 |

$$q_{k\nu} = \frac{\max_i y_i - \min_i y_i}{\hat{\sigma}_y} ,$$

when $\hat{\sigma}_y^2$ is an estimate $\sigma_y^2$ of the usual $x^2$ type with $\nu$ degrees of freedom and is independent of the $y_i$'s. The studentized range is simply the sample range standardized in the usual way. Let $\bar{x}_1, \bar{x}_2, \ldots \bar{x}_{16}$ be the means of the 16 cements indexed in some convenient fashion. Under the hypothesis of no difference in the cement means, we have that

$$\frac{\max \bar{x}_1 - \min \bar{x}_1}{s_m} ,$$

where $s_m^2$ is an estimate of $\sigma_m^2$, the variance of a mean, is a studentized range. The variance of each of these means is

$$\sigma_m^2 = \frac{\sigma^2}{2} ;$$

here $\sigma^2$ is the variance of an individual observation. We have an estimate of $\sigma^2$ from the error mean square of the ANOVA given in Table A-2a

$$\sigma^2 = 4.52 \times 10^{-4} .$$

Thus an estimate of the variance of each of the means is

$$s_m^2 = \frac{4.52}{2} \times 10^{-4} ,$$

or

$$s_m = 0.0150.$$

This estimate has $\nu = 16$ degrees of freedom and is independent of the $\bar{x}_i$'s.

As in equation (9.3.5) of Sarhan and Greenberg, we will declare two means, $\bar{x}_u$ and $\bar{x}_t$ to be significantly different whenever

$$|\bar{x}_t - \bar{x}_u| > q\, s_m$$

The multiplier, q, is the upper $\underline{\alpha}$ percent point of the studentized range described above. Such means are significantly different because they are further apart than one expects even the extreme values of a sample of means to be.

For these data, $\nu = 16$, $k = 16$, and letting $\underline{\alpha} = .05$, we have from the table of percentage points of the studentized range (Sarhan and Greenberg, p. 114)

$$q_{\underline{\alpha}} = 5.66 .$$

We will declare means significantly different whenever

$$|\bar{x}_t - \bar{x}_u| > 5.66\ (.015) = 0.085.$$

Now, order the means from smallest to largest as in Table A-3. Starting with the smallest mean, 0.191 (cement no. 11), we can say that any mean larger than 0.191 + 0.085 = 0.276 is significantly different. A vertical line may be drawn from cement no. 11 down to cement no. 14 indicating no difference. The means inbetween are necessarily not different from one another, but all means past cement no. 14 are different from the mean for cement no. 11.

The second smallest means is 0.194 for cement no. 26. Any mean larger than 0.194 + 0.085 = 0.279 is declared different. Here no line need be drawn for cement no. 26, like cement no. 11, is different from cement no. 5 but not different from no. 14.

Trying the third cement (no. 4), we have a new line to no. 70. This process is repeated until the last cement is covered by a line.

The same process was applied to the means for Environment II, but here the estimate of the variance of the means is

$$s_m^2 = \frac{(1.67) \times 10^{-4}}{2} \quad \text{or} \quad s_m = 0.0091.$$

Hence, two means are declared different whenever

$$|\bar{x}_t - \bar{x}_u| > (5.66)\ (0.0091) = 0.052.$$

The corresponding lines are drawn in Table A-3.

Both of the above analyses depend on the assumption that the two replicate measurements on the same cement in the same environment are statistically independent. Although the two specimens were exposed in separate test chambers, there were some elements in common (time, environmental controls, mixing of cement, and perhaps more). There exists a possibility that a correlation exists between the two measurements. The effects of this probably would be to underestimate the error term and hence overestimate the F values.

A similar effect would appear in Tukey's method because the same error term was used. The validity of this independent assumption was checked by replicate measurements (cement no. 16). The question of the existence of larger variances between occasions than within occasions was addressed.

Cement no. 16 (I) was measured under the same conditions but on two different occasions (July, 1971, December, 1971). Let

$$y_{ij} = \mu + a_i + e_{ij}$$

be the measurement on the $i^{th}$ occasion ($i = 1, 2$) and $j^{th}$ replication ($j = 1, 2$). Here,

$\mu$ = underlying "true value"
$a_i$ = error due to the $i^{th}$ occasion, but common to all replications taken on the occasion
$e_{ij}$ = error specific to $j^{th}$ replication of $i^{th}$ occasion.

We assume

$$a_i : N(0, \sigma_a^2)$$

$$e_{ij} : N(0, \sigma_e^2)$$

with all $a_i$'s, $e_{ij}$'s independent. Thus $\sigma_e^2$ is the "within" occasion variance. The variance of $y_{ij}$ is now

$$\sigma^2_{y_{ij}} = \sigma_a^2 + \sigma_e^2$$

The question is whether $\sigma_a^2$ is much different from zero, or in other terms, whether the previous analysis is valid since it was performed under the assumption that $\sigma_a^2 = 0$.

Let $y_{i\cdot} = \frac{1}{2}(y_{i1} + y_{i2})$.

Then

$$\sigma^2_{y_{i.}} = \sigma^2_a + \frac{\sigma^2_e}{2}.$$

We have an estimate of $\sigma^2_{yi}$, available from every pair, $y_{1\cdot}$ and $y_{2\cdot}$, of means of measurements on two different occasions

$$\hat{\sigma}^2_{yi.} = \frac{1}{2-1}\sum_{i=1}^{2}(y_{i\cdot} - y)^2 = \frac{1}{2}(y_{1.} - y_{2\cdot})^2$$

The data for these three pairs are

| $y_{1\cdot}$ | $y_{2\cdot}$ | $\frac{1}{2}(y_{1\cdot} - y_{2\cdot})^2$ |
|---|---|---|
| .294 | .297 | $4.5 \times 10^{-6}$ |
| .167 | .203 | $648.0 \times 10^{-6}$ |
| .632 | .635 | $12.5 \times 10^{-6}$. |

A simple average of this yields

$$\hat{\sigma}^2_{y_{i\cdot}} = 227 \times 10^{-6} \quad \text{(3 deg. freedom)}.$$

Thus from this source we have

$$\sigma^2_a + \frac{\sigma^2_e}{2} = 227 \times 10^{-6}.$$

Whereas, from the previous analysis, we have an estimate of $\sigma^2_e$ formed by pooling the error estimate from Table A-2a and A-2b

$$\hat{\sigma}^2_e = \frac{452 + 167}{2} \times 10^{-6} = 310 \times 10^{-6} \quad \text{(32 deg. freedom)}$$

Thus

$$F_{3,32} = \frac{\sigma^2_e + 2\sigma^2_a}{\sigma^2_e} = \frac{454}{310} = 1.5$$

is not significantly large, indicating that $\sigma^2_a$ is probably small.

It should be noted that even if we did accept the somewhat higher estimate of error

$$\hat{\sigma}^2_{y_{ij}} = 454 \times 10^{-6}$$

instead of the values used in Tables A-2a and A-2b the F's for cement would still be quite high.

In any event there is no evidence in the replicate data to suppose that the between occasion error is any larger than the within occasion error used in the analyses.