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

DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

by

David R. Lankard and Alvin J. Walker

August, 1972

614

BATTELLE
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

TABLE OF CONTENTS

APPENDIX A

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF FIGURES

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.

---

* 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

* 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) Adsorption at 100 RH/74 F (170 hours) Final Desorption at 75 RH/74 F (170 hours)
Environment II:	Initial Desorption at 75 RH/74 F (170 hours) Adsorption at 100 RH/74 F (170 hours) Final Desorption at 75 RH/74 F (170 hours)
Environment III:	Initial Desorption at 25 RH/74 F (170 hours) Adsorption at 100 RH/74 F (170 hours) 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 High Total Dimensional Change High Initial Rate of Weight Change	Cement 2
High Total Weight Change Low Total Dimensional Change High Initial Rate of Weight Change	Cements 9-18
Low Total Weight Change Low Total Dimensional Change Low Initial Rate of Weight Change	Cements 4-11
Low Total Weight Change High Total Dimensional Change Low Initial Rate of Weight Change	Cements 8-14-23
Intermediate to High Total Weight Change Intermediate to High Total Dimensional Change Intermediate to High Initial Rate of Weight Change	Cements 1-3-5-7-16-22-27-71

Intermediate to Low Total Weight Change Intermediate to Low Total Dimensional Change 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 High Total Dimensional Change High Initial Rate of Weight Change	None
High Total Weight Change Low Total Dimensional Change High Initial Rate of Weight Change	Cement 12
Low Total Weight Change Low Total Dimensional Change Low Initial Rate of Weight Change	None
Low Total Weight Change High Total Dimensional Change Low Initial Rate of Weight Change	Cement 10
Intermediate to High Total Weight Change Intermediate to High Total Dimensional Change Intermediate to High Initial Rate of Weight Change	Cements 15-17-19
Intermediate to Low Total Weight Change Intermediate to Low Total Dimensional Change 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], ($\Delta L/L$) 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	0.208	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)] ($\Delta L/L$) 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	0.154	--	--	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

ment 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
pe 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
FRAT10=        15.3322288630
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)	0.546
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)	0.623
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
10(II)	0.643
1(I)	0.645
15(II)	0.645
6(II)	0.647
5(I)	0.648
7(I)	0.651
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]00
A4 = 26.408002 000
A5 = 26.337424 000
SS3 = 0.070578 000
SS = 0.082208 000
SS2 = 0.011532 [illegible]00
SS3* = 0.002707097
SS2* = 0.000303 4375
SS* = 0.0013 40089
FRATIO= 6.2643774454
CRITICAL DIFF = 0.0802[illegible]78428

(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	=	3.6883080000
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	=	15.2777570399
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	=	1.7910916000
A4	=	1.7882535000
A5	=	1.7105370156
SS3	=	0.0777164844
SS	=	0.0805539844
SS2	=	0.0028375000
SS3*	=	0.0025069834
SS2*	=	0.0000886719
SS*	=	0.0012786347
FRATIO	=	28.2725877512
CRITICAL DIFF	=	0.0396182159

(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 = 37.2690000000
SUM2 = 21.7382830000
A4 = 21.7288035000
A5 = 21.7027868906
SS3 = 0.0260166094
SS = 0.0354961094
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.

ON THE METHOD OF SIMULTANEOUS COMPARISONS[a]

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

CEMENT NO	MEAN	SPECS
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	

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
FRAT10=        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
FRAT10=         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
FRAT10= 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
FRAT10=	5.6669375153
CRITICAL DIFF =	0.0628721750

(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
FRAT10= 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
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

SPECS

```
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
FRAT10=        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
FRAT1O=    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
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

SPECS

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

(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
FRAT10= 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
FRAT10= 11.2376910019
CRITICAL DIFF = 0.0051259431

(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
FRAT10= 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 71-27-18-7-22-16-5-24-2-1-14-3-23-8 27-18-7-22-16-5-24-2-1-14-3-23-8-4 1-14-3-23-8-4-11	71-27-23-16-1 27-23-16-1-2-24-18-22-7 16-1-2-24-18-22-7-8 5-3-11-14-4-9	9-71-18-27-16 71-18-27-16-7-24-2-3-1-22-5-23-4 27-16-7-24-2-3-1-22-5-23-4-8-14 5-23-4-8-14-11
Initial Desorption Environment II	9 18-71-7-2-27-24-22-16 71-7-2-27-24-22-16-1-3-4-5-14 22-16-1-3-4-5-14-23-8 23-8-11	27-71-16-1-23-9-3-5-24-11-7-14-4 71-16-1-23-9-3-5-24-11-7-14-4-22-2-18 16-1-23-9-3-5-24-11-7-14-4-22-2-18-8	9-2-1-22-71-24 2-1-22-71-24-27-7-3-16-23-5-4-14-8 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 27-16-17-5-1-3-18-8-71-22-2-24-14-23 24-14-23-4-11	3-16-27-23-1 16-27-23-1-5-2-11-8-71 27-23-1-5-2-11-8-71-4-9-22 23-1-5-2-11-8-71-4-9-22-14 1-5-2-11-8-71-4-9-22-14-7-24 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 22-5-24-14-4 4-11
Adsorption Environment I	18-9-22-71-2-7-23-5 9-22-71-2-7-23-5-27-3 22-71-2-7-23-5-27-3-11-1 71-2-7-23-5-27-3-11-1-8-16 7-23-5-27-3-11-1-8-16-4-14	1-27-18-16-23-8-71-24-2-21-7 11-5-14 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 9-2-22-7-24-71 2-22-7-24-71-27-1 7-24-71-27-1-3-16-4 24-71-27-1-3-16-4-11 71-27-1-3-16-4-11-23-8-5 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 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 11-23-2-1-8-5-4-3-16-27-7-71-22 1-8-5-4-3-16-27-7-71-22-18 5-4-3-16-27-7-71-22-18-24 22-18-24-9	9-5-14 5-14-1-3-8-27-7-18 14-1-3-8-27-7-18-22 1-3-8-27-7-18-22-16-23-71-2 8-27-7-18-22-16-23-71-2-11-24 16-23-71-2-11-24-4
Final Desorption Environment I	18-9-22-2 9-22-2-7-71 22-2-7-71-23-14-8 2-7-71-23-14-8-11 7-71-23-14-8-11-3-24-1-16-5 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 18-22-8-5-14-1-23-24-3-2-7-27-16-11-4
Final Desorption Environment II	18-9-2 9-2-22-7-71 2-22-7-71-24 22-7-71-24-3-1-16 71-24-3-1-16-4-27-8-11-14 24-3-1-16-4-27-8-11-14-23 27-8-11-14-23-5	27-14-8-71-3-2-9-16-24-22-7-1-23-5-11-18 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 71-22-2-24-3-16-1-27-4-7-14-11-23 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 3-11-7-16-2-23-71-27-8-4-24-14	23-14-3-16-24-27-4-5-2-22-11 3-16-24-27-4-5-2-22-11-18-71-8 24-27-4-5-2-22-11-18-71-8-7 5-2-22-11-18-71-8-7-9	9-1-18-71-11-3-5-22-7-16-24 1-18-71-11-3-5-22-7-16-24-23-27-2-14 18-71-11-3-5-22-7-16-24-23-27-2-14-4 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 13-19-10	10-19 15-6 17-12-13	15-17-12-6-19 12-6-19-13 19-13-10
nitial Desorption nvironment II	12-6-15 6-15-13-17-19 10	10-6 6-17-13-12-15-19	6-19-12-15 19-12-15-13-17 13-17-10
nitial Desorption nvironment III	19-12-6-15-10-13-17	10-19 19-13 13-17-15-12 12-6	19-15 15-12-6-17-13-10
lsorption nvironment I	12-15-17-13 15-17-13-19 13-19-6 6-10	10-15-19 19-6 13-17-12	12-6-15-19-13-17-10
lsorption nvironment II	12 15-13-17 13-17-19-6 10	10-17-15-13 17-15-13-19-6-12	12-17-19-15-13-6-10
lsorption nvironment III	12-19-17-13-15-10 19-17-13-15-10-6	10-17 17-13-19-15 13-19-15-12 6	10-19-17-12-15-13-6
nal Desorption vironment I	15-12-17-13 17-13-19 19-6 6-10	10-19-6-13-15-17-12	15-17-12-19-10-6 19-10-6-13
nal Desorption vironment II	12 15-13-17 17-19 19-6 6-10	10-19-6-13-17 19-6-13-17-12-15	12-19-17 19-17-13-6-15-10
nal Desorption vironment III	19-17-12-15-13-10-6	10 19-17-13-15 13-15-12-6	19-17 17-15-12-10-6 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 20-26	20-25 26	25-20-26
ıitial Desorption ıvironment II	25 20-26	26-20-25	25-20-26
ıitial Desorption ıvironment III	25-20-26	26-20 20-25	25-20 20-26
lsorption ıvironment I	25-20-26	25-20 26	26-20-25
lsorption ıvironment II	25-20-26	26-25 25-20	20-26-25
lsorption ıvironment III	26-20-25	26 25-20	26-25-20
.nal Desorption ıvironment I	25-20-26	26-20-25	25-20-26
.nal Desorption ıvironment II	25-20 26	26 20-25	20-25-26
.nal Desorption ıvironment III	26-20-25	26-20 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

nvironmental and est Conditions	Total Weight Change	Total Dimensional Change	Initial Rate of Weight Change
nitial Desorption nvironment I	70-74-72	72 74-70	74-72-70
nitial Desorption nvironment II	72-74-70	74-70-72	74-72 72-70
nitial Desorption nvironment III	70-74-72	74-70 70-72	70-74 74-72
dsorption nvironment I	72-74-70	72 74-70	70-74-72
dsorption nvironment II	72-74 74-70	70-74-72	72-70-74
dsorption nvironment III	70-74-72	70-74-72	70 74-72
inal Desorption nvironment I	72-70 70-74	74-70 70-72	72-70-74
inal Desorption nvironment II	72 70-74	70-74-72	70-72-74
inal Desorption nvironment III	72-74-70	74-70-72	72-74 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 73	73-21
Initial Desorption Environment II	73 21	21-73	73-21
Initial Desorption Environment III	73-21	21-73	73-21
Adsorption Environment I	73-21	21 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 21
Final Desorption Environment III	73-21	21-73	73 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

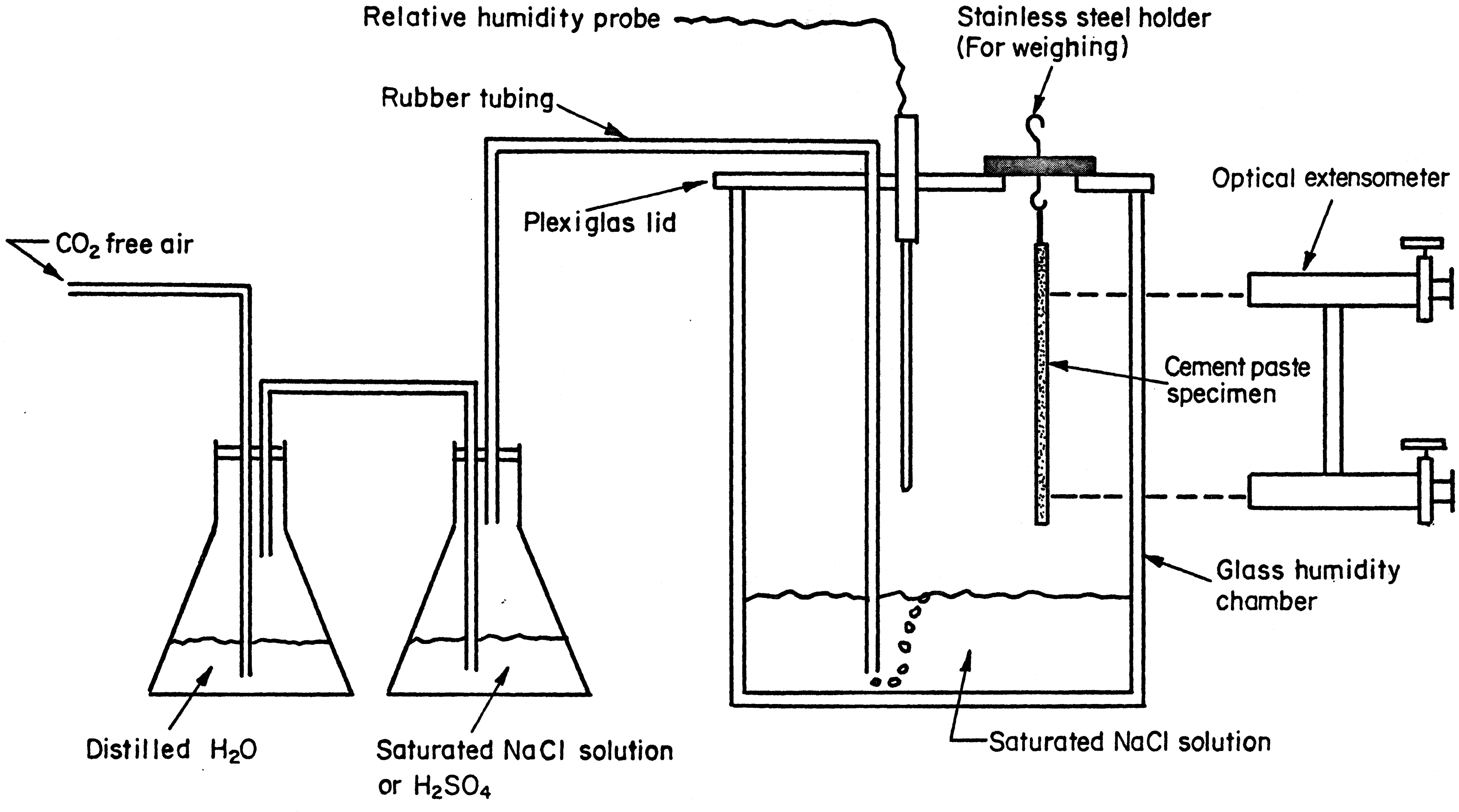

FIGURE 3. APPARATUS FOR MEASURING THE DEFORMATION AND WEIGHT CHANGE OF HARDENED CEMENT PASTES

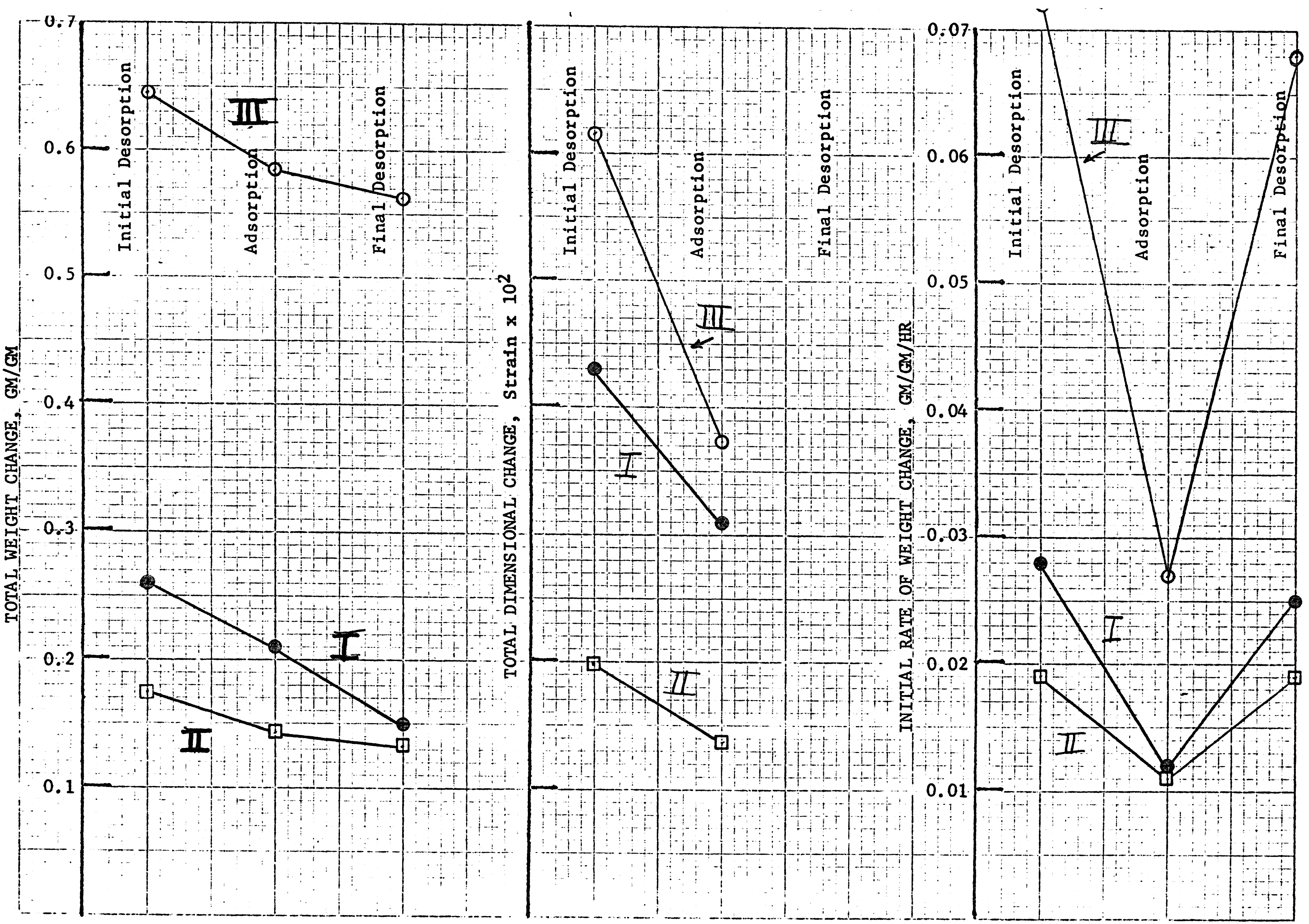

FIGURE 4. CEMENT #1, TYPE I. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

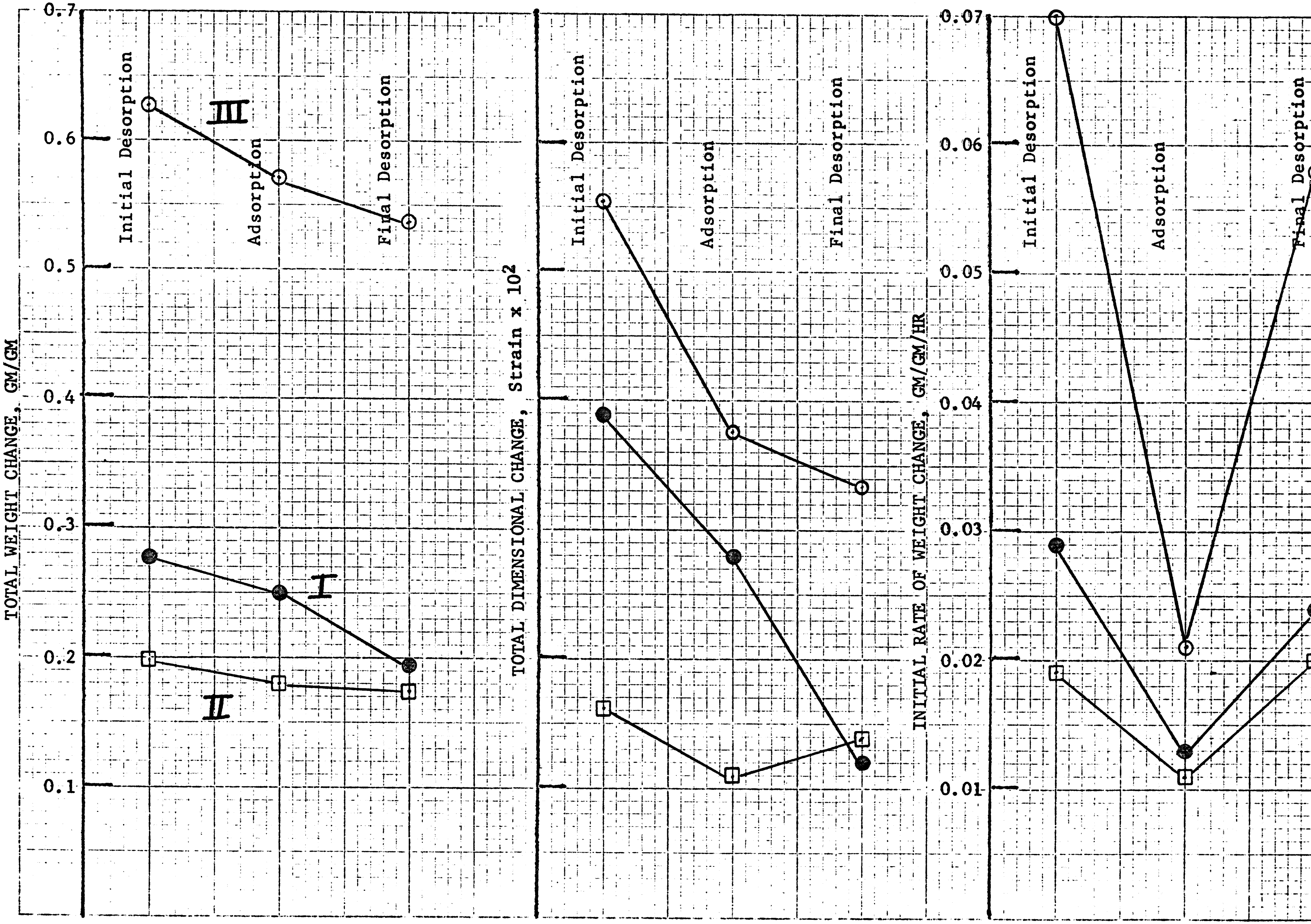

FIGURE 5. CEMENT #2, TYPE I. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

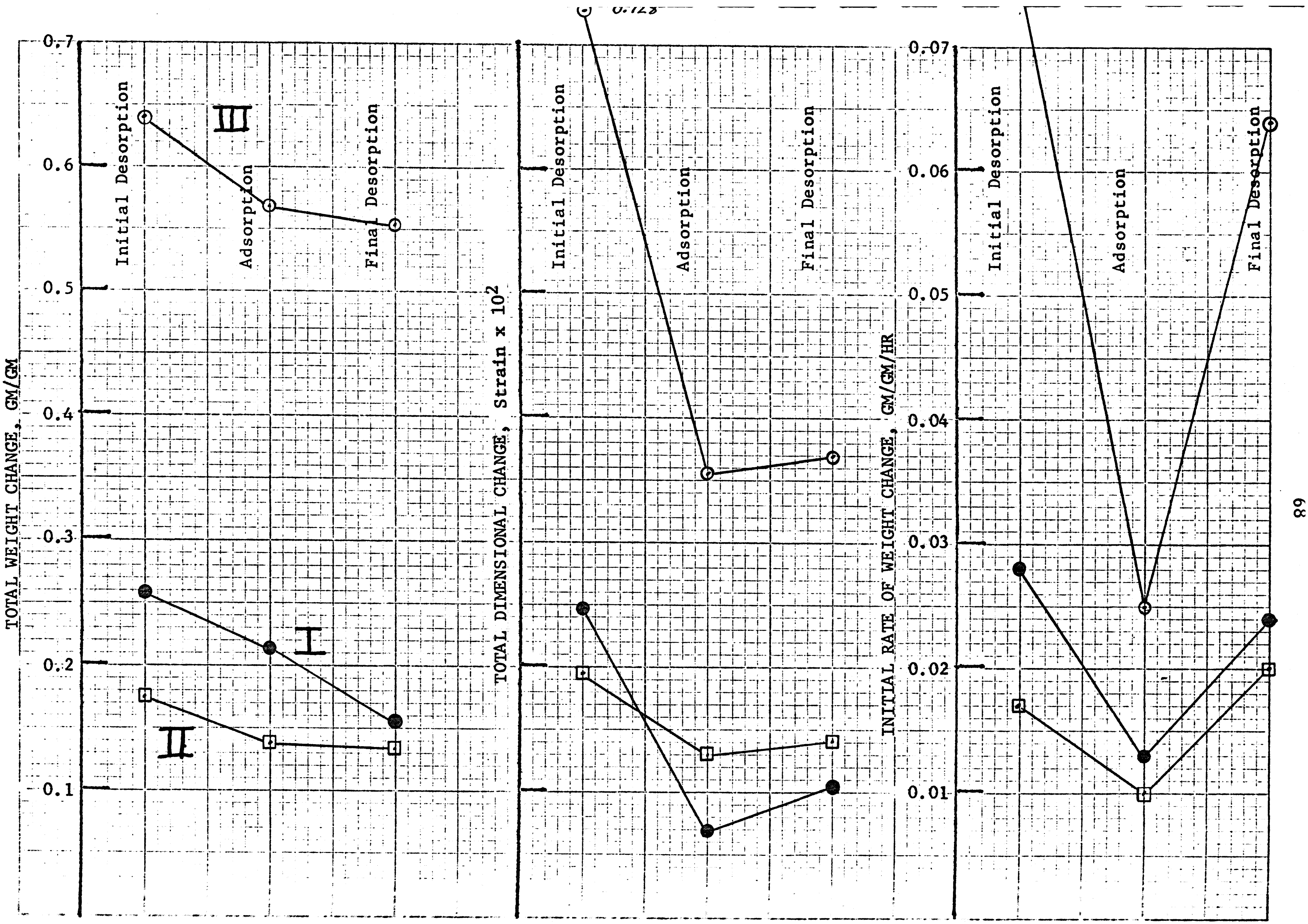

FIGURE 6. CEMENT #3, TYPE I. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

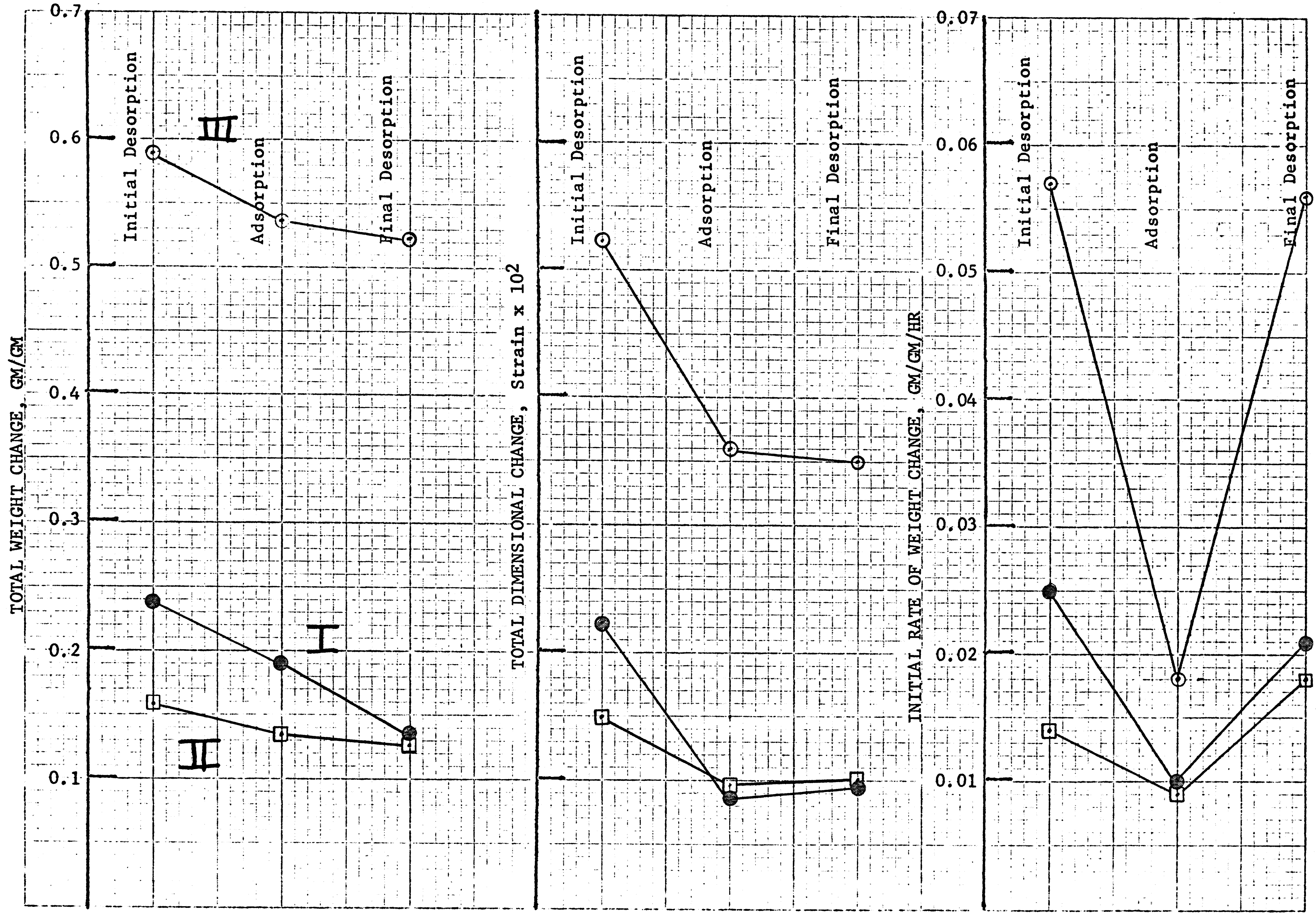

FIGURE 7. CEMENT #4. TYPE I. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

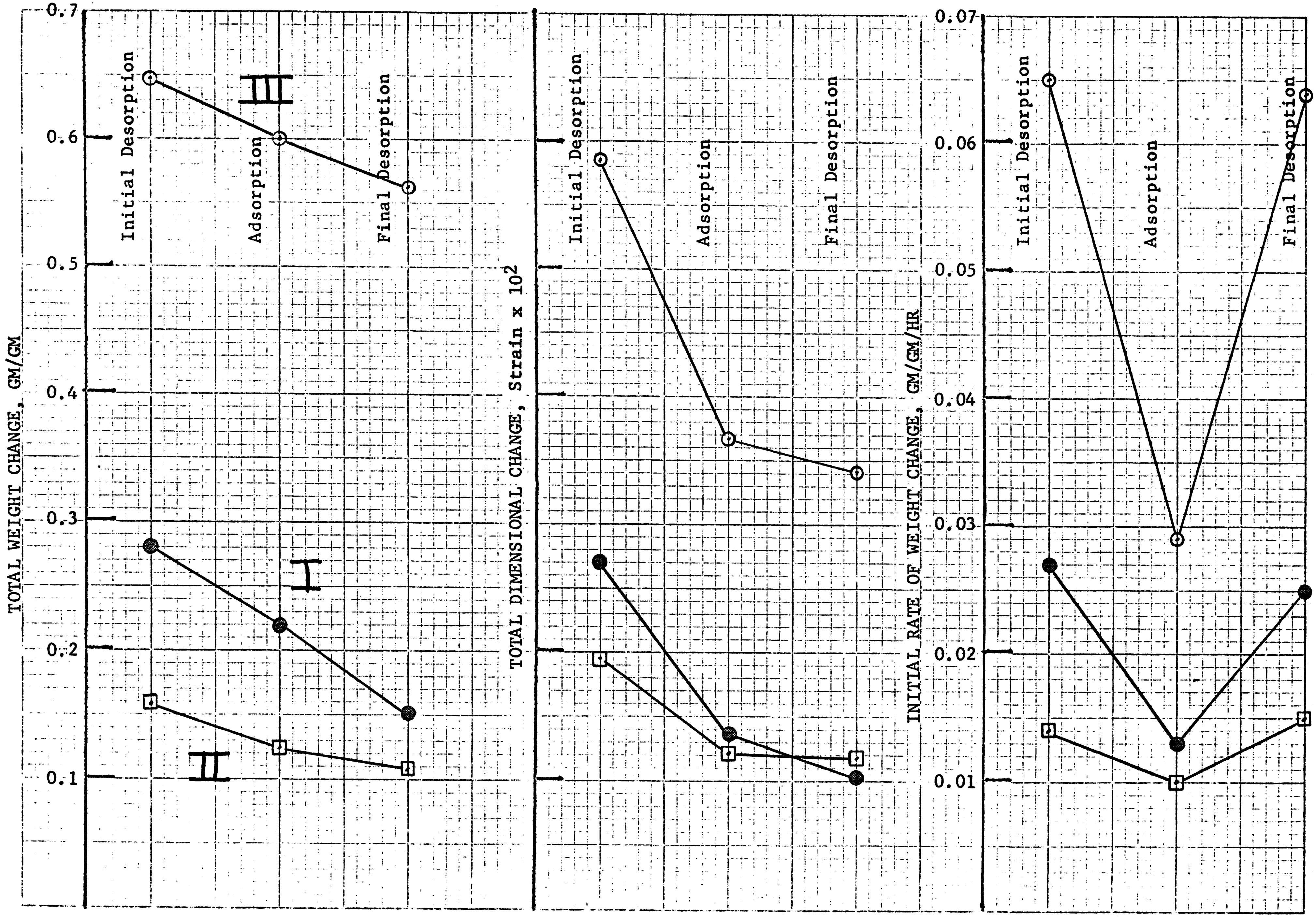

FIGURE 8. CEMENT #5. TYPE I. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

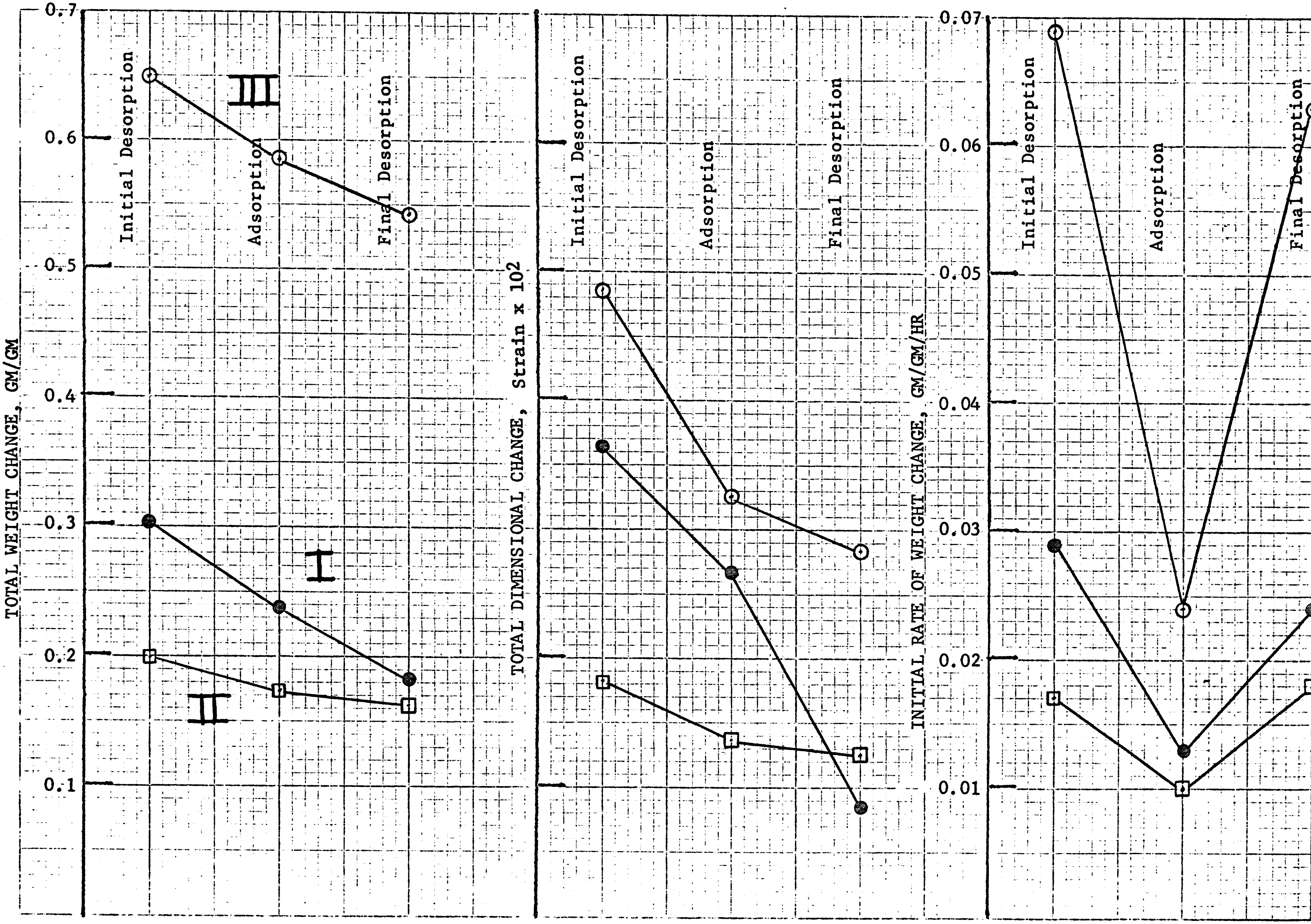

FIGURE 9. CEMENT #7. TYPE I. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

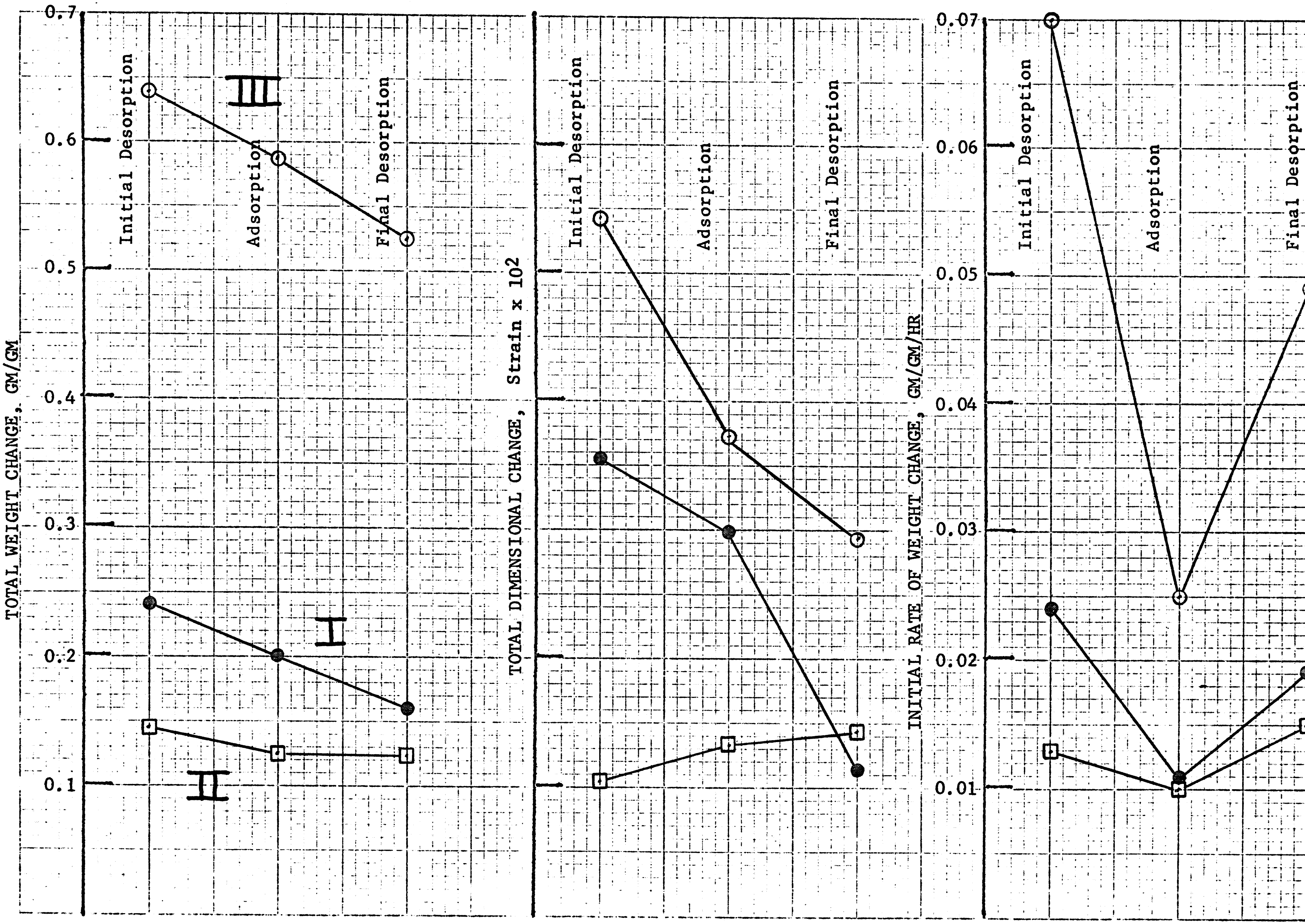

FIGURE 10. CEMENT #8. TYPE I. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

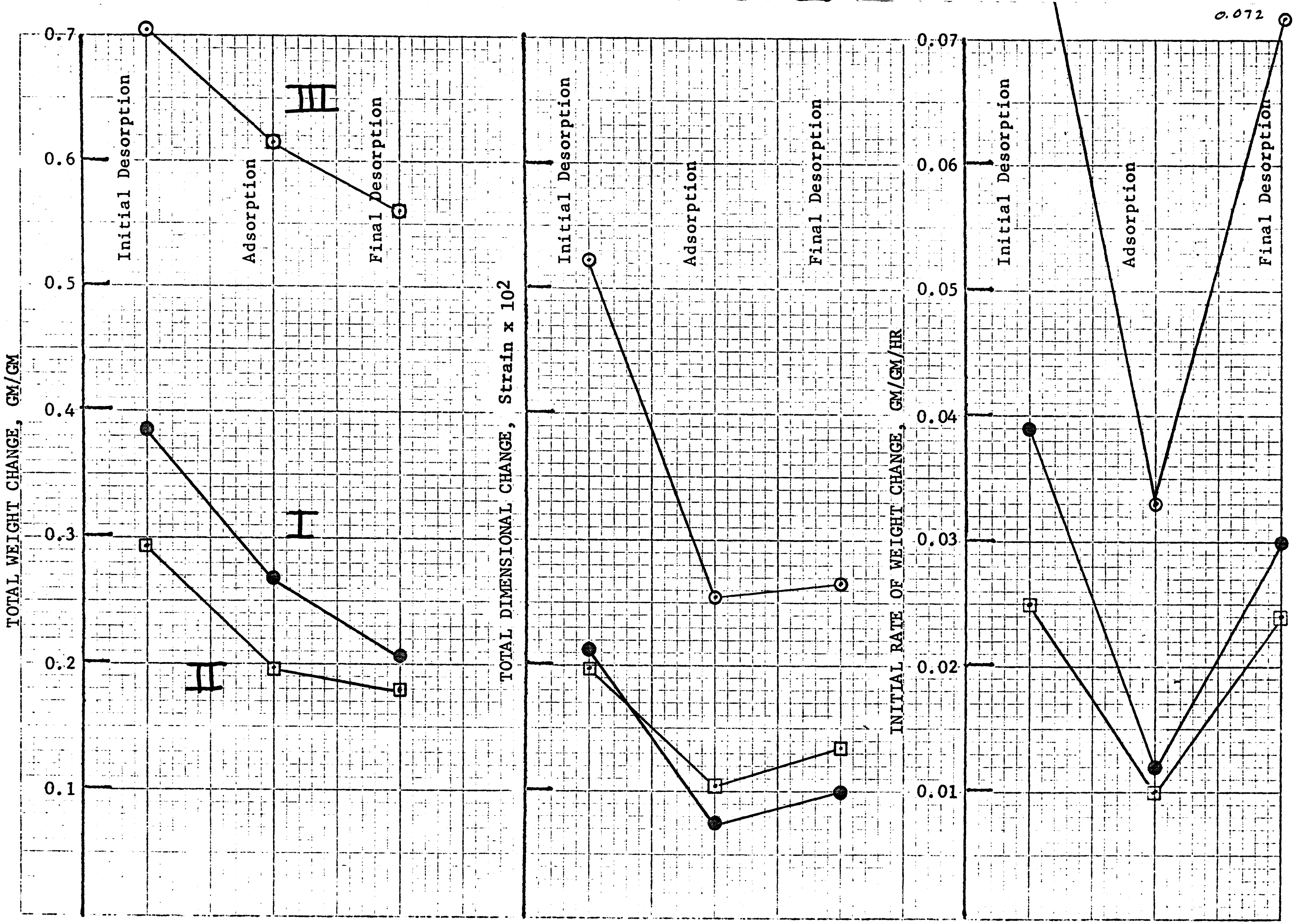

FIGURE 11. CEMENT #9. TYPE I. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0.5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

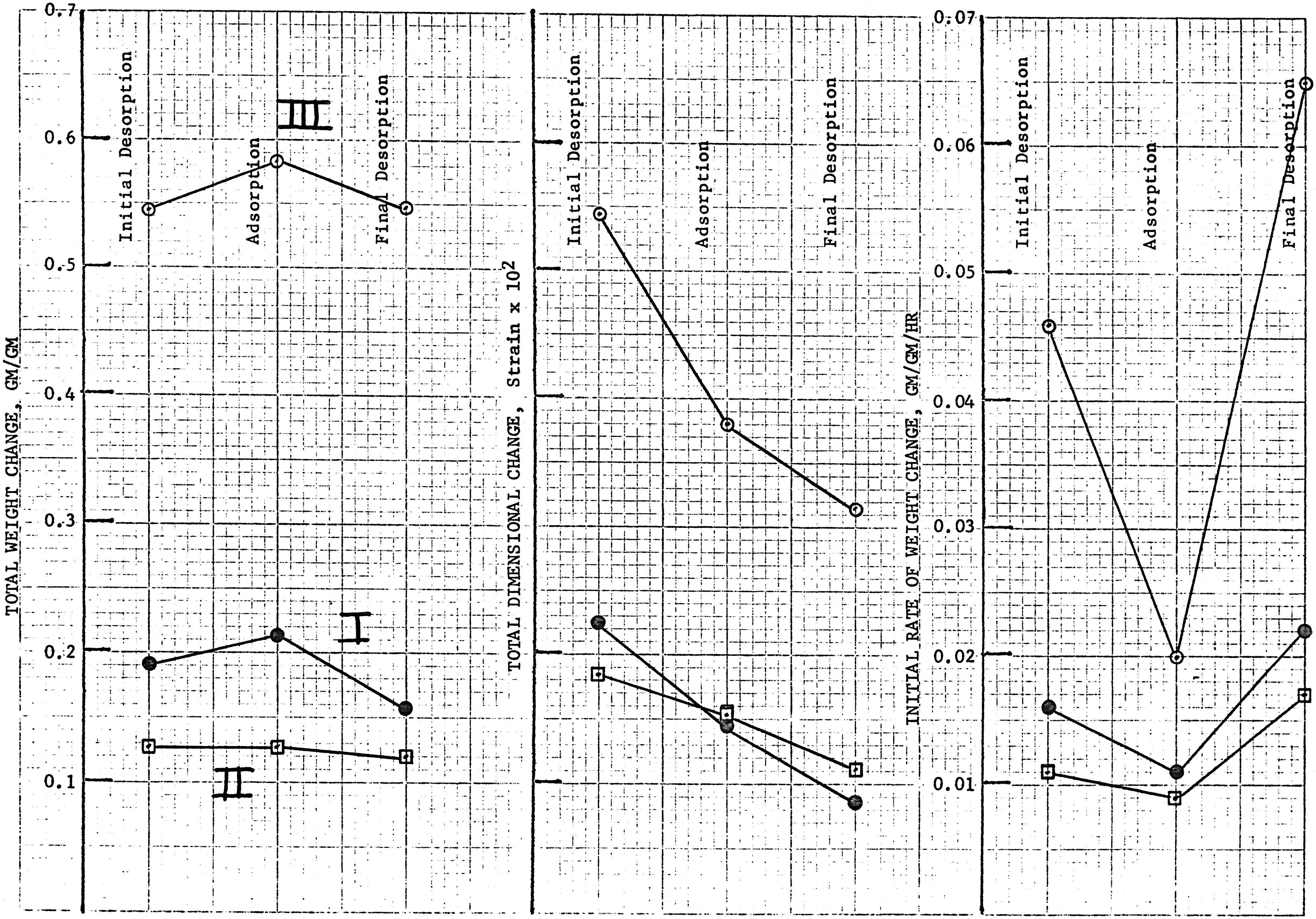

FIGURE 12. CEMENT #11.TYPE I. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

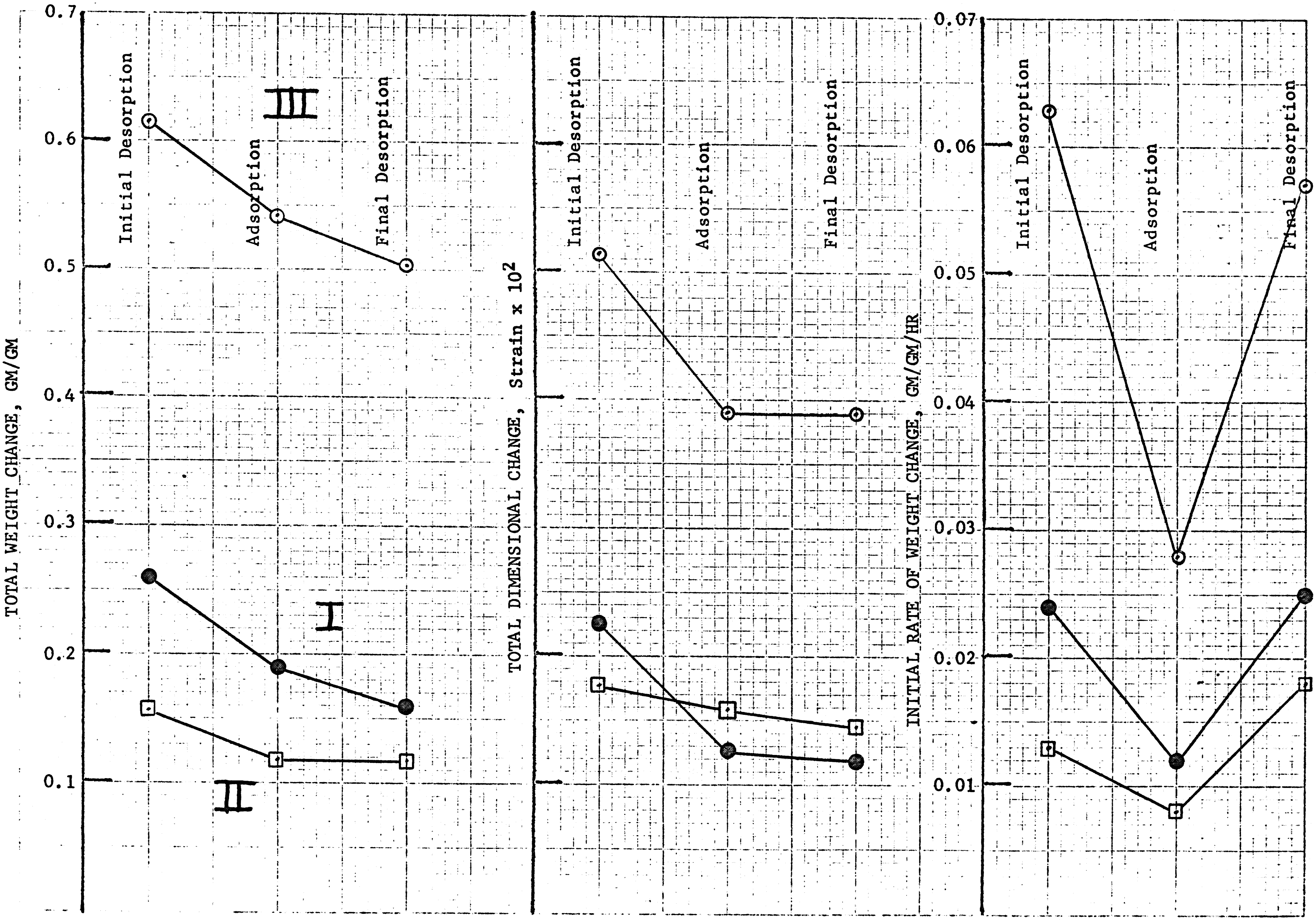

FIGURE 13. CEMENT #14.TYPE I. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

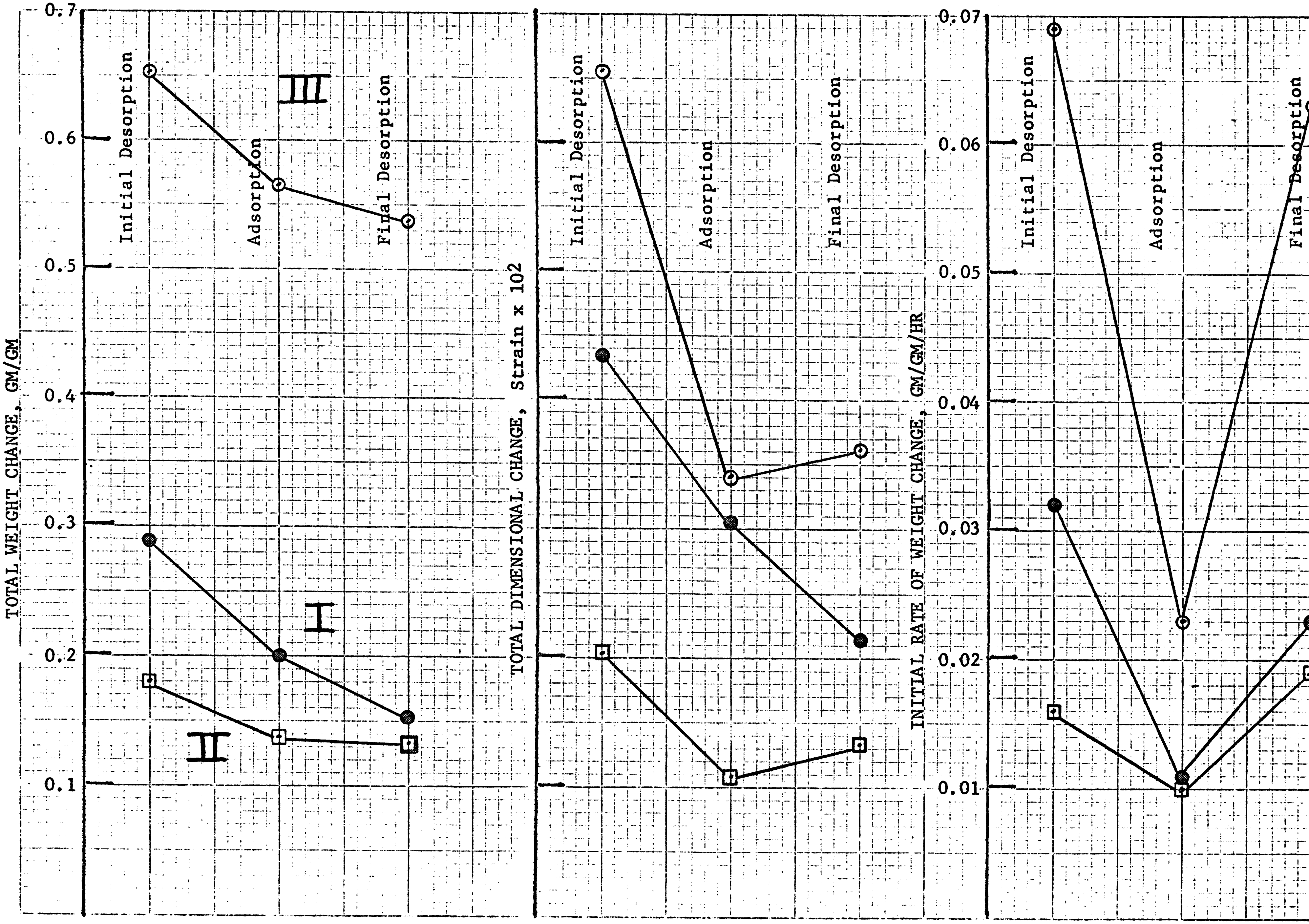

FIGURE 14. CEMENT #16 TYPE I. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

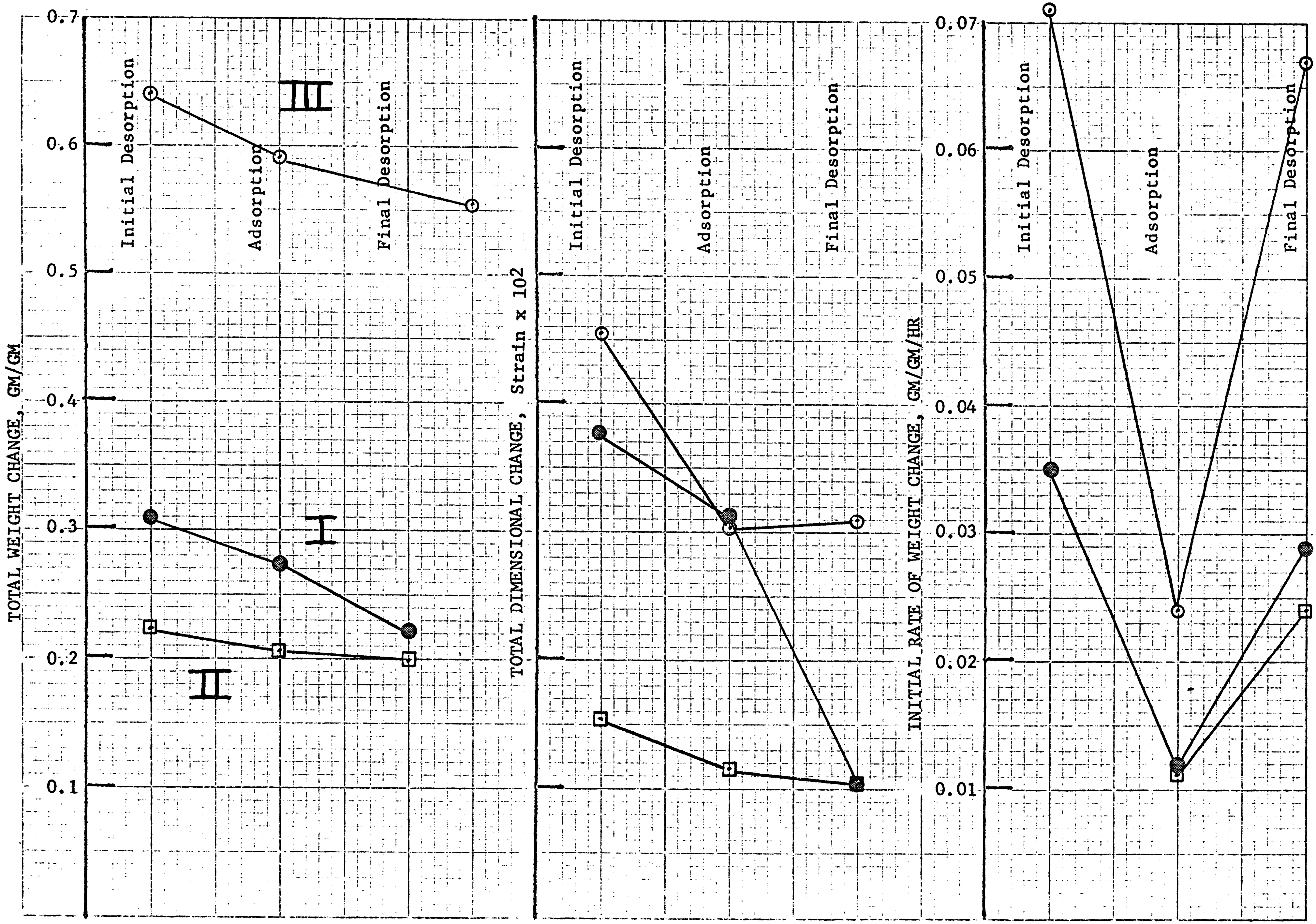

FIGURE 15. CEMENT #18. TYPE I. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

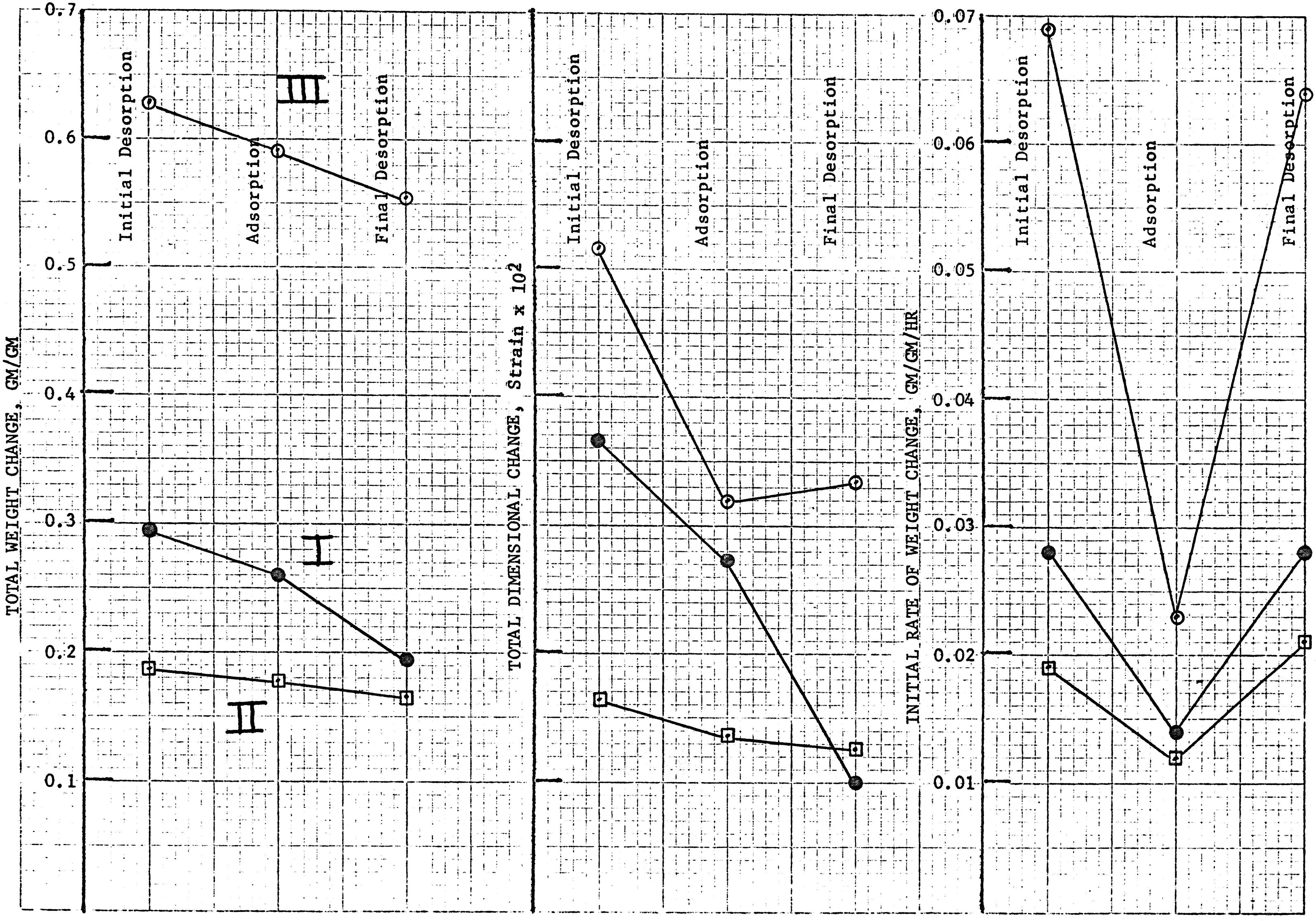

FIGURE 16. CEMENT #22. TYPE I. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

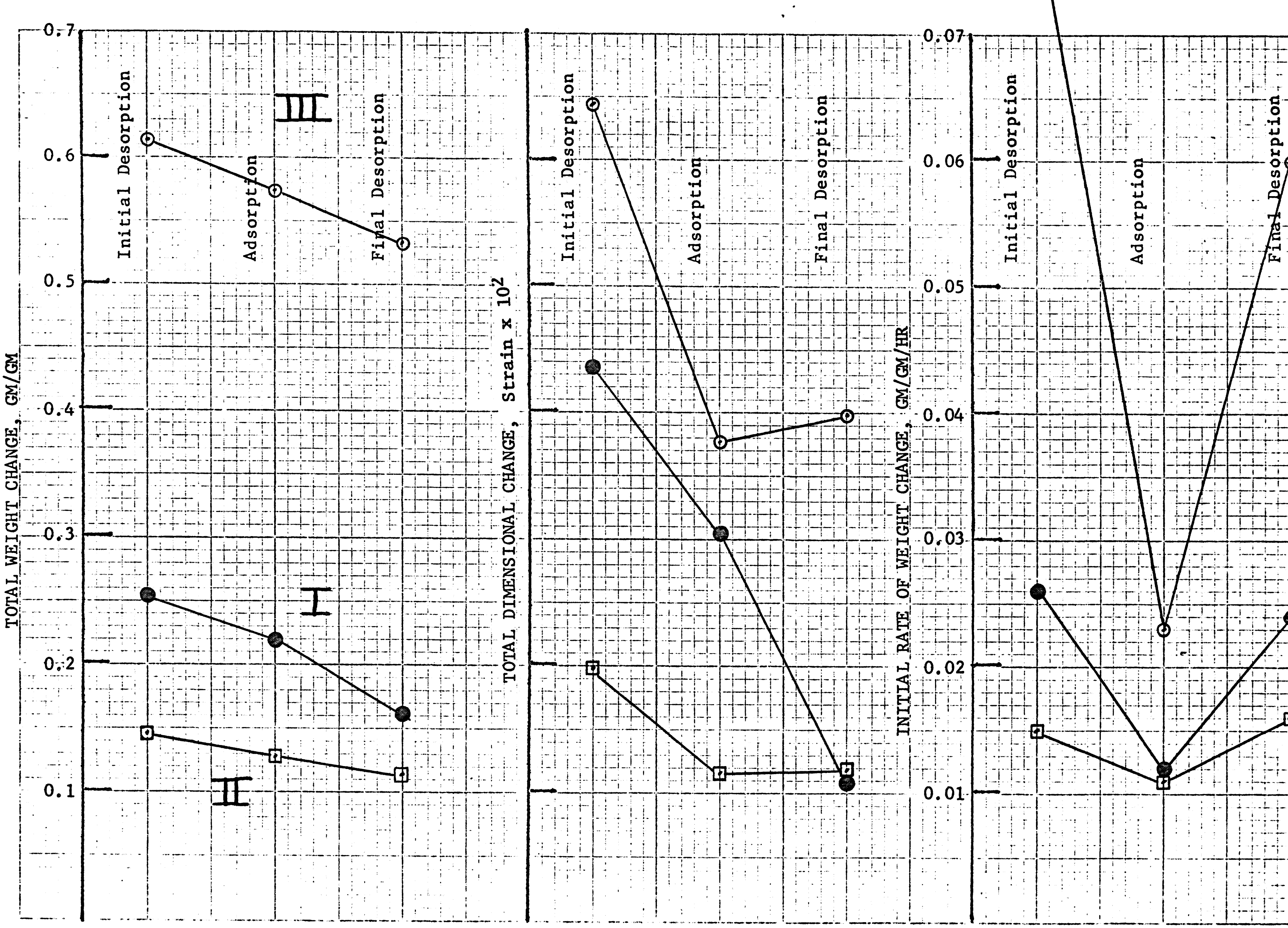

FIGURE 17. CEMENT #23.TYPE I. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0–5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION

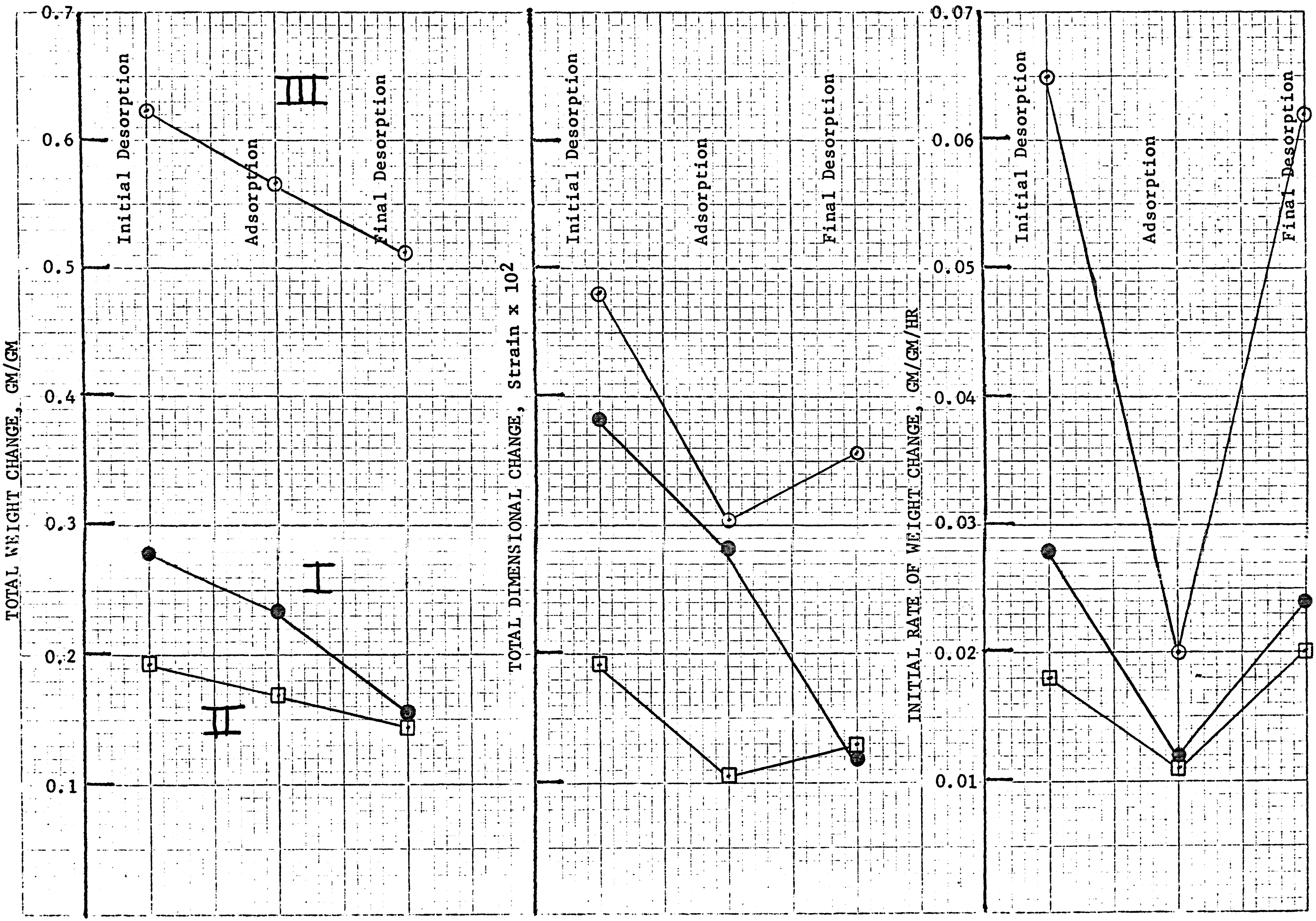

FIGURE 18. CEMENT #24 TYPE I. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

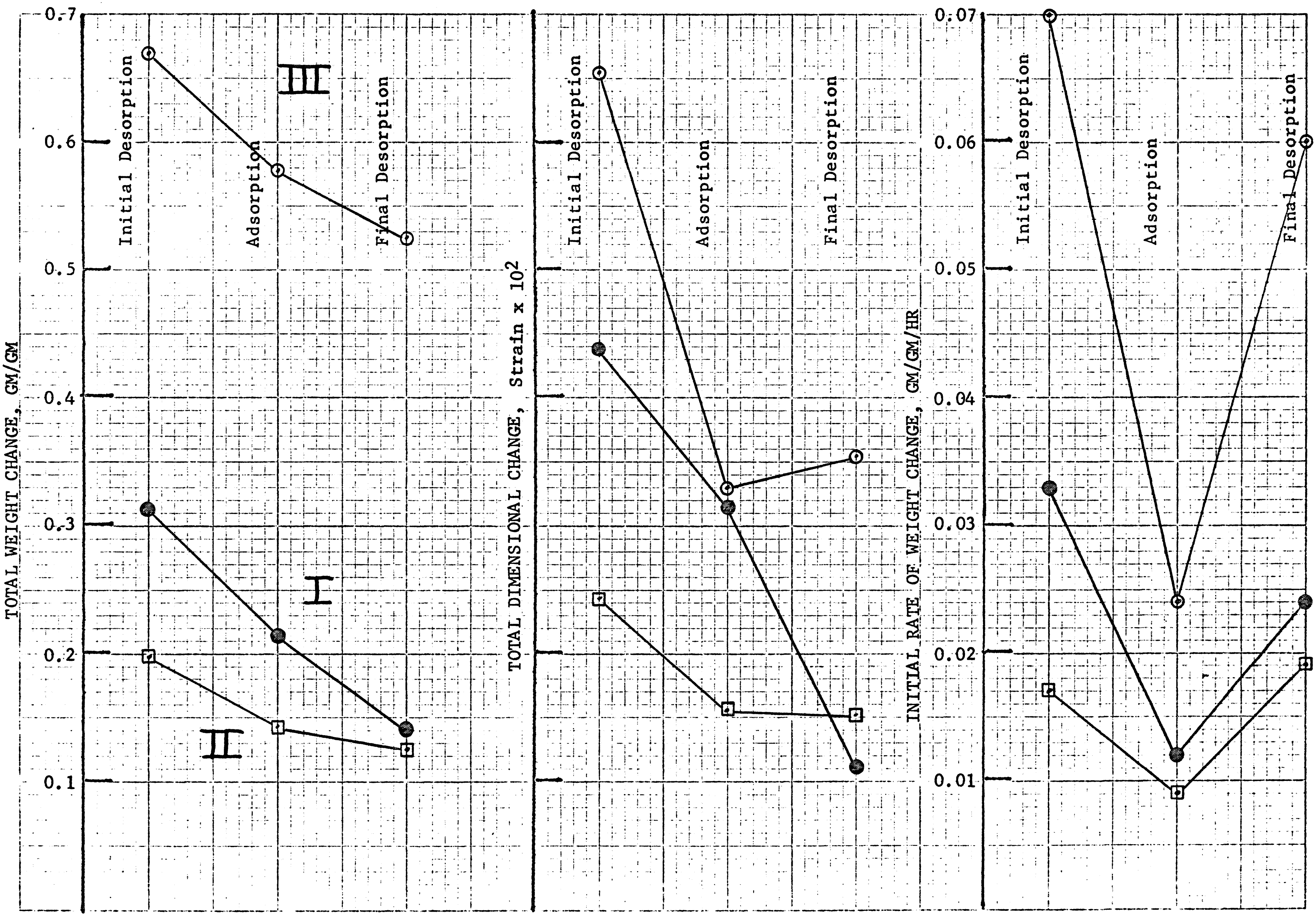

FIGURE 19. CEMENT #27.TYPE I. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

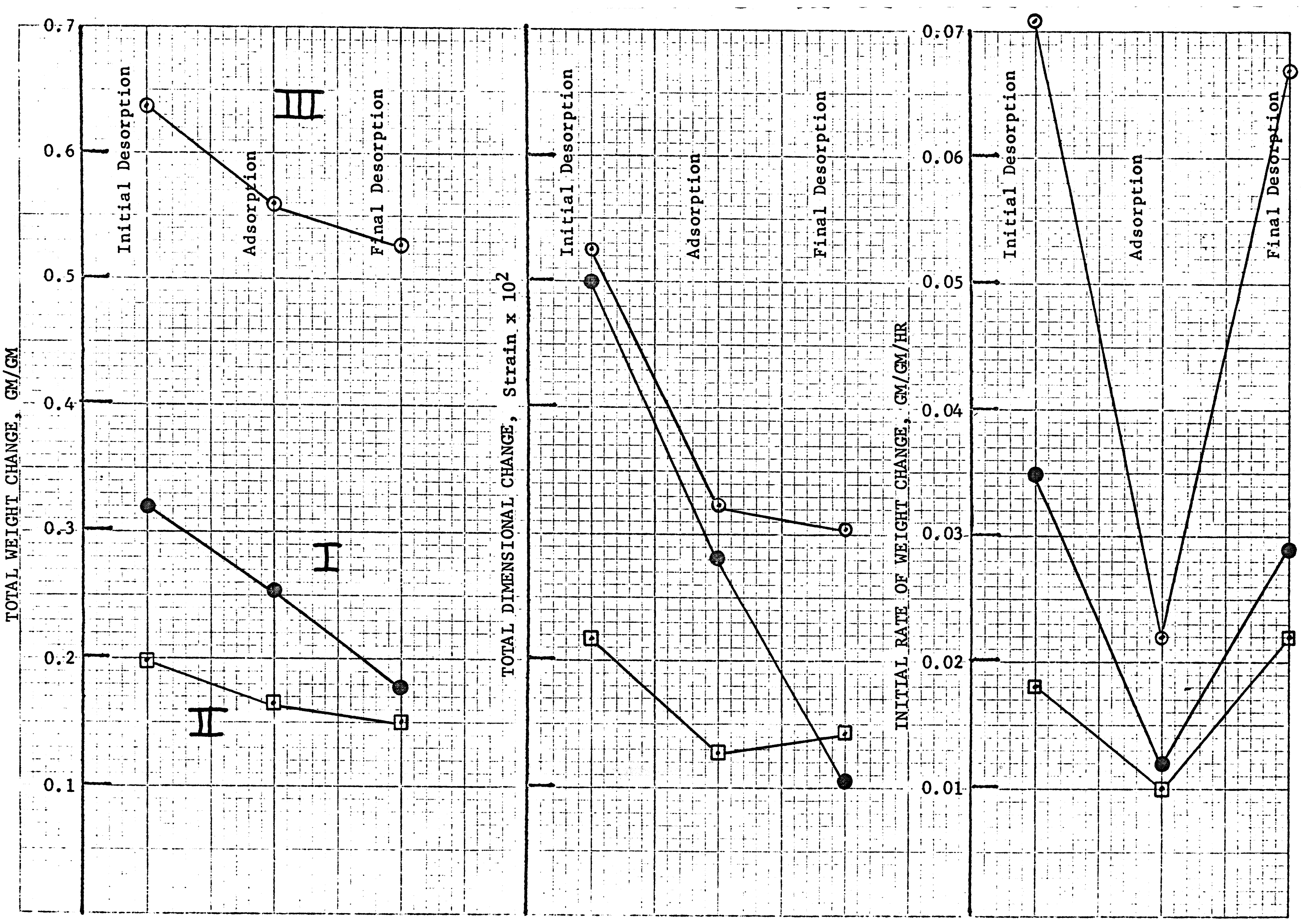

FIGURE 20. CEMENT #71.TYPE I. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

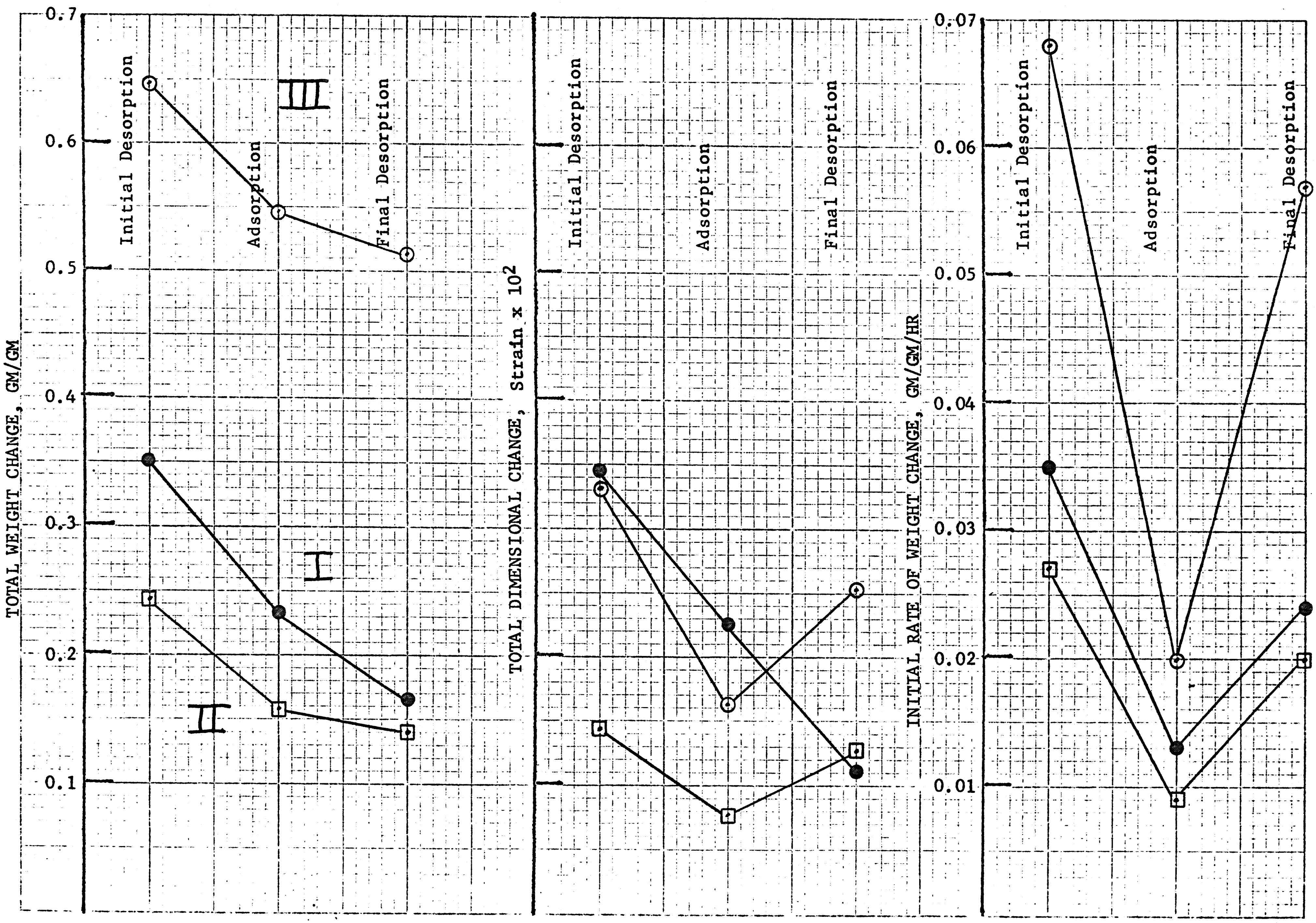

FIGURE 21. CEMENT #6. TYPE II. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

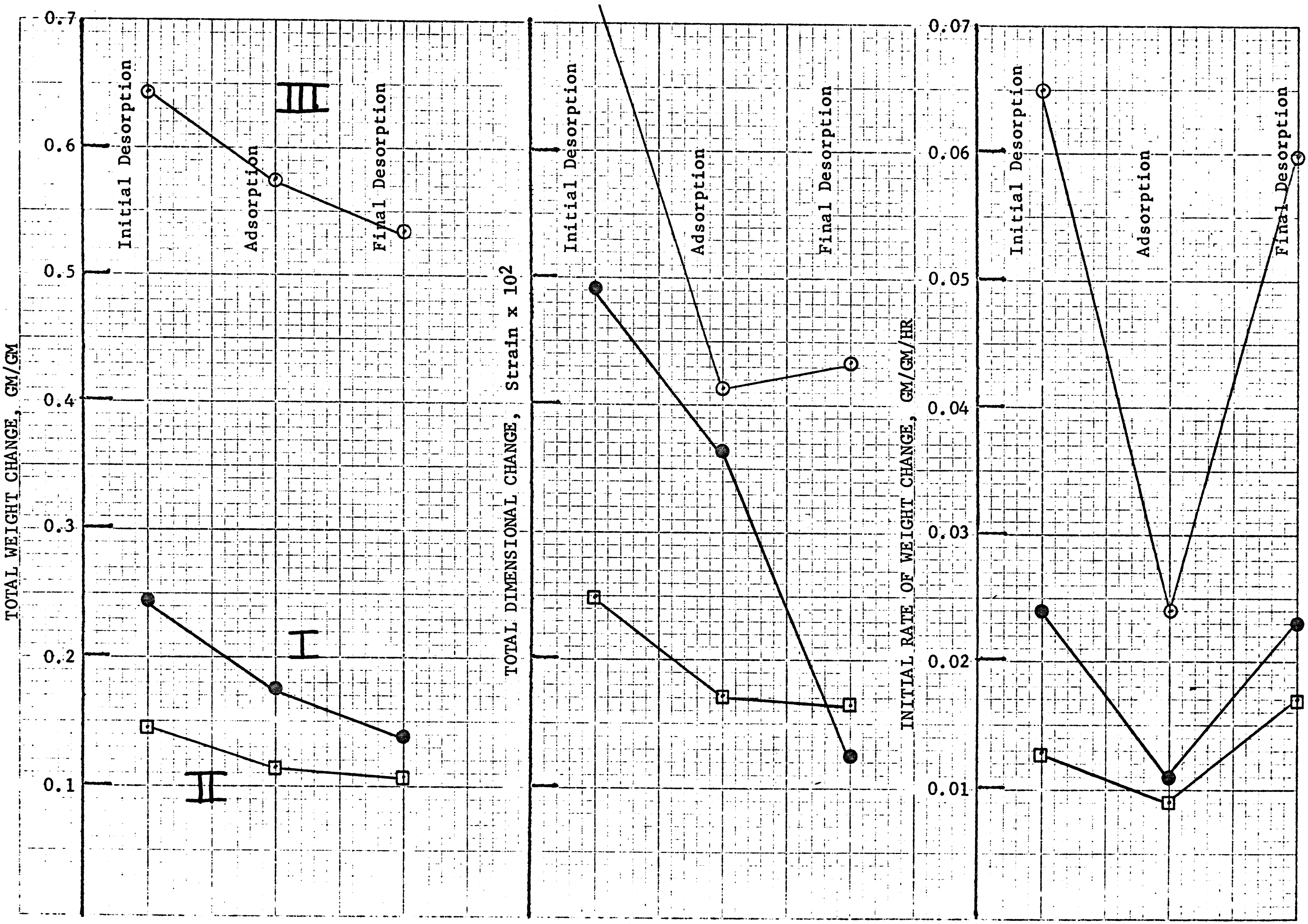

FIGURE 22. CEMENT #10.TYPE II. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

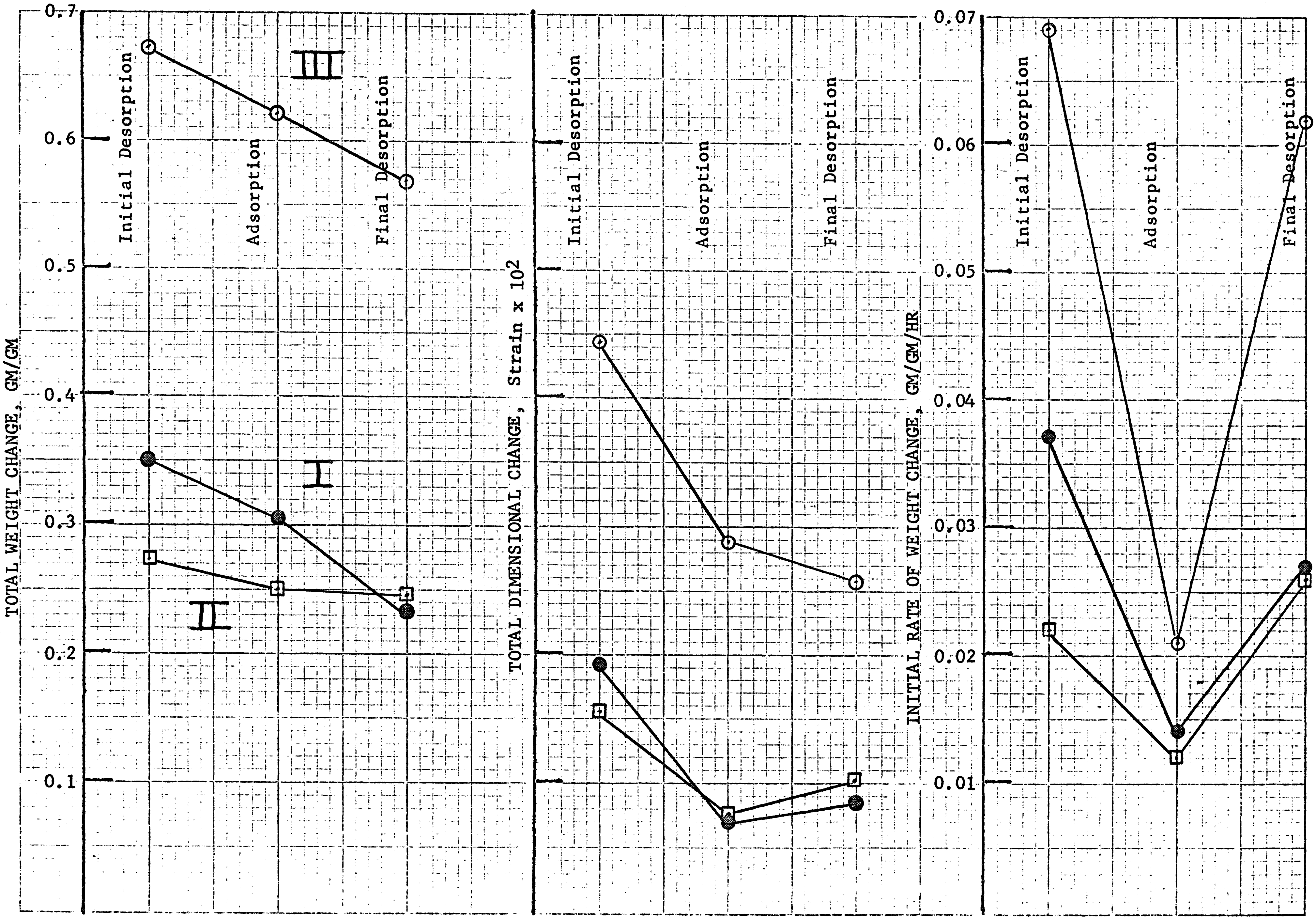

FIGURE 23. CEMENT #12.TYPE II. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

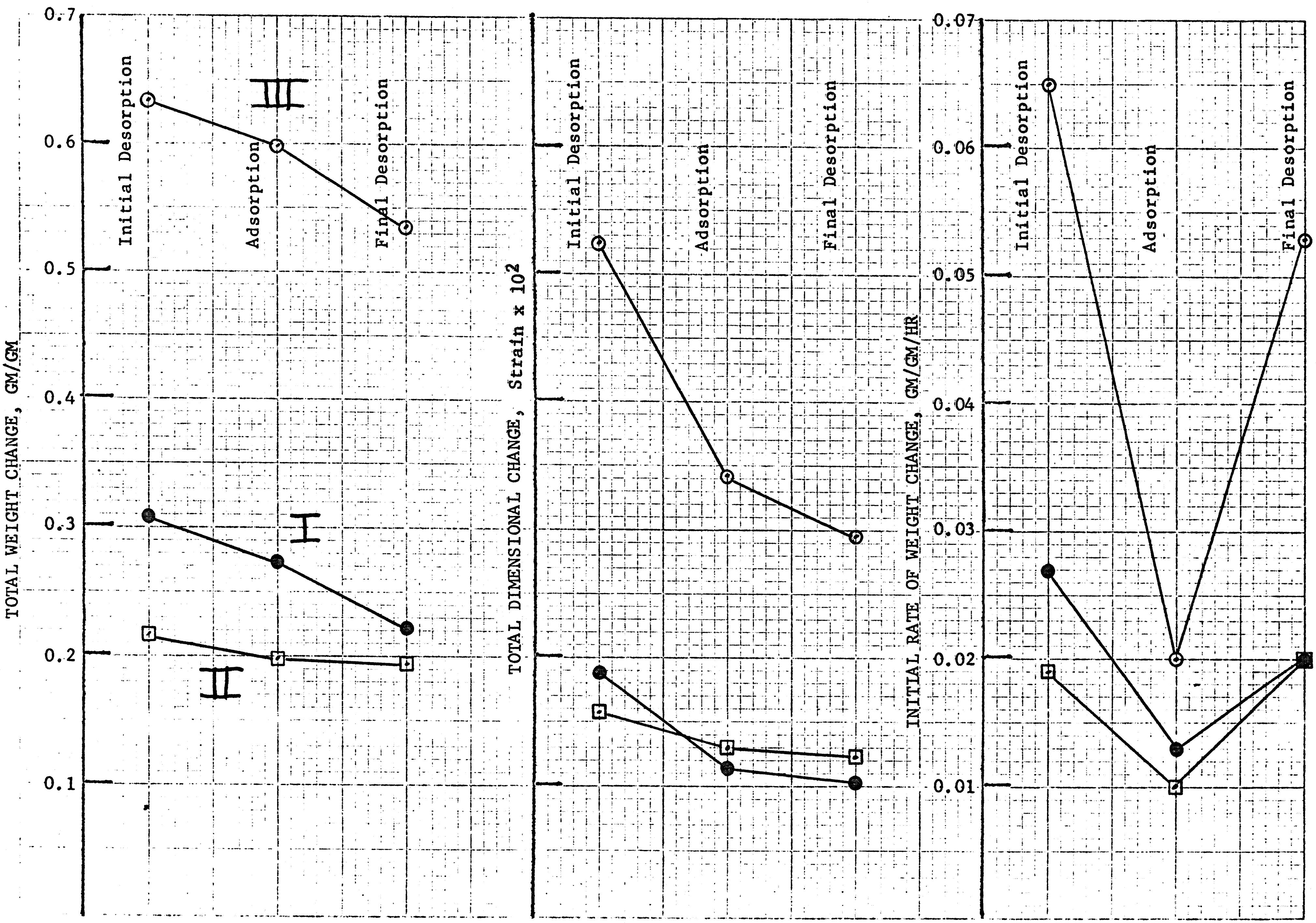

FIGURE 24. CEMENT #13.TYPE II. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

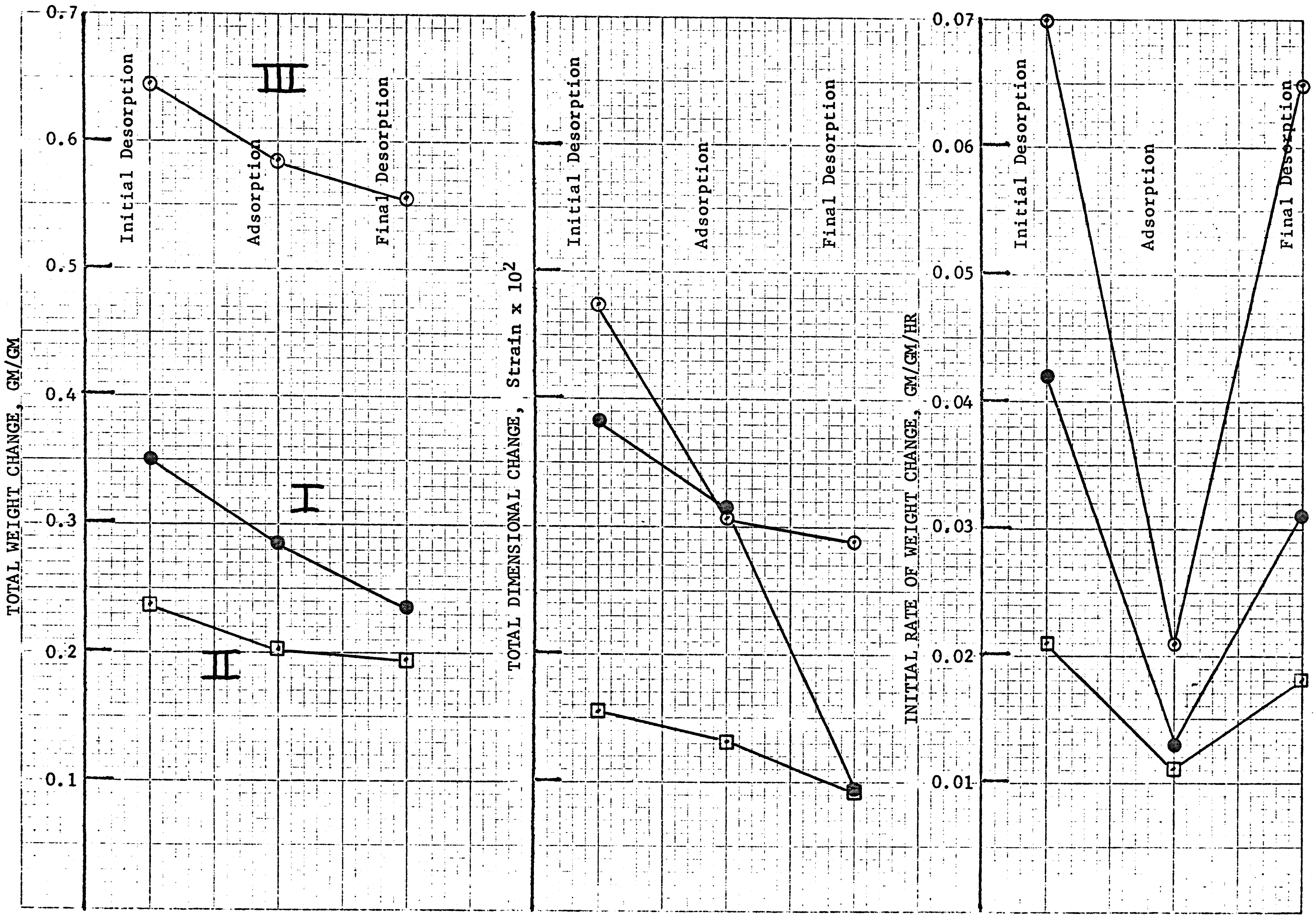

FIGURE 25. CEMENT #15 TYPE II. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

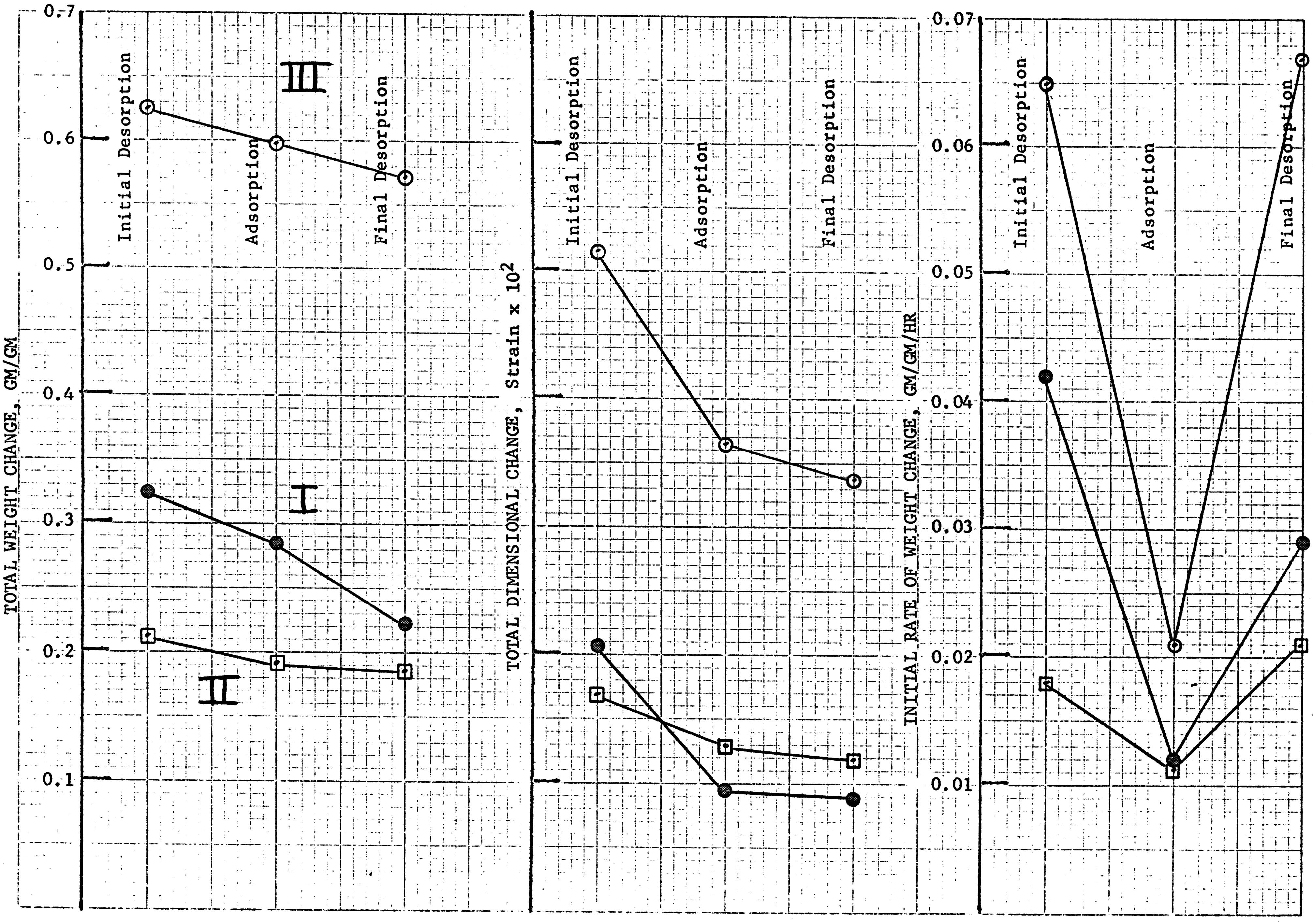

FIGURE 26. CEMENT #17.TYPE II. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

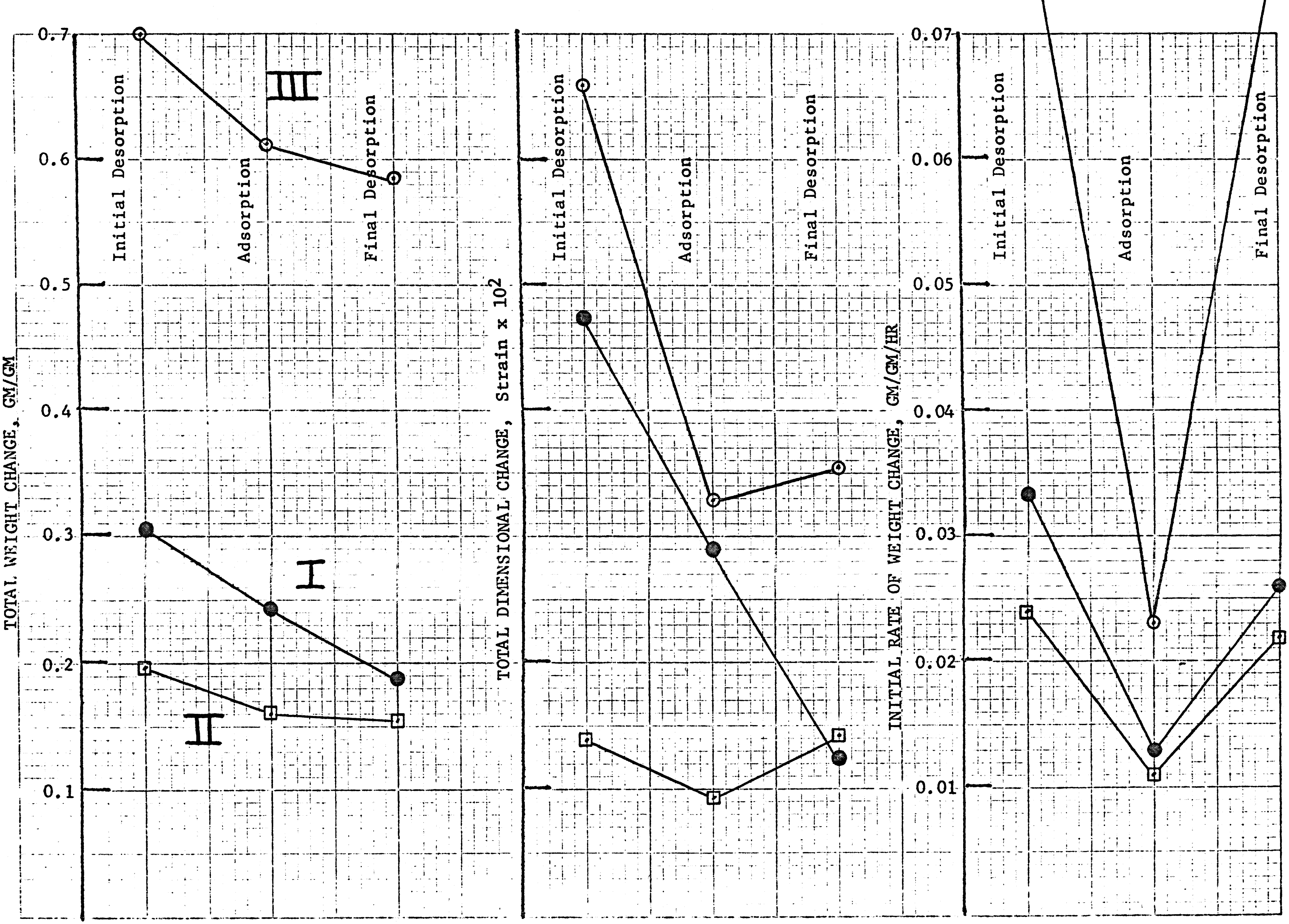

FIGURE 27. CEMENT #19.TYPE II. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION

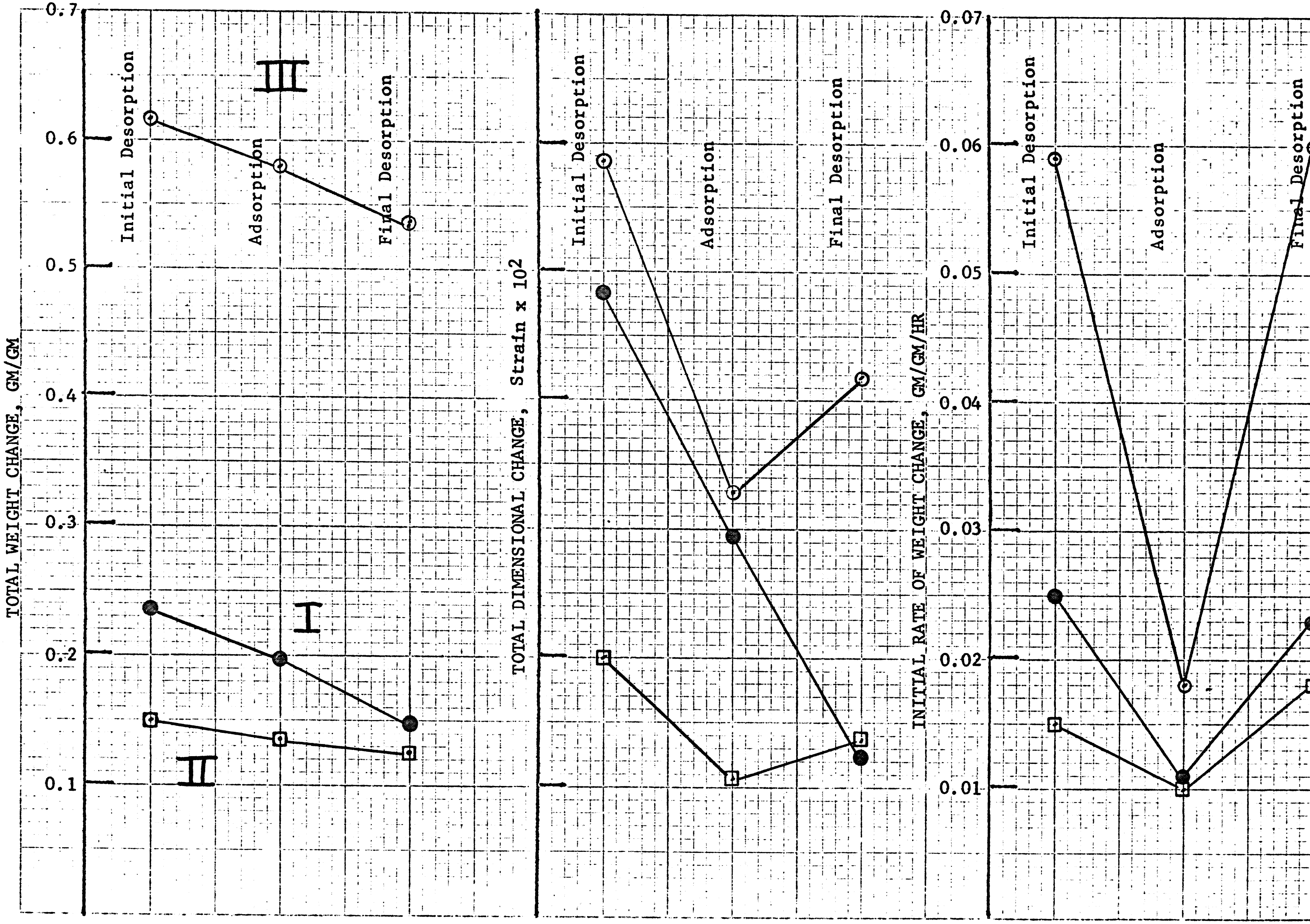

FIGURE 28. CEMENT #20. TYPE III. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

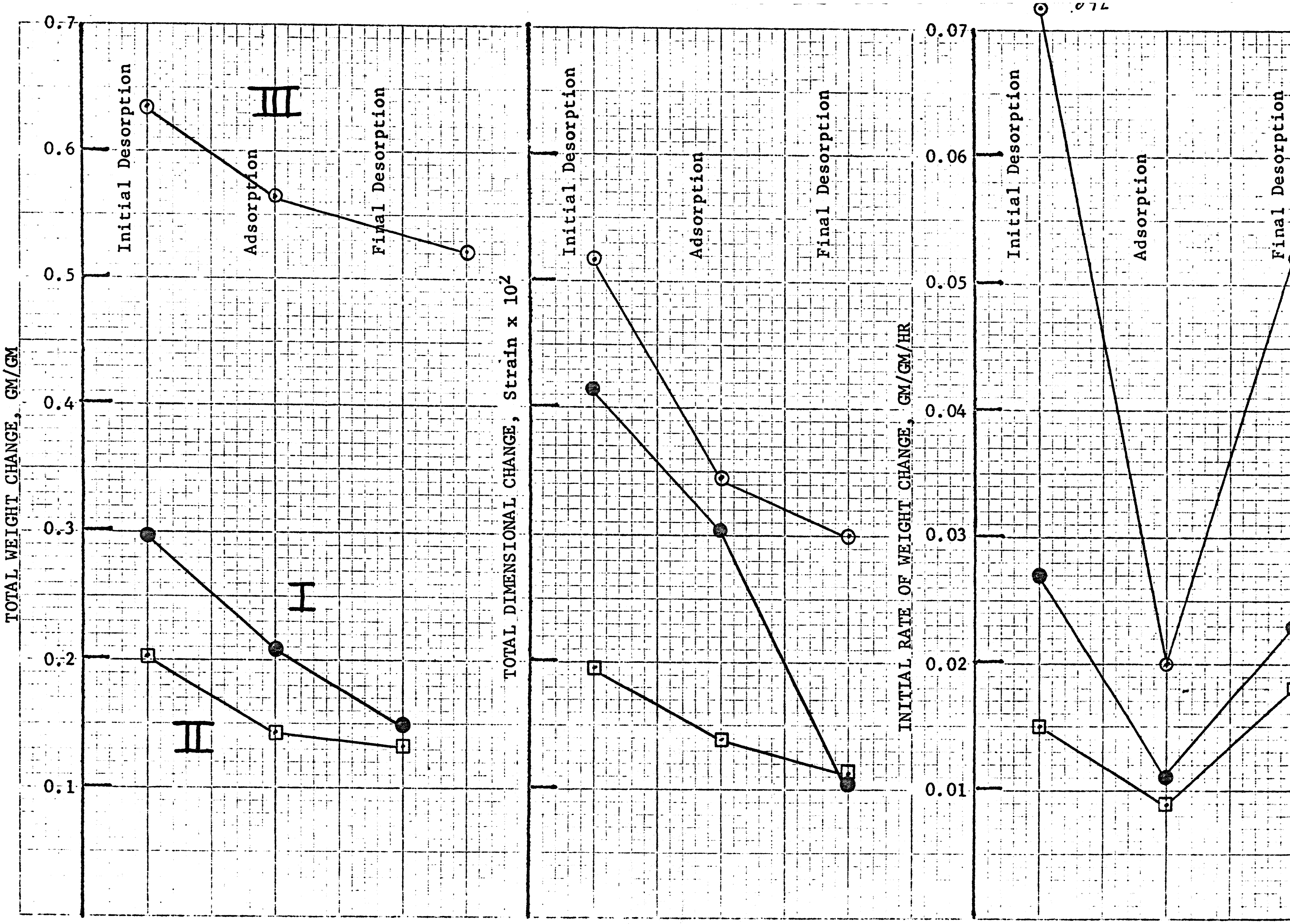

FIGURE 29. CEMENT #25.TYPE III.TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

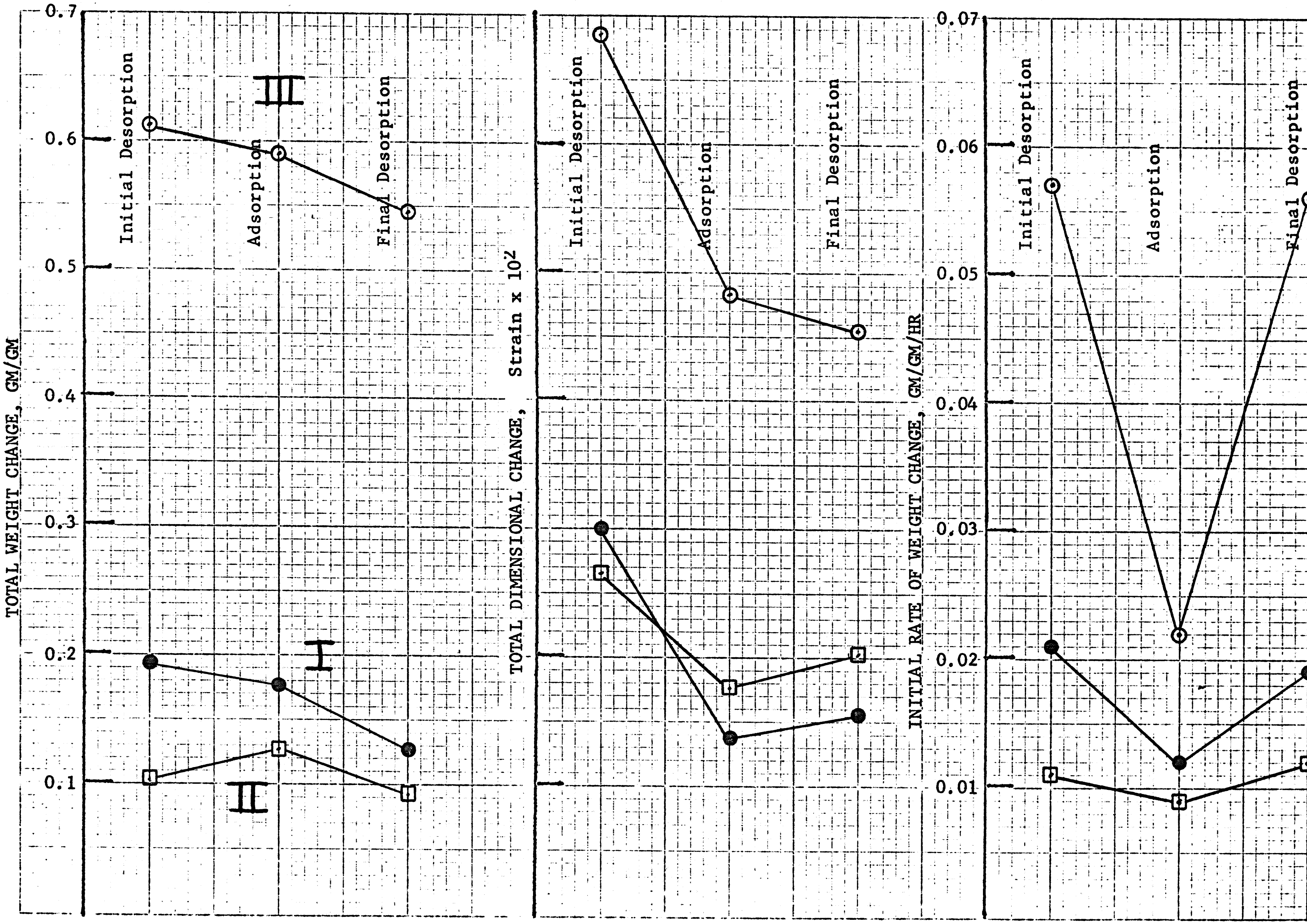

FIGURE 30. CEMENT #26. TYPE III. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

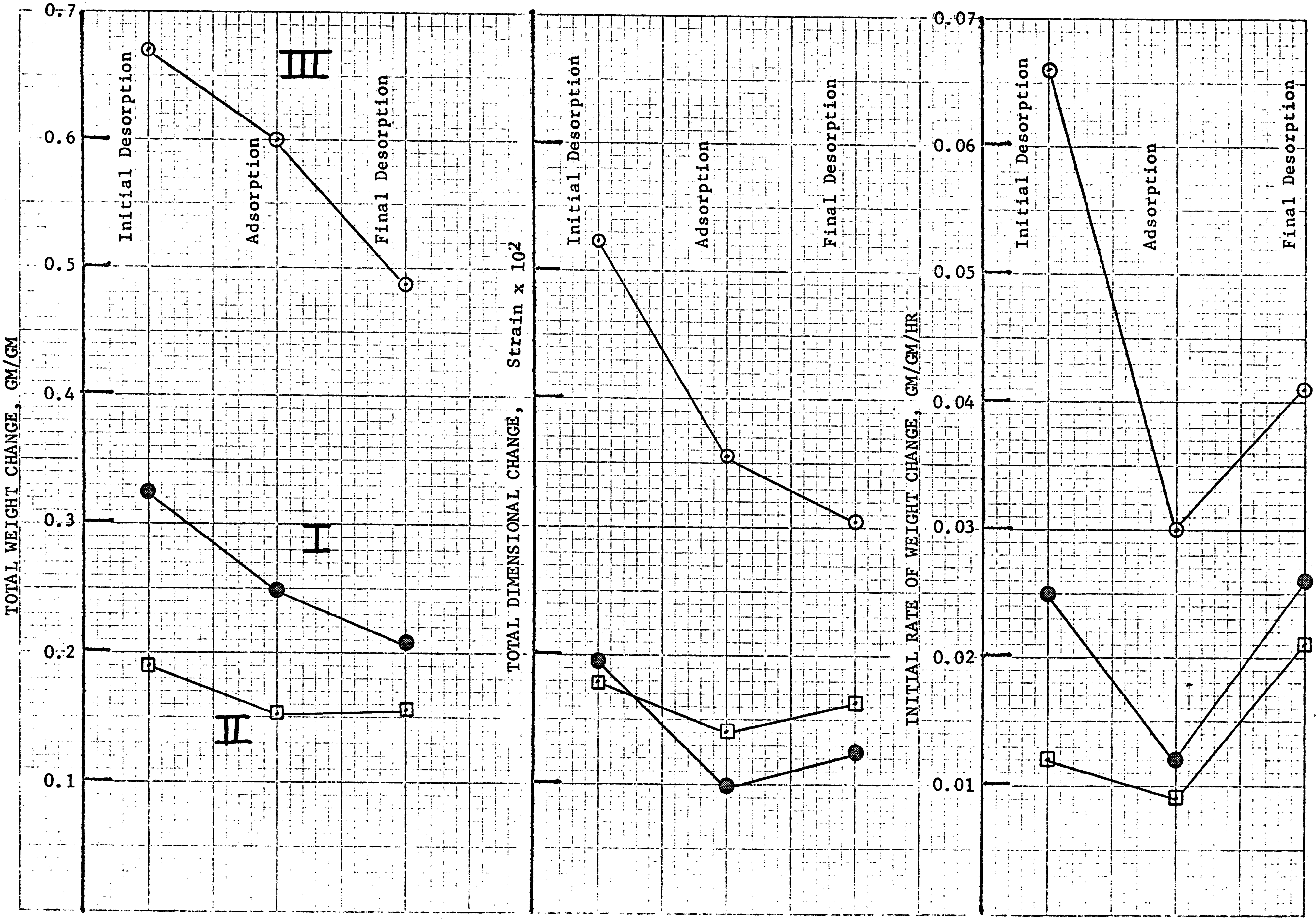

FIGURE 31. CEMENT #70.TYPE IV. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

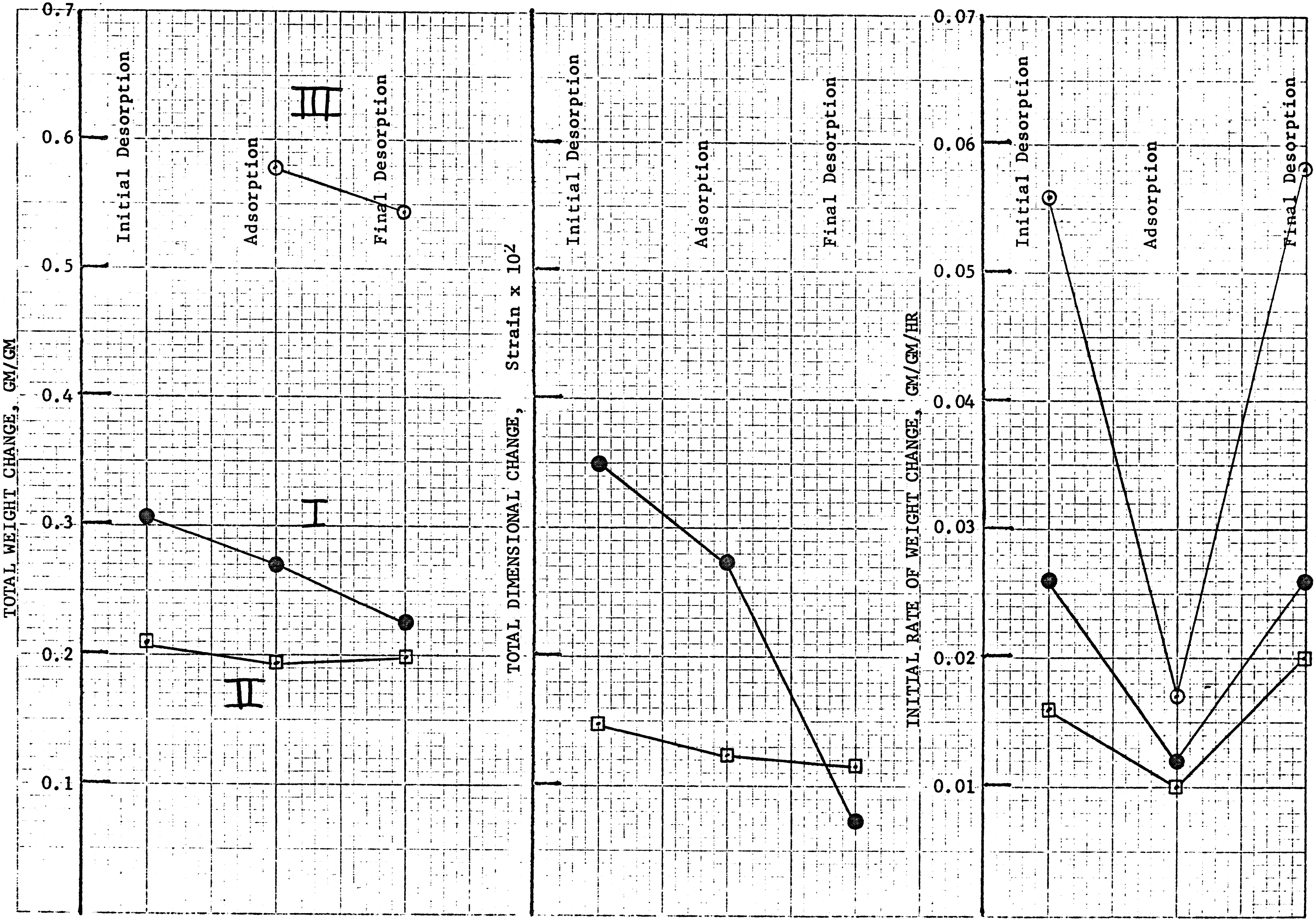

FIGURE 32. CEMENT #72.TYPE IV. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

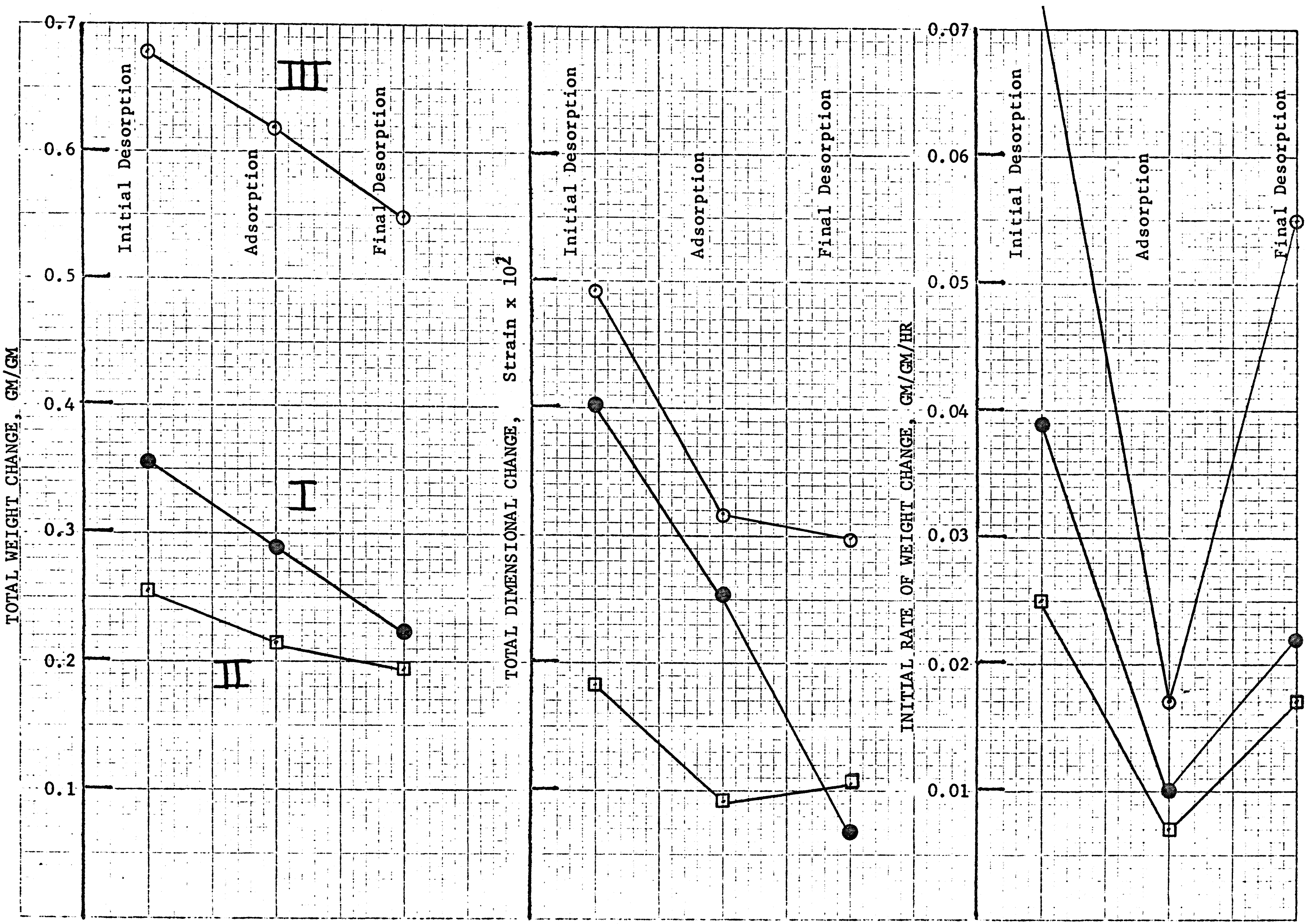

FIGURE 33. CEMENT #21.TYPE V. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

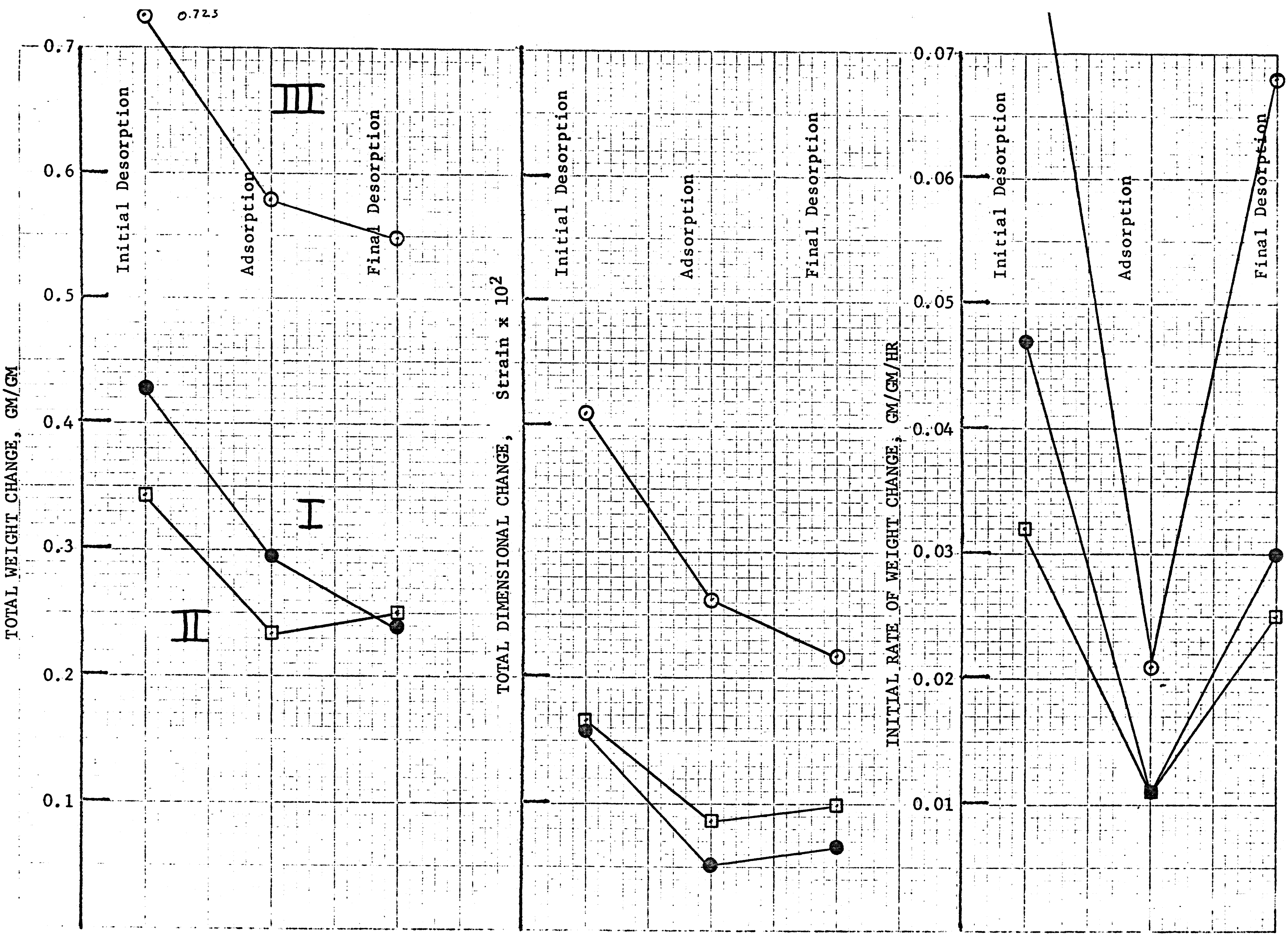

FIGURE 34. CEMENT #73,TYPE V. TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION

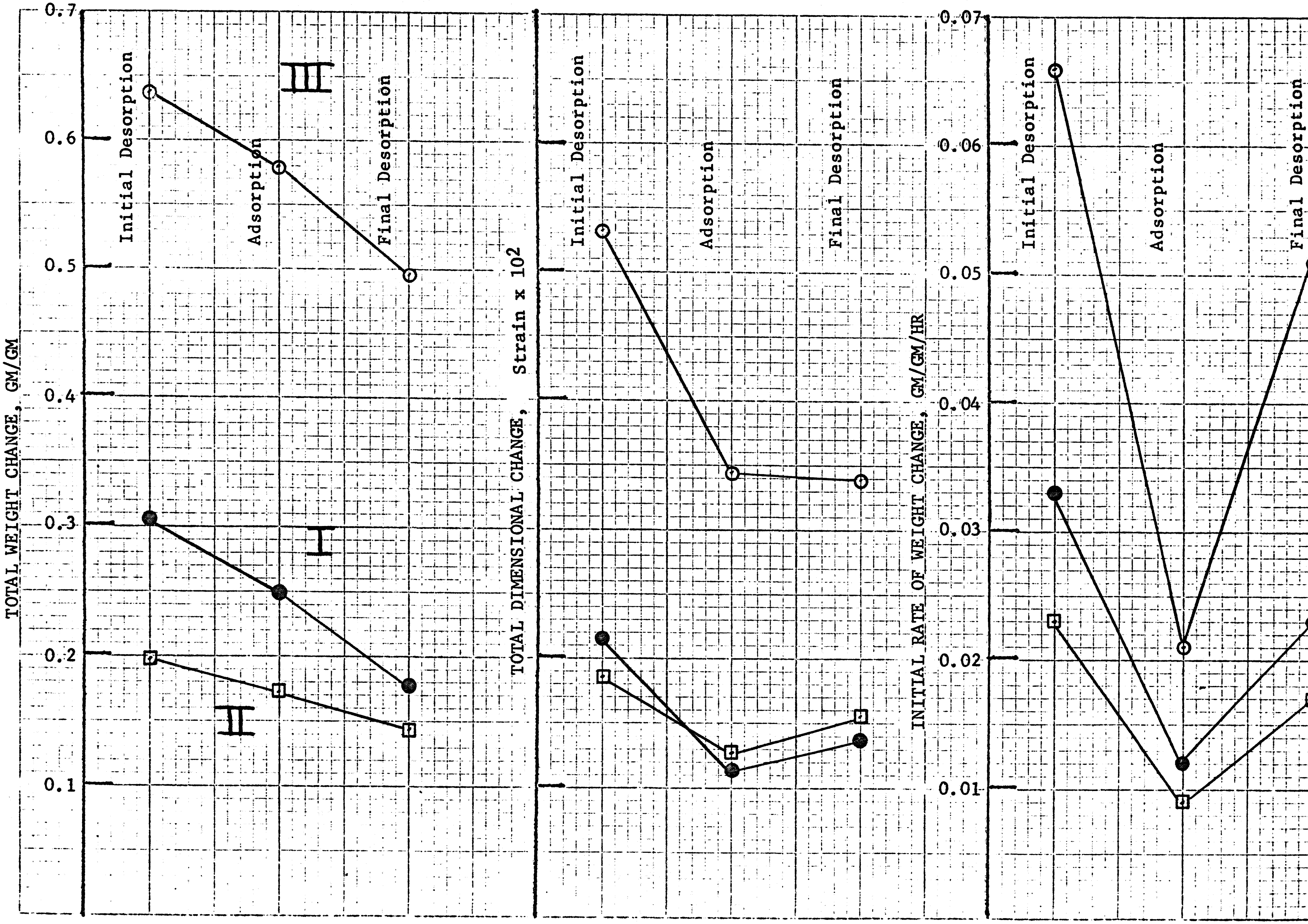

FIGURE 35. CEMENT #74. TYPE O.W.TOTAL WEIGHT CHANGE, TOTAL DIMENSIONAL CHANGE, AND INITIAL RATE OF WEIGHT CHANGE (0-5 HR) EXHIBITED DURING INITIAL DESORPTION, ADSORPTION, AND FINAL DESORPTION.

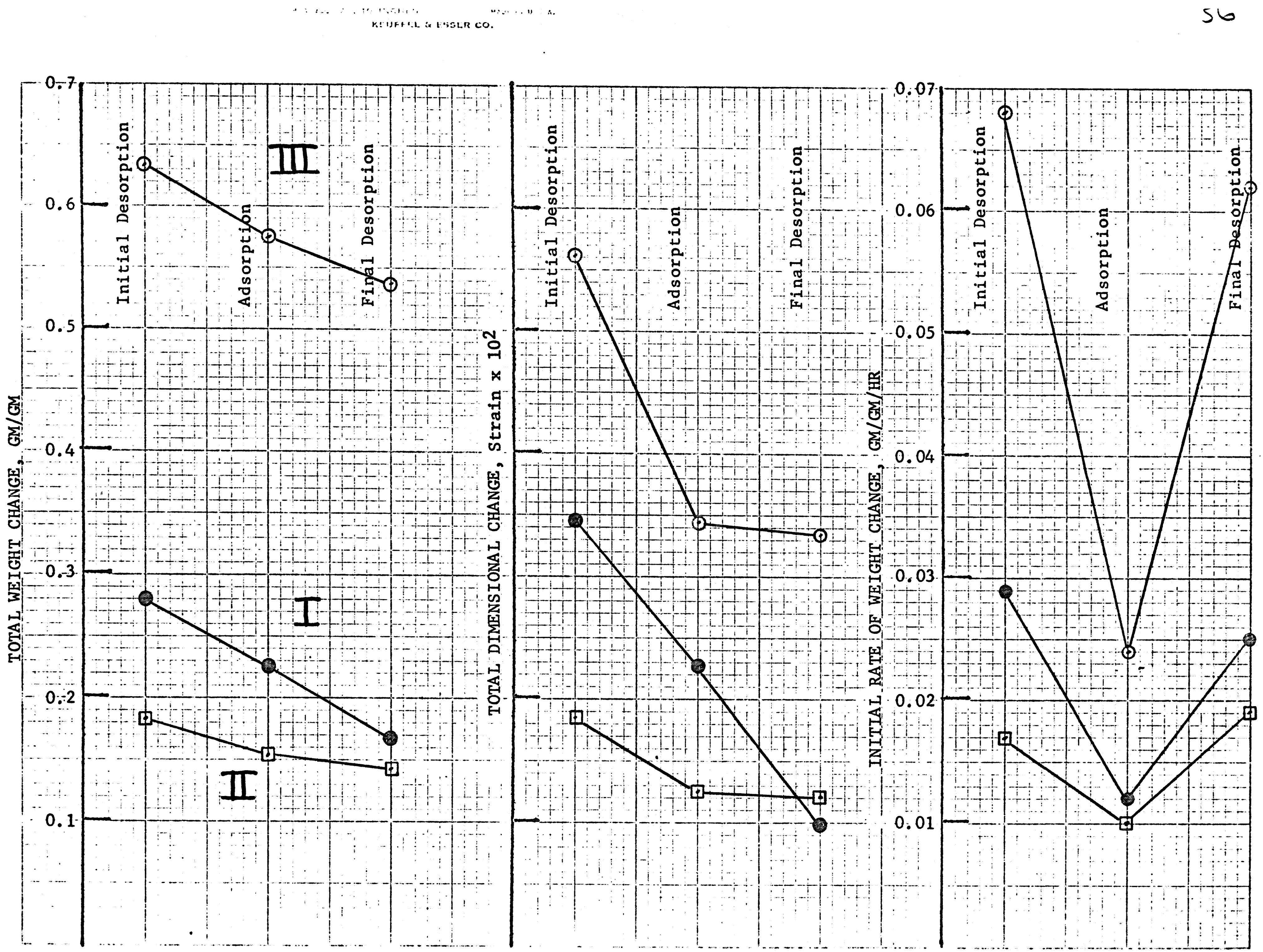

FIGURE 36. TYPE I CEMENTS (AVERAGE)

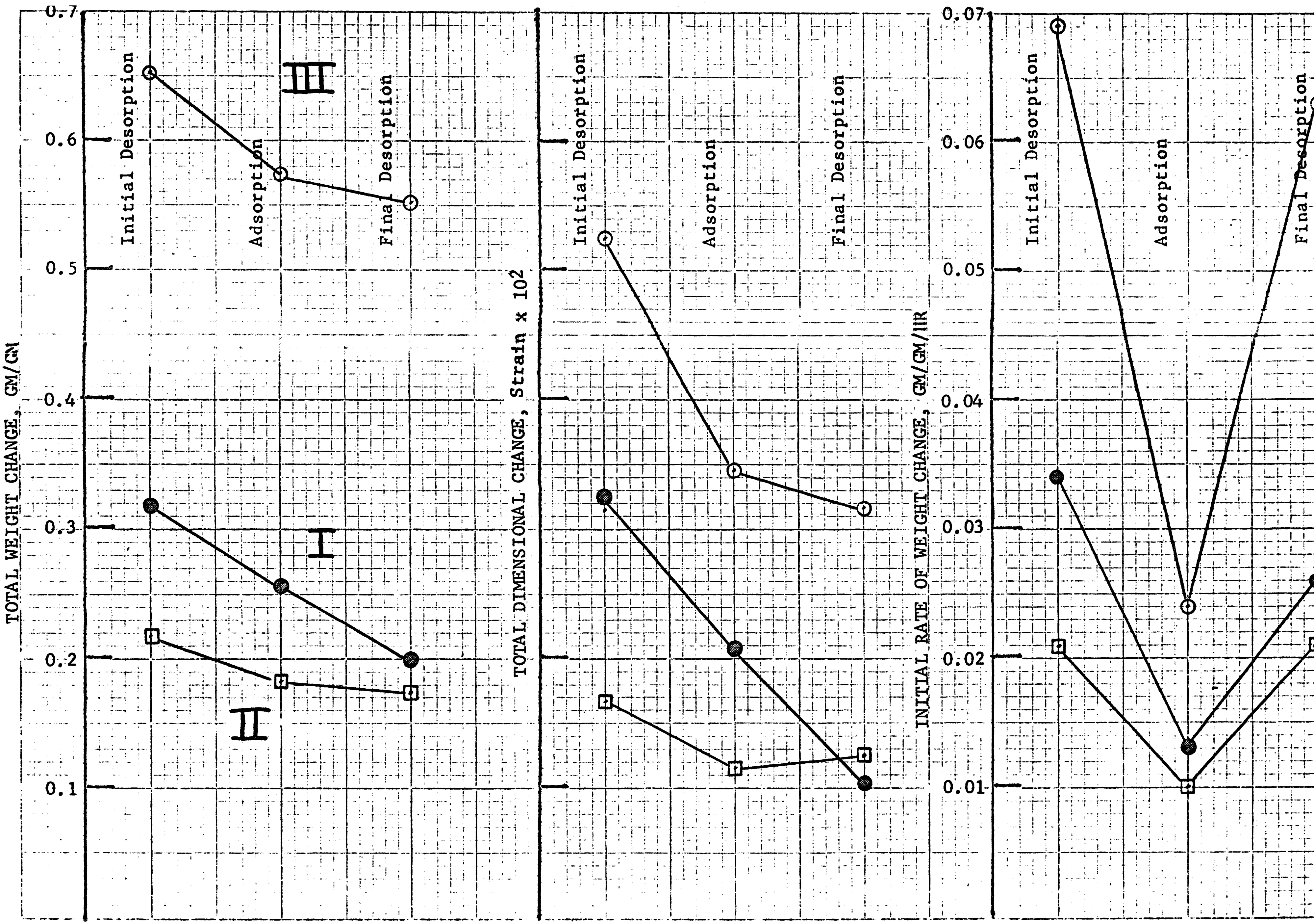

FIGURE 37. TYPE II CEMENTS (AVERAGE)

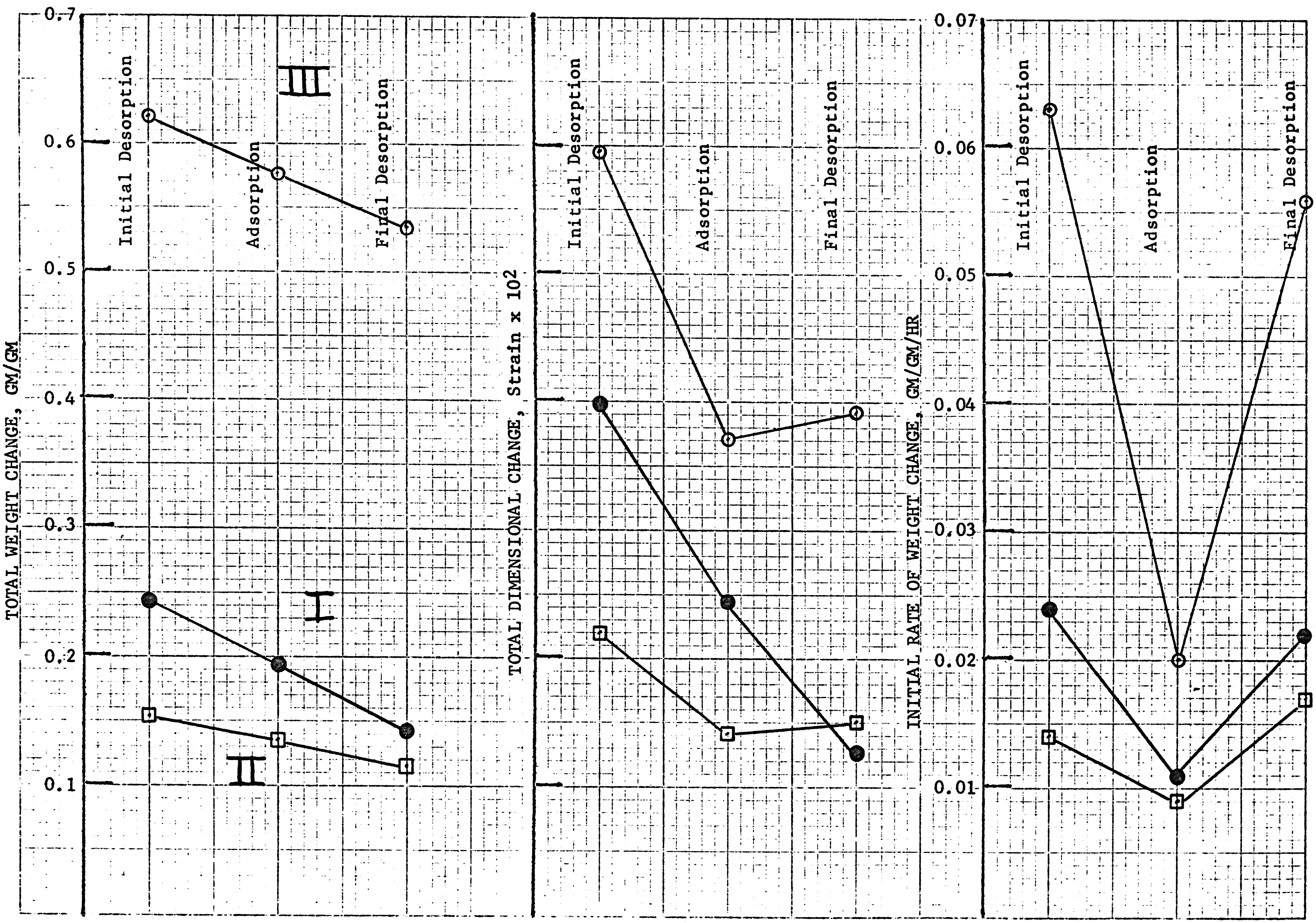

FIGURE 38. TYPE III CEMENTS (AVERAGE)

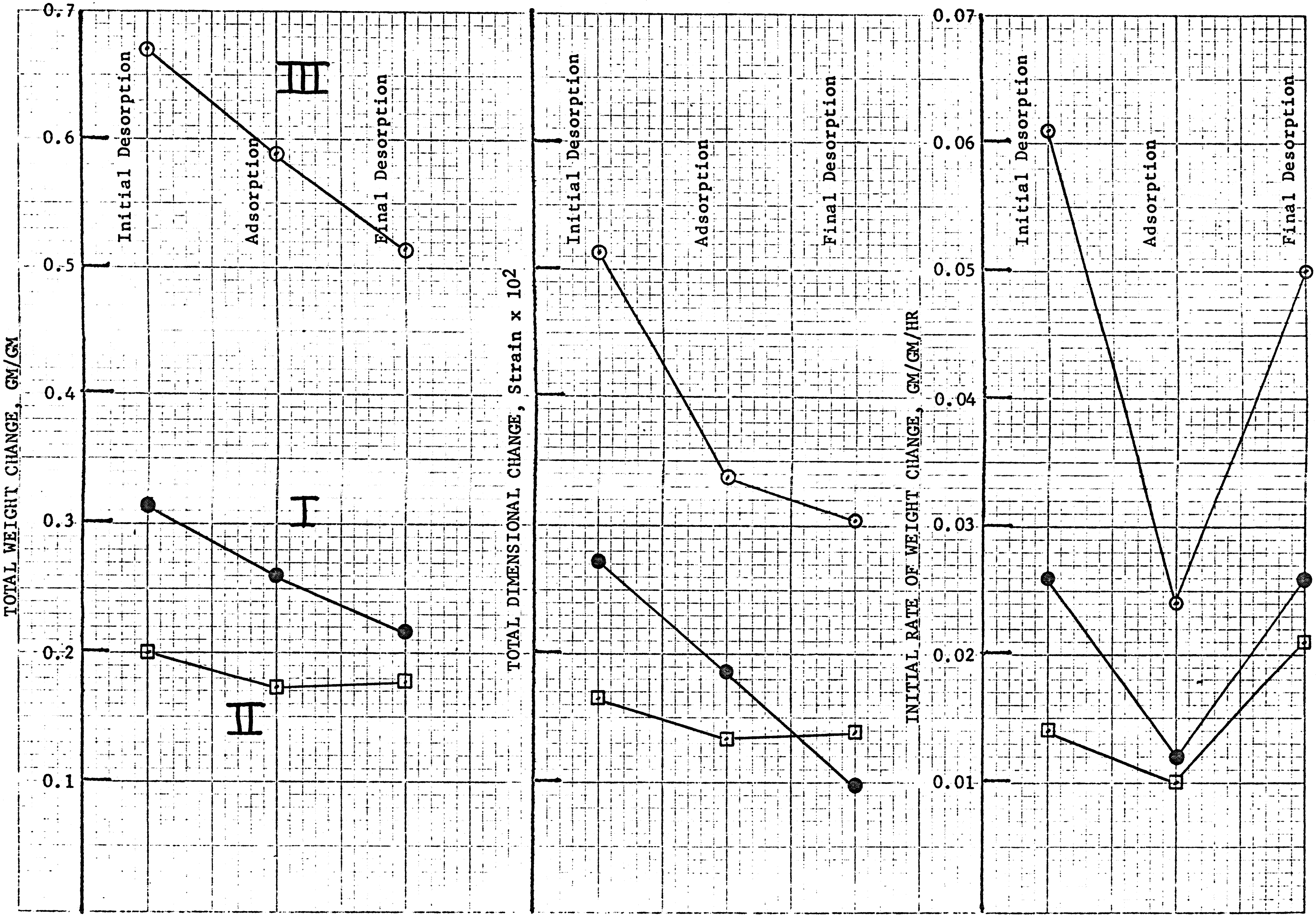

FIGURE 39. TYPE IV CEMENTS (AVERAGE)

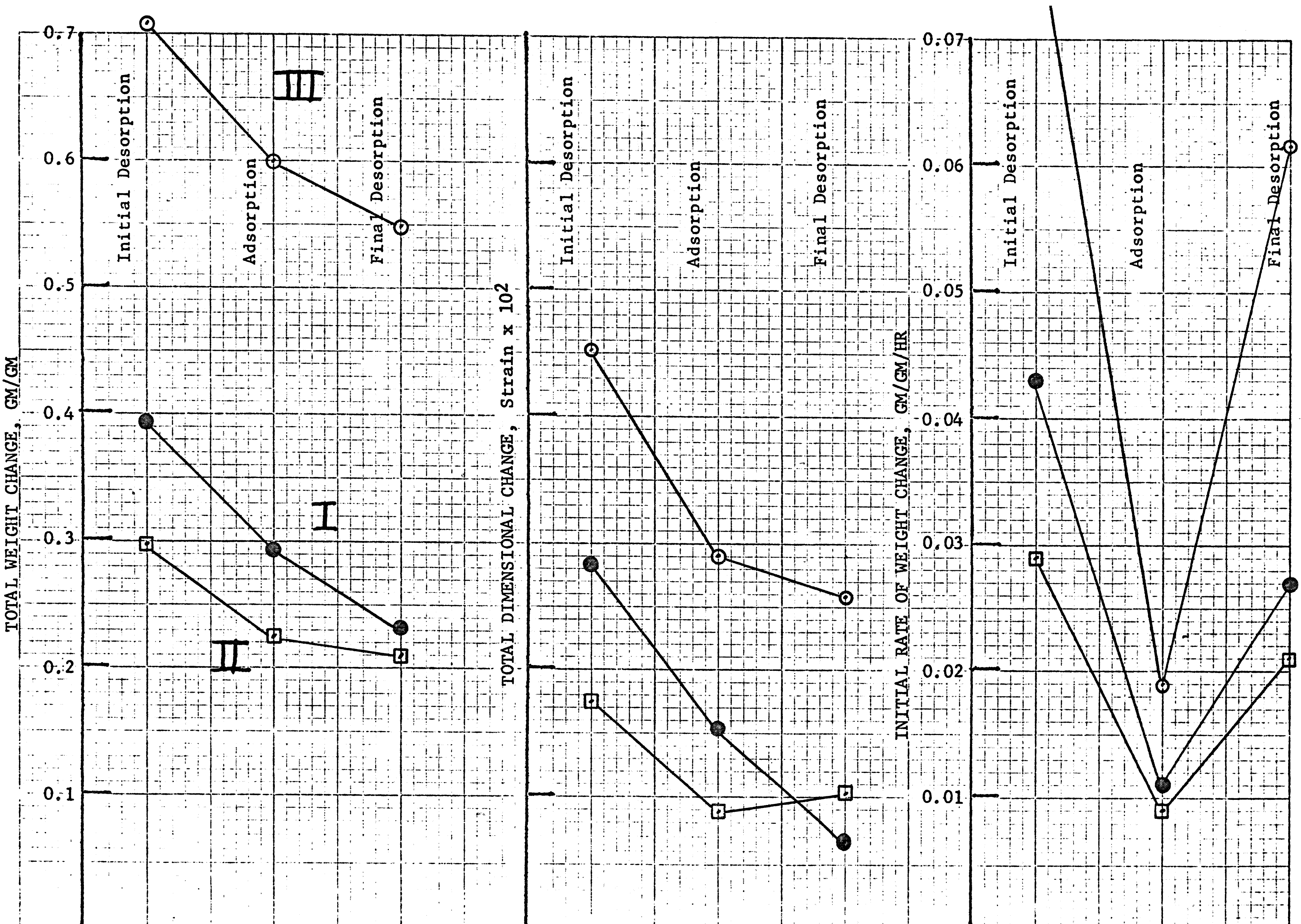

FIGURE 40. TYPE V CEMENTS (AVERAGE)

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 Average	ENVIRONMENT I Total Weight Loss Difference(a)	ENVIRONMENT II Total Weight Loss Average	ENVIRONMENT II Total Weight Loss 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 σ_y^2 of the usual x^2 type with ν 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 σ_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 σ^2 is the variance of an individual observation. We have an estimate of σ^2 from the error mean square of the ANOVA given in Table A-2a

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

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,

μ = 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 σ_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 σ_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 σ^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	4.5×10^{-6}
.167	.203	648.0×10^{-6}
.632	.635	12.5×10^{-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 σ^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 σ^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.