NATIONAL BUREAU OF STANDARDS REPORT

6499

Drying Shrinkage of Concrete Masonry Units
Determined by Different Methods

by

J. O. Bryson and D. Watstein

Report to
the Departments of
the Air Force, the Army, and the Navy

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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NBS PROJECT | **NBS REPORT**

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Four different procedures of measuring the drying shrinkage of concrete masonry units were compared in order to determine their suitability as possible standard test methods. The four test procedures were the ACI Reference (73°F and 50% R.H.), NBS Reference (73°F and 30% R.H.), Modified British (122°F and 17% R.H.), and Rapid (220°-235°F). In addition to varying the drying conditions, the size and shape of test specimens were also varied. The specimens were whole block, face shells cut in half lengthwise, thin laminas removed from the block at right angles to the face shell, and "remnant" block remaining after removal of the thin laminas.

The drying shrinkage tests were performed by all four procedures on both autoclaved and low-pressure steam cured block of expanded slag, expanded shale, cinders, pumice, and sand and gravel aggregates.

Considering the ACI Reference Method as a basis of comparison, both the NBS Reference and the Modified British Method showed about the same extent of departure from the results on the control specimens. The ratios of the NBS Reference results to the control specimens ranged from 0.69 to 1.22, while for the Modified British procedure these ratios ranged from 0.91 to 1.31. For the Rapid Method, these ratios ranged from 1.22 to 3.35.

Considerable reduction in the time required for completion of the shrinkage test at room temperature was achieved by the use of thin section specimens developed at the NBS.

1. INTRODUCTION

The dimensional instability of concrete masonry units is a problem of great concern for those connected with building construction. These units, in addition to varying in length with temperature, undergo shrinkage due to drying. The degree to which a concrete masonry unit will change in volume upon drying is known to depend primarily on the type of aggregate used in the concrete and the method of curing it received. Masonry walls constructed with concrete units that shrink excessively often develop cracks that are unsightly and sometimes damaging.

Attempts to prevent the development of cracks in concrete masonry walls by limiting the moisture content of the units at the time of construction have proven largely unsuccessful. There is at present a renewed interest in the development of a rapid and reproducible test procedure to serve as a standard method for determining the drying shrinkage potential of concrete block in acceptance tests. This is evidenced by the fact that two committees of the American Concrete Institute, Committee 213 on Lightweight Aggregates and Committee 716 on High-Pressure Steam Curing, have jointly sponsored a comparative study by four laboratories to determine the merits of different procedures for determination of shrinkage. The National Bureau of Standards is one of the laboratories participating in this study. The Bureau's participation in this study was supported as a subsidiary project of the Tri-Service Program.

2. SCOPE OF THE PROGRAM

The concrete masonry block used for the tests were units representing five different types of aggregate and both autoclave and low-pressure steam curing methods. The aggregate types were expanded blast furnace slag, expanded shale, sand and gravel, pumice, and cinders. In each case the block were supplied by a commercial source which normally produce them. All block were 8- by 8- by 16-in. units. Arrangements were made to secure both autoclaved and low-pressure steam cured units from the same plant in order to have aggregates of the same quality in blocks cured by both methods. Care was also taken to have the block delivered in time to be placed under test when the block were 28 days old. However due to some inadvertent delays, some block were placed under test about two to three weeks late.

Various types of specimens representing these block were placed under test using four methods of drying. These were the ACI Reference, NBS Reference, Modified British, and Rapid Methods of drying.

In addition to the shrinkage tests made on the units which were 28 days old, a second group of specimens were placed under test by the NBS Reference Method after they were aged indoors for about four months.

3. TEST PROCEDURES AND TEST SPECIMENS

All block were placed in a room controlled at a temperature of 73°F and 50% relative humidity for a minimum of 7 days prior to testing. At the end of this period the necessary cutting was done and gage plugs were installed.

All specimens of the same aggregate-cure combination were placed under test at the same time. The specimens were submerged in water at 73 ± 3°F for 48 hr prior to the test cycle, and the initial measurements of length and weight were made immediately after the soaking period. A Whittemore strain gage was used for measuring length changes over a 10-in. gage length.

ACI Reference Method

The specimens were stored for drying in a room where the temperature was controlled at 73 ± 3°F and the relative humidity was controlled at 50 ± 5%. The specimens were considered to be at equilibrium with the drying conditions when their average change in length was not greater than 0.002% over a period of 14 days.

Modified British Method [1] 1/

Following the initial measurements, which in all cases were scheduled to fall on a Friday, the specimens for this method were placed in a room controlled at 73 ± 3°F and 50 ± 5% relative humidity over a weekend, after which they were placed in an oven in which the temperature was controlled at 122 ± 2°F and the humidity controlled by a saturated solution of calcium chloride. These conditions have been reported as providing a relative humidity of about 17% [2]. The initial period of oven storage was 5 days. This was followed by cooling over the weekend in air-tight drums. Length measurements were made at the end of the cooling period. Subsequent drying periods of 48 hr followed by an overnight cooling period during the week, and a cooling period over-the-week-end at the end of the week were continued until equilibrium was reached. The specimens were considered to be at equilibrium when the average length change over a drying period of 6 days (or three 48 hr drying periods) did not exceed 0.002%.

1/ The numerals in brackets refer to list of references at the end of the report.

Rapid Method

The specimens were dried in an oven in which the temperature was controlled at 220°F to 235°F for 48 hr, after which they were placed in airtight cooling drums located in a room controlled at 73 ± 3°F. The measurements were made on the specimens after they had cooled to the temperature of the room. Additional drying periods of 24 hr followed by cooling in the drums were continued until equilibrium was reached. Equilibrium was considered to have been attained when the average change in length during an oven drying period of 24 hr did not exceed 0.002%.

NBS Reference Method

The specimens were dried in a room in which the temperature was controlled at 73 ± 3°F and the relative humidity was controlled at 30 ± 2%. Equilibrium was considered to have been attained when the average change in length did not exceed 0.002% over a 14 day period.

The test specimens used in this study are illustrated in figures 1 and 2. Whole block specimens illustrated in figure 2 were tested by each of the four methods for each of the aggregate-cure combinations. In addition to whole block specimens, representative specimens were cut and prepared for strain measurements. Two block of each aggregate-cure type were prepared as shown in figure 1 for the ACI Reference and Modified British Methods. This figure shows the half shell and thin slice specimens in the positions from which they were removed from the block. It can be seen that four half shell and two thin slice specimens were obtained from a block. One thin slice and two diagonally opposite half shells were tested by the ACI Reference Method and the remaining thin slice and half shell specimens were tested by the Modified British Method. Accordingly, the specimens that represented an aggregate-cure combination in the ACI Reference and Modified British tests were two whole block, two thin slices, and four half shells.

The specimens that were used in the tests of block of each aggregate-cure type by the NBS Reference Method were one whole block, one remnant block, and two thin slices. Figure 2 shows the remnant and slice specimens outlined on a whole block. A view of the actual specimens prepared for test by the NBS Reference Method are shown in figure 3.

Test specimens for the Rapid Method were only whole block tested in duplicate.

The location of gage plugs which received the points of the 10-in. Whittemore gage are shown in figure 2 for the whole block, remnant block and thin sections. The location of these gage points on the half shells is indicated in figure 1. It is noted that gage lines were established both on the inner and outer faces of the half shells.

The procedure used in fabricating the thin sections and placing them under test is described here in considerable detail. It was observed during the course of development of this specimen that it responded very rapidly to changing environment during the period of fabrication. It was thought advisable to specify a standardized procedure to be followed in the fabrication of the thin specimens in order to avoid certain irreversible length changes which are known to have occurred in those thin sections which were permitted to dry partially during the fabrication period.

The thin slice specimens were cut using a 22-in. diamond cutting wheel provided with depth and cross-feed controls. Diamond cutting wheels, of course, must be used with a liberal amount of water applied as a jet at the cutting edge. The slices were 1/2-in. thick. The cut through a 8- by 8- by 16-in. unit is made in two passes of the diamond cutting wheel.

After the first cut was made, holes for the Whittemore gage plugs were drilled sufficiently deep to assure that the thin slice specimen is perforated after the slice is removed by completion of the second cut. The holes for the Whittemore gage reference plugs in the thin slices as well as in the remnants and whole blocks were drilled with a 1/4-in. (#12) carbide tipped drill. The slice specimens were submerged in water immediately after cutting. The slices were removed from the water one at a time for installation of the plugs. As the gage plugs are installed, the specimens are completely covered with damp burlap and kept moist for 24 hours.

The reference holes in gage plugs were next drilled using a high speed 1.2 mm drill. The specimens were removed from under the burlap one at a time and were placed in water immediately after the holes are drilled, reamed and checked with a 10-in. Whittemore gage as being satisfactory. The soaking period was reckoned from the time the specimens were returned to the water following processing of the gage plugs.

4. RESULTS AND DISCUSSION

The equilibrium shrinkage values for the specimens tested by each of the four methods are given in table 1. These values are the averages for the respective types of specimens and, with the exception of the values determined by the Rapid Method are based on the shrinkage-time curves presented in figures 4 through 8. The values of shrinkage obtained from these curves correspond to the conditions of equilibrium previously defined.

It is immediately apparent from the data shown in figures 4 through 8 that for autoclaved block the size of the specimen has no important effect on the equilibrium value of shrinkage for a given test method. The shrinkage-time curves obtained for the autoclaved block with three types of specimens fall within a narrow band and in a random order for all three test methods shown. However, the average values of shrinkage determined by the three methods showed measurable differences. It was noted that the British values were somewhat higher than either the ACI Reference or NBS Reference values. When all the data obtained on the autoclaved block are taken into account, it is seen that the ratios of Modified British to ACI Reference values ranged from 1.08 to 1.29, while the ratios of NBS Reference to ACI Reference values ranged from 0.78 to 1.07.

The relative standings of the values obtained with the whole block specimens and the cut specimens were entirely different for low-pressure steam cured block tested by the Modified British and ACI Reference Methods. Without exception, the thin laminas showed the greatest values of shrinkage, the half shell specimens showed intermediate values and the whole block specimens showed the least values of shrinkage.

In general, the thin laminas also gave somewhat higher shrinkage values when tested by the NBS Reference Method than either the remnant or whole block specimens. However, the differences observed between the thin laminas and the parent remnant block in the NBS Reference series were considerably smaller than the corresponding difference for the ACI Reference series. Thus, as can be seen from table 1, the differences between equilibrium shrinkage values for the laminas and half shell specimens ranged up to 0.01% in the ACI Reference series, and to a maximum of 0.004% in the NBS Reference series. It is noted that in making this comparison the half shell specimens and the remnant block specimens are considered as comparable test specimens.

An examination of the time-shrinkage curves in figures 4 to 8 reveals another important distinction between the results obtained by the NBS Reference Method on one hand and both the Modified British and the ACI Reference Methods on the other hand. In general, the low-pressure steam cured block dried at 30% relative humidity (the NBS Reference Method) exhibited a measurably lower rate of shrinkage as they approached a state of equilibrium than did the block dried by either the Modified British or the ACI Reference Methods. This fact is brought out graphically by the differences in the slopes of the curves near their ends. The time-shrinkage curves of low-pressure steam-cured block of pumice, cinders and expanded slag may be singled out in this respect. It is also noted that for pumice block tested by the Modified British Method, the criterion for equilibrium shrinkage was not met by the end of the test after 23 days drying in the oven.

The foregoing remarks concerning the differences in the rates of shrinkage obtained by the three methods as the block approached equilibrium are not applicable to the autoclaved block. It is apparent from an examination of these data that in general the slopes of the shrinkage-time curves nearing the ends of the drying cycles were nearly the same for both the ACI and NBS Reference Methods. Only in case of pumice block was there a significant departure from this observation; the whole block and remnant block specimens in the NBS Reference series showed a reversal in the shrinkage movement. It is significant that the laminas cut from autoclaved pumice block did not exhibit such a reversal in the shrinkage movement, indicating that presence of significant amounts of moisture in the slower drying larger specimens was essential to produce such a reversal of shrinkage.

In view of the inconsistency of the effect of specimen size on shrinkage values, a comparison of the results for the different methods was made using only the values obtained from whole block. Table 2 gives the equilibrium shrinkage ratios for whole block specimens tested by the Modified British, Rapid, and NBS Reference Methods using the results from the ACI Reference tests as standard values. The shrinkage ratios show that the Modified British and NBS Reference whole block specimens shrink about the same amount as the whole block specimens tested by the ACI Reference Method. The specimens from the Modified British tests had shrinkage ratios for the different aggregate-cure combinations ranging from a low of 0.91 for low-pressure cinder units to a high of 1.31 for autoclaved slag units, while the ratios for the NBS Reference specimens ranged from 0.69 for autoclaved slag units to 1.22 for low pressure sand and gravel units. The ratios for the specimens tested by the Rapid Method show that drying shrinkage measured by this method bore no consistent relationship to the values obtained by the ACI Reference Method. For the low-pressure steam cured block the ratios of Rapid to ACI Reference values ranged from 1.22 to 2.64; for autoclaved block, these ratios ranged from 2.12 to 3.35. It is obvious that if the ACI Reference values for whole block specimens are to be considered as being most nearly representative of the performance of the block under actual service conditions, then the values obtained by the Rapid Method cannot be relied upon for predicting the performance of masonry in service.

It is generally assumed that the equilibrium shrinkage values observed by the ACI Reference Method represent very nearly the maximum values of shrinkage which the block develop at that temperature and humidity. In order to verify this hypothesis, several low pressure steam cured whole block specimens were permitted to dry for a prolonged period following the attainment of equilibrium shrinkage values. The results of these few tests are given in table 3. It can be seen that the increases in the drying shrinkage during the additional drying

periods ranged from 9% for pumice block to 35% for sand and gravel block. It appears that shrinkage studies of concrete masonry units, particularly the low pressure steam cured variety, should be carried out over considerably longer periods than were used in this study in order to arrive at the "ultimate" shrinkage values.

The tendency for low-pressure cured block, tested by the ACI Reference Method to continue to shrink for long periods of time may possibly be explained by the fact that in addition to the drying shrinkage of concrete, carbonation shrinkage also develops under favorable conditions. Results reported by other investigators [3, 4] indicate that the conditions of drying used in the ACI Reference Method are conducive to carbonation shrinkage. Verbeck [4] reported that carbonation shrinkage was quite small at 30% relative humidity. This fact would seem to offer an explanation of the significant differences in the behavior of the specimens of various sizes in the ACI and NBS Reference series. The relatively good concordance of the shrinkage values obtained with the laminas, the parent remnant block, and the whole block specimens in the NBS Reference series is a direct consequence of low carbonation shrinkage at a relative humidity of 30%.

In order to determine the effect of prolonged storage on the shrinkage properties of block, a second group of specimens were tested by the NBS Reference Method. The specimens were obtained from block that were left over from the original source. The block had been stored in a room for four months where there was no temperature or humidity control. The shrinkage-time curves for this second group are presented in figure 9. It can be seen that the shrinkage curves for the second group of autoclaved specimens were practically identical with those obtained from the first group. However, the second group of low-pressure cured specimens had shrinkage equilibrium values that were reduced from 25 to 50% compared with the shrinkage of similar specimens from the first test. The results from this second test indicate that the shrinkage of low-pressure cured block is significantly reduced after several months of indoor storage whereas the shrinkage of autoclaved block is apparently unaffected by such storage.

The suitability of a drying shrinkage test procedure is also determined by the length of time required to attain equilibrium. The ages at equilibrium for the Modified British, the ACI Reference, and the Rapid Methods are shown in figures 10 and 11, while the data for the NBS Reference Method are given in figure 12.

In the ACI Reference Method the length of drying of whole block specimens to equilibrium ranged from 31 to 85 days for low pressure cured block, and from 28 to 36 for autoclaved block. The use of laminas in the ACI Reference series did not produce a uniform reduction in the time required to attain equilibrium. In four cases out of five,

the use of laminas resulted in an appreciable reduction in the drying time, for both low-pressure cured and autoclaved block. In the other two cases, the use of laminas increased the period of drying to equilibrium.

In the Modified British series, the length of drying of whole block specimens to equilibrium ranged from 11 to 23 days for low-pressure cured block and from 11 to 15 days for autoclaved block. The use of half shells and laminas did not appreciably affect the length of drying to equilibrium. The Modified British Method generally requires a much shorter time for specimens to reach equilibrium than is required by the ACI Reference. However, when the time required for cooling is added to the oven drying time, as many as 40 days may be required to reach equilibrium. This was the case for the pumice specimens (it is noted that for every 4 days of oven drying there were approximately 3 days of cooling).

In the Rapid Method equilibrium was established in a much shorter time than was required by any of the other methods. In no case was as much as a week of drying needed to bring about equilibrum. The average number of drying days needed to meet the equilibrium requirement was 4, and in only one case (low-pressure pumice) was as many as 6 days needed.

In the NBS Reference series, the time required for whole block and remnant block specimens to attain equilibrium ranged from 24 to 42 days for low-pressure cured block and 18 to 26 days for autoclaved block. The use of laminas reduced the time required to: from 19 to 27 days for low-pressure cured block and from 15 to 17 days for autoclaved block. It is noted that the criterion adopted for judging the attainment of equilibrium in NBS Reference series calls for a 14 day period of observations. In view of the fact that at 30% relative humidity both the low-pressure steam cured block and the autoclaved block exhibited a significantly lower rate of shrinkage as they approached equilibrium than at 50% relative humidity, it appears possible to accelerate the test by reducing the period for checking equilibrium to 7 days. If this were done, the time required for the shrinkage test using the laminas would be reduced to periods ranging from 12 to 20 days for low-pressure cured block and from 8 to 10 days for autoclaved block.

5. SUMMARY

1. The ACI Reference, Modified British, and NBS Reference Methods produced roughly the same equilibrium shrinkage on whole block specimens. The ratios of Modified British to ACI Reference values ranged from 0.91 to 1.31 while for NBS Reference series these ratios ranged from 0.69 to 1.22.

2. The shrinkages obtained by the Rapid Method bore no consistent relationship to the values obtained by ACI Reference Method. For the low-pressure steam cured block the ratios of Rapid to ACI Reference values ranged from 1.22 to 2.64; for autoclaved block these ratios ranged from 2.12 to 3.15.

3. The size of the specimen had no important effect on the equilibrium values of shrinkage for autoclaved block tested by a given method. However, the average values of shrinkage for the three types of specimens determined by each of the three methods in which the size of specimen was a variable, showed measurable differences. With all specimens taken into account, the ratios of Modified British to ACI Reference values ranged from 1.08 to 1.29, while for NBS Reference Method these ratios ranged from 0.78 to 1.07.

4. In the ACI Reference and Modified British series, the laminas showed the greatest shrinkage, the half shells showed intermediate values and whole block showed the least values of shrinkage. In general, the thin laminas also gave somewhat higher shrinkage by the NBS Reference Method than either the remnant or whole block specimens, but the differences were considerably smaller than the corresponding differences for the ACI Reference series.

5. The rate of shrinkage of low-pressure steam cured block as they approached equilibrium, was markedly lower when dried by the NBS Reference Method than for block dried by either Modified British or ACI Reference Method. However, for autoclaved block the rate of shrinkage as the block approached equilibrium was nearly the same for both ACI and NBS Reference Methods.

6. The use of laminas did not produce a uniform reduction in the time required to attain equilibrium by the ACI Reference Method. However, in the NBS Reference Method, the use of laminas reduced the time to attain equilibrium significantly in all cases. In view of the fact that it appears possible to shorten the period for checking equilibrium in the NBS Reference Method from 14 to 7 days, the time required for the shrinkage test by this method using laminas might be reduced to periods ranging from 8 to 20 days.

7. Tests of a group of block by the NBS Reference Method after prolonged storage indoors indicate that shrinkage of low-pressure cured block is significantly reduced, whereas shrinkage of autoclaved block is apparently unaffected by such storage.

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REFERENCES

[1] Modified British Method of Test for Drying Shrinkage of Concrete Products, Corps of Engineers Specification CRD-C73.

[2] Physical Properties of High-Pressure Steam-Cured Concrete Block. Progress Report of ACI Committee 716, Proc. of the American Concrete Institute, Vol. 49, 1953, p. 745-756.

[3] Investigation of the Moisture-Volume Stability of Concrete Masonry Units, J. J. Shideler, Portland Cement Association Bulletin D3, March 1955.

[4] Carbonation of Hydrated Portland Cement, G. J. Verbeck, Portland Cement Association Bulletin 87, Feb. 1958.

Table 1. Equilibrium shrinkage values, percent

Method	Specimen	Aggregate-Cure Combination									
		Slag L.P. *	Slag H.P. *	Shale L.P.	Shale H.P.	Sand & gravel L.P.	Sand & gravel H.P.	Pumice L.P.	Pumice H.P.	Cinders L.P.	Cinders H.P.
ACI Reference	Whole block	0.046	0.016	0.055	0.022	0.023	0.017	0.078	0.034	0.043	0.020
	Half shell	0.055	0.015	0.063	0.024	0.026	0.018	0.079	0.037	0.046	0.019
	Lamina	0.064	0.015	0.065	0.026	0.027	0.017	0.083	0.035	0.056	0.018
Modified British	Whole block	0.045	0.021	0.055	0.023	0.028	0.019	0.080 2/	0.041	0.039	0.024
	Half shell	0.048	0.019	0.061	0.024	0.031	0.019	0.079 2/	0.038	0.042	0.022
	Lamina	0.058	0.019	0.069	0.028	0.031 1/	0.020	0.079	0.034	0.047	0.023
Rapid	Whole block	0.057	0.037	0.067	0.054	0.045	0.036	0.206	0.114	0.054	0.043
NBS Reference	Whole block	0.041	0.011	0.052	0.022	0.028	0.018	0.080	0.039 3/	0.044	0.019
	Remnant	0.047	0.013	0.050	0.021	0.028	0.016	0.082	0.041 3/	0.045	0.020
	Lamina	0.051	0.012	0.052	0.021	0.028	0.020	0.083	0.033	0.047	0.020

* L.P. and H.P. refer to low-pressure steam and high-pressure steam curings, respectively.

1/ One specimen.

2/ Criterion for equilibrium shrinkage was not met in 23 days of drying. The value reported is the maximum value of shrinkage.

3/ Maximum values.

Table 2. Shrinkage ratios for whole block with the ACI Reference series as a base.

	Aggregate-Cure Combination									
	Slag L.P.	Slag H.P.	Shale L.P.	Shale H.P.	Sand & gravel L.P.	Sand & gravel H.P.	Pumice L.P.	Pumice H.P.	Cinders L.P.	Cinders H.P.
Modified British to ACI Reference	0.98	1.31	1.0	1.05	1.22	1.12	1.03	1.21	0.91	1.20
Rapid to ACI Reference	1.24	2.31	1.22	2.45	1.96	2.12	2.64	3.35	1.26	2.15
NBS Reference to ACI Reference	0.89	0.69	0.95	1.0	1.22	1.06	1.03	1.15	1.02	0.95

Table 3. Shrinkage observed beyond the equilibrium values as defined by the criterion for the ACI Reference series.

Aggregate	Cure	Specimen type	Drying period at equilibrium	Shrinkage at equilibrium	Maximum drying period	Maximum observed shrinkage	Increase in shrinkage beyond equilibrium
			days	percent	days	percent	percent
Slag	L.P.	Whole block	50	0.046	201	0.058	26
Sand & gravel	L.P.	Whole block	31	0.023	178	0.031	35
Pumice	L.P.	Whole block	85	0.078	153	0.085	9
Cinders	L.P.	Whole block	70	0.043	138	0.050	16

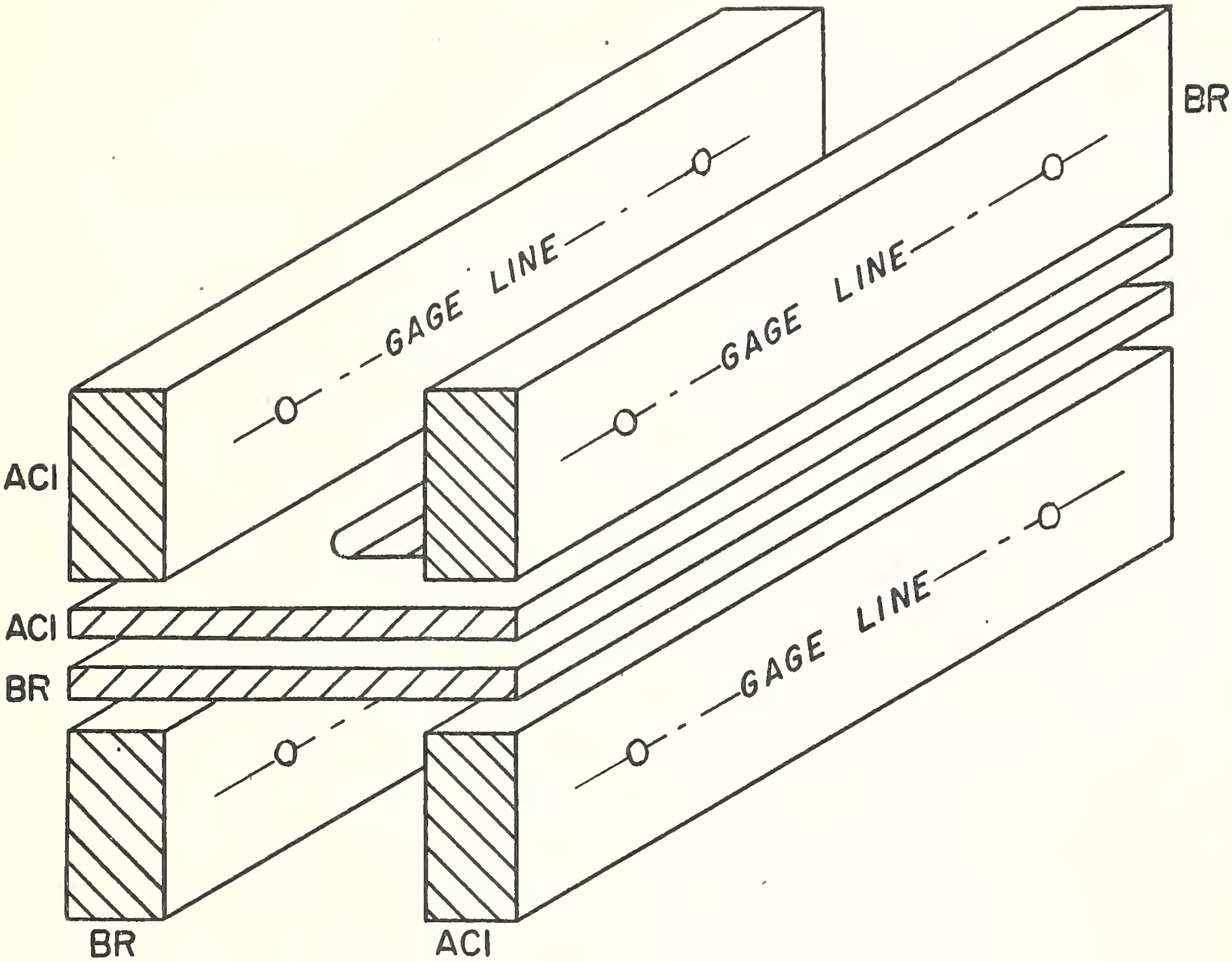
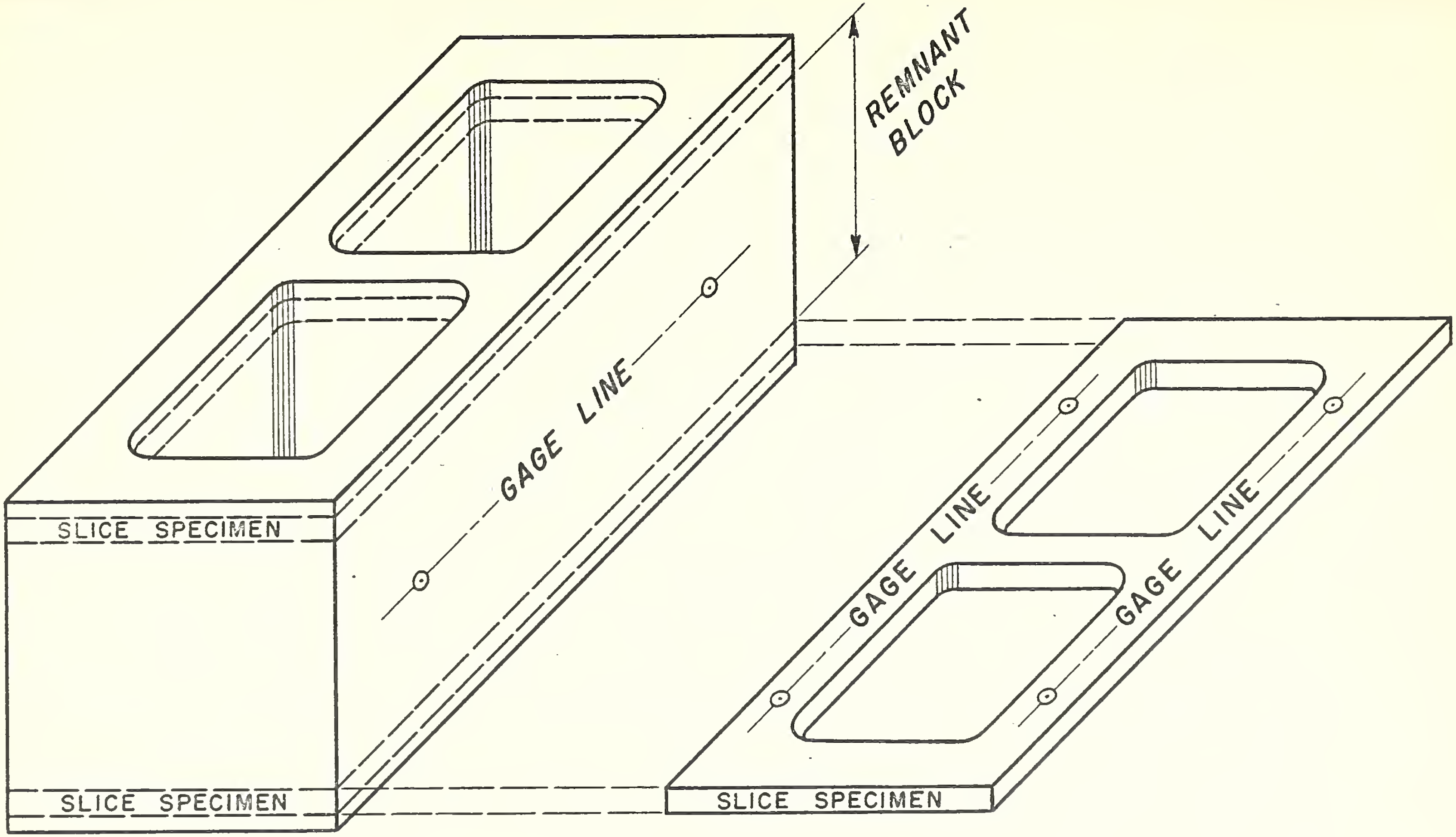


Figure 1 Half shells and thin laminas shown in the positions from which they were cut from block.



(a) WHOLE BLOCK AND REMNANT BLOCK SPECIMENS

(b) SLICE – SPECIMEN

FIGURE 2 RELATIONSHIP OF THE THIN LAMINAS AND REMNANT BLOCK TO THE WHOLE BLOCK FOR THE NBS REFERENCE TEST.

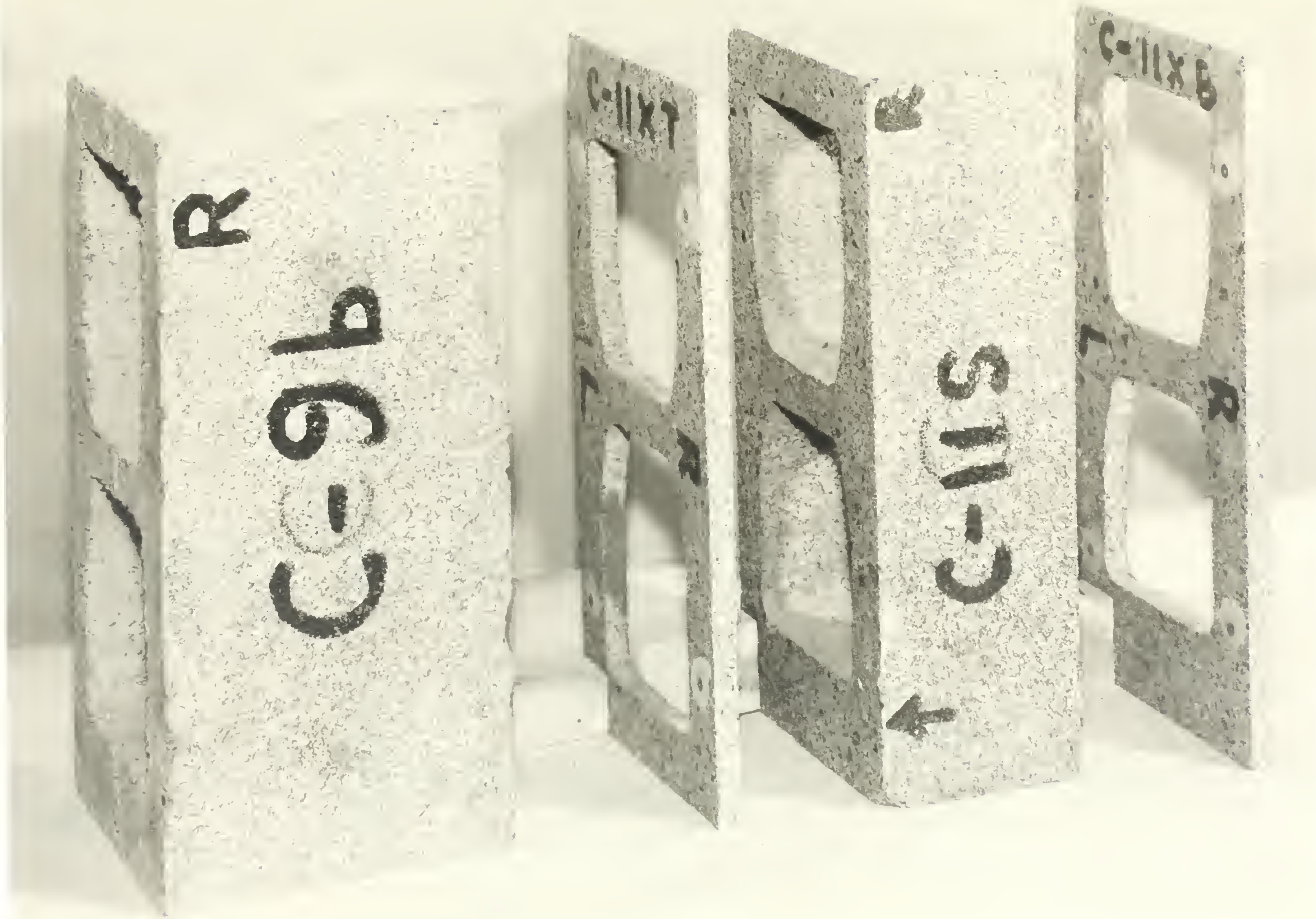


FIG. 3 VIEW OF ACTUAL SPECIMENS REPRESENTING AN AGGREGATE – CURE COMBINATION IN THE NBS REFERENCE TEST.

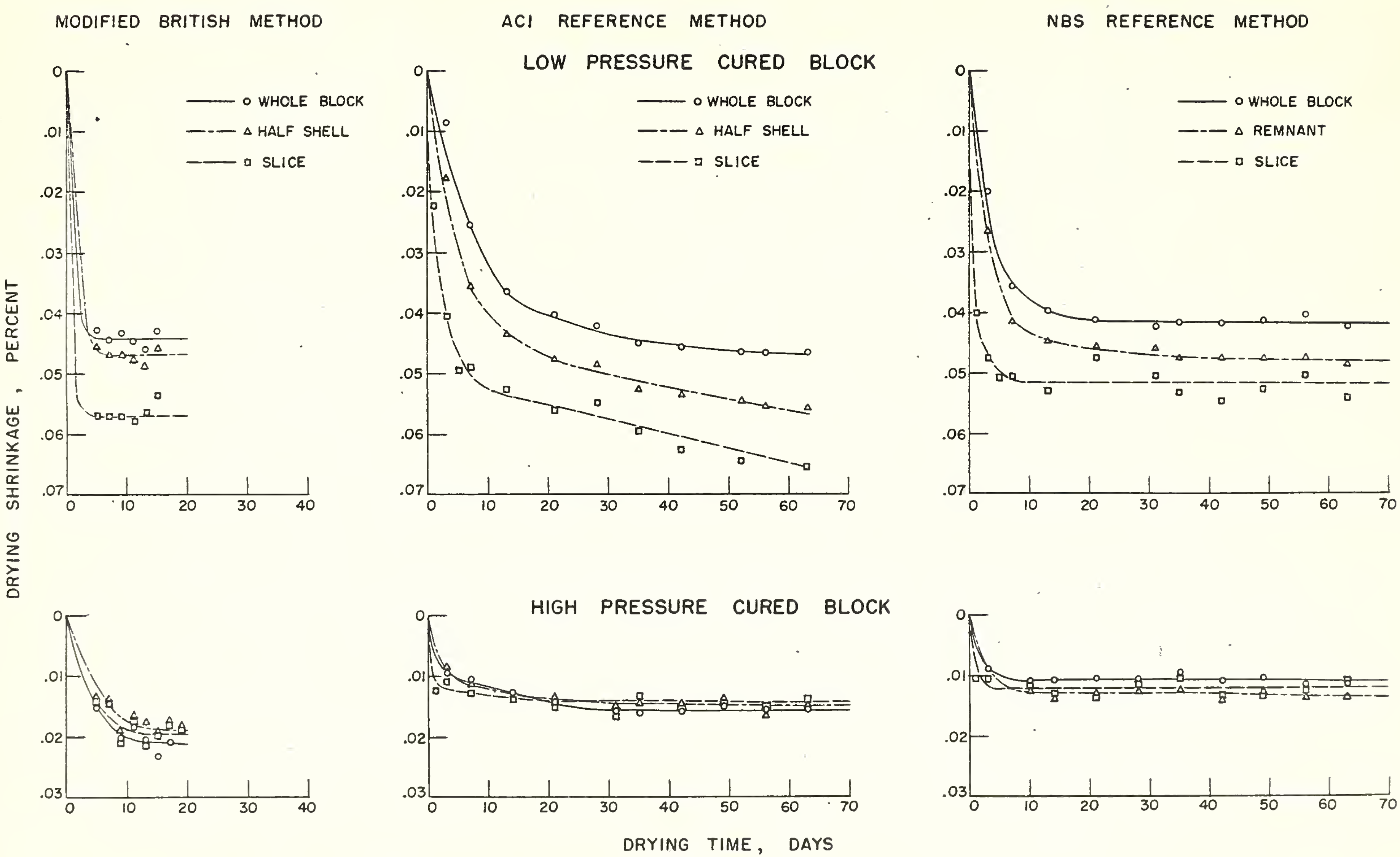


FIG. 4 SHRINKAGE VS TIME CURVES, EXPANDED SLAG AGGREGATE SPECIMENS.

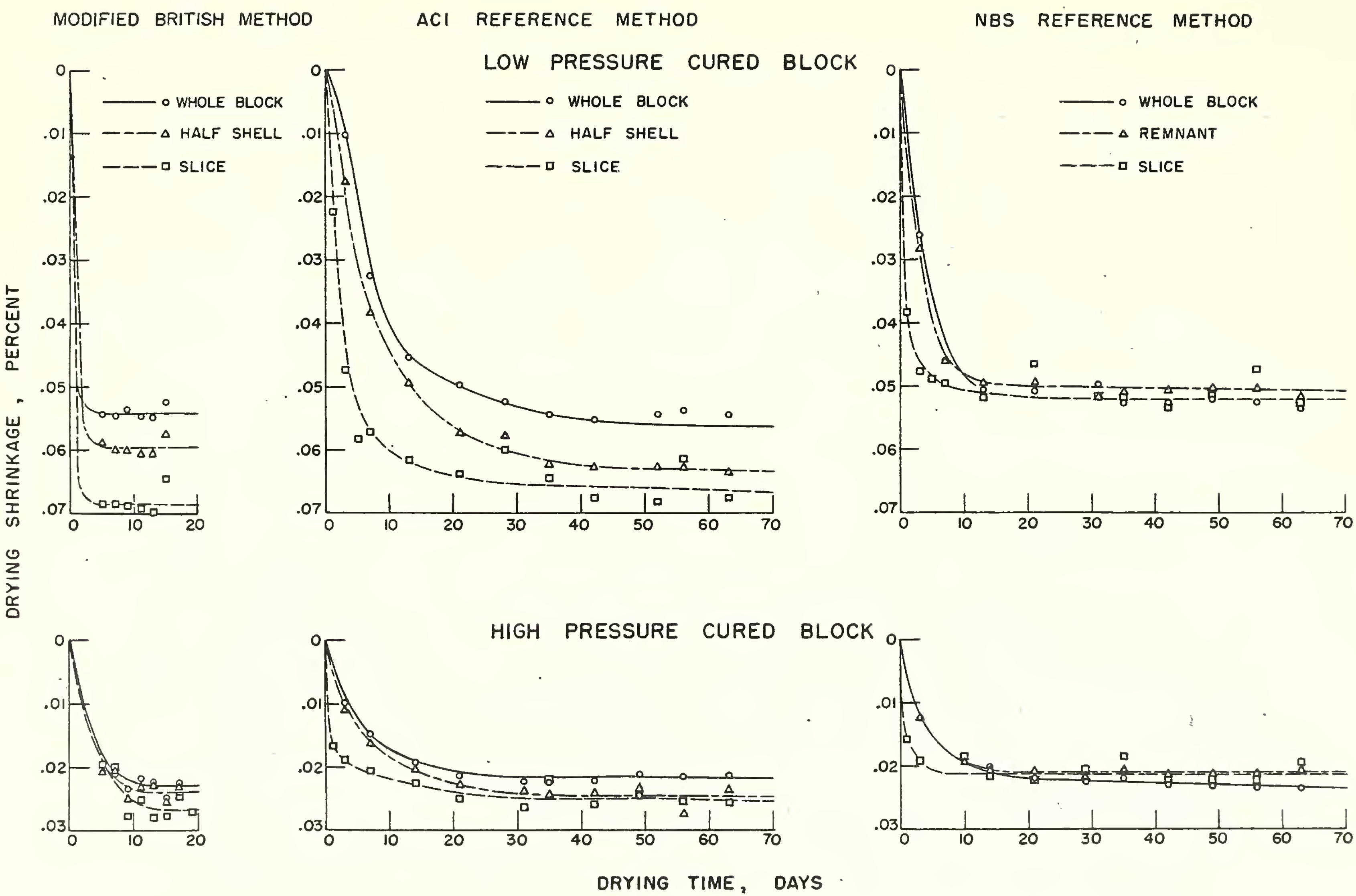


FIG. 5 SHRINKAGE VS TIME CURVES, EXPANDED SHALE AGGREGATE SPECIMENS

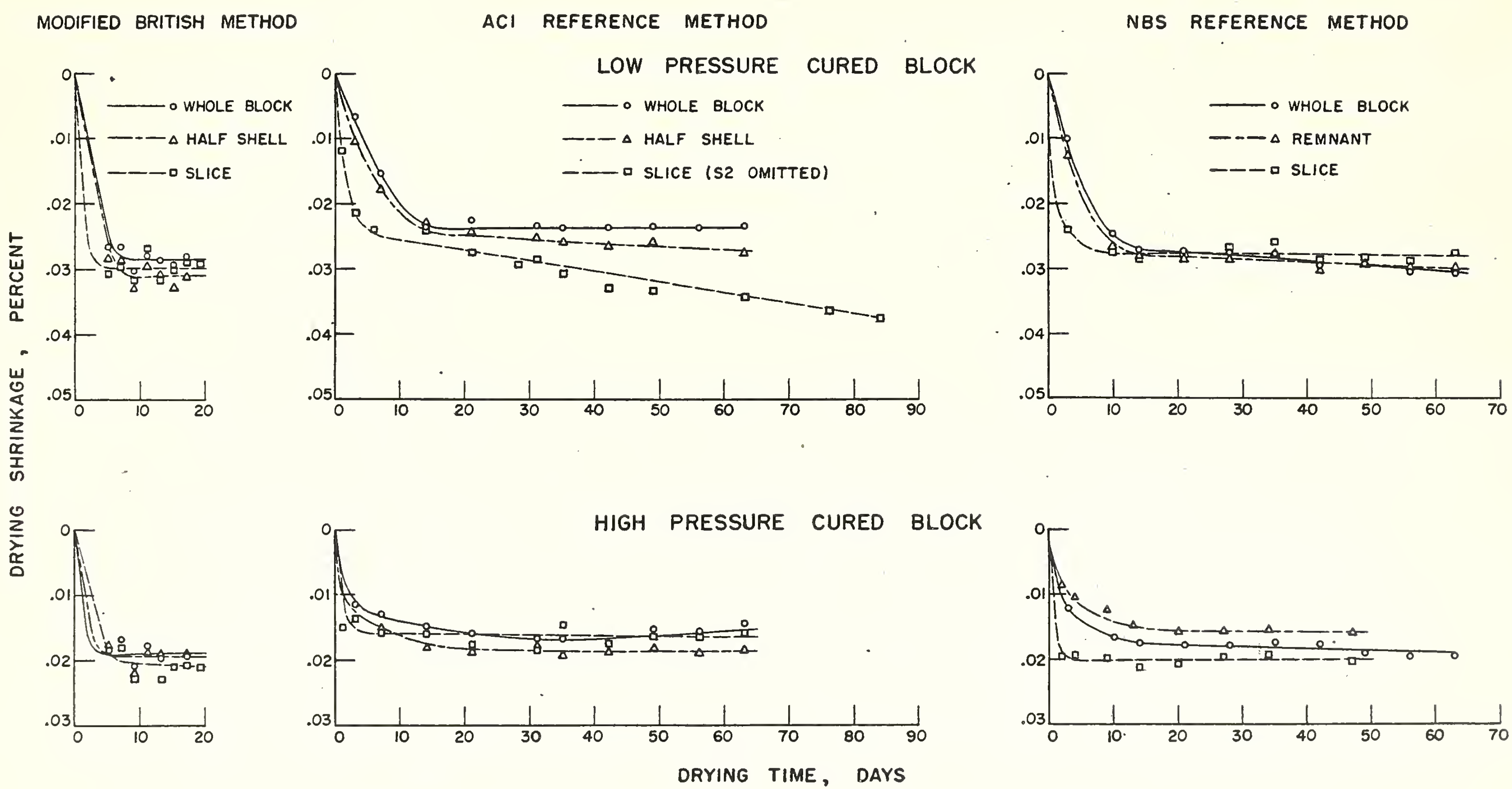


FIG. 6 SHRINKAGE VS TIME CURVES, SAND & GRAVEL AGGREGATE SPECIMENS

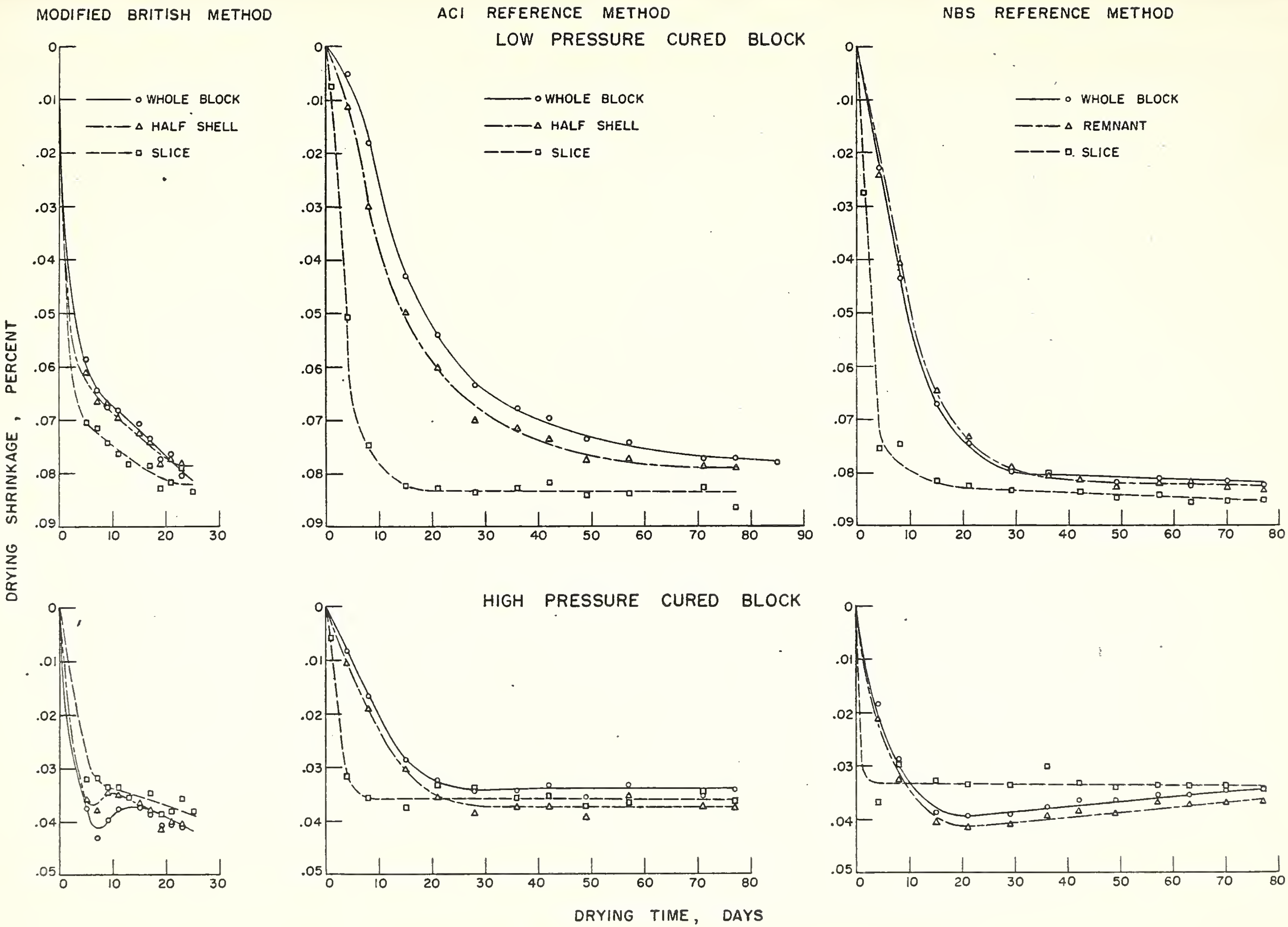


FIG. 7 SHRINKAGE VS TIME CURVES, PUMICE AGGREGATE SPECIMENS

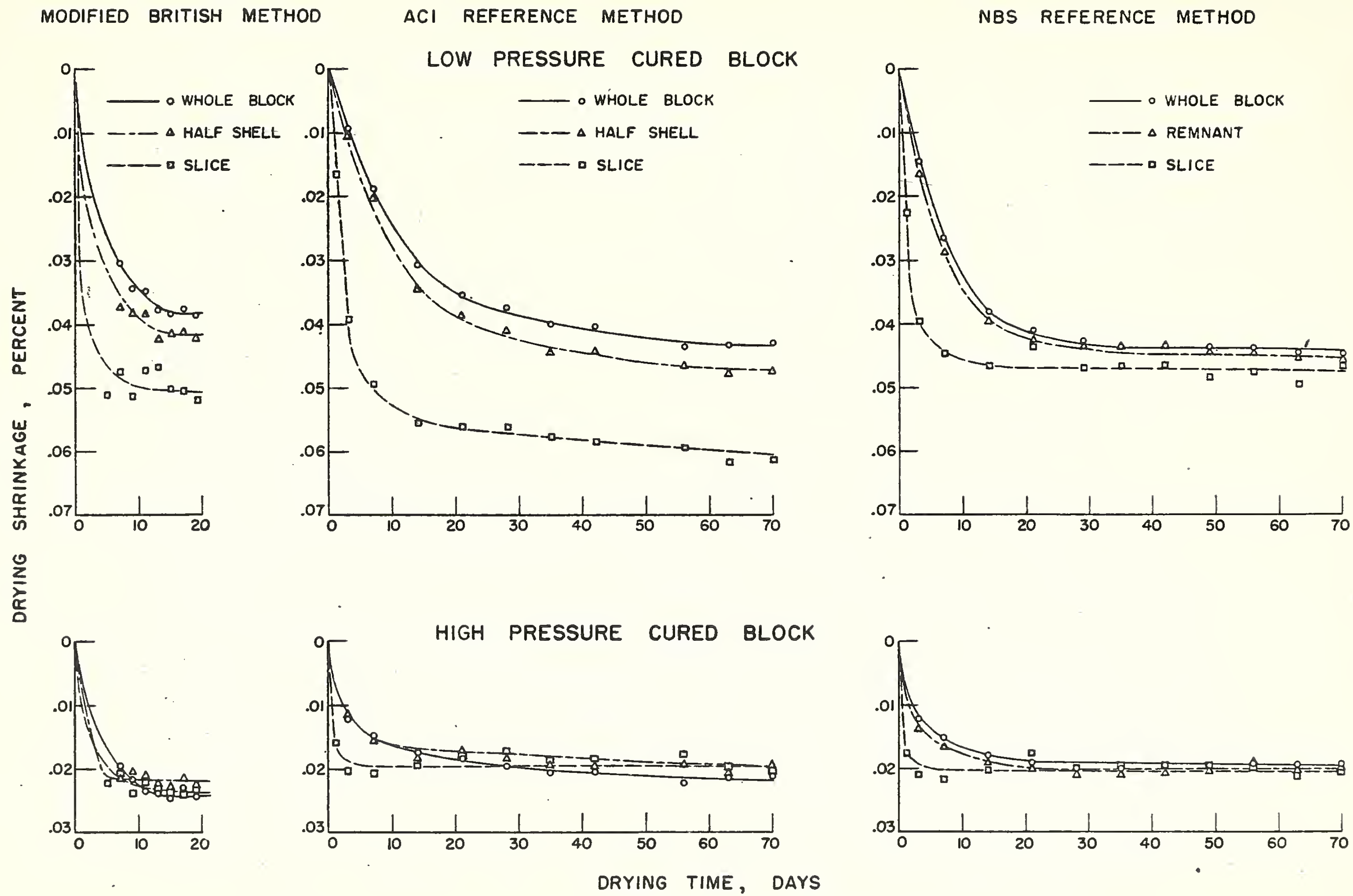


FIG.8 SHRINKAGE VS TIME CURVES, CINDER AGGREGATE SPECIMENS

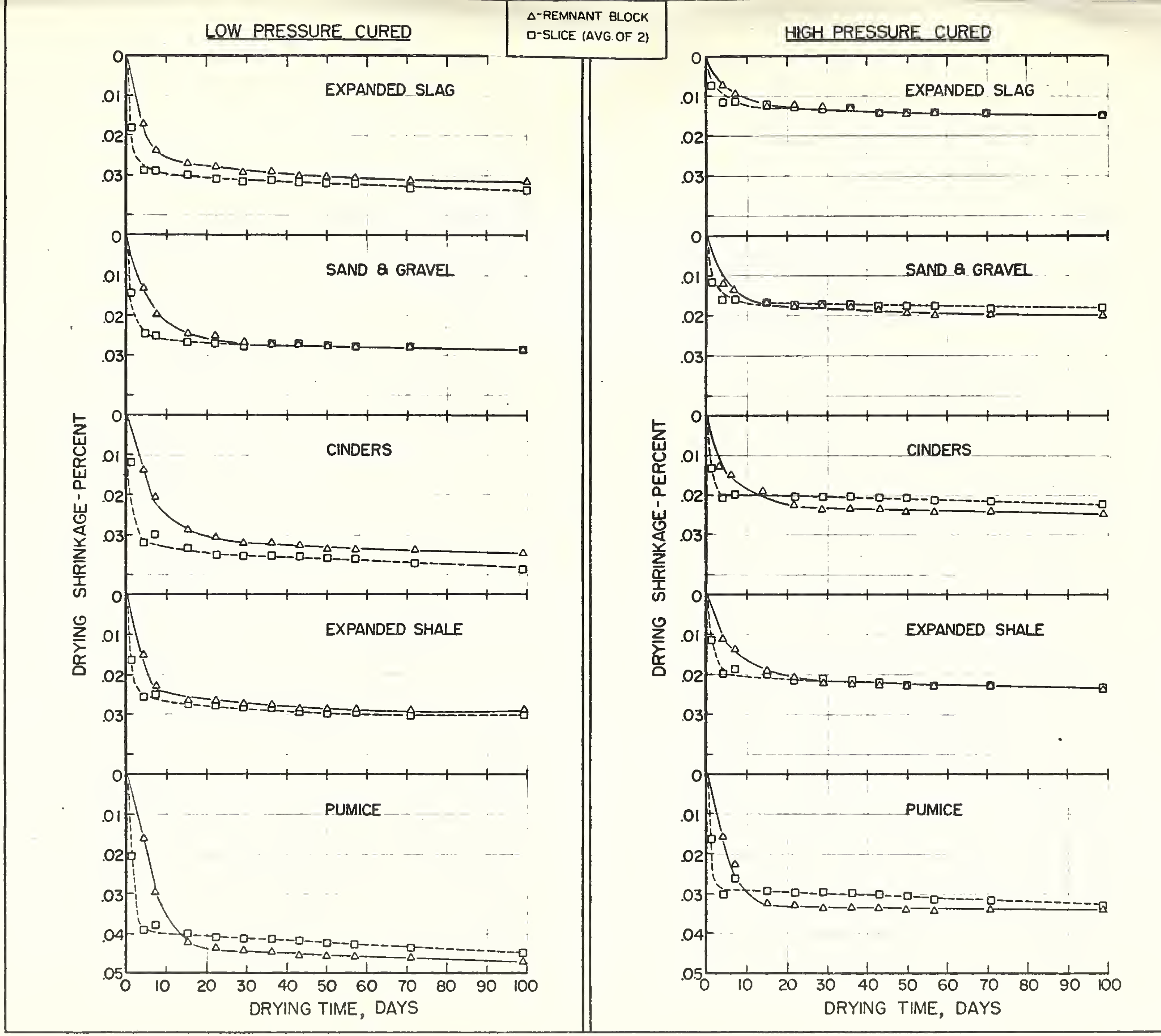
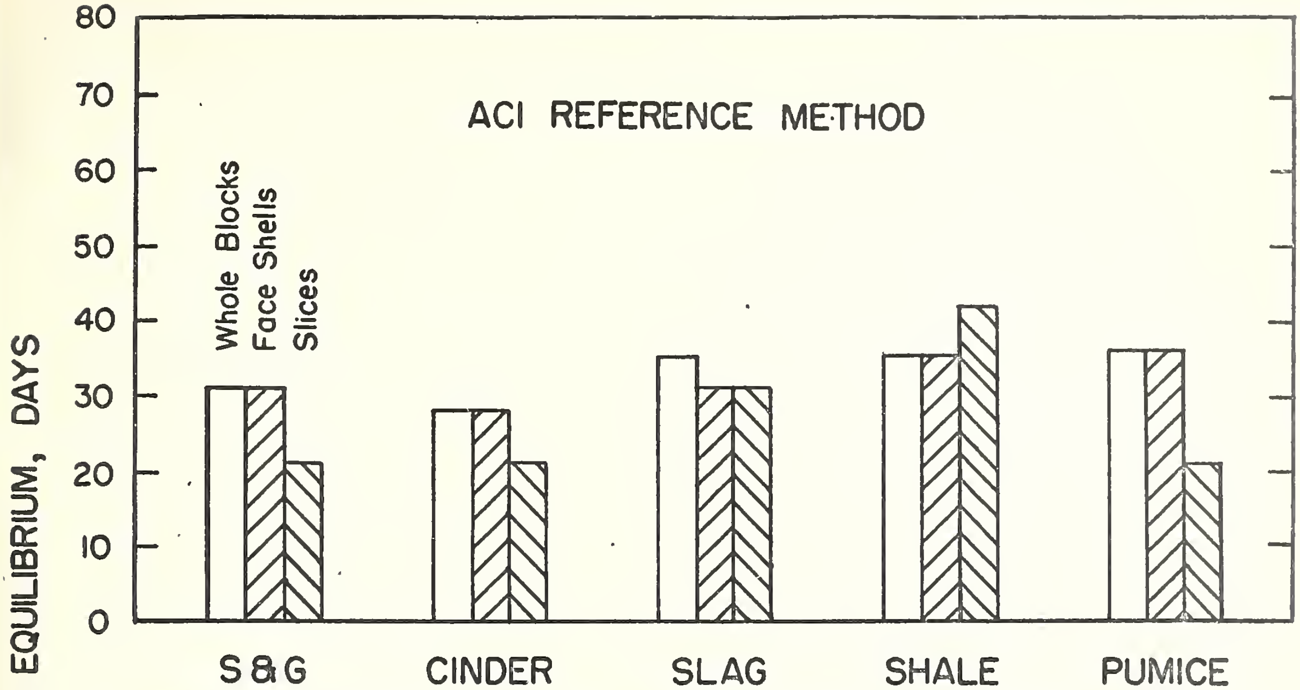
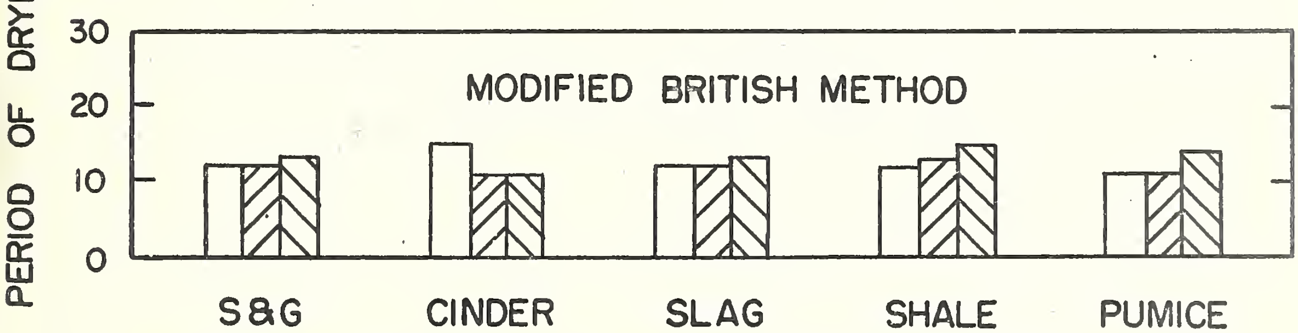


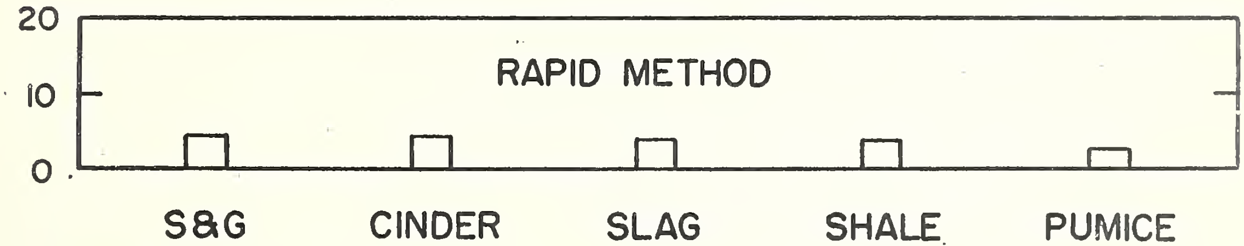
FIGURE 9 SHRINKAGE VS TIME CURVES FOR THE SECOND GROUP OF SPECIMENS TESTED BY THE NBS REFERENCE METHOD. (THE SECOND GROUP OF SPECIMENS WERE AGED INDOORS FOR 4 MONTHS BEFORE TESTING)



Note: 1 The period of drying to equilibrium for the ACI Reference specimens is defined as the drying time at the end of the first 14 day period during which the shrinkage was 0.002%.



Note: 2 The period of drying to equilibrium for the Modified British specimens is defined as the drying time at the end of the first 6 day period during which the shrinkage was 0.002%.



Note: 3 The period of drying to equilibrium for the Rapid specimens is defined as the drying time at the end of the first 24 hour period during which the shrinkage was 0.002%.

FIG. 10 PERIOD OF DRYING TO EQUILIBRIUM, HIGH PRESSURE CURED CONCRETE BLOCKS.

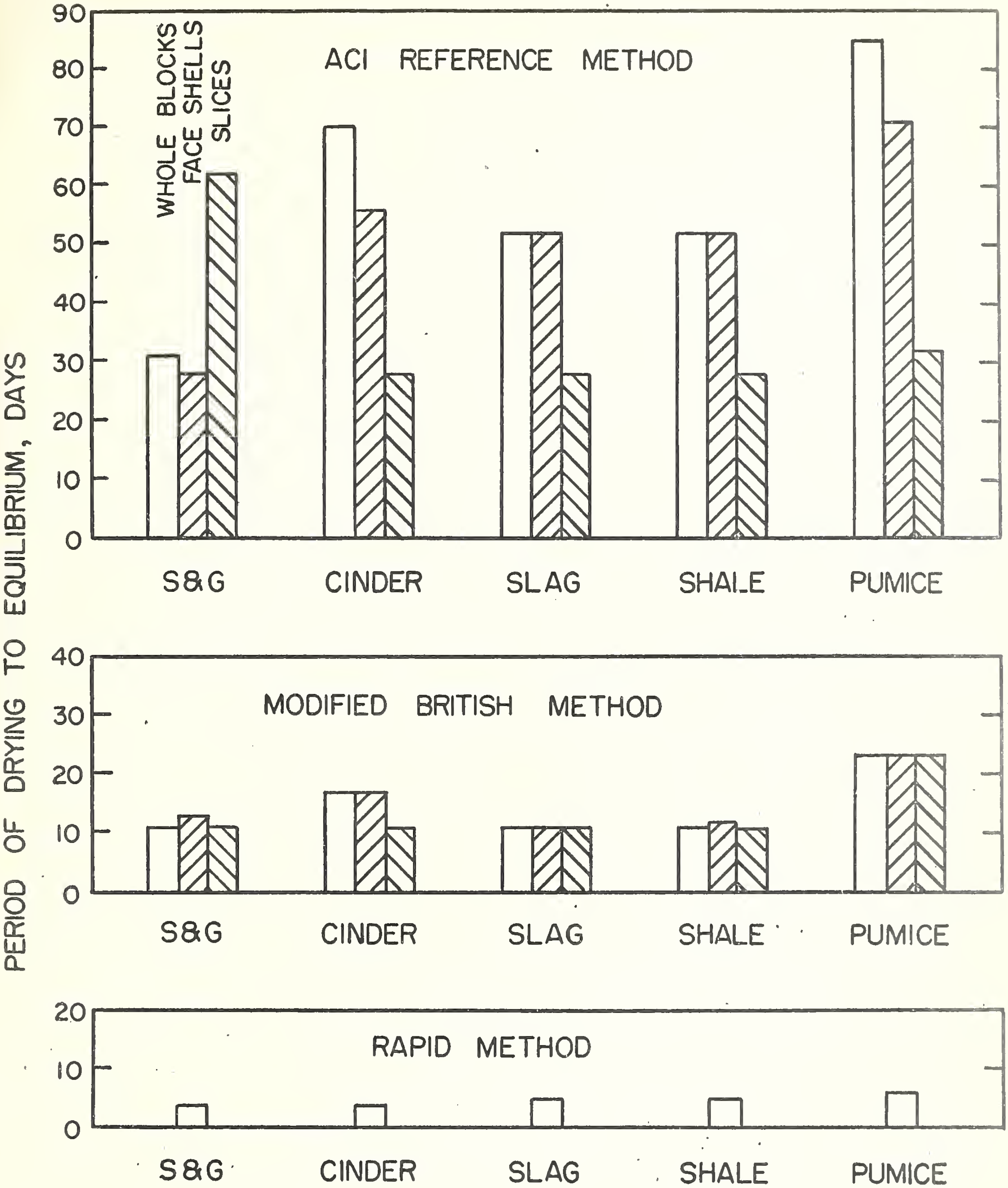


FIG. 11 PERIOD OF DRYING TO EQUILIBRIUM, LOW PRESSURE CURED CONCRETE BLOCKS.

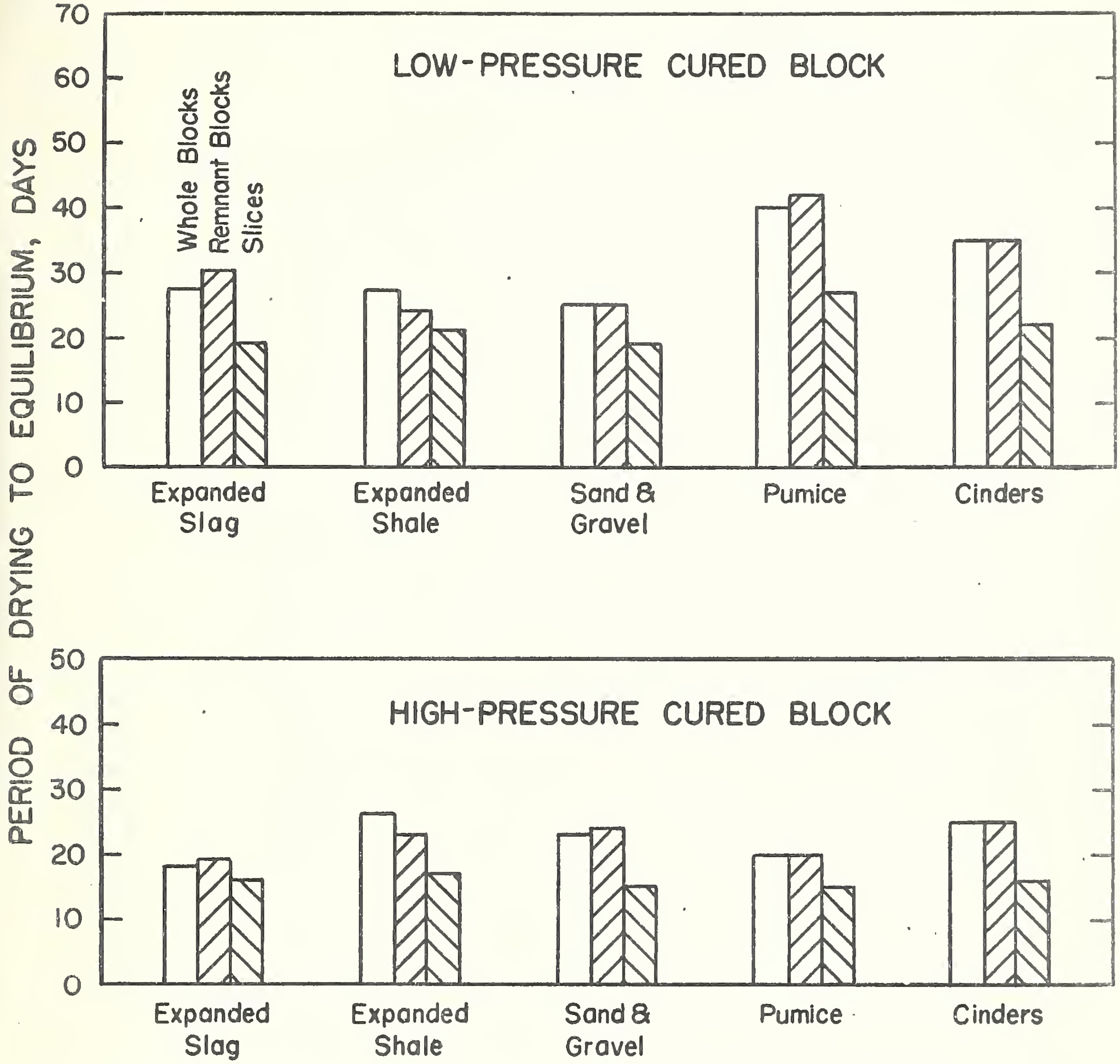


Fig. 12 Period of drying to equilibrium for specimens tested by the NBS Reference Method. (The period of drying is defined as the drying time at the end of the first 14 day period during which the shrinkage change was 0.002 percent.)

U.S. DEPARTMENT OF COMMERCE
Frederick H. Mueller, Secretary

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

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NBS