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A COMPARATIVE STUDY OF TYPE N MORTARS

by

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PREFACE

This report describes further work done as part of the continuing study of masonry in the Atlantic Region with regard to materials, performance and practice. Three kinds of mortars, including some made with mortar mix have been compared as to pertinent properties. The author, a member of the staff of the Atlantic Regional Station of the Division in Halifax, is engaged full time in research on masonry.

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J.I. Davison

The increased use of masonry cements and packaged mortar mixes in recent years has been accompanied by frequent inquiries concerning the relative merits of these proprietary products and traditional cement-lime mortars. In the fall of 1964, a study of the properties of the respective mortars containing cementitious materials commonly used in the area was initiated; it was completed in August 1967, when freeze-thaw cycling tests on surviving mortar cubes were terminated at 567 cycles.

The program was designed to provide a comparison of three mortars - 1 : 1 : 6 Portland cement: hydrated lime: sand, 1 : 3 masonry cement: sand, and masonry mortar mix: sand. The three combinations were considered to be Type N mortars by Composition, as defined by the National Building Code of Canada.

MATERIALS

All cementitious materials were obtained locally. They included a masonry cement, and a 1 : 1 : 6 masonry mortar mix containing Portland cement and hydrated lime.

It is generally understood that masonry cement is produced by intergrinding cement clinker and limestone, while the proprietary mortar-mix is a mixture of Portland cement and hydrated lime. Thus, in the masonry cement the limestone, an inert material, is simply a filler, while the hydrated lime in the mortar mix acts as a plasticizer and ultimately as a cementitious material when it carbonates. In addition to these basic ingredients both products contain certain additives; for example, the presence of an air-entraining agent is confirmed by their high air content levels.

It should be noted that the composition of these proprietary products may be changed from time to time at the manufacturer's discretion, without notice to the consumer. Thus, the data acquired in this study reflect the properties of the products available on the local market in 1964 and are not necessarily representative of similar products currently available.

In addition to local Portland cement and hydrated lime, an American-manufactured Portland cement and an American-manufactured Type S hydrated lime, both acquired during a recent ASTM Round-Robin mortar test series, were used in some 1 : 1 : 6 mortar samples.

Air-entrained Cement-lime Mortars

The program also included conventional 1 : 1 : 6 cement-lime mortars with air-entraining agents added to make their air contents comparable with that of the masonry mortar mix mortars. The air-entraining agent used was neutralized vinsol resin.

The aggregate used was blended Ottawa sand, consisting of equal parts graded and standard 20-30 mesh.

PROCEDURES

Procedures outlined in the CSA Specification for Masonry Cement A8-1956 were used except as noted in the following paragraphs.

Preparation of Mortar

Materials were proportioned by volume but actual quantities were weighed, using the respective weights calculated as directed in CSA Spec. A8-1956. The following unit weights were used as a basis for calculations:

Masonry cement	-	70 lb/cu ft.
Masonry mortar mix	-	50 lb/cu ft.
Hydrated lime	-	40 lb/cu ft.
Portland cement	-	94 lb/cu ft.
Sand	-	80 lb/cu ft.

The mixing procedures outlined in the Specification were followed with the exception that mortars were mixed to a flow of 120 ± 2 per cent instead of 105 to 115 per cent.

Plastic Mortar

Air content and water retention were determined on separate batches of the plastic mortars, and twelve 2-inch cubes were molded from each mortar.

Hardened Mortar

The twelve cubes of each mortar were divided into four groups of three. The first two groups were used for compressive strength tests at 7 and 28 days; the third group was used for absorption tests, and the last group for freeze-thaw cycling. The last two tests were done after a 28-day curing period.

Absorption Tests

After the curing period, cubes were dried for 72 hours at 175°F, their dry weights recorded, and absorption (when cubes were set in water to a depth of $\frac{1}{4}$ inch for 1 hour) determined. Following this the 24-hour immersion absorption was also determined.

Freeze-thaw Cycling

Despite well recognized objections to rating the durability of mortar cubes on the basis of their resistance to laboratory freeze-thaw cycling, these tests were included in the absence of an acceptable alternative. The cycling test was a modified version of the test used for bricks (CSA A82.2-1954, Standard Methods of Sampling and Testing Brick) in which the cubes were frozen in air in a saturated condition and thawed in water. After being removed from the water, the cubes were wiped surface dry and set out for freezing on wooden strips in a metal container, to prevent them from resting in any water that might drain from them.

RESULTS

A) 1:3 masonry mortar mix

Mortar prepared with 1:3 mortar mix: sand proportions at a flow of 120 per cent showed low water retention and compressive strength values. Because of this, two other tests were conducted using mortars prepared under different conditions. One had the same proportions of cementitious material and sand, but the flow was increased to 135 per cent; in the second, the proportions were altered to follow the recommendations of the manufacturer; 1 part mortar mix was combined with $2\frac{1}{4}$ parts aggregate.

Results of tests on these three mortars are compiled in Table I. As noted above, the compressive strength value of 702 psi at 28 days for the 1: 3 mortar mix: sand at 120 per cent flow was low and would classify the mortar Type 0 rather than Type N under the requirements of the National Building Code. The water retention at 64.7 is below the minimum requirement of 70 in the ASTM Specification for Mortar for Unit Masonry (C270). However, it is noted that the 64.7 value was obtained using an initial flow of 120 per cent rather than the 100 to 115 per cent value defined in the ASTM Specification. The mortar stiffened rapidly when mixing was completed, and this factor combined with the low values for retention and compressive strength (which were confirmed by results of tests on a duplicate mix) resulted in a decision to test the mortar at a higher flow, 135 per cent. While this did not materially change the water retention value, the increased water content resulted in a substantially lower compressive strength value.

The other alternative, the 1: $2\frac{1}{4}$ mortar mix: sand combination at 120 per cent flow, produced an acceptable 71.7 retention value and a 1222 psi compressive strength, the latter well above the minimum requirement for a Type N mortar.

The seven-day compressive strength tests were conducted to provide an early indication of the trend of the results. They were quite consistent with 28-day values and therefore have not been included in this report.

Freeze-thaw cycling test results are summarized in Table II. Cubes were considered to have failed when (a) severe cracking or surface spalling occurred, or (b) weight losses reached 5 per cent of the original dry weight. Three of the four cubes which failed, A8, H6, and K9, did so because of weight losses (i.e., they gradually eroded away until the 5 per cent figure was surpassed) while K12 failed with a severe surface spalling.

Figures 1 and 2 show the extent of the deterioration in the mortar mix cubes (A, H, J) that survived the 567 cycles. Top surfaces of the cubes are shown in Figure 1, where minor rounding of corners is noted. More extensive deterioration patterns are apparent in Figure 2, where considerable rounding of corner edges has occurred on the bottom surfaces of the same cubes.

It should be noted that two of the three 1 : $2\frac{1}{4}$ mortar mix: sand cubes (K), which had compressive strength values almost double those of the other mortar-mix cubes, failed after 270 and 336 cycles, while the remaining cube had the lowest weight loss among cubes surviving the 567 cycles.

SUMMARY

The 1 : $2\frac{1}{4}$ mortar mix: sand mortar had water retention and compressive strength values which meet the requirements for a Type N mortar. Values for 1 : 3 mortar mix: sand mortars at two flows did not meet water retention requirements of ASTM C270, and their lower compressive strength values would classify them as Type 0 rather than Type N.

Despite its higher compressive strength, the 1 : $2\frac{1}{4}$ mortar mix: sand cubes had the highest rate of failure in freeze-thaw tests, followed by the 120 per cent flow 1 : 3 mortar mix: sand and the 135 per cent flow combination. While none of the last two types of cubes failed after 567 cycles, they showed the greatest average weight losses and therefore the poorest durability.

In view of the results for the mortar mix mortars, the original intention to compare the various mortars on the basis of a 1 : 3 cementitious material: sand proportion was altered, and the mortar mix mortar is included on a 1 : $2\frac{1}{4}$ proportion basis.

B) Conventional 1: 1: 6 Cement-Lime, 1: 1: 6 Masonry Mortar Mix and Masonry Cement Mortars

Results of tests on the three types of mortars are compiled in Table III. It includes four 1: 1: 6 cement-lime mortars, one containing American cement and lime, one of local cement and lime, and one each of the above containing an air-entraining agent. The latter is intended to raise the air contents of the conventional cement-lime mortars to a comparable level with the masonry mortar mix. This was done using the 1: 3 masonry mortar mix: sand at 120 per cent flow as a basis. Thus, air content values in the table for the air-entrained cement: lime mortars are some 3 per cent higher than the value for the 1: $2\frac{1}{4}$ mortar mix: sand mortar. Data in the table indicates that air content in the masonry cement mortar is 57.5 per cent higher than in the masonry mortar mix. It is also interesting to note that air content in normal cement lime mortars is 6.5 and 7.6 per cent, with the one containing the Type S hydrate being 1.1 per cent higher than the one containing the local hydrate. The reduction in water requirement of the cement-lime mortars with the addition of an air-entraining agent at constant flow (120 per cent) should also be noted.

Water retention values (WRV) for all mortars exceeded the value of 70 required as a minimum in ASTM Spec. C270. The two cement-lime mortars with high air contents had the highest WRV value - the highest individual value being recorded by the American cement-lime mortar. The masonry cement and the normal cement-lime mortars had comparable values with the masonry mortar mix having the lowest value.

The masonry mortar mix and the masonry cement mortars had the lowest 1-hour absorption (rate of absorption) and the masonry cement mortar also had the lowest 24-hour immersion absorption, followed by the masonry mortar mix and the traditional cement-lime mortars in that order. The addition of an air-entraining agent had no effect on the American cement-lime mortar but it did result in a reduction in absorption values for the local cement-lime combination.

Highest compressive strength values occurred with the traditional cement-lime mortars. In fact, values for the masonry cement and the masonry mortar mix were only 34 and 48 per cent respectively, of the average value for the two normal cement-lime mortars. Values for all mortars were well above the minimum requirements for a Type N mortar, and the cement-lime mortars qualified by compressive strength as Type S mortars. The addition of the air-entraining agent reduced the average compressive strength of the cement-lime mortars to 64 per cent of the value for the non-air-entrained mortars. It is notable that this reduction, attributed to the effect of the increased air content, occurred despite a rather substantial reduction in the water requirement. However, the reduced compressive strength values for the high air content cement-lime mortars were still well above the values for the mortar mix and masonry cement mortars, and well above the minimum requirement for a Type N mortar.

Results of freeze-thaw cycling tests on cubes of these mortars are summarized in Table IV.

Resistance of mortars to freeze-thaw cycling can be rated as follows: 1) Cement-lime with high air content, 2) masonry cement, 3) masonry mortar mix, 4) normal cement lime. The cement-lime mortars with no air-entraining agents failed after an average of 74 and 119 cycles - the latter figure indicated slightly higher resistance for the American cement-lime mortar. However, the improvement over the local cement-lime mortar was not significant by comparison with the results for the other cubes. Two of the masonry mortar mix cubes failed at an average 303 cycles, while the surviving cube was in good condition with a weight loss of only 1.6 per cent. None of the masonry cement cubes had failed after 567 cycles - their average weight loss (2.1 per cent) was considered to be moderate and visual observation indicated it to be caused by loss of small pieces from corners and edges accompanied by a minor rounding of edges. The high air content cement-lime mortars survived freeze-thaw cycling in excellent condition: weight losses were negligible and visual observation failed to reveal any real deterioration.

Cubes surviving 567 cycles of freezing and thawing are shown in Figures 1 and 2. However, the 1: $2\frac{1}{4}$ masonry mortar mix cube is not included; instead the 1: 3 mortar mix: sand cubes A, H, and J are shown. Figure 2 illustrates the pattern of deterioration - the masonry mortar mix cubes gradually eroded away starting at the corners and edges. Failure occurred in these cubes when weight losses reached five per cent. There was some rounding of edges on the masonry cement cubes but weight losses were primarily the result of broken corners. Pictures indicated no change in the high air content cement-lime mortar cubes.

SUMMARY

Tests on three mortar combinations have indicated:

1) Masonry mortar mix mortar had a lower water retention than cement-lime and masonry cement mortars; the last two had comparable values.

2) Masonry cement mortar had lowest over-all absorption values.

3) Cement-lime mortar had best compressive strength values.

4) With one exception, masonry cement and masonry mortar mix mortars performed better than cement-lime mortar during freeze-thaw cycling tests.

5) The addition of an air-entraining agent to the cement-lime mortars raised their air content level from 7.0 to 18.6 per cent. The result was improved water retentivity, lower absorption and compressive strength values, and superior resistance to freeze-thaw cycling.

C) <u>1: 1: 6 Cement-Lime Mortars - Different Combination of Materials</u>

In the previous section two cement-lime mortars were used, one containing American cement and lime and the other local cement and lime. As a further check on these four materials, tests were done on two more mortar combinations, one containing American cement and local lime and the other local cement with American lime. Only air contents and compressive strength tests were conducted.

A summary of results, including values for the original two mortars is given in Table V.

RESULTS

The highest compressive strength value was obtained with the American cement and local lime, while the American cement and lime produced the second highest value, indicating that the American cement was slightly stronger than the local cement. However, the spread between the low and high values for the four combinations was only of the order of 13 per cent of the high value.

Both mortar combinations containing the American Type S hydrated lime had slightly higher air contents (approximately 1 per cent) than mortars containing the local hydrate.

On the basis of the minor differences in results, it would appear reasonable to suggest that the two cements and the two limes are comparable in quality insofar as their use in 1 : 1 : 6 cement-lime mortar is concerned. Water retention values in Table II indicate a superiority of the American Type S hydrated lime over the local lime, but mortars containing the latter adequately meet Specification requirements. There is certainly no evidence in the data in this study to justify the current proposal in ASTM Committee C12 to eliminate Type N hydrated lime (Canadian hydrated lime qualifies as Type N) from the Specification for Mortar for Unit Masonry (C270).

TABLE I

PROPERTIES OF 1 : 1 : 6 MASONRY MORTAR MIX MORTARS

Mortar Proportions	Water Used (ml)	Flow (%)	Air Content (%)	Water Retentiveness	Absorption (%) 1 hr.	Absorption (%) 24-hr. Immersion	28-Day Compressive Strength (psi)
1 : 3 Mortar Mix : Sand	225	120.3	18.6	64.7	2.2	10.0	702
1 : 3 Mortar Mix : Sand	238	135.9	19.6	64.5	1.9	10.6	600
1 : $2\frac{1}{4}$ Mortar Mix : Sand	258	121.6	15.3	71.7	2.0	11.3	1222

TABLE II

RESULTS OF FREEZE-THAW CYCLING TESTS ON MASONRY MORTAR MIX MORTAR CUBES

Mortar Proportions	Cube No.	Freeze-Thaw Cycles to Failure	Wt. Loss (percentage of original) After 567 Cycles	
1:3 mortar	A8	523		
mix: sand	A9	---	3.9	
120 % flow	A12	---	3.5	
	H6	490		Avg. 3.3
	H9	---	2.4	
	H12	---	3.4	
1:3 mortar	J6	---	2.8	
mix: sand	J9	---	3.6	Avg. 3.6
135% flow	J12	---	4.4	
1:2$\frac{1}{4}$ mortar	K6	---	1.6	Avg. 1.6
mix: sand	K9	336		
120% flow	K12	270		

TABLE III

PROPERTIES OF CONVENTIONAL CEMENT-LIME, MASONRY MORTAR MIX, AND MASONRY CEMENT MORTARS

No.	Mortar	Water Used (ml)	Flow (%)	Air Content (%)	Water Retentiveness	Absorption (%) 1 hr.	Absorption (%) 24-hr. Immersion	28-Day Compressive Strength (psi)
1.	1: $2\frac{1}{4}$ Mortar Mix: Sand	258	121.6	15.3	71.7	2.0	11.3	1222
2.	a) 1: 1: 6PC: L: S	260	120.5	7.6	82.3	3.3	10.3	2615
3.	b) 1: 1: 6PC: L: S	268	119.2	6.5	80.9	4.1	10.5	2501
4.	a)* 1: 1: 6PC: L: S	240	120.4	18.8	93.1	3.0	10.3	1461
5.	b)* 1: 1: 6PC: L: S	235	118.9	18.5	84.1	2.9	9.8	1787
6.	1: 3 Masonry Cement: Sand	207	121.0	24.1	82.3	2.3	8.6	865

a = American Portland cement and Type S hydrated lime
b = Local Portland cement and hydrated lime
* = air-entraining agent added

TABLE IV

RESULTS OF FREEZE-THAW CYCLING TESTS

Mortar Mix	Cube No.	Freeze-Thaw Cycles to Failure	Weight Loss (Percentage of Original) After 567 Cycles	
1:3 mortar mix sand	K6	---	1.6	
	K9	336		
	K12	270		
1:1:6PC:L:S a) 7.6%A/C	B8	164*		
	B9	139*		
	B12	53*		
a) 18.8%A/C	C8	---	0.3	
	C9	---	0.2	Average, 0.2
	C12	---	0	
b) 6.5%A/C	D8	80+		
	D9	71+		
	D12	71+		
b) 18.5%A/C	E8	---	0.0	
	E9	---	0.0	
	E12	---	0.0	
1:3MC:S	L6	---	1.4	
	L9	---	2.5	Average, 2.1
	L12	---	2.3	

a = American cement and Type S hydrated lime.
b = Local cement and hydrated lime.
* = Average cycles to failure, 119. Type of failure, surface spalling.
+ = Average cycles to failure, 74. Type of failure, surface spalling. These cubes literally exploded.

TABLE V

PROPERTIES OF FOUR 1:1:6 CEMENT-LIME MORTARS USING 2 CEMENTS AND 2 LIMES

Mortar Composition	Water Requirement (ml)	Flow (%)	Air Content (%)	28-Day Compressive Strength (psi)
U.S. Cement + lime	260	120.5	7.6	2615
Local Cement + lime	268	119.2	6.5	2501
U.S. Cement + local lime	265	119.3	6.6	2744
Local Cement + U.S. lime	263	120.0	7.3	2398

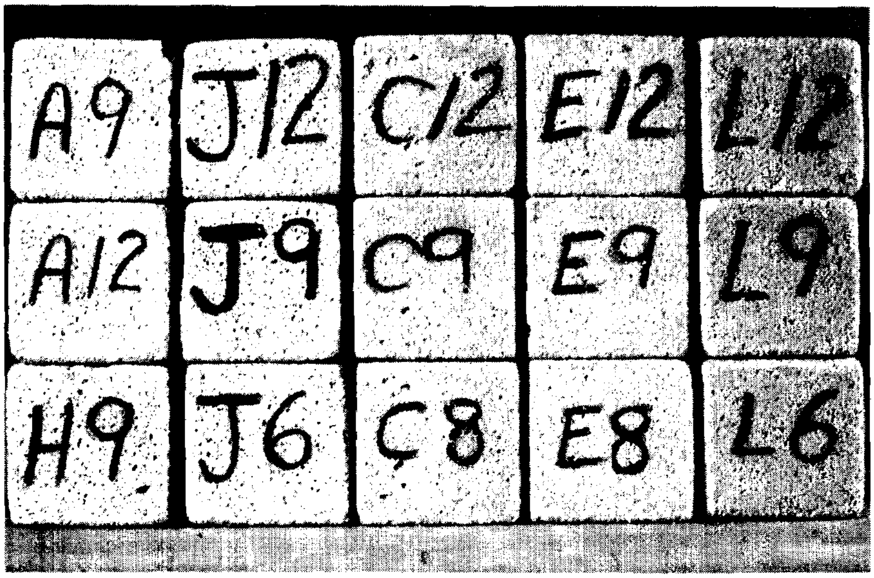

Figure 1 Top Surfaces of Mortar Cubes Surviving 567 Freeze-Thaw Cycles

A and H - 1: 3 masonry mortar mix: sand 120% flow
J - 1: 3 masonry mortar mix: sand 135% flow
C - 1: 1: 6 U.S. cement: U.S. lime: sand
E - 1: 1: 6 local cement: local lime
L - 1: 3 masonry cement: sand
Minor rounding of edges for A, H, J, and L cubes

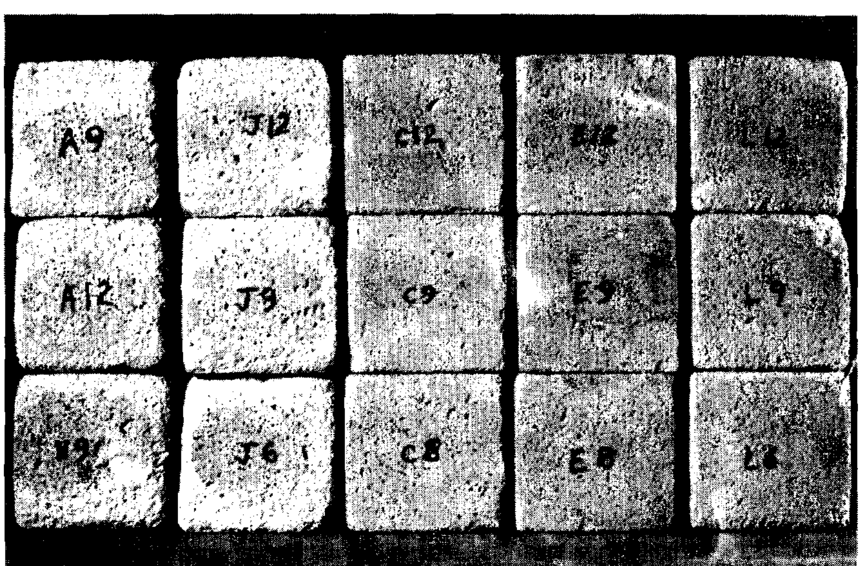

Figure 2 Bottom Surfaces - Same Mortars as in Figure 1
Note: Rounded edges and corners for A, H, and J cubes.
Minor rounding of edges and broken corners for L cubes.