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COLD WEATHER PROTECTION REQUIREMENTS FOR A LOW STRENGTH REPOINTING MORTAR

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ABSTRACT

This paper assesses whether the 28-day protection period for a low strength Portland cement/lime repointing mortar before exposure to freezing temperatures could be reduced. This requirement, by the Heritage Conservation Directorate at Public Works & Government Services Canada, was used for repointing mortars in the conservation of historic masonry.

The performance of the mortar was evaluated for frost durability in accelerated laboratory testing as well as some testing at an outdoor exposure site. The mortar was tested as part of small sandstone masonry prisms to more realistically simulate practice.

An interim recommendation is that the protection period can be reduced to 7 days. During the first three days, the mortar should be damp cured by using damp burlap covered with plastic at a masonry temperature above 10°C. This is followed by four additional days of protection from wind and precipitation with the masonry temperature above 0°C. Further tests to assess lower curing temperatures and possible longer protection periods against precipitation, and field experience with repointed mortar joints are needed before firmly adopting these recommendations. They should not be taken as a green light for construction in winter. Repointing of mortar joints during periods when freezing conditions may occur should be discouraged, but can be inevitable if projects run late or unusual weather conditions occur.

KEYWORDS: repointing, mortar, cold weather construction, freezing, curing.

INTRODUCTION

The main objective of the work described in this paper was to assess whether the 28-day protection period before repointing mortar is exposed to freezing temperatures could be reduced. This period was required by the Heritage Conservation Directorate at Public Works & Government Services Canada (HCD/PWGSC). The freeze-thaw performance of a low strength Portland cement/lime mortar specified by HCD for heritage stone masonry was evaluated. Test conditions were related to site conditions where possible. The mortar was tested as part of small stone masonry prisms to more realistically simulate practice (as opposed to mortar samples on their own).

TEST PROGRAM

Masonry prisms were constructed for testing in a freeze-thaw cabinet and at an outdoor exposure site in winter (both at the Institute for Research in Construction (IRC)). The control prisms, cured in a standard environment, were also built to assess mortar properties and flexural tensile bond. The prisms were built at two different times (phases 1 and 2).

Phase 1: Prisms were tested in a freeze-thaw cabinet, 5 and 41 days after construction in July 2001. Prisms were placed in four different curing environments before testing (meant to approximately simulate site conditions). Two control prisms were later moved to the outdoor exposure site as part of the phase 2 tests.

Phase 2: Prisms were tested in the freeze-thaw cabinet or moved to the outdoor exposure site, 5 to 6 days after construction in December 2001. Prisms were exposed to one curing environment before testing. A different mason built the prisms. Two prisms were also built with pointed mortar joints to replicate even more closely repointed mortar joints.

The masonry prisms consisted of 5 units stack bonded with 10 mm mortar joints. A template was used to provide a more consistent thickness for the mortar joints, and a jig ensured good vertical alignment (Figure 1). The prisms were made with new saw-cut St Canut sandstone (Table 1), a stone used as a replacement for the Nepean sandstone used in many Parliamentary buildings. The nominal size of the stones was 90 x 90 x 30 mm. Stones were lightly misted with water before constructing the prisms. The pointed prisms were built one day with full bed joints, which were then raked back 25 mm on one face; the following day the joints were pointed.

Table 1 – Properties of St Canut Stone

Bulk density (kg/m^3)	2527
Porosity based on bulk & absolute densities (%)	5.4
Water absorption by immersion (% by weight)	
24 hour	0.77
Vacuum saturation	1.75
Water absorption by capillary action	
Initial rate of absorption (kg/m^2/min)	0.078
Water absorption coefficient (kg/m^2/sec^{½})	0.0060

The mortar evaluated was a 1:2½:8 white Portland cement: hydrated lime (type SA): damp sand mortar mix by volume. The lime contains an integral air-entraining agent. As a check one mortar mix without air-entrainment was also made (using type S hydrated lime). A local masonry sand was used (Grandmaitre). The mortar water content was adjusted to give a Vicat cone reading in the range 20 to 30 mm (~55-80% flow). Repointing mortars have a lower initial water content than bedding mortars (flow range 35-80% compared to 100-150%).

Mortars were mixed in a mortar mill, which is a horizontal pan mixer with large wheels and scrapers that rotate around the pan compressing the mortar (but with a small space between the rollers and the pan so that the sand particles are not crushed). The mortar mill was designed for mixing mortars containing lime putty. The wheels break up any clumps of lime that may form. The mill is currently used by HCD on site for mortar mixes with high lime content.

Figure 1 – Mason Building Masonry Prisms (phase 1)

Curing conditions were meant to approximately simulate site conditions:

Phase 1 prisms tested in the freeze-thaw cabinet 5 days after construction.

- **A.** Prisms misted two times a day for three days while kept in air at 24°C and 60% relative humidity. Then in indoor air.
- **B.** Prisms kept damp for three days by covering with wet burlap and polyethylene (24°C). Then in indoor air.

Phase 1 prisms tested in freeze-thaw cabinet 41 days after construction.

- **C.** Prisms misted two times a day for three days while kept in air at 24°C and 60% relative humidity. Then moved to an environment simulating an unheated enclosure during late autumn with temperatures still above freezing (6-11^{o}C, relative humidity 75-80%).
- **D.** Prisms kept damp for three days by covering with wet burlap and polyethylene (24°C). Burlap then removed and polyethylene kept a further four days. Then in indoor air meant to simulate a heated enclosure during the winter (21-23^{o}C and relative humidity 50-85%). In practice the humidity is likely to be lower.

Phase 2 prisms tested in the freeze-thaw cabinet or moved to the exposure site 5 to 6 days after construction.

Curing conditions as in B above.

Control prisms

- **Ac.** Prisms misted two times a day for three days while kept in air at 24°C and 60% relative humidity. Then in air at 24°C and ~50% relative humidity.
- **Bc.** Prisms kept damp for three days by covering with wet burlap and polyethylene (24°C). Then in air at 24°C and ~50% relative humidity.

Mortar cubes

Mortar cubes were kept in their 50 mm moulds covered in plastic for three days and then taken out of the moulds and cured in air at 24°C and ~50% relative humidity.

Table 2 lists the measured properties of the mortar. The mortar cube strength at 28±1 days varied from 5.0 to 8.3 MPa for the air-entrained mortar with one exception, an unexpectedly high result of 13.8 MPa. The reason for this is unknown. The mortar without air entrainment had a strength of 9.0 MPa. The variability is quite high, but may be partly due to the higher water content in two of the mixes in phase 1.

Table 2 – Mortar Properties

Mortar mix details		Plastic mortar properties			Hardened mortar properties			
Mix number	Water/ binder ratio	Vicat cone[2] (mm)	Flow[2] (%)	Air[2] content (%)	Mortar cubes[4] Compressive strength (MPa)		Mortar joints[1] Bulk density (kg/m^3)	Porosity (%)
					27-29 d	225 d		
Phase 1								
1.1	0.75	21	65	11.6	6.4	-	-	-
1.2	0.83	28 (17)	77	15.5	5.2	-	-	-
1.3	0.79	31	88	17.3	5.0	-	1830	31
Phase 2								
2.1	0.76	26 (11)	63	7.8[3]	9.0	10.9	1920	28
2.2	0.76	28 (15)	68	13.8	13.8	15.3	-	-
2.3	0.76	26 (16)	65	16.2	8.3	9.4	-	-
2.4	0.76	27	72	13.2	7.3	8.2	1810	32

1. Based on an average of two to three mortar joint samples taken from control prisms cured at 24°C and ~50% relative humidity. Tested in accordance with a Dutch report on pointing mortars [1]. The porosity determined from the bulk density assuming an absolute density of 2650 kg/m^3.
2. Vicat cone in accordance with ASTM C780 [2]. Readings in brackets were taken at the end of prism construction (1.7 to 2.2 hours). Mix 1.1 was retempered after 1 hour to a Vicat value of 22 mm. Flow in accordance with ASTM C270 [3]. Air content measured with a small vacuum air meter.
3. Mix 2.1 did not contain an air-entraining agent.
4. Average of three cubes tested in accordance with CSA A179 [4] except for the curing conditions.

FREEZE-THAW TEST

The freeze-thaw test is a uni-directional test, where only one face of the masonry prisms is exposed during the test; the other faces are protected by insulation (Figure 2). This simulates conditions on the surface of exterior walls on buildings. The test is adapted from a Dutch standard [5, 6]. Water is sprayed onto the exposed face during the thaw phase, simulating rain for a period of 8 hours (10-20°C; temperature of the cold water line). During the freezing phase, lasting 16 hours, the air temperature drops to either –5°C or –20°C representing slow and fast freezing rates (alternates between cycles). This was repeated for 24 cycles (for a few prisms extended to 57 cycles). There were two changes from the normal test procedure used at IRC:

1. The 5-day-old masonry prisms were not pre-immersed in water before the start of the freeze-thaw cycling. This was done to simulate more closely construction practice where a protected wall would suddenly be exposed to rainy conditions before freezing. The 41-day-old prisms were subjected to a standard freeze-thaw test by immersing them in water for 7 days before the start of the freeze-thaw cycles (a more severe condition was adopted because of the good test performance of the 5-day-old prisms). Mortar in the prisms pre-immersed in water and surviving 24 cycles is expected to perform adequately on exterior vertical walls on buildings.
2. The exposed face of two 5-day-old prisms was covered with plastic to protect it from the water spray. This was meant to simulate masonry protected from direct moisture but exposed to freeze-thaw cycles.

After the test, the mortar was visually assessed for damage. The moisture content of some mortar joints was measured immediately before and after the test, as well as the flexural bond strength between the mortar and the stone (using a bond wrench). Tables 3 and 4 show the results.

Figure 2 – Freeze-Thaw Test During a Thaw Cycle

Table 3 – Results for Phase 1

Prisms tested and curing procedure		**Moisture content[1] (%)**	**Flexural bond (MPa)**	**Joints tested for bond**	**Age tested (days)**
5 day old prisms after 24 freeze-thaw cycles (mortar mix 1.2)					
A cure	4 prisms	-	0.54	16	35
	1 prism	10.0	0.27[2]	4	29
	1 prism	9.9[3]	0.38[2]	4	29
B cure	4 prisms	-	0.43	16	35
	1 prism	11.0	0.29[2]	4	29
41 day old prisms after 24 freeze-thaw cycles (mortar mix 1.1)					
C cure	4 prisms	-	0.42	16	81
	1 prism	10.7	0.37[2]	4	77
	1 prism	11.4[3]	0.22[2]	4	77
D cure	4 prisms	-	0.53	16	81
	1 prism	11.8	0.36[2]	4	77
Control prisms laboratory (mortar mix 1.3)					
Bc cure	1 prism	9.2	0.41[2]	4	5
Ac cure	4 prisms	-	0.70	15	35
Ac cure	1 prism	-	0.77	4	371
Bc cure	1 prism	-	0.67	4	371
Control prisms moved to exposure site (Dec 01-Jul 02)					
Ac cure	1 prism	-	0.85	4	371
Bc cure	1 prism	-	0.79	3	371

Notes to Table 3

1. Moisture content based on an average of four mortar joints from a single prism.
2. Bond strength from masonry prisms in a damp condition (damp prisms have lower bond strengths). The other prisms were tested in an air-dry condition.
3. Face of prism protected from direct wetting during thaw phase by a polyethylene cover.

Table 4 – Results for Phase 2

Prisms tested and mortar mix[1]	Moisture content[2] (%)	Observations after freeze-thaw test or exposure site	Flexural bond after freeze-thaw test		
			Flexural bond (MPa)	Joints tested	Age (days)
After 24 freeze-thaw cycles					
Mix 2.3, 1 prism	-	Mortar Ok. Loss of bond 1 joint.	0.18	3	38
1 prism	-	Mortar Ok.	0.11	4	38
Mix 2.4, 1 prism	-	Mortar Ok.	0.26	4	38
1 prism	10.9	Mortar Ok. Loss of bond 1 joint.	0.13[3]	3	38
Mix 2.1 (no air) 1 prism	12.6	Mortar Ok. Loss of bond in all joints.	0	4	38
1 prism	14.2	Minor surface damage to bottom two mortar joints. Loss of bond all joints.	0	4	38
After 57 freeze-thaw cycles					
Mix 2.3, 1 prism	-	Mortar Ok.	0.22	4	88
1 prism	11.0	Mortar Ok.	-	3	88
1 prism	-	Mortar Ok.	0.21	4	88
Mix 2.4, 1 prism	-	Mortar Ok.	0.17	4	88
Repointed, Mix 2.2 & 2.3, 1 prism	-	Minor damage observed to one mortar joint at 33rd cycle.	-		
1 prism	10.9	Minor damage observed to one mortar joint at 33 and 57 cycles.	-		
Exposure site (Dec 01 to Jul 02)					
Mix 2.1 (no air), 2 prisms	-	Mortar Ok. Two mortar joints without bond (handling?)	0.39	6	223
Mix 2.3, 4 prisms	-	Mortar Ok.	0.53	16	222
Control prisms					
Mix 2.4	5.0	-	0.14[3]	4	4
Mix 2.2, 5 prisms	-	Two mortar joints had lost bond before bond test (handling?).	0.18	18	39
4 prisms	-	1 joint without bond before test.	0.12	15	224

1. **B** or **Bc** curing procedure used for the prisms.
2. Moisture content by weight based on an average of four mortar joints taken from one prism except for repointed prism where three joints were used (one joint had been damaged).
3. Bond strength of masonry prisms tested in a damp condition.

No material damage was observed to mortar with air entrainment after 24 freeze-thaw cycles. Mortar without air entrainment had minor damage in one of two prisms (Table 4). The moisture content in this mortar (12.6 & 14.2%), measured immediately after the freeze-thaw test, was also higher than the air-entrained mortars, indicating a higher risk of damage.

Loss of bond after the freeze-thaw test was observed in phase 2. All the joints in the two masonry prisms with mortar without air entrainment had debonded. The loss was much less with the air-entrained mortar; only two joints out of sixteen had debonded. In phase 1 there was no loss of bond in the air-entrained mortars and the bond strength was also much higher.

The reason for the better bond strength is likely to be the method of construction because even the control prisms had poor bond in phase 2. The mason in phase 2 was different from phase 1. The mason in phase 1:

1. Compacted the mortar more while placing it into the mortar template. He also used a 0.5 kg plastic head mallet to tap stones into position (Figure 1), while the mason in phase 2 used the handle of his trowel.
2. Built the prisms faster.

One prism in each phase was tested at 4 to 5 days at the start of the freeze-thaw test to give an indication of moisture content and early bond strength development (Phase 1: moisture content 9.1%, bond 0.41 MPa; Phase 2: moisture content 5.0%, bond 0.14 MPa). The lower bond in phase 2 again reflects the lower bond obtained with the other prisms in phase 2. Note the bond strength of damp prisms is lower than dry prisms. With more results, the moisture content and bond strength could serve as an indication of the potential to resist freeze-thaw damage.

Six prisms were left in the freeze-thaw cabinet for 57 cycles (Table 4). Minor damage to the mortar was observed in the two prisms that had been repointed. The junction between the pointing and bedding mortar may inhibit moisture transfer, increasing the risk of damage.

There was not a significant difference in the freeze-thaw results (mortar damage and bond) due to the different curing methods, the difference in test age (5 versus 41 days), or the protection of two prisms from direct wetting during the thaw phase (Table 3).

Masonry prisms at the outdoor exposure site performed well. Thermocouples attached to two prisms showed that they were exposed to at least 34 freeze-thaw cycles[1]. The mortar survived without material damage and with only minor loss of bond. This is not surprising considering the good behaviour of the mortar in the freeze-thaw cabinet. Furthermore, the level of moisture in the mortar is very unlikely to have reached the level achieved in the freeze-thaw cabinet. One sample taken from the exposure site prisms had a moisture content of 8.4%. Mortar bond at the exposure site was better than in the control prisms kept in the laboratory (Phase 1: 0.79 & 0.85 MPa (exp.) vs 0.67 & 0.77 MPa (control) at 371 days; Phase 2: 0.53 MPa (exp.) vs 0.12 MPa (control) at 224 days). The mortar without air-entrainment had a lower strength than the air-entrained mortar (0.39 vs 0.53 MPa). Normally the opposite is true. The better results from the exposure site are an indication that the standard laboratory curing conditions used needs to be adjusted to better reflect outdoor curing conditions.

COLD WEATHER PROTECTION REQUIREMENTS

Construction delays may extend the conservation work to the end of November or early December. Therefore, freshly laid mortars may need protection from rain and frost. Current masonry standards have protection requirements for cold weather that are mainly aimed at

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[1] Thermocouples installed in January. Freeze-thaw cycles were based on hourly readings. One freeze-thaw cycle was assumed to occur when a negative temperature was followed by three consecutive positive temperatures. This approach was adopted to avoid as much as possible counting small oscillations about 0°C as freeze-thaw cycles.

modern masonry. HCD have additional requirements for low strength high lime mortars including extended protection periods, and temperature and humidity controls to avoid premature drying out of mortars due to heaters.

A review of cold weather construction research showed that the resistance of mortar to freeze-thaw damage is influenced by the strength development of the mortar, air-entrainment in the mortar, and, perhaps most important for new mortar, the water content of the mortar when freezing occurs. Fresh mortar has a high water content (11 to 16%), which is rapidly reduced when the mortar comes into contact with the masonry units (one measurement on fresh mortar in the present test program gave a water content of 13.5%; Vicat cone 22 mm). The initial reduction in water content is dependent on the suction characteristics of the masonry unit, and the water retention properties of the mortar. To avoid frost damage, modern recommendations say the moisture content of the mortar should be 6% or lower [7,8]. Korhonen et al [9,10], looking at type N to M mortars, recommended a value of 8% that could be increased to 10% with air-entrained mortars. Only one freeze-thaw cycle was used in the study. Performance under extended freeze-thaw cycles is needed to confirm the results. The results from the present tests show that the mortar with air entrainment had no freeze-thaw damage with moisture contents in the range 9.9 to 11.8% measured immediately after the test. Davison [11] found good results were possible with walls built in winter conditions provided no frozen materials or materials with ice were used in construction, and uncompleted masonry was protected by an adequate waterproofing material.

Codes and standards address cold weather requirements in a variety of ways. In Canada and USA, cold weather requirements apply when the air temperature drops below 4°C. Masonry units must be dry and not covered in snow. In USA, their temperature should not be less than -7°C [12]. Mortar temperature should be in the range of 5 to 49ºC (generally achieved by heating of sand and/or mixing water). Korhonen et al [9, 10] found high mortar temperatures were not necessary because 40°C mortar does not stay above freezing appreciably longer than 5°C mortar, and recommended a range of 5 to 20°C. They also recommended masonry units should be warmed to at least 5°C. This is more critical for low suction masonry units [7]. The degree of protection needed after placement of the mortar depends on the air temperature. Canadian [13] and US [12] specifications adopt a similar approach. The Canadian one is slightly more conservative. It also refers specifically to a type O mortar, a 1:2:9 Portland cement:lime:sand mix similar to the one used in this paper. After construction is finished, 3 days protection is required for such a mortar. The protection depends on the air temperature. When the temperature is in the range of 0 to 4ºC, the masonry should be protected from rain and snow, and for 0 to -4ºC, the masonry is to be completely covered; for -4 to -7ºC, the masonry is to be completely covered with insulating blankets, and below -7°C, the masonry is to be maintained at a temperature above 0°C by using an enclosure with supplementary heat. These approaches reduce the risk of damage by freezing, although there may still be a problem with long term strength if the mortar dries out and further hydration of the hydraulic binder is stopped. Later wetting will restart the hydration. In sheltered locations rewetting may be needed after the winter. An initial damp curing period will act as a safety net.

CONCLUSIONS

The tests in the present report show that a 1:2½:8 mortar protected for a period of 4 to 6 days at temperatures of 20-24°C can perform well during subsequent freeze/thaw cycles. Mortar with air entrainment survived up to 57 freeze-thaw cycles except for two pointed prisms where minor damage occurred. In the two masonry prisms without air entrainment, there was loss of bond in all mortar joints, and minor mortar damage to two joints after 24 cycles. Therefore, one recommendation is that 1:2½:8 mortars have air entrainment when used in winter conditions (10-16% air in fresh mortar). This will also improve its long-term freeze-thaw resistance. The HCD recommended 28-day protection period against freezing can be reduced. An interim recommendation is that this period can be reduced to 7 days for a 1:2½:8 air-entrained mortar in combination with St Canut stone. This protection period may also be appropriate for similar mixes with air-entrainment and other types of stone. During the first three days, the mortar should be damp cured by use of damp burlap covered with plastic at a mortar temperature above 10°C (this will ensure some initial strength for the mortar). This is followed by a further 4 days protection from wind and precipitation at a mortar temperature above 0°C. Max/min thermometers and a relative humidity gauge should be used to ensure conditions are complied with. These recommendations are still more conservative than those adopted by the Canadian masonry construction standard.

Further tests to assess lower curing temperatures and possible longer protection periods against precipitation, and field experience with repointed mortar joints are needed before firmly adopting the requirements. These recommendations should not be taken as a green light for construction in winter. Pointing with lower strength mortars during periods when freezing may occur should be discouraged, but may sometimes be inevitable.

Factors requiring further investigation include moisture content, construction procedures, pointing of mortar joints, and tests with different masonry units especially more absorbent ones. There is a need to relate moisture content likely to be achieved in actual buildings with the water content achieved in the freeze-thaw tests. Construction procedures also need to be more carefully reviewed since they also influence durability. Good compaction of the mortar into the masonry joint will ensure a better bond between the mortar and stone. Good compaction may also avoid the minor damage observed in the mortar of two masonry prisms with raked joints that had been repointed. Such damage was not observed in the prisms with full mortar bedding. This also shows the usefulness of testing the mortar as it is used in practice as opposed to mortar samples on their own.

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REFERENCES

1. SBR/CUR. De kwaliteit van voegen in metselwerk (The quality of pointing mortars in masonry). Report SBR299/CUR98-3, 2nd edition. Appendix F. Stichting Bouwresearch, the Netherlands. 1998.
2. ASTM C780-02. Test method for preconstruction and construction evaluation of mortars for plain and reinforced unit masonry. American Society for Testing and Materials.
3. ASTM C270-04. Specification for mortar for unit masonry. American Society for Testing and Materials.
4. CSA A179-94. Mortar and grout for unit masonry. Canadian Standards Association.
5. RILEM. Unidirectional freeze-thaw test for masonry units and wallettes. Draft recommendation MS.A.3. Materials and Structures. Vol 31, Oct 1998. pp 513-521
6. NEN 2872. Testing of stone like materials – Determination of frost resistance (unidirectional freezing in a fresh water environment). Netherlands Standards Institute. 1989.
7. Sneck, T. Winter masonry construction. Proceedings 1st Canadian Masonry Symposium. 1976. pp 238-246
8. Portland Cement Association. Cold weather masonry construction. Masonry Information. IS248.02. 2003. 4 p
9. Korhonen, C.J., Cortez, E.R., and Thomas, R.D. Minimum thermal protection for cold weather masonry. Proceedings of the International Conference on Cold Regions Engineering. Fairbanks, Alaska. 1996. pp 128-140
10. Korhonen, C.J., Thomas, R.D., and Cortez, E.R. Increasing cold-weather masonry construction productivity. Cold Regions Research & Engineering Laboratory, US Army Corps of Engineers. 1997. 53 p
11. Davison, J.I. Cold weather masonry construction. CBD 123. National Research Council, Institute for Research in Construction. 1970.
12. ACI 530.1/ASCE 6/TMS 602. Specification for masonry structures. 2002.
13. CSA A371-04. Masonry construction for buildings. Canadian Standards Association. 2004