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A STUDY OF THE PERFORMANCE OF PANELS CONTAINING LOW-SUCTION EXTRUDED BRICKS AND LIME MORTAR

by

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PREFACE

The Division has over many years been concerned with the properties of lime mortars and of the masonry made from them. The excellent condition of some old masonry buildings has been attributed to the use of lime mortar, but on the other hand attempts to use straight lime mortars have not always been without difficulty. Small panels made with lime mortar and local bricks have been constructed and set out for exposure at various times of the year. The observations made on them, as part of the continuing program of masonry research being carried out at the Atlantic Regional Station of the Division in Halifax, are now reported.

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

Ottawa
May 1963

N. B. Hutcheon
Assistant Director

A STUDY OF THE PERFORMANCE OF PANELS CONTAINING LOW-SUCTION EXTRUDED BRICKS AND LIME MORTAR

by

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Results of leakage and bond strength tests in early studies on panels assembled with extruded, low-suction bricks manufactured in the area and a variety of mortar combinations indicated inferior, unsatisfactory performance of panels containing lime mortars (1 part lime: 3 parts sand). This evidence is consistent with general current practice in the field where lime mortars have not given good results, but it conflicts with the satisfactory performance of many old buildings containing lime mortar which have survived up to 100 years in an area characterized by severe weather exposure. There are several things that may explain current inability to obtain satisfactory performance with lime mortar including (1) the use of low-suction extruded bricks in place of higher suction hand-moulded units and (2) the trend developed in recent years of year-round construction as opposed to the confinement of building operations to optimum weather conditions during the summer season.

Accordingly a study was initiated to investigate (1) the compatibility of extruded low-suction bricks and lime mortar and (2) the effect of weather at various seasons of the year on the curing of masonry containing lime mortar. Two panels were assembled each month: the control panel was cured under regulated conditions (70°F temperature and 50 per cent R.H.) in the laboratory and its duplicate was cured at the exposure site (roof of the Atlantic Regional Laboratory). The curing period lasted 6 months. After curing the panels were flashed with polyethylene sheeting and Lasto-Meric in the usual manner and tested for leakage. A minimum of 2 weeks later bond strength tests were conducted.

Sixty panels were assembled between April 1959 and October 1961. Substantial leakage totals and low bond strength values for all panels have indicated conclusively the incompatibility of lime mortar and the bricks used in the study. Nevertheless, the results have also indicated the beneficial effects of curing during the warm summer weather period. The relative effects of inside and outside curing were also apparent.

MATERIALS

Extruded bricks in the suction range of 0 to 5 gm/min/30 sq in. were used for 46 panels, while the remaining

14 panels contained a brick with a higher suction range, 5 to 20 gm/min/30 sq in. All bricks were oven-dried before use. As noted previously the mortar consisted of 1 part lime putty and 3 parts sand by volume. The lime putty was obtained from a local supplier and was reportedly slaked for 1 month prior to sale. The sand was also obtained locally; it generally meets the grading limits of the Canadian Standards Association. Panels were assembled by the usual DBR procedure (1). Mortars were mixed to low flow (100-110 per cent) and a 60-sec time interval was used. Bricks and mortar were joined with a "heavy" tap. Fifty of the panels had 3/8-in. mortar joints. One-quarter-in. joints were used for the remaining 10 panels; this was an attempt to assess the merits of "thin joints," typical in older masonry buildings in the area.

Panels cured at the exposure site were protected on four sides by a wooden frame (Figure 1). The top, back, and two ends were covered; the bottom rested in the recessed frame of a saw-horse shaped support 17 in. above ground level and, except for that portion resting in the frame, was open to the air. This design was intended to minimize the possibility of water collecting between the bottom of the panel and its support and "wicking" up into the brick. Thus the front face of the panel was exposed to normal weather conditions during the curing period. All panels cured at the exposure site were oriented south.

Leakage and bond strength tests were conducted according to usual DBR methods (1). Information on panel assembly and results of tests can be seen in Tables I and II.

DISCUSSION

The panels were very fragile; their lack of strength is evident from the bond strength values given in Table II. Fifteen of the panels were broken in handling before they could be tested.

Tests on panels assembled during the first three months (April, May, June 1959) revealed greater leakage totals but higher bond strength values for panels cured outside than for those cured under controlled conditions. Values recorded under "weight change" during the curing period indicate a difference between the two methods of curing (Table II). These figures were obtained by comparing the weight of the completed panel before curing with the weight of the panel just prior to the leakage test; in the meantime the polyethylene flashing had been added. Thus to determine the true picture, the "weight change" figures should be corrected by subtracting the weight of the polyethylene cover. It was also noted that panels cured under controlled conditions absorbed greater amounts of water during the leakage tests than did panels cured under exposure, an indication that the former were drier at the time of the test. Visual observations of fractured panels after bond strength tests revealed a greater extent of carbonation for those cured in the laboratory. There was a carbonated ring exceeding 1 in. in width around the perimeter of the mortar bed for these panels; the carbonated perimeter around the mortar bed of the exposure-cured panels was never more than 3/4 in. in width. There was, however, a greater contrast in colour between carbonated and uncarbonated areas of the exposure-cured panels, possibly indicating more complete carbonation and explaining the higher bond strength values for these panels. The carbonation process had not progressed sufficiently in any of the panels to prevent water penetration of the mortar joint; the lesser extent of bond for exposure-cured panels would then explain the higher leakage totals despite better bond strength values. Typical mortar joints can be seen in Figures 2, 3 and 4. The pattern of test results described for the above panels was typical of results obtained throughout the study.

The next six panels to be cured at the exposure site were lost when they toppled and broke during a gale in January 1960. Results of the tests on their control panels were reasonably consistent with an average total leakage of 1217 ml and an average bond strength value of 3.1 psi. These panels were characteristically fragile; bond strength values were only obtained for 13 of the 30 mortar joints in the six panels.

Ten panels were assembled in the January to June 1960 period (none were assembled in May) and one of these, the January control panel, was broken prior to testing. This group is notable in that the highest and second lowest leakage totals for exposure-cured panels occurred for panels assembled in February and June, respectively. Excessive leakage occurred for exposure-cured panels assembled in January, February and March. The same general pattern of results occurred for initial panels except for panels assembled in April where leakage was greatest for the one cured in the laboratory.

Again the same general pattern continued for results on panels assembled during the last six months of 1960. The lowest leakage total for exposure-cured panels occurred for the panel assembled in November; excessive leakage was recorded for the December panel.

During the next five months (January to May 1961) eight panels were assembled using bricks in the higher (5 to 20 gm/min/30 sq-in.) suction range. Two of these were broken before test and several of the remaining six panels "lost" one brick and were tested as 4-brick panels. The pattern of the test results was similar to that discussed previously.

The last ten panels were assembled with low-suction (under 5 gm) bricks and 1/4-in. mortar joints. Test results revealed some improvement with thinner mortar joint panels cured in the laboratory. Nevertheless, there appeared to be less bond between bricks and mortar than for previous panels. Only two of the exposure-cured panels survived for testing and leakage totals for these were higher than for the laboratory-cured duplicates. The difference in weight resulting from the two curing procedures referred to previously was also noted. These panels were very fragile and excessive water penetration during leakage tests indicated that there would be no merit in continuing this study.

Leakage results for the study are shown graphically in Figure 2. It will be noted that leakage totals for exposure-cured panels were higher than totals for laboratory-cured panels except in three instances. It is also evident that panels assembled during the April-November period performed better than panels assembled during the November-April period; this was true for laboratory-cured as well as exposure-cured panels. Bond strength values were low for all panels (low values coupled with inconsistent results) and in some instances insufficient results for proper assessment make closer examination meaningless. There is, however, sufficient evidence to support the statement made previously that highest bond strength values occurred for exposure-cured panels while there was a better extent of bond for those cured under laboratory conditions. A comparison of bonding pattern for panels cured on exposure and under controlled laboratory conditions may be seen in Figures 3, 4 and 5.

The differences in weight change as a result of outdoor- and laboratory-controlled curing were consistently noted throughout the study. There was an average increase of 213 gm for exposure-cured panels compared with an average loss of 62 gm for those cured under controlled conditions. The Lasto-Meric-polyethylene sheet flashing was added between weighings, however, and must be accounted for. Average gain in weight to panels as a result of adding the flashing was 143 gm. Correcting the weight changes noted above, the gain for exposure-cured panels becomes 70 gm and the loss for laboratory-cured panels 205 gm.

A change of weight during curing results from (1) the carbonation process in which slaked lime absorbs carbon dioxide from the air to form calcium carbonate and (2) variations in moisture content of the panels. It is not possible to assess the respective contributions of these two factors to the over-all weight change without a chemical analysis to determine the extent of carbonation. It is fair to assume, however, that differences in weight changes between the two curing methods were primarily due to variations in moisture content. This assumption is substantiated by increased water absorption for drier laboratory-cured panels during leakage tests. It should also be recorded that weight changes for exposure-cured panels do not represent true averages as their moisture contents reflect day-to-day weather conditions. The results do indicate, however, that curing at outdoor exposure sites occurs with higher moisture contents in the panels than for those cured in a controlled atmosphere at 70°F and 50 per cent R.H.

This variation in the moisture content level of panels during the curing period also provides an explanation for superior extent of carbonation indicated for (1) panels cured during summer weather, both on exposure site and in the laboratory and (2) panels cured under controlled conditions when compared with those cured on exposure. It is known that maximum carbonation occurs when moisture content is at equilibrium in the relative humidity range of 50 to 75 per cent. During the winter months the relative humidity at exposure sites is often above the upper limit of this range, thus having a detrimental effect on carbonation. In fact, the over-all average relative humidity taken from weather records indicates a value near the upper level of the desirable limit.

Inferior carbonation of mortar joints in laboratory-cured panels during the winter months possibly results from lower concentrations of carbon dioxide in the air. Extra humidification is necessary in the winter to maintain the desired relative humidity and the spray can remove some of the carbon dioxide from the air. In this study, the controlled room used was small and the volume change of air through the conditioner quite rapid.

Moisture content losses to matched pairs of bricks having suction values comparable to values for bricks used in panels were determined in conjunction with panel assembly. Values were determined on the basis of 1½- and later 3-min contacts with the bricks. Values in Table I indicate that moisture content losses were not high enough to have a detrimental effect on brick-mortar bond, particularly for a 1-min time interval.

CONCLUSION

A study involving leakage and bond strength tests on panels assembled with lime mortars and low-suction extruded bricks has established the incompatibility of this combination.

No improvement in brick-mortar bonding was effected by (1) using brick having suction values up to 20 gm/min/30 sq in. or (2) using 1/4-in. mortar beds instead of conventional 3/8-in. joints. Lower leakage totals for panels assembled during the April to November period suggest improved carbonation of lime mortar during the warmer weather. This has been attributed to relative humidities in a range resulting in moisture contents more conducive to improved carbonation during the summer period. Panels cured under controlled laboratory conditions exhibited the same behaviour, and in this case inferior carbonation was explained by lower concentration of carbon dioxide in the air during winter months. Differences in weight between panels cured under controlled conditions and at outdoor exposure sites were also noted and primarily attributed to higher levels of moisture content in the latter panels. Bond strength results indicate stronger bond for panels cured on exposure while visual observations revealed a better extent of bond between brick and mortar for panels cured indoors.

The study also indicated that lime-mortar joints are slow to carbonate. Visual observations at the end of a 6-month curing period revealed that the extent of carbonation in mortar joints of panels cured outside was only slightly better than 50 per cent, and under 70 per cent for panels cured inside. This means that masonry erected during unfavourable fall and winter weather and not properly protected for a sufficient period of time is particularly vulnerable to damage from leakage and frost penetration and ultimately from rain penetration because of incomplete carbonation of the lime mortar.

REFERENCE

1. Ritchie, T. A small-panel method for investigating moisture penetration of brick masonry. Materials research and standards, Vol. 1, No. 5, May 1961, p. 360-367 (reprinted as NRC 6162).

TABLE I

PANEL ASSEMBLY DATA

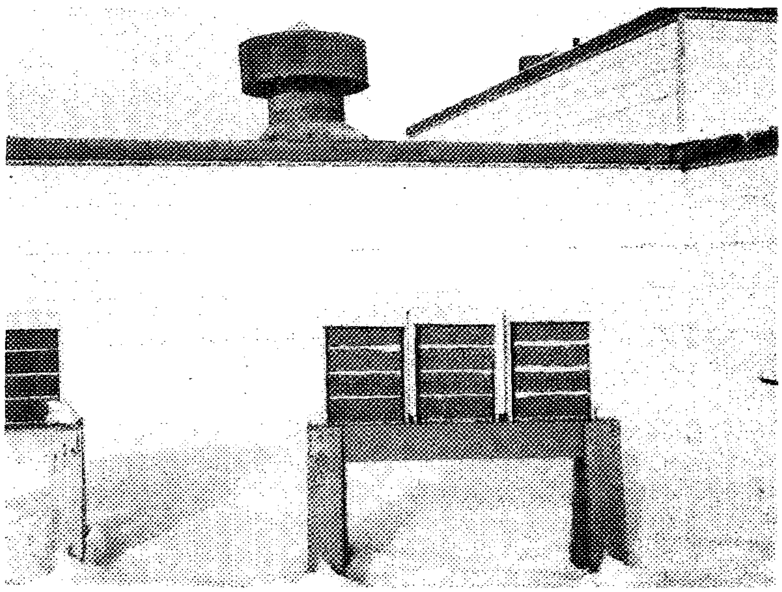
Date of Panel Assembly	Brick Suction, gm/min/30 sq in.	Mortar Flow, % 1	Mortar Flow, % 2	Suction Brick Pairs, gm/min/30 sq in.	M/C Loss from Mortar, % 1	M/C Loss from Mortar, % 2	Weight of Mortar Used in Panels 1	Weight of Mortar Used in Panels 2
1959								
April	1-3	106	102	2.0 & 2.0	1.2	1.4	1218	1250
May	1-3	104	104	2.2 & 2.2	0.9	1.5	1201	1171
June	1-3	104	103	2.2 & 2.2	1.2	1.0	1251	1246
July	1-3	105	103	2.0 & 2.3	1.5	1.3	1236	1294
Aug.	1-3	106	107	2.8 & 2.4	1.2	0.9	1201	1172
Sept.	1-3	111	111	2.0 & 2.2	1.3	---	1137	1140
Oct.	1-3	110	111	1.1 & 0.6	1.1	0.6	1187	1210
Nov.	1-3	---	106	2.3 & 1.6	---	1.4	---	1228
Dec.	1-3	---	107	1.2 & 1.2	---	1.2	---	1202
1960								
Jan.	1-5	106	108	3.3 & 3.3	1.7	1.8	1270	1343
Feb.	1-5	108	108	3.5 & 3.5	1.7	2.3	1262	1214
March	1-5	104	105	3.0 & 3.0	1.5	1.1	1246	1232
April	5-10	105	106	9.0 & 9.0	1.4*	2.1+		1307
May	6-10	104	107	9.2 & 9.2	1.4*	2.4+	1383	1354
June	10-12	105	107	11.5 & 11.2	2.6*	2.6+	1385	1355
July	2-5	104	105	3.1 & 3.3	1.0*	1.2+	1272	1245
Aug.	2-5	109	108	2.8 & 3.2	2.0*	2.2+	1215	1155
Sept.	2-5	104	104	2.5 & 2.5	1.0*	0.8+	1189	1342
Oct.	2-5	104	104	2.5 & 2.5	1.4*	1.5+	1247	1189
Nov.	2-5	105	108	2.8 & 2.8	1.8*	2.1+	1198	1220
Dec.	2-5	105	104	2.8 & 2.8	1.7*	2.1+	1260	1223
1961								
Jan.	5-10	---	104	7.3 & 7.4	---	2.1+	---	1330
March	4-7	106	106	6.2 & 7.0	0.9*	1.9+	1410	1415
April	10-20	105	106	17.7 & 17.8	1.8*	3.5+	1474	1463
May	5-14	106	104	19.0 & 19.0	3.0*	6.0+	1412	1435
June	1-4≠	108	108	2.0 & 2.8	1.4*	2.6+	760	720
July	1-4	107	107	2.8 & 2.5	1.1*	2.5+	720	770
Aug.	1-5	106	107	3.7 & 3.8	1.1*	1.7+	740	705
Sept.	0-3	104	104	1.6 & 1.7	0.4*	1.3+	727	707
Oct.	0-2	107	107	1.5 & 1.8	0.4*	1.1+	765	738

* $1\frac{1}{2}$-min contact   + 3-min contact   ≠ $1\frac{1}{4}$-in. mortar joint

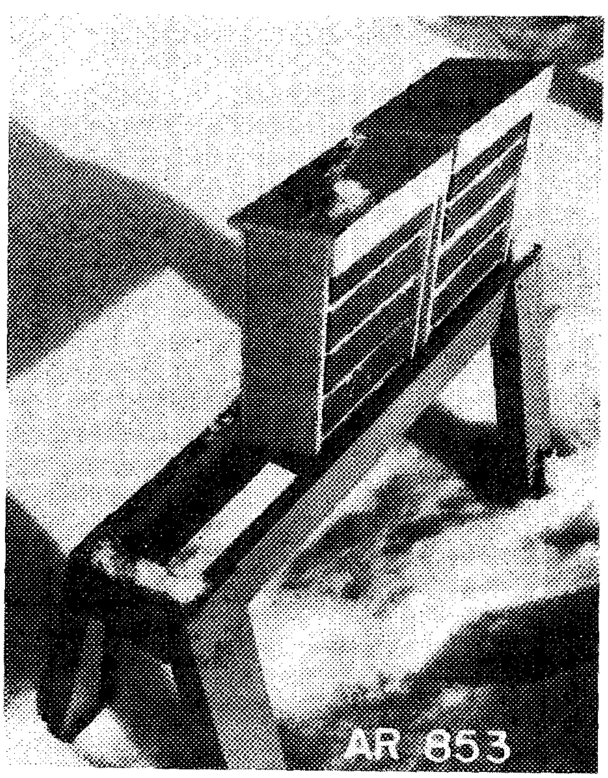
TABLE II

RESULTS OF LEAKAGE AND BOND STRENGTH TESTS

Date of Panel Assembly	Weight Change during Curing Period, gm		Total Leakage, ml		Water Absorbed during Leakage Test, gm		Average Bond Strength, psi	
	1	2	1	2	1	2	1	2
1959								
April	+195	- 61	1938	2034	277	437	6.0	0.8
May	+257	- 58	1870	1323	198	397	3.7	1.5
June	+252	-198	2549	1307	242	419	---	1.1
July	---	- 64	---	1112	---	487	---	1.3
Aug.	---	- 55	---	885	---	325	---	3.2
Sept.	---	- 42	---	841	---	447	---	1.5
Oct.	---	- 93	---	1132	---	373	---	1.5
Nov.	---	-125	---	1379	---	320	---	5.6
Dec.	---	- 85	---	1952	---	395	---	5.3
1960								
Jan.	+112	---	4859	---	450	---	2.1	---
Feb.	+ 53	- 69	24,876	2890	422	530	4.8	1.6
March	+133	---	3646	2014	332	532	1.1	0.6
April	+225	- 45	831	1308	358	233	2.7	0.9
May	---	---	---	---	---	---	---	---
June	+307	- 25	811	514	268	533	5.4	4.5
July	---	---	---	880	---	528	1.1	1.9
Aug.	+315	- 90	1173	632	390	562	6.3	---
Sept.	+259	-105	1405	1125	387	607	2.4	1.0
Oct.	+295	- 59	1163	883	348	520	2.0	---
Nov.	+207	-110	762	1652	405	695	6.0	5.8
Dec.	+ 55	- 82	11,721	2942	323	607	0.3	0.9
1961								
Jan.	---	---	---	---	---	---	---	---
March	---	- 75	4338	1707	315	615	4.5	2.4
April	---	- 88	1694	819	478	990	3.6	5.2
May	+270	- 37	2248	1478	410	865	1.9	1.5
June	+315	---	3016	449	253	568	2.1	1.1
July	---	+ 32	---	1441	---	637	---	1.5
Aug.	---	+ 30	---	866	---	432	---	1.4
Sept.	+165	+ 18	977	420	215	195	2.7	2.1
Oct.	---	- 5	---	545	---	165	---	2.7



(a)



(b)

Figure 1

Panels being cured at exposure site on ARL roof

(a) General view

(b) Detail of supporting frame

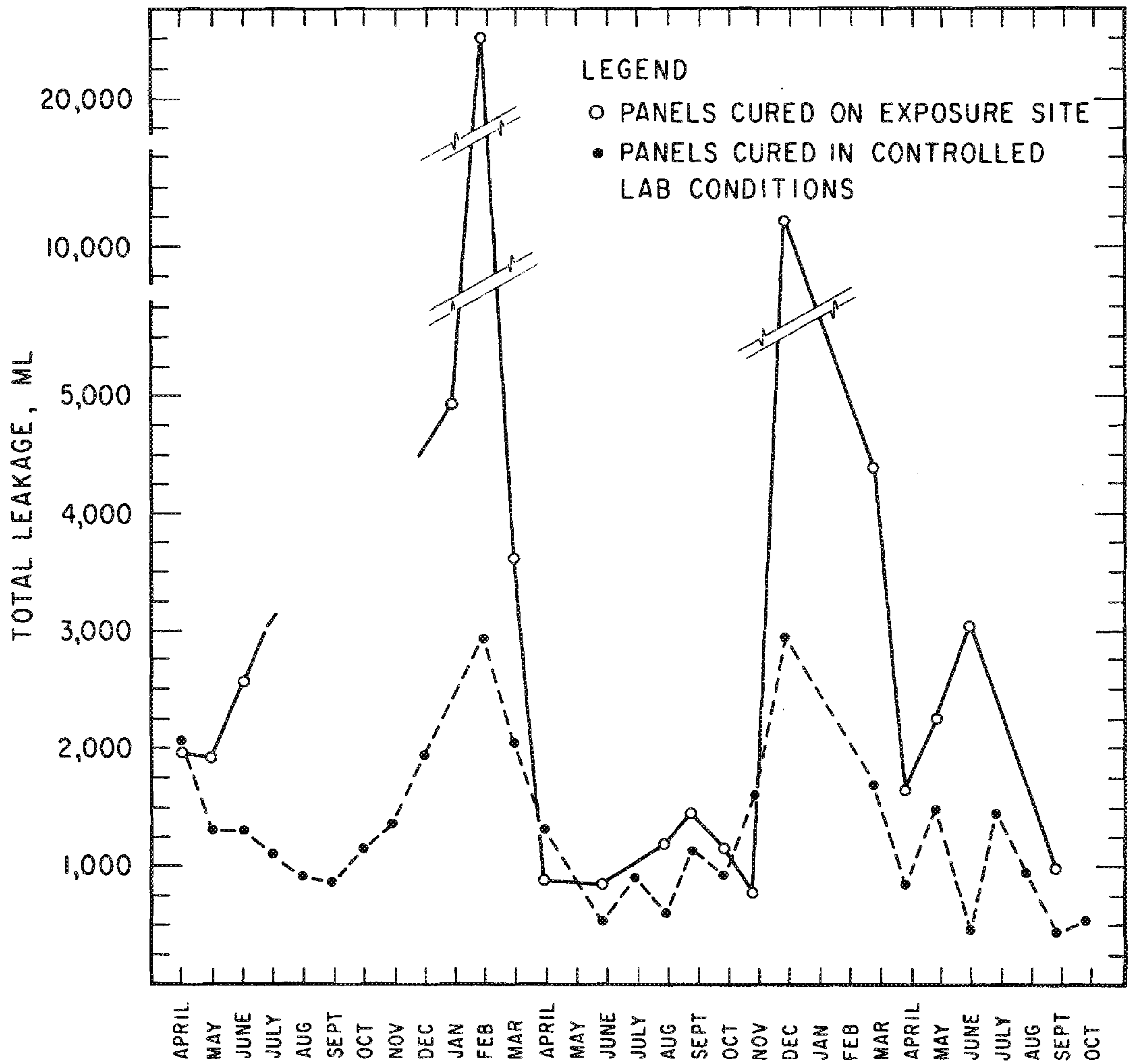


FIGURE 2

LEAKAGE TOTALS FOR LIME-MORTAR PANELS

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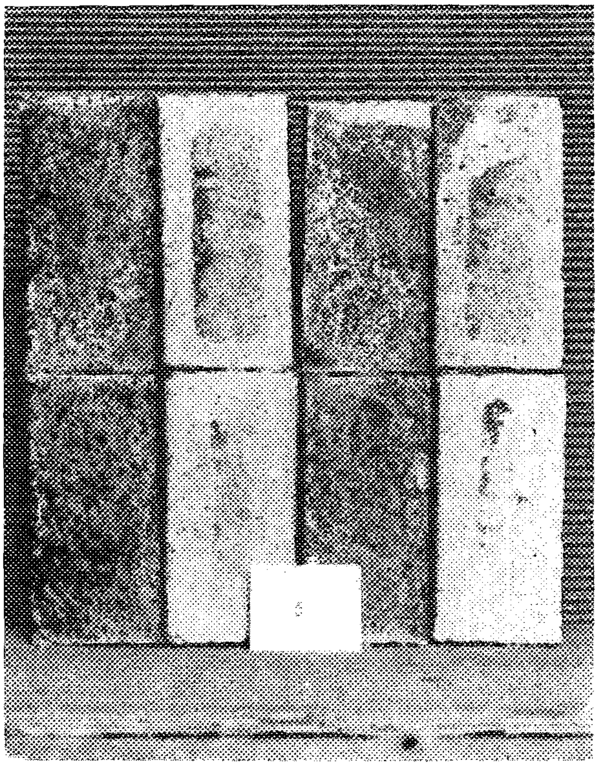

Figure 3

Top Row - Mortar joints from panels cured at outdoor exposure site.

Bottom Row - Panels cured under controlled laboratory conditions - greater extent of bond but less contrast between carbonated and uncarbonated areas.

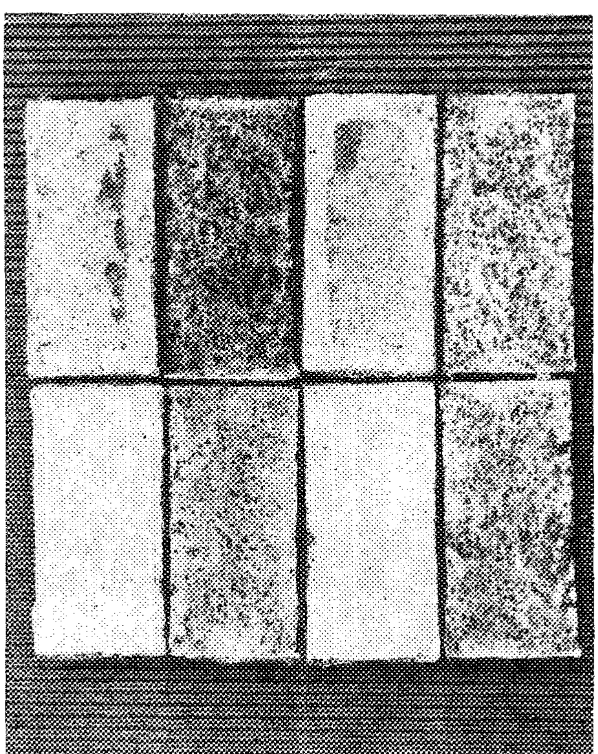

Figure 4

Top Row - Mortar joints from panels cured at outdoor exposure site.

Bottom Row - Mortar joints from panels cured under controlled laboratory conditions.

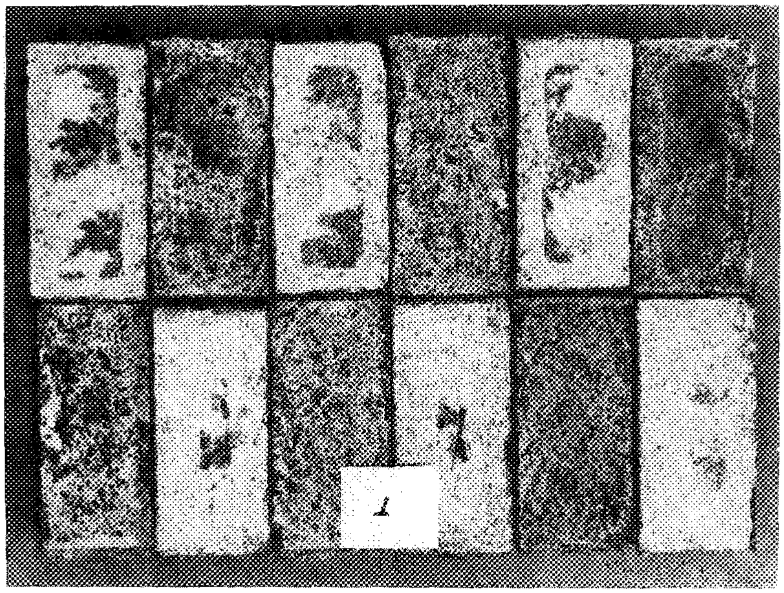

Figure 5

Top Row - Mortar joints from panels cured at outdoor exposure site.

Bottom Row - Mortar joints from panels cured under controlled laboratory conditions.