OVERVIEW OF MORTARS FOR CANADIAN HISTORIC STRUCTURES

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ABSTRACT

Mortar for historic structures must comply with good conservation principles and be compatible with the historic fabric as far as feasible; it must also be appropriate for the material to be bonded and its service conditions. Good conservation principles dictate that mortar be not too strong and be the sacrificial material rather than the masonry unit.

In Canada, three types of mortar are currently being used for historic masonry projects; these types are lime mortars, hydraulic lime mortars, and Portland cement/masonry cement - lime based mortars.

These types of mortar can differ significantly in their properties in both the plastic and hardened states with perhaps the greatest differences pertaining to compressive strength, flexibility, water and vapour transmission rate, and frost durability. The paper provides an overview of the three types of mortar to help the conservation specialist in the selection of the most appropriate mortar mix for a historic masonry project.

KEYWORDS

Mortars, historic structures, lime, hydraulic lime, cement.

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INTRODUCTION

Until the late 1800's lime/sand mortars were used extensively in Canada, the U.S.A., and elsewhere in the world. These mortars exhibit good workability and high water retentivity in the plastic state and develop compressive strength slowly through a process called carbonation; the hardening process of carbonation takes place as the calcium hydroxide of the lime reacts with carbon dioxide in the air to form calcium carbonate. In many Canadian locations, limes for mortar in the same time period were sought where the lime had some hydraulic characteristics; depending on the degree of hydraulicity of the limes, resultant hydraulic lime mortars could gain compressive strength much more rapidly than lime/sand mortars and provide final strengths comparable to some cement based mortars. Once Portland cement became readily available in Canada and elsewhere in the world in the late 1800's and early 1900's, more and more mortar mixes employed the faster setting cement as a partial lime replacement. Portland cement in the presence of water hardens relatively rapidly by a process called hydration. Proprietary masonry cements came on the market in Canada and the U.S.A. in the late 1920's to simplify job-site mixing operations and to more closely control strength variations. The compressive strengths of both Portland cement and masonry cement based mortars are too high and resultant deformabilities too low for historic masonry structures; these properties can be improved by the addition of lime. What also improves with the presence of lime is the water and vapour transmission rate of the mortar; a reasonably high rate is often desirable to permit moisture entrapped in the masonry to escape through the joints without causing potential frost or salt crystallization damage.

The conservation of historic masonry typically requires mortar types N and O, with some specialized use of type K; note that when using mortar proportions by volume and typical North American practice of Portland cement/lime/sand mixes, types N, O and K would correspond to 1/1/6, 1/2/9, and 1/3/12, respectively. While CSA Standard A179-94, “Mortar and Grout for Unit Masonry”, (Canadian Standards Association, 1994) allows these types to be specified on the basis of either Proportion Specifications (proportions by volume) or Property Specifications (compressive strength of mortar cubes), this Standard is written largely for modern masonry and hence should be complemented with specialized clauses in any specifications dealing with historic masonry projects. There are several reasons why CSA A179 in itself does not suffice:

1. Types O and K are not dealt with in the mandatory part of the Standard and hence have no proper legal standing as part of contract documents unless specialized clauses address them.

2. Mortar for historic masonry is normally batched by volume. Following the Proportion Specifications of CSA A179 typically produces compressive strengths two to three times higher than the minimum strengths of the Property Specifications (Beall, 1997). Such high strengths are inappropriate for historic masonry because they limit deformability and could cause damage to the units. Moreover, increased compressive strength does not ensure proper bond and satisfactory durability. For compatibility between mortar and unit as well as for long term satisfactory performance, mortar for historic masonry requires specialized considerations.

3. The CSA Standard basically deals with bedding mortars for a range of standard units without any specialized clauses for bedding mortars for relatively non-absorptive stone units as well as for pointing mortars; the latter two mortars are key mortar mixes for many historic masonry projects. Note for instance, that the strength of laboratory prepared bedding mortars in the CSA Standard is based on a flow of 110 to 115% while the flow of bedding mortars for historic stone masonry is often less than 50 % and pointing mortars often exhibit no flow.

Further comments about the three types of mortar for Canadian historic projects, namely lime mortars, hydraulic lime mortars, and Portland cement/masonry cement-lime mortars, follow.

LIME MORTARS

Lime/sand mortar has been in use for several thousand years. Mortars containing lime must be exposed to air to permit carbonation by carbon dioxide but must not be exposed to drenching rain until the joint surface has "skinned" or hardened. Too rapid drying means that carbonation will not occur properly with the material losing bond with aggregate and reduction in joint plasticity; too slow and the surface of the joint may never set properly. Water placed on the joint too early will cause lime to be sucked out of the joint by capillary action and lime streaks to stain the face of the wall. Difficult to mix and slow to cure, lime/sand mixes may be superior in longevity (although weaker) than other formulations "gauged" with Portland cement or hydraulic lime. Thin elements, such as tracery, may carbonate far more rapidly than more massive elements such as thick walls. Their initial softness, slow rate of set, and the need for careful mixing can be liabilities. These are, however, compensated by the benefits of this proven system. The flexible joint permits a range of structural movement. Carbonation re-heals cracks as does the dissolving of lime and re-deposition in acidic rainwater to maintain joint integrity. Lime mortar, more porous than most building stones and gauged mortars, acts as a wick to draw moisture from masonry (resulting in drier walls and reduced spalling), and disinfects embedded wood elements.

Lime/sand mortars are most appropriate for the restoration of historic structures where imposed loads are already supported or can be supported for a sufficient length of time to permit the mortar to develop adequate strength from both a loading and durability point of view.

HYDRAULIC LIME MORTARS

Hydraulic limes, that is limes that achieve hydraulic set in the presence of water, are obtained from burning limestones that contain clay impurities. The reactive aluminates and silicates in the clay combine with the lime to give the hydraulic properties. The speed of set relates directly to the amount of clay in the limestone. Early specifications and examples of mortars on sites suggest that historically limes for mortar were used where the lime had some hydraulic properties. The limes varied from those giving a very slow set which could be slaked to form a putty, to those giving a very rapid set and which would not slake at all. The hydraulic limes were described as “feebly”, “moderately”, and “eminently” hydraulic where the percentage of active impurities directly related to the speed of set. This classification of limes according to their hydraulicity was introduced by Louis Vicat in the nineteenth century and is still the basis for defining the characteristics of hydraulic limes today (CEN 459-1, 2000).

A full range of hydraulic limes are once again available in Canada and offer a viable alternative to non-hydraulic lime and cement/lime based mortars, particularly for conservation work. Their hydraulic characteristics must not be confused with Portland cement. They typically retain good water vapour permeability and the ability to accommodate movement and are slower to cure. Moderately hydraulic limes have been used on a number of major conservation projects in Canada over the past five years, and typically have performed satisfactorily to date. With experience, hydraulic lime mixes can be “fine tuned” with the addition of pozzolanic additives and/or porous particulate as part of the aggregate content so that their use can be extended to more vulnerable areas of a building and masonry of differing characteristics. At the present time their use is restricted to a limited number of specialists and practitioners working in the conservation field, but if the trend that has occurred in Europe is repeated here, then their use will grow with application in the new construction market.

CEMENT/LIME MORTARS

Portland Cement/Lime Mortars

Pure Portland cement/sand mortars display harsh workability, inadequate water retentivity, an undesirably low water and vapour transmission rate, too much compressive strength, and too little deformability; their use should be avoided for historic masonry. In Portland cement/lime mortars, the lime contributes to the mortar’s workability and retentivity while the Portland cement controls the mortar’s strength gain and final compressive strength. The interaction between the two binders - Portland cement and lime - means the greater the proportion of Portland cement in a mix the greater the compressive strength but the worse the workability and water retentivity, and conversely, the greater the proportion of lime in a mix the lower the compressive strength but the better the workability and water retentivity. For a project’s particular masonry units, a good Portland cement/lime mix design must ensure just the right proportions between the two binders, sand aggregate and water to achieve satisfactory compatibility with the masonry units. Compatibility between units and mortar is vital for ease of construction (a harsher mortar will not work well with a fairly absorptive unit), proper bond, and long term durability. Since unit properties vary widely - from low strength (soft), highly absorptive clay bricks to high strength, relatively non-absorptive granites - proper compatibility is not a given but must be carefully defined for each project. Mortars for historic masonry should be weaker and more porous than the units they are binding.

Masonry Cement / Lime Mortars

Today's masonry cements typically contain a complex variety of materials including Portland cement and / or hydraulic cement, plasticizers (possibly including hydrated lime), and air entraining agents. Although masonry cements are manufactured to CSA Standard A8, specific ingredients vary between manufacturers and also for a given manufacturer. In specifying masonry cement mortars, care should therefore be exercised in ensuring that a particular masonry cement has a proven performance record under the climatic conditions of the heritage masonry project. A masonry cement mortar's compressive strength is typically too high and its deformability too low for historic masonry assemblies; these properties, as well as the water and vapour transmission rate, can be improved by the addition of lime in a somewhat analogous fashion as for Portland cement mortars.

DURABILITY

Durability is a prime requirement of any mortar. While new mortar should match existing mortar as closely as possible, there are many instances where the repeated failure of old mortar calls for an improved mix which, however, must still ensure that the mortar is the sacrificial material in the masonry rather than the masonry unit. Under the typically harsh Canadian climatic conditions frost resistance is vital. For satisfactory freeze-thaw performance of Portland cement/lime and masonry cement/lime mortars, present knowledge indicates that mortars should contain about 8 to 15% air. While some practitioners may not agree with this range of air contents, it is generally recognized that the air must be intentionally entrained air which produces millions of extremely small voids uniformly distributed throughout the mortar; expansive forces from freezing moisture within the mortar can then be accommodated by the voids without damage to the mortar. For Portland cement/lime mortars a range of 8 to 15% can be achieved by using type SA lime or type S lime with an air entraining agent; in the latter case, air entraining agent can be added in proportions of up to about 0.08% of total binder weight (Portland cement and lime). The agent should be pre-mixed with a small portion of the mix water that is then added to the mix. For masonry cement/lime mortars, 8 to 15% of air is typically achieved by the air entrainer included in the masonry cement. Only type S lime should be combined with masonry cement as the type SA lime's air entrainer may not be compatible with the masonry cement's air entrainer. Some masonry cements can produce higher air contents than desirable especially from a bond point of view (bond is reduced by too much air present at the mortar-unit interface). This has led to the recent introduction of "mortar cements" which essentially are more tightly controlled masonry cements. Although mortar cements are not yet widely available and widely used in Canada, mortar cement/lime mortars would likely perform as well as masonry cement/lime mortars under Canadian climatic conditions.

The performance of hydraulic lime mortars used on major Canadian heritage structures over the past five years is being monitored on some projects. Observations to date indicate satisfactory performance.

TESTING

Testing programs for Portland cement/lime and masonry cement/lime mortars used in traditional masonry assemblies have shown that mechanical properties and durability are greatly affected by changes of parameters such as: sand gradation within CSA standards, flow, mixing method, combination of various brands of lime and air entraining agents, moisture content of sand and binder/aggregate ratio. Variation can be quite considerable; up to two to three hundred percent variations have been observed when testing the compressive strength of mortar prepared based on the same mix design with variable site parameters as listed above. Further, mortars should be designed for specific masonry units. Bond strength is particularly sensitive to variations of any parameters. The balance between the level of moisture at the surface of the masonry unit and the moisture content of the mortar is especially difficult to determine. Consequently, common practice now recommends that preconstruction testing and construction testing be carried out for all substantial masonry conservation projects to define all key parameters and ensure quality of repair work. The additional cost of testing would be largely offset by the savings generated by the extended life cycle of the masonry assembly. General guidance for testing is contained in Appendix B of CSA A179-94 “Mortar and Grout for Unit Masonry” and in APT publications (Fontaine et al, 1998, Suter et al, 1998, and Thomson et al, 1998).

For small projects, a minimal test program must check that the air content in the plastic state is in the right range for frost durability and that the compressive strength is not too low, too high, or too variable (too high a strength reduces deformability). For larger projects, a minimal test program additionally would require Vicat cone measurements for control of workability and bond tests to ensure the bond between mortar and unit exceeds a minimum acceptable level. To measure air content, an air meter made by Technical Innovations, Cleveland, Ohio, is useful; the instrument uses a small quantity of mortar (a concrete air meter can also be used but would require a much larger mortar quantity) and works reliably except for very low flow mortars. While flow of mortar is another desirable quantity to determine as part of a test program, a flow table can only be readily used in the laboratory; instead, as an indicator of flow and hence workability, a Vicat cone instrument (top diameter 40mm, height 86mm, weight 180g) has proven useful both in the laboratory and in the field. Recent studies indicate that there exists a reasonable correlation between Vicat cone penetration measurements and flow. For a range of Portland cement/lime pointing mortars, the studies show that flow in percent is approximately equivalent to the Vicat cone penetration measurement in mm multiplied by 0.4, i.e. 60% flow ≈ 24mm Vicat cone penetration (Maurenbrecher, 1998).

CONCLUDING REMARKS

The three types of mortar dealt with in this paper, namely lime mortar, hydraulic lime mortar, and cement/lime mortar, provide a wide range of workability, strength and flexibility as indicated in Fig.1. It can be seen that all three types cover at least portions of the type O mortar which is widely used in the conservation of historic structures. Note that as shown on the left margin of Fig.1, in the selection of an appropriate repair mortar the conservation specialist must also take into account the exposure conditions of the historic fabric of a particular project. While for relatively severe exposure conditions cement / lime mortars towards the type N range are likely best, all three mortars merit consideration for more standard and benign exposure conditions.

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Figure 1 Mortar selection chart for historic masonry structures.