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Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/20337839
Internal Report (National Research Council of Canada. Division of Building Research), 1967-09-01

NATIONAL RESEARCH COUNCIL OF CANADA

DIVISION OF BUILDING RESEARCH

COMPARISON OF LABORATORY AND OUTDOOR CURING OF CEMENT-LIME MORTARS

by

J. I. Davison

Internal Report No. 354

of the

Division of Building Research

OTTAWA

September 1967

PREFACE

Lime mortars used in some fine masonry buildings built during the past century are still in good condition. This excellent durability is contradicted by the early deterioration of these mortars in laboratory freeze-thaw tests. This may be due to inadequate curing prior to testing, and/or severe conditions of the test.

The relation between laboratory and outdoor curing of cement-lime mortars has been studied at the Atlantic Regional Station of the Division in Halifax where weather conditions include frequent wind-driven rains and a high incidence of freeze-thaw cycling during the winter months. The results of observations on 2-in. cubes of a variety of cement-lime mortar is reported.

The author is a chemist and a Research Officer with the Division, engaged in studies of masonry performance in the Atlantic Provinces.

Ottawa
September 1967

R. F. Legget
Director

COMPARISON OF LABORATORY AND OUTDOOR CURING OF CEMENT-LIME MORTARS

by

J. I. Davison

The use of lime as a construction material is thought to have originated during the Stone Age (1). The first recorded use of lime in masonry mortars was in Egyptian pyramids between 4000 and 2000 B.C. From that time until the beginning of the present century lime was the basic cementitious material in mortar.

Since the introduction of portland cement during the early part of the century, cement-lime mortars containing varying proportions of cement and lime have been extensively used. These mortars combine two materials, each with desirable properties to contribute to the end product. Cement adds strength, particularly early strength, to the slow-setting lime mortars. This is essential in an age when speed is of the essence and construction is carried on year-round in all kinds of weather, much of which is unfavourable for the rapid carbonation of lime. The lime improves the workability and water retentivity of the cement mortars, properties essential in ensuring maximum bond with the masonry units.

The use of standards and their accompanying methods of test by the construction industry has been widely accepted in the twentieth century, facilitating the use of countless new materials and the more intelligent use of the old ones. Tests currently used in North America for masonry mortars are carried out in the laboratory using the mortar materials proposed for use in a particular job. Since laboratory procedures do not always resemble field practice, the results of the tests may not apply to field conditions. Thus, the fact that the lime mortar of many old buildings is highly durable is contradicted by laboratory tests in which such mortar breaks down readily during early stages of freeze-thaw cycling. There are frequent suggestions that a more realistic (less severe) durability test is required. It seems more logical to improve the laboratory curing procedure because current methods of test do not appear to permit sufficient carbonation to take place in test samples compared with that occurring in the field.

This has been suggested by other workers. For example, in a 1947 study of masonry deterioration, Foran, Vaughan and Reid [2] noted the lack of a satisfactory method for curing cement-lime mortars, and briefly studied artificial carbonation in a CO_2 atmosphere.

Studies by the Division of Building Research using small-panel masonry units, in which leakage and bond strength tests were conducted on small brick panels containing a number of cement-lime mortars, have been criticized on the basis that curing periods were not long enough to permit adequate carbonation of the lime used in the mortar.

As a result of these and other observations, a program was designed to compare the results of current laboratory procedures with outdoor curing for a number of cement-lime mortars.

CURRENT TEST METHODS

At present, ASTM Specification C270, Mortar for Unit Masonry, lists the following five cement-lime mortar combinations (volume proportions):

Type M	1:$\frac{1}{4}$:3	cement:lime:sand
Type S	1:$\frac{1}{2}$:4$\frac{1}{2}$	cement:lime:sand
Type N	1:1:6	cement:lime:sand
Type O	1:2:9	cement:lime:sand
Type K	1:3:12	cement:lime:sand

The Specification includes a curing procedure for 2 in. cubes to be used in compressive strength tests at 28 days. It requires cubes of Type M and S (high-cement) mortars to be cured for 7 days in a moist cabinet and 21 days in water. Type N and O mortars are stored in the moist cabinet for 28 days and Type K (high-lime) mortar cubes are cured in air. Cubes are then tested in the condition achieved during curing (i.e. high-cement mortars are tested wet; cement-lime mortars, moist; and high-lime mortars, air dry).

The curing of high-cement and cement-lime mortars in water or a moist cabinet ensures proper hydration of the cement. The resulting strength of the cement should be reasonably equivalent with that of a masonry wall in the field. These mortars in effect receive an "accelerated" curing, as the mortars in masonry walls do not always remain wet or moist during early stages of their curing. Lime mortars stored in air cure as carbon dioxide from the air combines with the lime to form calcium carbonate. It is a slow reaction and there is little doubt that the carbonation occurring in 28 days is only a minor fraction of the end product in masonry walls.

Current curing procedures for cement-lime mortars do not appear to facilitate carbonation of the lime to the same extent that they accomplish hydration of the cement.

There are several ways in which curing procedures could be improved. The curing period could be extended beyond 28 days, but the length of time spent testing is then prohibitive for the construction industry. A more practical method, somewhat analogous to the use of water in hydrating cement mortars, would be to store the cubes in a CO_2 atmosphere. Before considering improvements on current procedures, however, it is necessary to establish that there is a greater discrepancy between the end products of laboratory and field curing for lime mortars than there is for cement mortars.

Staley [3] studied compressive strength values for 2- by 4-in. cylinders of cement-lime mortars at 28 days and 6 months, and found that the ratio of strengths (6 months to 28 days) increased as the percentage of lime in the mortar was increased. In a later discussion of Staley's work, Voss [4] suggested that 6-month values are significant because occupancy of a new building, involving full loads of design, is usually delayed by at least 6 months from the time the masonry is completed. He summarized Staley's results by averaging values for three mortar mixes as follows:

Proportions	Compressive Strength, psi		
Cement:lime:sand (volume)	Age 28 days	Age 6 months	% increase
1:0:2.5	3780	5160	36.5
1:1:5	1330	2300	73.0
1:2:7.5	575	1270	121.0

All of Staley's specimens were stored in a moist cabinet for the length of the curing period.

EXPERIMENTAL

General

Staley's approach was used in this study to assess long-term outdoor and laboratory curing on the basis of compressive strength values. Preparation and laboratory curing of specimens followed current ASTM procedures, however, and long-term curing was conducted on an outdoor site. Thus, 2-in. cubes replaced the 2- by 4-in. cylinders and laboratory curing conditions varied with cement-lime proportions in the mortar.

A second method of assessing the degree of carbonation achieved during the curing period was sought. Chemical analysis was rejected because of the problem of obtaining a representative sample from a 2-in. cube with a thinly carbonated outer layer. A modified differential thermal analysis procedure was finally adopted. In the absence of proper equipment, it was decided to determine weight losses after ignition to 550 and 1000°C. This procedure assumes dissociation of $Ca(OH)_2$ at the lower temperature, and of $CaCO_3$ at the higher.

Five different combinations, four of the mortars in the ASTM Mortar Specification and a 1:3 (lime:sand) mortar, were included in the study as follows (volume proportions):

Type S	2:1:9	cement:lime:sand
Type N	1:1:6	cement:lime:sand
Type O	1:2:9	cement:lime:sand
Type K	1:3:12	cement:lime:sand
Type L	1:3	lime:sand

Materials

Two series of cubes were studied. Mortars for the first series contained "Limo" hydrated lime, a high calcium hydrate. A high calcium lime putty obtained from a local supplier was used in the second series. Before being sold, it is aged one month, after slaking. Other materials were Maritime Brand Portland Cement and a mixture of equal parts graded and 20-30 Ottawa sand.

The materials for the respective mortars were proportioned according to the procedure outlined in ASTM Specification C91, using densities of $87\frac{1}{2}$ lb per cu ft for portland cement, 50 lb per cu ft for hydrated lime and 83 lb per cu ft for lime putty. The figure for lime putty was obtained from a density determination in the laboratory.

Mixing

Mixing procedures outlined in ASTM Specification C91 were followed, with one notable exception. Instead of mixing to a constant flow 110 per cent ± 5 mortars were mixed to a constant consistency as measured by the dropping ball penetration test developed at the British Building Research Station. This decision resulted from field observations that masons use different mortars at different flow rates. Studies have indicated that the B.R.S. penetration test gives a better approximation of the mason's assessment of mortar workability than other methods of measurement, including the ASTM flow table. In the DBR program, the amount of water necessary to produce a mortar having a penetration of 10.5 ± 0.5 mm was predetermined. As mortars were mixed for molding cubes, their flow values were also determined.

Thirty-six 2-in. cubes were molded with each mortar. This required four batches, nine cubes being molded from each batch.

The following flow values were obtained for the different mortar combinations in Series I which, as previously noted, were mixed to a constant consistency. Values have been corrected to a penetration of 10 mm; using a factor of 6 per cent for each mm the penetration varies from 10.

Type S	125%
Type N	115%
Type O	112%
Type K	110%
Type L	102%

These values suggest that when mortars are mixed to a constant consistency the flow values decrease as the lime content in the mortar is raised. This indicates the improvement in "workability" contributed to the mortar by the lime. Using mortars at constant consistency with variations in flow appears to be a more realistic laboratory procedure in terms of field practice. Flow results are shown graphically in Figure 4.

Flow values for the mortars in Series II, mixed to a constant consistency, were determined as below and are shown graphically in Figure 4. Values have been corrected to a penetration of 10 mm.

Type S	119%
Type N	113%
Type O	110%
Type K	105%
Type L	88%

The fact that the flow curve for Series II mortars lies below the curve for Series I mortars (Figure 4) is explained by the greater workability of lime putty as compared with hydrated lime.

Laboratory Curing

After the cubes were molded, molds containing Types S, N, and O mortars were stored in a moist cabinet. After 48 hours, the molds were stripped and the cubes numbered 1 to 36. Cubes designated for laboratory curing (see Table I) were returned to the moist cabinet and at seven days, the Type S cubes were immersed in water for the remainder of the 28-day curing period. Types N and O mortars were stored in the moist cabinet for the entire curing period. Types K and L mortars were stored in air (70°F and 50% RH) initially and cubes designated for laboratory curing remained stored in air during the curing period.

Outdoor Curing

All cubes for outdoor curing were placed in shelters on the exposure site after their removal from the molds at 48 hours. The exposure site was on the roof of the NRC Atlantic Regional Laboratory. Shelters were designed (Figure 1) so that five sides of the cubes were protected and the sixth was exposed to the weather. Parallel wooden strips, $\frac{1}{4}$ in. by $\frac{1}{4}$ in. along the length of the shelter, supported the cubes above the floor and ensured a free circulation of air around them while protective wooden strips along the front top of the shelters prevented snow and rain from beating in on top of the specimens. Shelters were 36 in. long to accommodate 16 cubes. They were mounted on racks (Figure 1) eighteen inches above roof level. In placing the cubes in the shelters, the top surface of the cube as cast in the mold became the surface exposed to the weather. The cubes were placed far enough apart to permit a circulation of air. Shelters were oriented so that the exposed side of the cubes faced south. Pictures of specimens on exposure are shown in Figure 2. Curing periods on the exposure site were 3, 6, and 12 months.

Testing

(a) Compressive Strength - Upon completion of their curing period, laboratory specimens were tested in the condition they had achieved during curing, i.e. Type S were tested wet, Types N and O were tested in a moist condition, and Types K and L were tested dry. Initially, exposure-cured cubes were tested as they were removed from the shelters. An early set of results for cubes removed during a rain storm and tested in a wet condition produced abnormally low values. Thereafter, cubes were stored overnight in air at 70°F and 50% RH, prior to testing. Tests were conducted according to procedures outlined in ASTM Specification C109.

(b) Weight Loss on Ignition - For this test, two cubes were selected from the 28-day specimens and three from each of the 3-, 6-, and 12-month specimens. On the Friday preceding the week of the respective compressive strength tests, the specimens selected for weight loss tests were cut into eighths and the resulting 1-in. cubes were numbered as in Figure 3. Samples 1, 4, and 7 were dried over the weekend, and their dry weights recorded.

They were then placed overnight in a muffle oven in crucibles heated to 550°C, and the weight recorded. This procedure was repeated and the weight loss was determined after the second burning. Samples were then heated to 1000°C overnight, weighed, the procedure repeated and weight loss recorded as before. The object of repeated burning at the two temperatures was to ensure that constant weight had been reached before calculating weight losses. After a few runs it was found that second burnings were unnecessary and they were discontinued. The losses upon ignition at the two temperatures were calculated as a percentage of the dry weight of the samples.

Series I

(a) Preparation - Mortars for cubes in this Series contained hydrated lime. It was used in the dry state, except for Type L cubes for which it was soaked for 48 hours prior to use.

Initially a schedule for molding and testing cubes was drawn up and is shown in Table II. Cubes were molded between mid-May and mid-July; thus, specimens cured on exposure had the benefit of favourable summer curing weather during their early life. It should be recorded that the schedule was followed as originally drawn up, with very minor exceptions.

Results

(a) Compressive Strength - The average compressive strength values for Series I cubes are shown in Table III, which also includes the percentage improvement for exposure curing at 3, 6, and 12 months over the values after 28-day laboratory curing. The results indicate a steady increase in compressive strength values for each mortar as the length of the curing period was increased. Numerically, the greatest increases occurred for mortars containing the most cement (Type S), and decreased as the lime content was increased. Thus, as the curing period was increased from 28 days to 12 months, Type S cubes registered an improvement of 1711 psi, while at the other end of the scale, the increase for the Type L mortar was only 323 psi.

The relation of the 12-month value to the 28-day value is, however, more significant. For Type S mortar the gain is 53 per cent, while for Type L mortar it was 320 per cent. This means that 28-day values for Type S mortars are six times more realistic in terms of 12-month exposure-cured cube values, than Type L mortar. Similar comparisons for the widely used Type N and O mortars indicate that laboratory-cured Type S mortars are $1\frac{1}{2}$ and 2 times, respectively, more realistic in terms of 12-month exposure-cured specimens.

Compressive strength values and comparative improvements are shown graphically in Figures 5 and 6.

(b) Weight Losses on Ignition - Weight losses on ignition to 550 and 1000°C for the different mortars are compiled in Table IV and shown graphically in Figures 7 and 8. An examination of Figure 7 shows considerable fluctuation in results after ignition to 550°C. Only the Type L mortar produced a predictable pattern, with the greatest amount of $Ca(OH)_2$ (indicated by weight loss) at 28 days, and progressively smaller amounts at 3, 6, and 12 months. The pattern also suggests that the most rapid carbonation occurred between 3 and 6 months. Results for the other four mortars do not suggest any consistent pattern.

Figure 8 indicates more consistent results for weight losses after ignition to 1000°C. The amount of $CaCO_3$ (weight loss) increased progressively from low values for 28-day specimens to maximums for 12-month cubes. The only exception occurred for the Type O (1:2:9 C:L:S) mortar, where the six-month value exceeded that for the 12-month samples. The break in the 12-month curve suggests that the error is in the 12-month value for the Type O mortar.

The curves in Figure 8 also indicate that the amount of $CaCO_3$ increased with increasing lime content in the mortars. Thus, the weight losses for ignition to 1000°C increased from 5.1 to 6.8 per cent for Type S and from 5.8 to 9.4 per cent for Type L mortar cubes. The only exception was the Type O mortar at 12 months, the low value referred to above.

Figure 8 suggests that the most rapid carbonation occurs between 28 days and 3 months, and that the reaction slows down between 3 and 12 months. This contradicts results shown in Figure 7, which indicate that most curing occurs between 3 and 6 months.

Because of their greater consistency, weight losses at 1000°C are considered the more reliable of the two ignitions.

Conclusions

Compressive strength values suggest an increasing discrepancy for the ratio of strengths (12 months to 28 days) for cement-lime mortars as the lime proportion in the mortar is increased. They also indicate a relatively steady rate of curing for mortars containing high proportions of cement, contrasted with a more rapid curing rate during the first six months of the period for mortars having a higher proportion of lime.

Loss of weight on ignition to 550 and 1000°C shows promise as an indication of the extent of carbonation. This was illustrated best by values for samples ignited to 1000°C, where a relatively consistent pattern emerged. Weight loss records indicate that the greatest rate of carbonation occurs during the first three months of the curing period.

Series II

(a) Preparation - The schedule for molding and testing Series II cubes is also included in Table II. Cubes in this series, with mortars containing lime putty, were molded between 9 August and 9 September. High lime content mortar cubes were assembled first to permit a maximum of favourable fall weather for the cubes designated for exposure curing. As in Series I, there were no major problems in following the schedule as it was laid out.

Results

(a) Compressive Strength - Average compressive strength values and percentage improvement for exposure curing after 3, 6, and 12 months over 28-day laboratory curing, are compiled in Table V and illustrated graphically in Figures 9 and 10. The pattern lacks the consistency shown in results for Series I mortars, but the same general trend is observed. Low values for Type L (lime) mortar cubes at 3 months are attributed to testing when damp. These are the cubes previously referred to as being removed from exposure during a rain storm and tested without drying. Other variations in results are not so easily explained, as, for example, the low value for Type O cubes at 6 months. Only the results for Types N and O mortars (omitting the 6-month value for Type O) are comparable to results for Series I. The improvement in values for exposure-cured Types S and K cubes was greater in Series II than in Series I, while Type L values showed less improvement. To make the same comparisons previously used, the ratio of strengths (12 months to 28 days) for Type N mortar was only 5 per cent higher than for Type S mortar. Type O was 50 per cent better and Type L showed an improvement of about $2\frac{1}{2}$ times. The greatest improvement over the ratio of strengths (12 months to 28 days) for Type S mortar was for Type K mortar: its ratio was $6\frac{1}{2}$ times greater.

(b) Weight Losses on Ignition - Weight losses for Series II mortars after ignition to 550 and 1000°C are listed in Table VI and shown graphically in Figures 11 and 12.

No consistent pattern emerged from weight loss data after ignition to 550°C, except support of the obvious fact that there was more $Ca(OH)_2$ (weight loss) as the percentage of lime in mortars increased. Examples of inconsistencies are seen in results for Type S mortar, where greatest weight losses occurred after 6 months curing, and smallest losses in 28-day specimens. Again, with Type L mortar, greatest losses occurred for specimens cured 3 months and smallest losses in 6-month specimens. Similar inconsistencies occurred in other mortar combinations.

Losses after ignition to 1000°C were a little more consistent. For each mortar, weight losses rose as the length of the curing period was increased. With increasing lime content in the mortars through Types S, N, and O, larger weight losses were recorded indicating increased formation of $CaCO_3$. The suggestion of a lesser degree of carbonation in Types K and L mortars was directly opposite the indication of compressive strength values.

As in Series I, records of weight loss data indicate greatest rate of carbonation between the 28-day and 3-month curing periods; it then seems to level off during the remainder of the 12-month period. As already indicated, this is contradicted by compressive strength values for Types K and L mortars after 12 months' curing.

Conclusions

Although they do not display the same consistency as Series I, compressive strength values for Series II mortars containing lime putty support the trend of results for Series I, in which increasing discrepancies in the ratio of strengths (12 months to 28 days) occurred with increased lime content in the mortars.

Results of compressive strength tests suggest that greatest improvement for Type S mortar occurred between 28 days and 3 months, while for Type K mortar, the greatest improvement was between 6 and 12 months. Results for Type L mortar are difficult to assess due to an abnormally low value for 3-month cubes.

Results of weight loss determinations on mortars after ignition to 550 and 1000°C were inconsistent. Values for losses at the lower temperature are meaningless, but a somewhat better pattern at the higher temperature suggests that this method may be of some assistance in assessing the degree of carbonation.

Comparison of Results from Series I and Series II

Four reasons are suggested for differences in results for the two Series.

1. Difference between hydrated lime and lime putty. It is suggested that cubes of lime putty may have dried at a slower rate and that this may have retarded the curing process.

2. Series I cubes molded during the May-July period enjoyed optimum curing weather during their early life. Series II cubes, molded during the August-September period, had only a short period of good curing weather before winter. They encountered best curing conditions near the end of the period.

3. Specimens were not necessarily in the same condition, with respect to moisture content, when tested for compressive strength. Overnight storage at 70°F and 50 per cent RH undoubtedly was an improvement, but was not long enough to ensure uniform conditions at the time of test.

4. The pattern of the 12-month to 28-day ratio for compressive strength values was more consistent than those for 3 and 6 months. Many of the inconsistencies were eliminated as a result of longer curing.

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TABLE I

SCHEDULE OF CUBES FOR TESTS

Cubes Numbered 1 to 36 After Removal From Molds

28-Day Laboratory Curing

Ignition - cubes #12, #30
Comp. Strength - cubes #1, #16, #23, #34

3-Months Exposure Curing

Ignition - cubes #7, #24, #31
Comp. Strength - cubes #4, #13, #18, #19, #27, #28, #36

6-Months Exposure Curing

Ignition - cubes #6, #10, #29
Comp. Strength - cubes #3, #9, #14, #17, #20, #26, #33

12-Months Exposure Curing

Ignition - cubes #2, #22, #35
Comp. Strength - cubes #5, #8, #11, #15, #21, #25, #32

TABLE II

SCHEDULES FOR MOLDING

AND

TESTING CUBES

Series I

Mortar Type	Date Molded	Date Tested 28 Days	3 Months	6 Months	12 Months
Type S	May 25&27/65	June 23	Aug. 25	Nov. 25	May 25/66
Type O	June 7&9/65	July 6	Sept. 7	Dec. 7	June 7/66
Type K	June 14&16/65	July 13	Sept. 14	Dec. 14	June 14/66
Type L	July 2 & 5/65	Aug. 2	Oct 4	Jan. 3/66	July 5/66
Type N	July 13&15/65	Aug. 9	Oct 12	Jan. 12/66	July 13/66

Series II

Mortar Type	Date Molded	Date Tested 28 Days	3 Months	6 Months	12 Months
Type L	Aug. 9&11/65	Sept. 8	Nov. 10	Feb. 10/66	Aug. 11/66
Type K	Aug. 16&18/65	Sept. 15	Nov. 17	Feb. 17/66	Aug. 18/66
Type O	Aug. 23&25/65	Sept. 22	Nov. 24	Feb. 24/66	Aug. 25/66
Type N	Aug. 30 Sept. 1/65	Sept. 29	Dec. 1	Mar. 2/66	Sept. 1/66
Type S	Sept. 7&9/65	Oct. 7	Dec. 9	Mar. 9/66	Sept. 8/66

TABLE III

SUMMARY OF COMPRESSIVE STRENGTH VALUES

AVERAGE COMPRESSIVE STRENGTH VALUES (PSI)

Mortar	Laboratory 28 Days	Exposed 3 Months	Exposed 6 Months	Exposed 1 Year
Type S	3253	3358	4064	4964
Type N	1650	1903	2182	2911
Type O	646	859	916	1347
Type K	266	598	770	1048
Type L	101	161	268	424

IMPROVEMENT OVER 28 DAY VALUES, PER CENT

Mortar	At 3 Months	At 6 Months	At 1 Year
Type S	3 %	25 %	53 %
Type N	15 %	32 %	76 %
Type O	33 %	42 %	108 %
Type K	125 %	189 %	294 %
Type L	59 %	165 %	320 %

TABLE IV

WEIGHT LOSSES FROM DIFFERENT MORTARS ON IGNITION TO 550 AND 1000°C

Series I

	28 Day		3 Month		6 Month		1 Year	
Mortar	550°C	1000°C	550°C	1000°C	550°C	1000°C	550°C	1000°C
Type S	4.3 %	5.1 %	3.9 %	5.6 %	4.0 %	5.9 %	3.3 %	6.8 %
Type N	4.2 %	5.0 %	2.5 %	5.8 %	4.1 %	7.8 %	3.7 %	8.4 %
Type O	4.2 %	5.3 %	3.3 %	7.3 %	1.9 %	8.2 %	2.1 %	8.1 %
Type K	2.3 %	5.5 %	3.6 %	7.0 %	3.5 %	8.0 %	2.8 %	9.0 %
Type L	3.1 %	5.8 %	2.9 %	8.6 %	1.2 %	8.8 %	0.9 %	9.4 %

TABLE V

SUMMARY OF COMPRESSIVE STRENGTH VALUES

Series II

AVERAGE COMPRESSIVE STRENGTH VALUES (PSI)

Mortar	Laboratory 28 Days	Exposure 3 Months	Exposure 6 Months	Exposure 1 Year
Type S	2781	3648	3840	4661
Type N	1469	1727	1852	2506
Type O	525	629	554	1065
Type K	138	254	278	755
Type L	125	95*	201	329

*Cubes damp when tested

IMPROVEMENT OVER 28 DAY VALUES, PER CENT

Mortar	At 3 Months	At 6 Months	At 1 Year
Type S	31 %	38 %	68 %
Type N	17 %	26 %	71 %
Type O	20 %	6 %	103 %
Type K	84 %	100 %	447 %
Type L	-24 %	61 %	164 %

TABLE VI

WEIGHT LOSSES FROM DIFFERENT MORTARS AFTER IGNITION TO

550 AND 1000°C

Series II

WEIGHT LOSS ON IGNITION

(PER CENT DRY WEIGHT)

	28 Day		3 Month		6 Month		1 Year	
Mortar	550°C	1000°C	550°C	1000°C	550°C	1000°C	550°C	1000°C
Type S	3.7 %	4.7 %	3.9 %	5.5 %	4.7 %	5.6 %	3.9 %	6.0 %
Type N	3.8 %	4.6 %	3.2 %	6.2 %	2.8 %	6.8 %	3.5 %	8.1 %
Type O	3.2 %	4.1 %	2.0 %	6.4 %	2.7 %	7.7 %	2.1 %	8.8 %
Type K	1.9 %	4.7 %	2.4 %	6.4 %	2.7 %	7.8 %	2.9 %	7.8 %
Type L	1.3 %	4.7 %	2.3 %	6.4 %	0.8 %	7.0 %	1.0 %	7.1 %

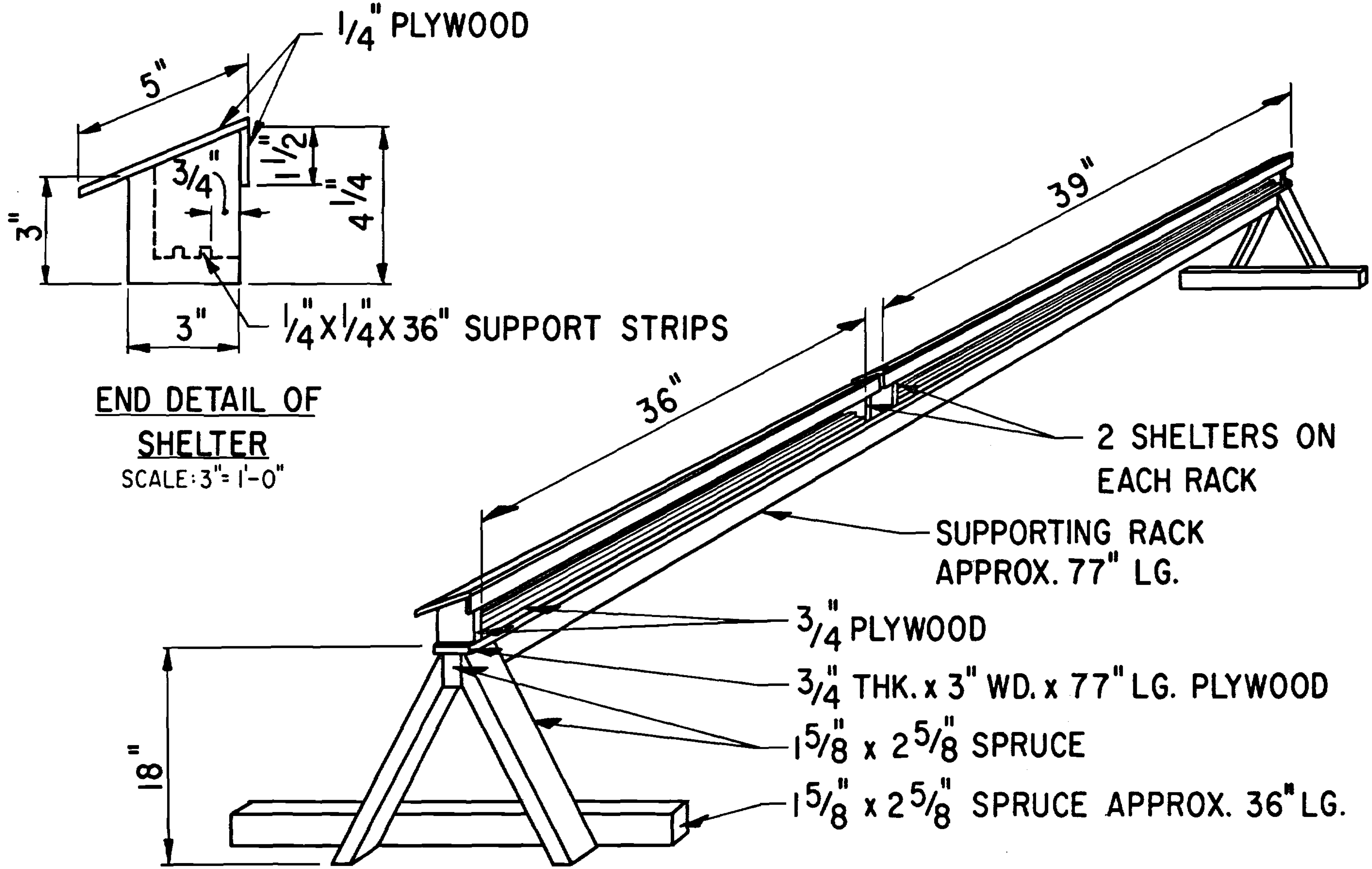
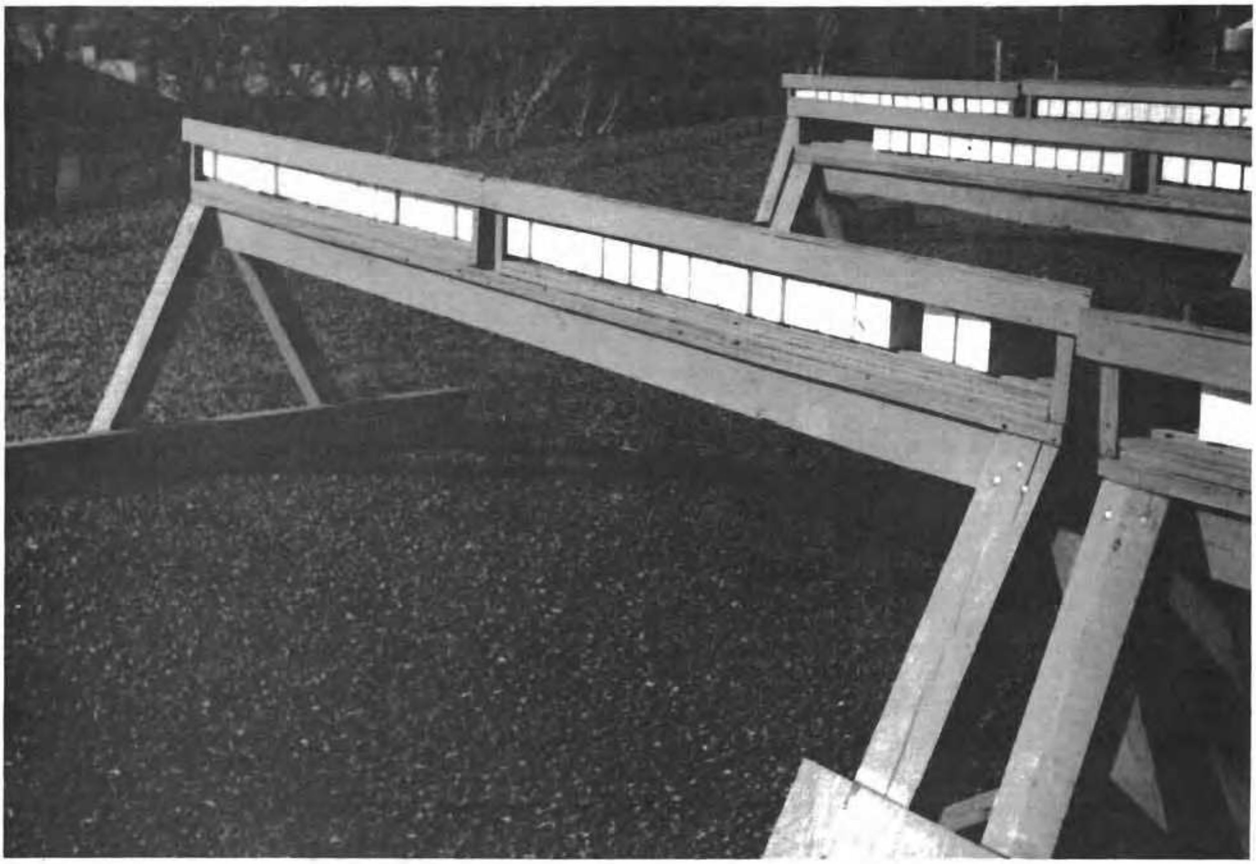
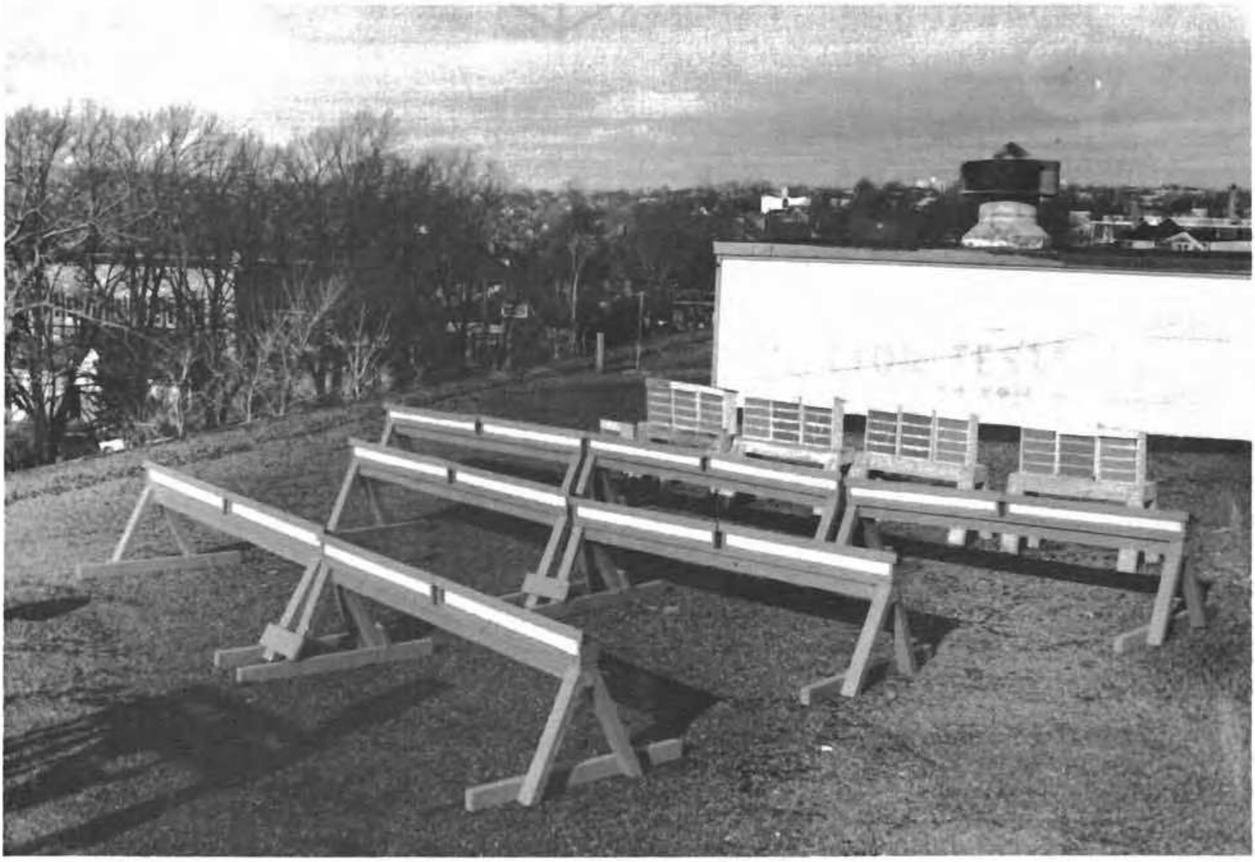


FIGURE I SHELTER AND RACK FOR MORTAR CUBES

BR 3911-1



(a) Close-up of Shelter and Rack



(b) General View

FIGURE 2 - CUBES CURING ON EXPOSURE SITE

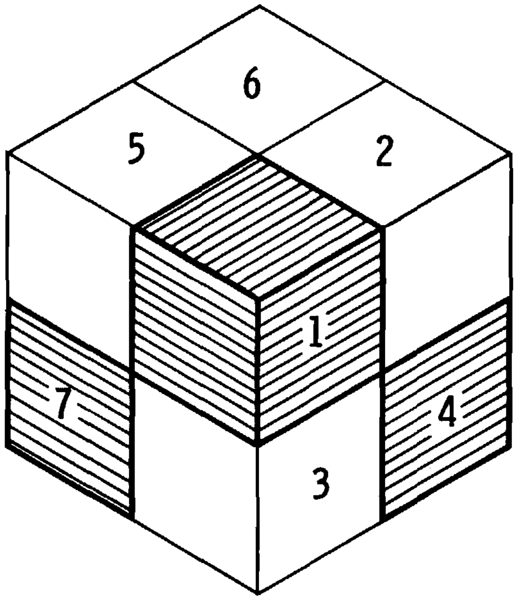


FIGURE 3

DIVISION OF CUBES FOR IGNITION TESTS

BR 3911-2

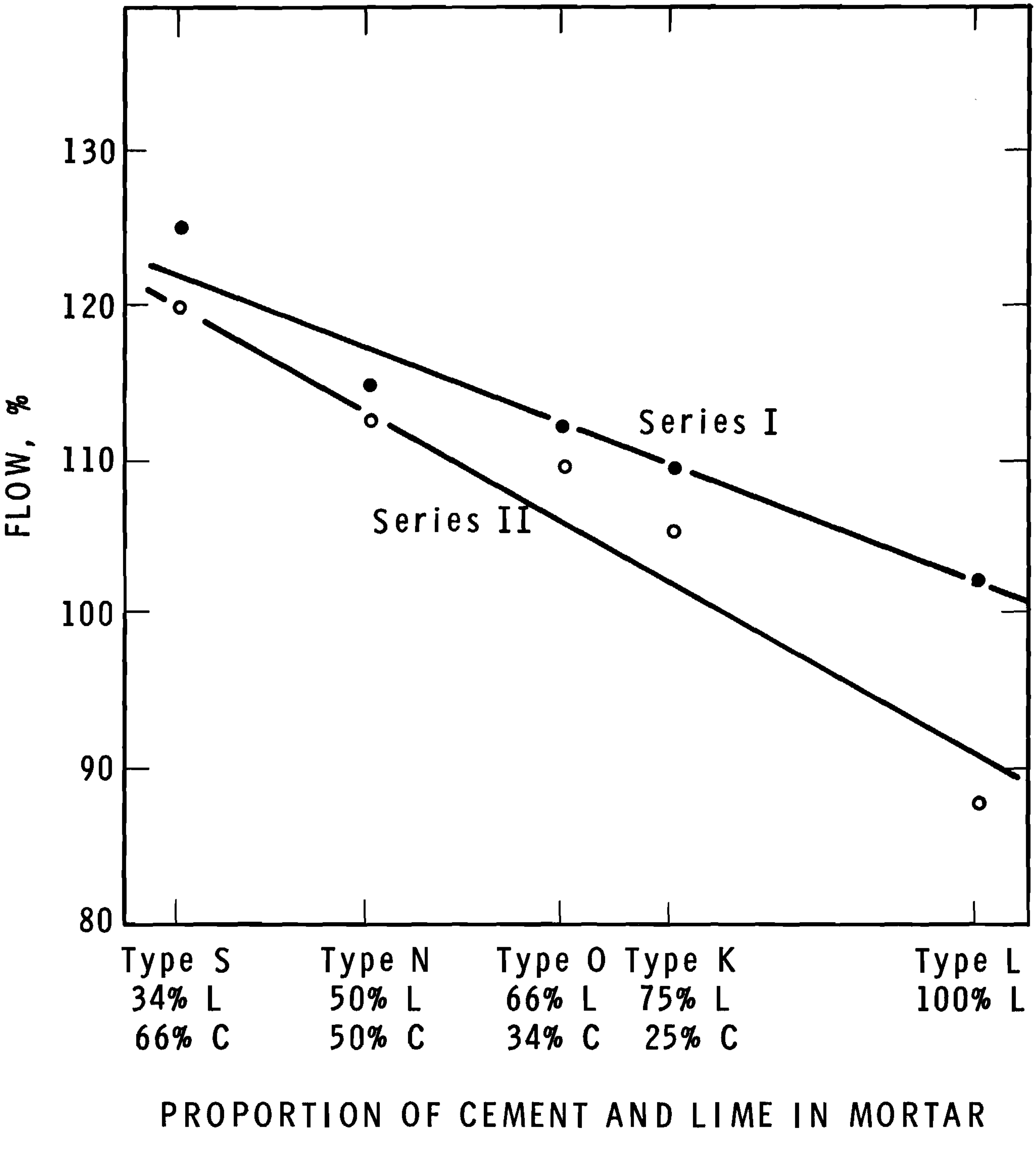


FIGURE 4

FLOW VALUES FOR MORTARS CORRECTED TO 10MM PENETRATION

BR 3911-3

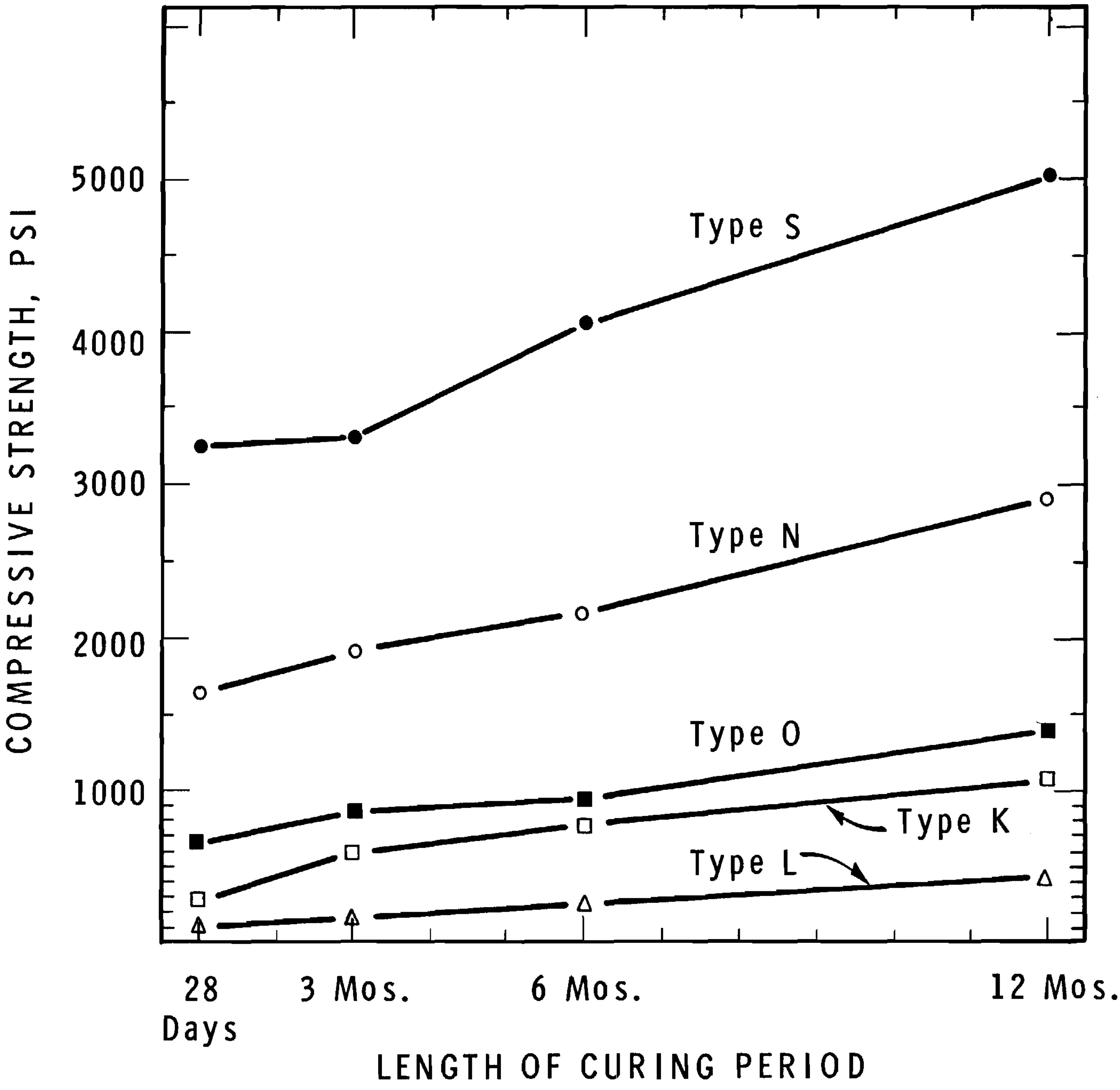


FIGURE 5

COMPRESSIVE STRENGTH VALUES FOR SERIES I CUBES

BR 3911-4

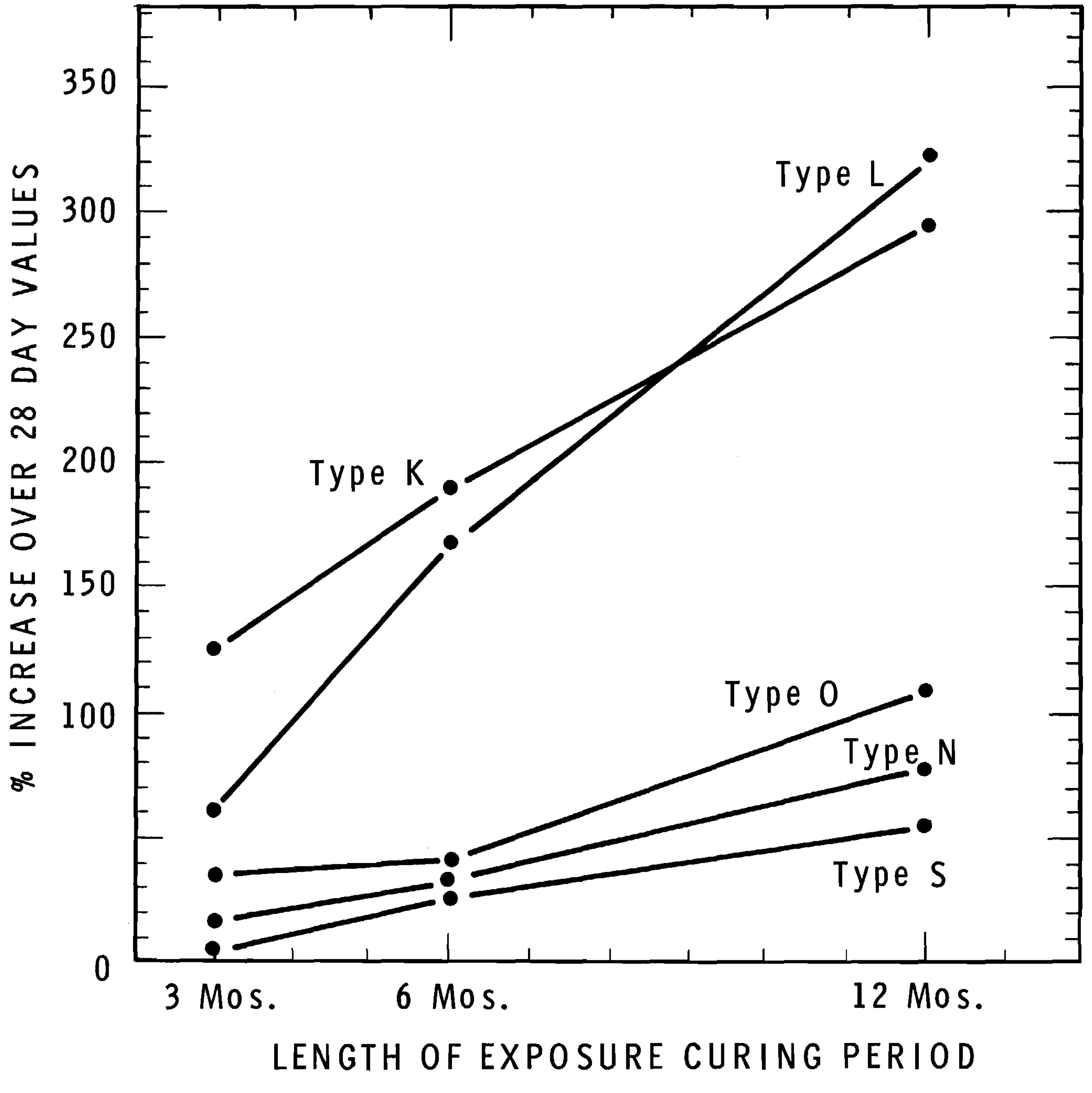


FIGURE 6

IMPROVEMENT IN COMPRESSIVE STRENGTH VALUES FOR CUBES CURED ON EXPOSURE SITE OVER LABORATORY CURED SPECIMENS, SERIES I

BR 3911-5

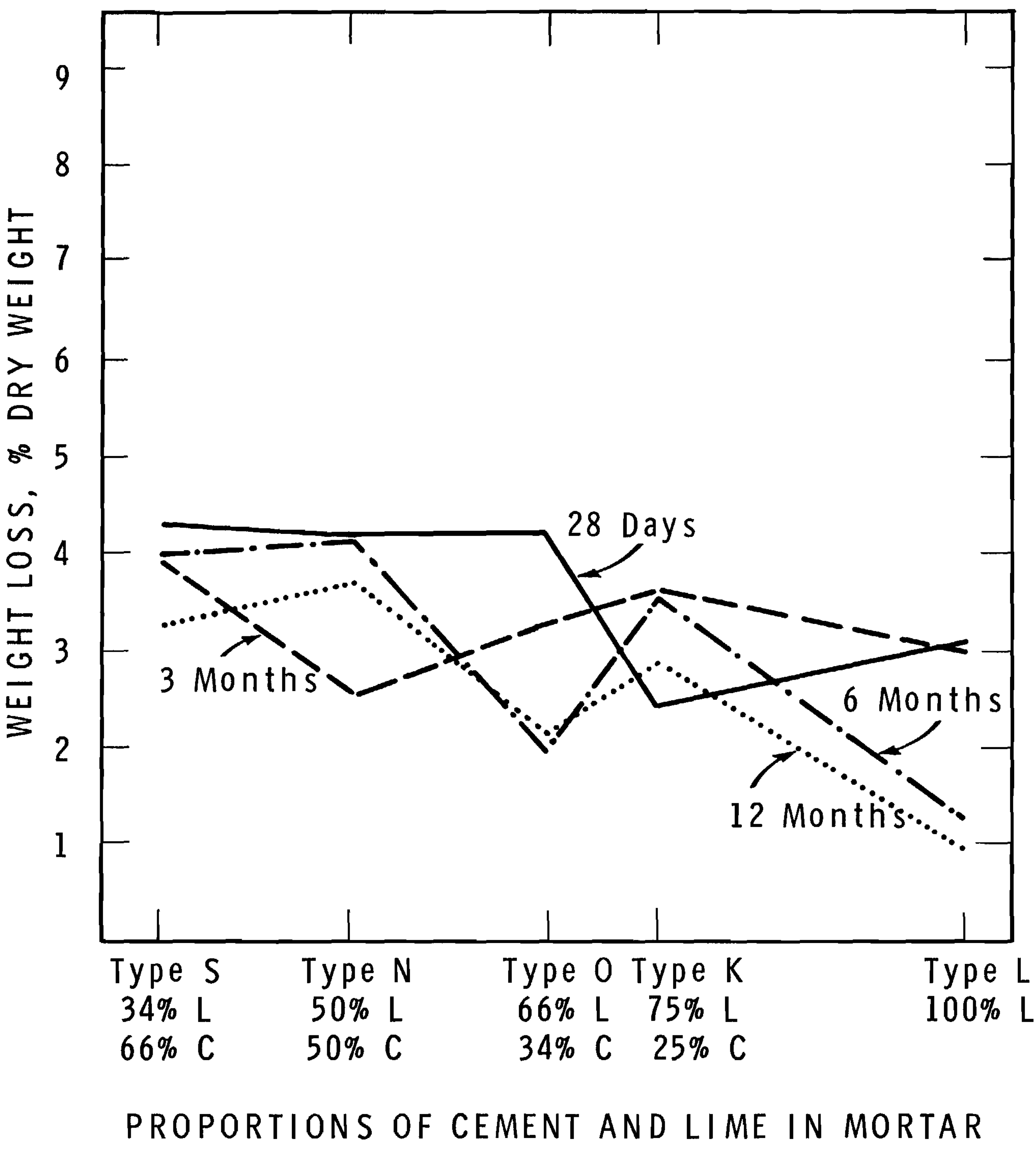


FIGURE 7

WEIGHT LOSSES FOR MORTARS AFTER IGNITION TO 550°C, SERIES I

BR 3911-6

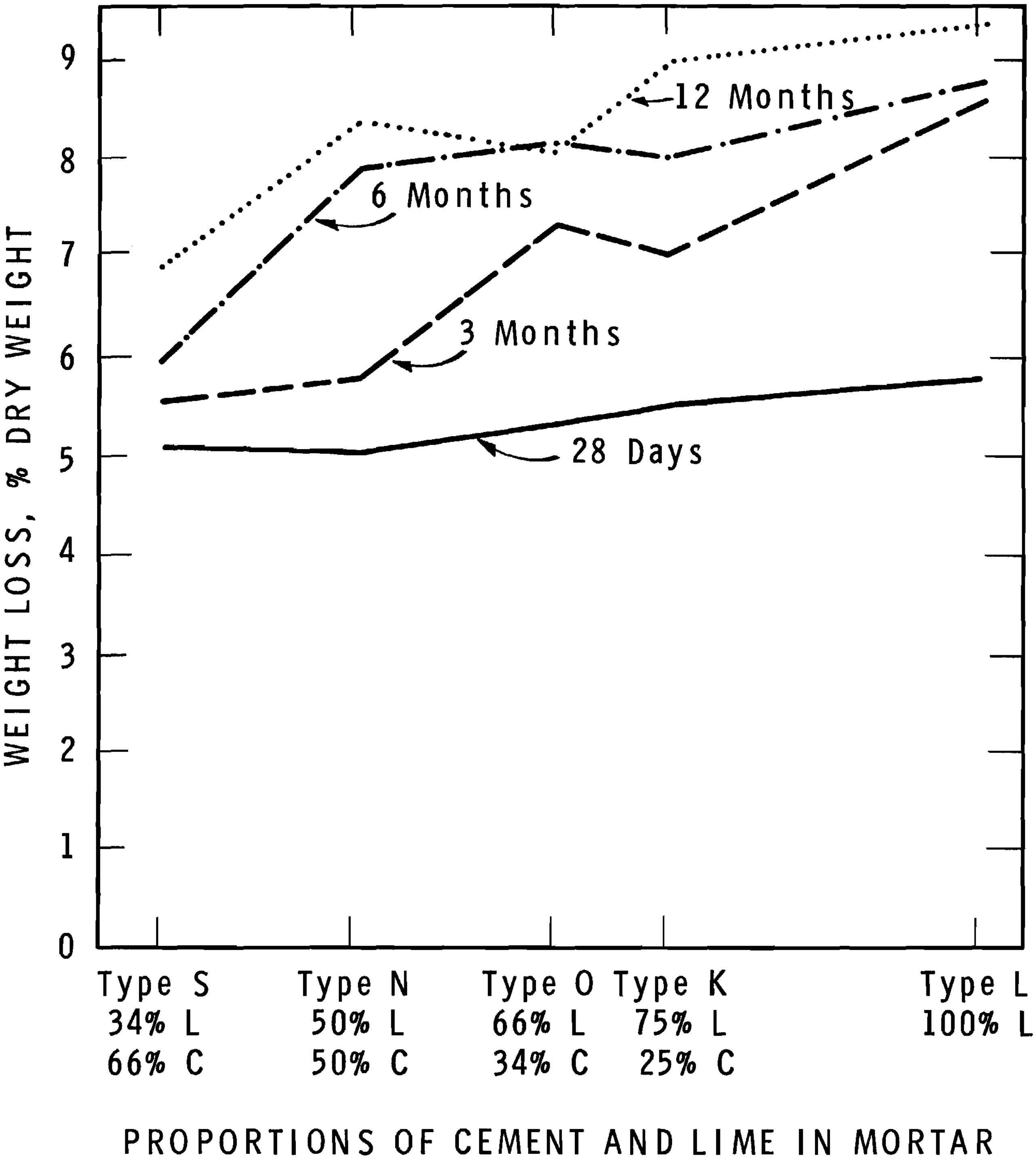


FIGURE 8

WEIGHT LOSSES FOR MORTARS AFTER IGNITION TO 1000°C, SERIES I

BR3911-7

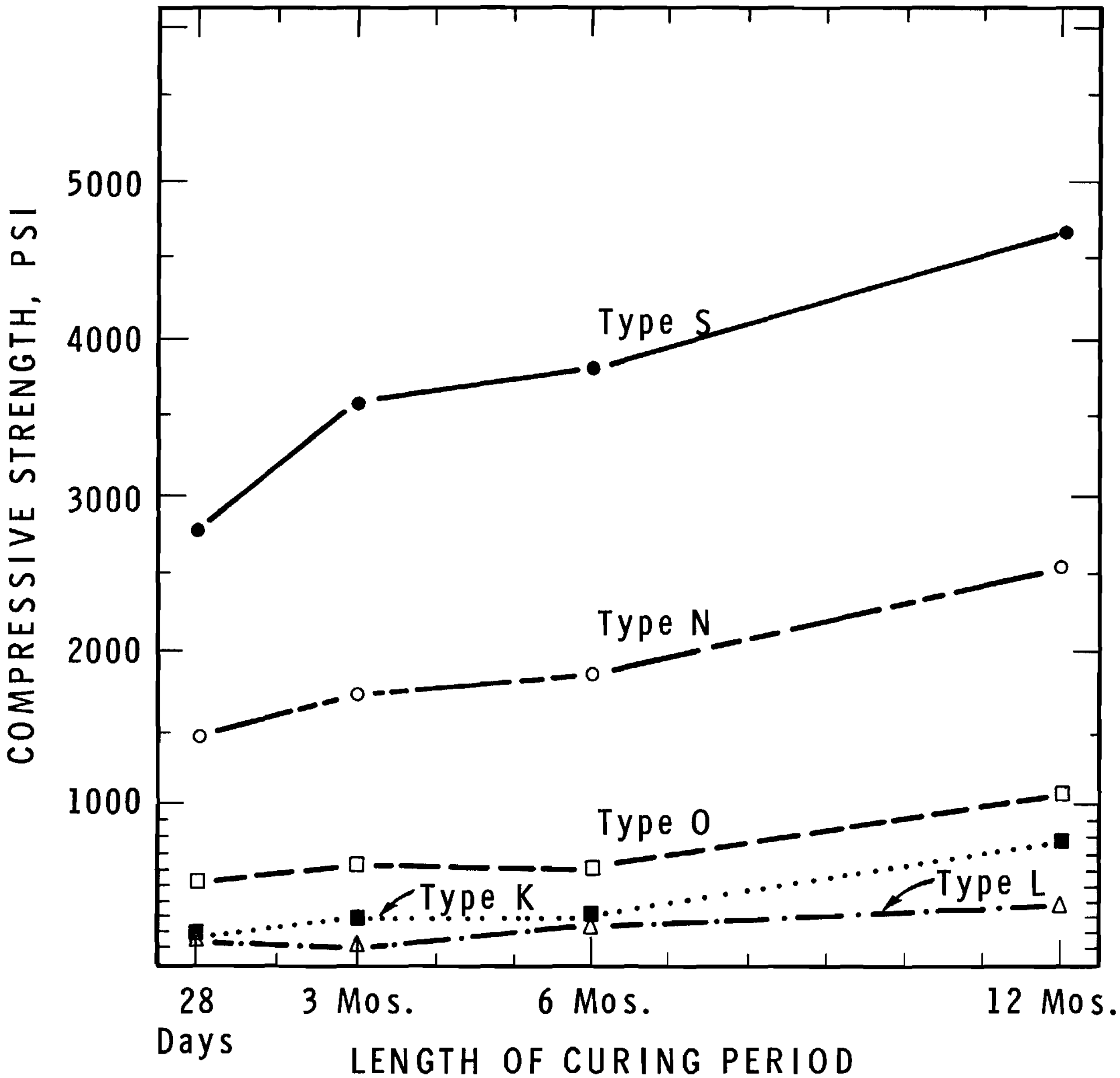


FIGURE 9

COMPRESSIVE STRENGTH VALUES FOR SERIES II CUBES

BR 3911-B

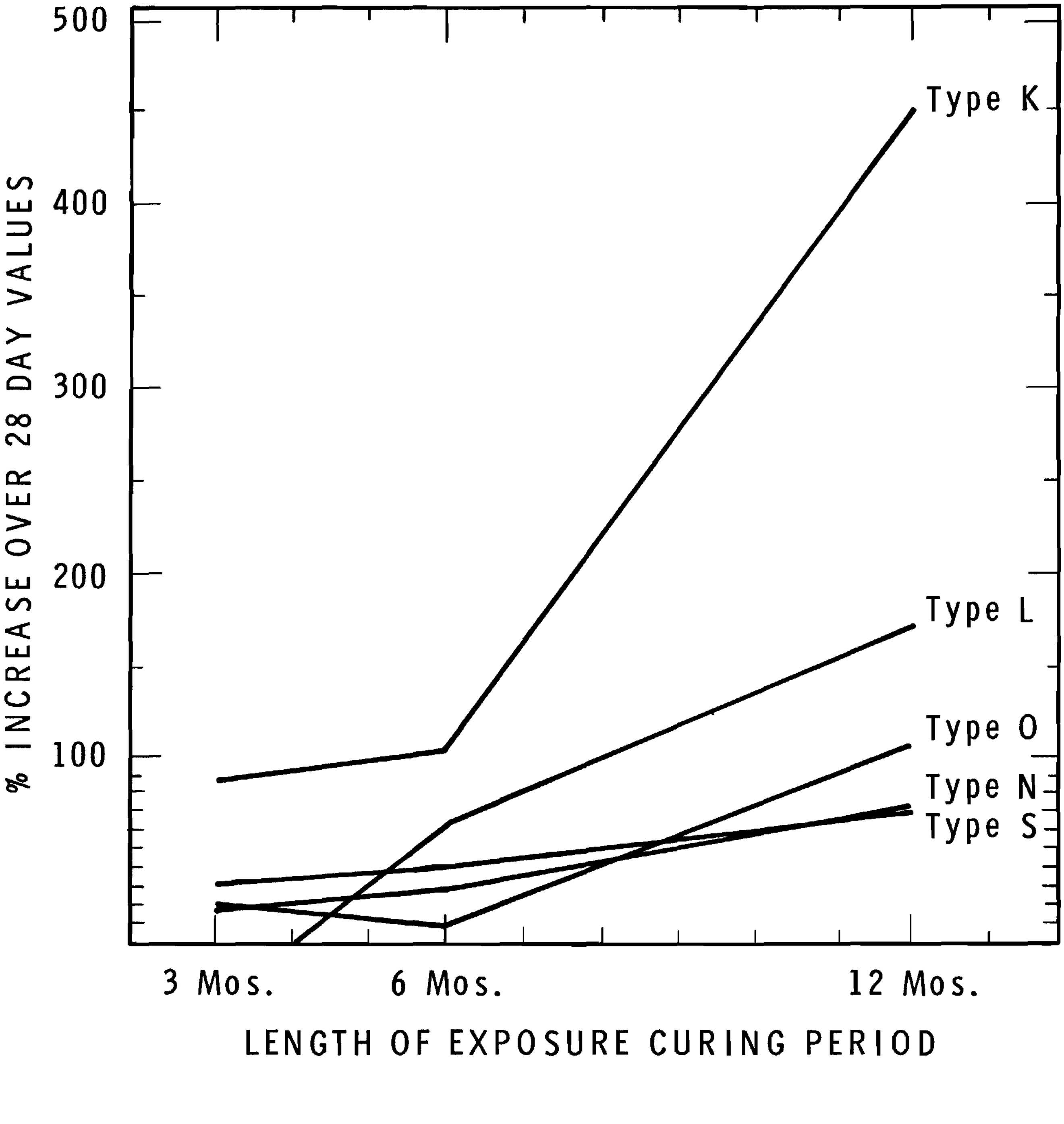


FIGURE 10

IMPROVEMENT IN COMPRESSIVE STRENGTH VALUES FOR CUBES CURED ON EXPOSURE SITE OVER LABORATORY CURED SPECIMENS, SERIES II

BR 3911-9

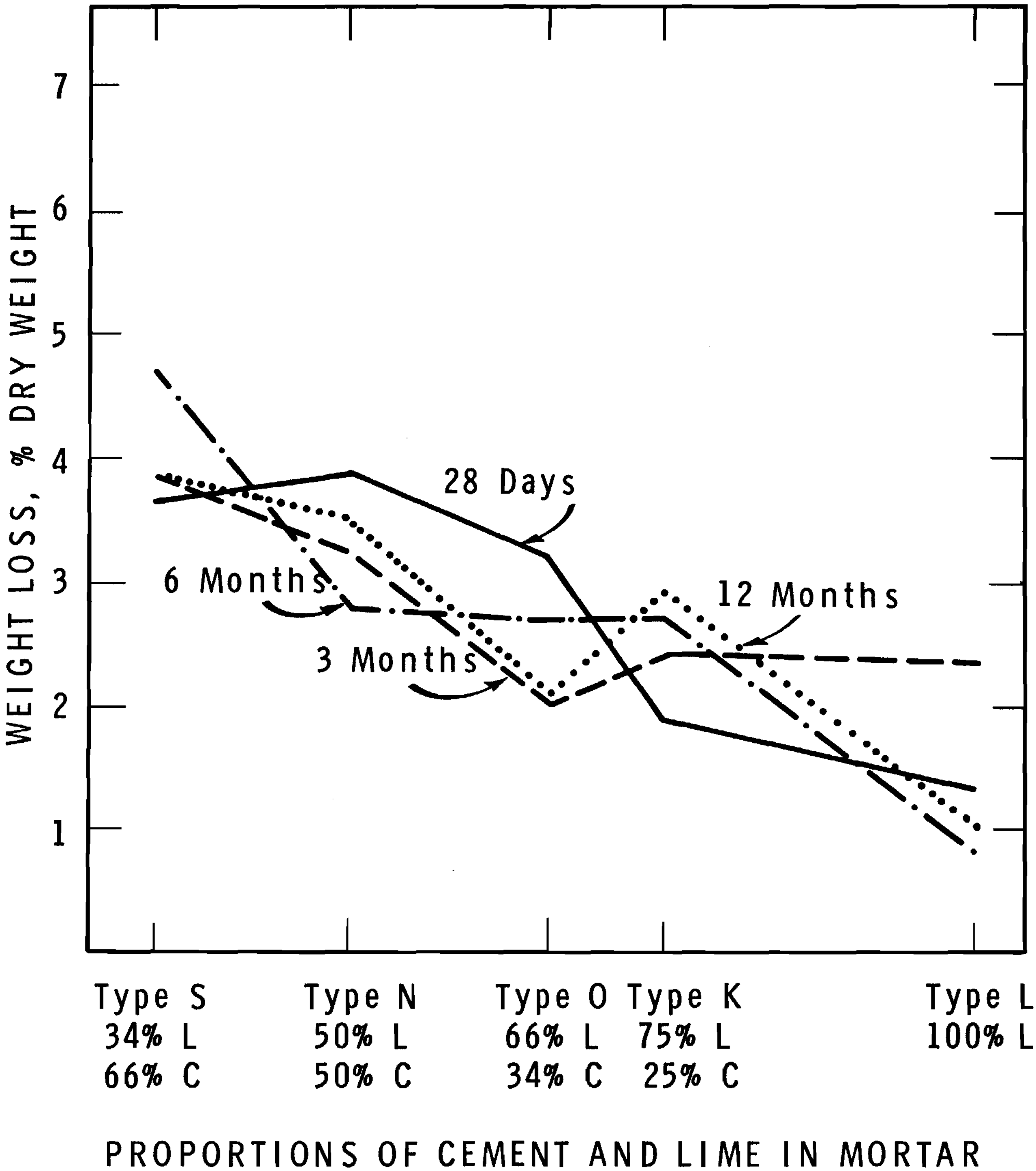


FIGURE 11

WEIGHT LOSSES FOR MORTARS AFTER IGNITION TO 550°C. SERIES II

BR 3911-10

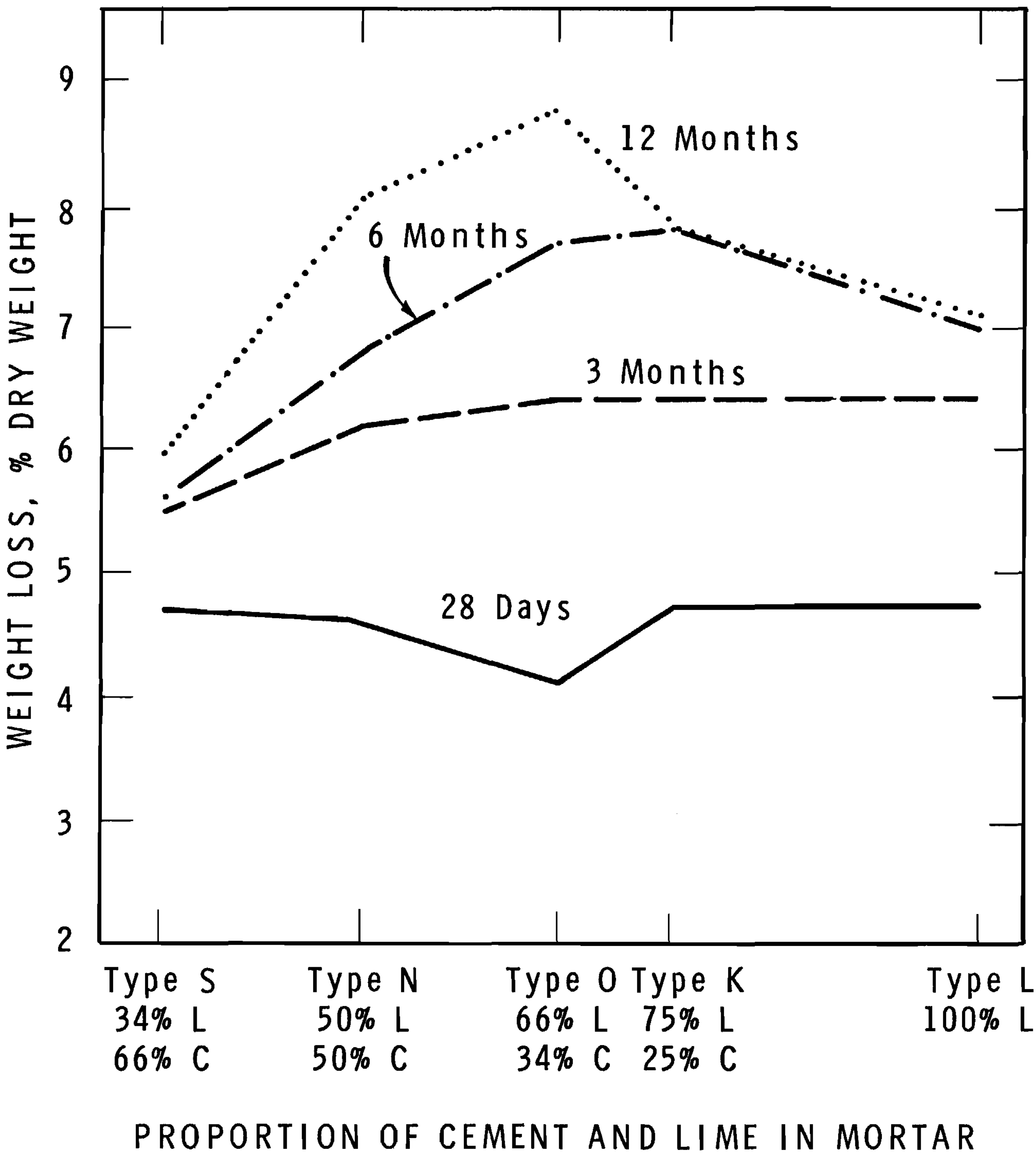


FIGURE 12

WEIGHT LOSSES FOR MORTARS AFTER IGNITION TO 1000°C, SERIES II

BR 3911-11