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Understanding Mortar

It is critical to appreciate mortar's properties and how the ingredients in mortar affect performance

Before specifying mortar for a project or using it in the field, it is important to understand why the performance of mortar is vital to the successful performance of masonry and how the ingredients in mortar affect its performance. Mortar is the material that binds together masonry units and binds joint reinforcement and connectors to the masonry units. Mortar also is used as a spacer between masonry units and as a means of leveling and plumbing the units.

More importantly, mortar plays a crucial role in the resistance of masonry to water penetration. In a typical clay masonry wall (or in a water-repellent-treated concrete masonry wall), water does not significantly permeate the masonry units or the mortar itself. However, water may penetrate the interface between mortar and masonry unit if the bond between the two materials is deficient.

Finally, mortar affects the appearance of the masonry assembly. Both the color of the mortar and the method of finishing (tooling) the joints affect the visual impression that masonry makes.

Mortar properties

Three important properties of mortar are workability, bond, and compressive strength.

Workability. Workability is perhaps the most important property of plastic (fresh and not yet hardened) mortar. Workability is the ease with which the mortar moves under the trowel. In fresh mortar, workability is achieved when the aggregate particles move like ball bearings, lubricated by the surrounding cement paste and by other plasticizing ingredients, such as hydrated lime or entrained air. Some indications of workability are:

- The mortar spreads easily with the trowel.
- The mortar supports the weight of the masonry units.
- The mortar adheres to masonry surfaces (is sticky).
- The mortar extrudes readily from the joint when the mason applies pressure to the unit.

In the field, the mason measures workability by the response of the mortar to the trowel. In the laboratory, we measure workability with standardized tests of water retentivity, flow, consistency, plasticity, cohesion (ability to stick together), and adhesion (ability to stick to other materials). Factors that affect mortar workability include air content, lime content, sizes and shapes of sand particles, and amount of water.

Water-retentivity is the ability of the mortar to resist rapid loss of mixing water to air and to absorptive masonry units. If mortar does not have good water-retentivity, it stiffens quickly, making it very difficult to obtain water-resistant mortar joints in the masonry assembly.

Bond. Bond is an important property of hardened mortar. Two facets of bond critical to a masonry assembly's performance are extent-of-bond and bond strength (known to structural engineers *as flexural tensile strength*).

Extent-of-bond is a measure of the actual contact area at the interface of the mortar and masonry unit. Good extent-of-bond exists when the mortar-to-unit contact is complete and intimate. Good extent-of- bond prevents water penetration through the masonry assembly and is achieved when the mortar is workable and water-retentive, the masonry units have a medium initial rate of absorption (IRA), and the workmanship is good, with completely filled mortar joints. Extent-of-bond can be measured directly by a microscopic examination of the cross section per ASTM C 1324 (Ref. 1) or indirectly by a water penetration test in accordance with ASTM E 514 (Ref. 2).

Bond strength is a measure of the tensile stress required to break the bond between mortar and masonry unit (that is, to create a crack at the interface). Factors that affect bond strength include: mortar composition, especially cement content and air content; masonry unit properties such as surface texture, initial rate of absorption, and moisture content; quality of workmanship; and conditions of curing.

Using bond-wrench equipment in accordance with ASTM C 1072 (Ref. 3) or using the procedures of ASTM C 952 (Ref. 4) the laboratory can measure bond strength.

Compressive strength. By reading most project specifications and seeing the emphasis placed on this property by architects and engineers, one would think that compressive strength is the single most important mortar property. In fact, it is not as important to the performance of the masonry assembly as workability and bond. Architects and engineers single out compressive strength as a selection criterion largely because it is easily measured. Compressive strength is increased with more cement in the mix but is decreased with higher ratios of water to cementitious materials and higher ratios of sand to cementitious materials.

Mortar's compressive strength has significantly less influence on the compressive strength of the masonry assembly than does the compressive strength of the masonry units. For example, the compressive strength of Type S mortar is 140% greater than that of Type N mortar, but Type S mortar increases the strength of the masonry assembly by only about 20%. However, when the compressive strength of the masonry units is increased 50%, the compressive strength of the masonry assembly increases by about 40%.*

Mortar materials

Mortar is a combination of water, aggregate, and cementitious materials. Each ingredient serves an important purpose in the mortar mix.

Water. Water facilitates mixing of the aggregate and cementitious materials. Sufficient water is essential for hydration, the chemical process that gives mortar its strength. Additional water, above and beyond the amount needed to hydrate the cement, is also needed for workability, for absorption by the masonry units, and to account for evaporation. Potable water should be used in mortar because water that is safe to drink generally does not have contaminants that may adversely affect mortar properties.

Aggregate. Aggregate is the granular material, usually sand, that is used in the mortar mix to reduce the required proportion of cementitious materials and to resist shrinkage of the cement. For workability

*Based on tabulated values of compressive strength of masonry in the Masonry Standard Joint Committee's *Specification for Masonry Structures* (Ref. 12).

Mortar should always be of lower compressive strength than the masonry units that make up the masonry assembly.

and strength, each particle of aggregate must be coated with a matrix (combination) of cementitious material and water. If sand particles of uniform size (large or small) are used in the mortar, the total volume of voids between sand particles is greater and more of the cementitious matrix is required in the mix than if sand particles of varying sizes are used.

Well-graded sand, containing particles of varying sizes, is desirable because the required proportion of matrix to aggregate is decreased and the total volume of water used in the mix is decreased. Lower proportions of cement and water result in reduced shrinkage of the mortar. Less shrinkage means a lesser tendency for the mortar to crack.

Particle sizes and gradations of masonry sand are specified by ASTM C 144 (Ref. 5). Sand not complying with these grading requirements can still meet the requirements of that standard, however, provided that it can be used to produce a mortar that complies with the property specification of ASTM C 270 (Ref. 6).

Cementitious materials. Cementitious materials have adhesive and cohesive properties both when in a plastic state and when hardened. Mortar includes one of three categories of cementitious materials: portland cement (sometimes combined with other hydraulic cements) and lime, masonry cement, or mortar cement.

Portland cement, which is governed by ASTM C 150 (Ref. 7), is a hydraulic cement (it can harden even when under water) that is produced by pulverizing clinker. Portland cement is used in mortar to increase compressive strength, bond strength, and durability. However, a mortar containing portland cement as the only cementitious material lacks plasticity, has low water-retentivity, and is harsh (less workable).

Lime is used in conjunction with portland cement in a mortar mix. The form of lime may be hydrated lime, governed by ASTM C 207 (Ref. 8), or may be quicklime mixed with water per ASTM C 5 (Ref. 9). The advantages of combining lime with portland cement in mortar include increased workability and water retentivity, and the ability to deform slowly in the hardened state, thereby accommodating some structural movement.

A mortar with good workability extrudes readily from the joint when the mason applies pressure to the unit.

Masonry cement is a proprietary prepackaged blend of portland cement or blended hydraulic cement with plasticizing materials (such as hydrated lime or pulverized limestone) and other ingredients. The standard that governs masonry cement, ASTM C 91 (Ref. 10), does not place limitations on what materials may be used to manufacture a masonry cement. The standard does, however, state physical requirements for the cement, such as fineness, compressive strength, air content, and water retention.

Masonry cements include an air-entraining additive that gives the mix excellent workability. Because of this entrained air, however, masonry cement mortars may have lower bond strengths than non-air-entrained portland cement/lime mortars. According to most building codes, allowable flexural tensile stress (bond strength) values for unreinforced masonry with masonry cement mortar or air-entrained portland cement/lime mortar are 40% to 50% less than when the masonry uses non-air-entrained portland cement/lime mortar.

Although there is research evidence to support the building code reduction in allowable flexural tensile strength of masonry with masonry cement mortar, the evidence is not clear relative to the extent of bond. While some researchers report reduced extent of bond and increased water penetration in masonry constructed with masonry cement mortar, other researchers report no difference in the water resistance of masonry with masonry cement mortar compared to that of masonry with non-air-entrained portland cement/lime mortar.

Mortar cement is similar to masonry cement in that it is also a proprietary prepackaged blend of materials intended to be mixed with sand and water to produce mortar. However, unlike masonry cement, the governing standard for mortar cement, ASTM C 1329 (Ref. 11), includes a minimum bond-strength requirement in addition to requirements for fineness, time of setting, autoclave expansion, compressive strength, air content, and water retention. The intent of the standard's bond-strength requirement is to produce a mortar that is equivalent in bond strength to the same type of portland cement/lime mortar.

Like masonry cement, mortar cement includes an air-entraining additive to give the mix workability. However, the ASTM standard for mortar cement limits its entrained air to a lower volume percentage than is permitted for masonry cement. The ASTM standard for mortar cement was first published in 1996. Many design professionals are unfamiliar with this mortar, and it is not often specified.

Mortar mixes

Mortar is specified by one of two methods: by proportion or by property. It is inappropriate to combine requirements from the two methods of specifying mortar. A proportion specification dictates the relative quantities of each ingredient to be included in the *field-prepared mortar mix.* The proportion specification is the default method given by ASTM C 270. A property specification, on the other hand, dictates minimum or maximum values for certain physical properties of a *laboratory-prepared mortar mix.* The physical properties addressed by ASTM C 270 are minimum compressive strength, minimum water retention, and maximum air content.

Other properties, such as flexural tensile (bond) strength, may be specified by the project architect/engineer if considered important to the successful performance of the masonry but are not included in ASTM C 270. Property requirements in addition to those included in the ASTM standard are seldom specified.

Mortar mixes are designated as Type M, S, N, or O. These are listed in order of highest to lowest compressive strength and also in order of lowest to highest workability. Because no single mortar type is ideal, mortar type should be specified based on the best mix for the project and not simply based on high compressive strength. Mortar should always be of lower compressive strength than the masonry units that make up the masonry assembly.

Within each mortar type, any of the three categories of cementitious materials (portland cement/lime, masonry cement, or mortar cement) may be used unless restricted by the project documents. For mortar specified by proportion, the relative volumes of the ingredients are given in Table 1 for portland cement/lime mortar, and Table 2 for masonry cement mortar and mortar cement mortar.

The mortar mix need not adhere to the material proportions exactly as shown because the standard for mortar gives a range for these proportions. For example, Type N portland cement/lime mortar is shown (in Table 1) to consist of 1 part portland cement, 1 part lime, and 6 parts sand. In fact, for each part of portland cement, between 0.5 part and 1.25 parts of lime can be used and between 3.38 and 6.75 parts of sand can be used (2.25 to 3 times the combined volume of cement and lime).

Table 3 gives the minimum and maximum properties for mortars specified by the property method. These properties are evaluated on a laboratory-prepared mix of mortar. The laboratory mortar mix differs from the field mortar mix in that the amount of water that is added to

TABLE 1: PORTLAND CEMENT / LIME MORTAR BY PROPORTION SPECIFICATION

MORTAR TYPE	PORTLAND CEMENT	LIME	SAND
M	1	1/4	3 3/4
S	1	1/2	4 1/2
N	1	1	6
O	1	2	9

TABLE 2: MASONRY CEMENT AND MORTAR CEMENT BY PROPORTION SPECIFICATION

MORTAR TYPE	MASONRY CEMENT TYPE OR MORTAR CEMENT TYPE	PORTLAND CEMENT OR BLENDED CEMENT	SAND
M	1		3
or			
M	1	1	6
S	1		3
or			
S	1	1/2	4 1/2
N	1		3
O	1		3

TABLE 3: MORTAR BY PROPERTY SPECIFICATION†				
MORTAR TYPE	MIN. 28-DAY COMPRESSIVE STRENGTH, PSI	MIN. WATER RETENTION %	MAX. AIR CONTENT %	
			Masonry Cement	Mortar Cement or PC/L
M	2500	75	18	12
S	1800	75	18	12
N	750	75	20*	14**
O	350	75	20*	14**

† Based on ASTM C 270
*Maximum air content when structural reinforcement is incorporated into masonry cement mortar shall be 18%.
**Maximum air content when structural reinforcement is incorporated into mortar cement mortar or portland cement/lime mortar shall be 12%.

the laboratory mix is limited and is based on a standardized measurement of flow.

In the field, the mortar standard does not limit the amount of water that a mason can add to the mix. This is a significant difference from concrete construction. Water in mortar is not limited in the field because some of the mixing water will be absorbed by the masonry units and some will be lost to evaporation. The mason is able to judge the correct amount of water to add to the mix based on the type of masonry unit and ambient conditions.

Water content in mortar is self-regulating: If too much water is added, the masonry units will float on the mortar, and the mason will not be able to lay them; if too little water is added, the mortar mix will be unworkable, the mason will not be able to adequately spread the mortar, and the mortar will not stick to the units. In recognition of the necessary input by the mason in the field, ASTM C 270 states that mortar is to be mixed "… with the maximum amount of water to produce a workable consistency."

An understanding of how water, aggregate, and cementitious materials affect the properties and field performance of mortar helps assure the design and construction of water-resistant and attractive masonry buildings.

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REFERENCES

1. ASTM C 1324, "Standard Test Method for Examination and Analysis of Hardened Masonry Mortar."
2. ASTM E 514, "Standard Test Method for Water Penetration and Leakage Through Masonry."
3. ASTM C 1072, "Standard Method for Measurement of Masonry Flexural Bond Strength."
4. ASTM C 952, "Standard Test Method for Bond Strength of Mortar to Masonry Units."
5. ASTM C 144, "Standard Specification for Aggregate for Masonry Mortar."
6. ASTM C 270, "Standard Specification for Mortar for Unit Masonry."
7. ASTM C 150, "Standard Specification for Portland Cement."
8. ASTM C 207, "Standard Specification for Hydrated Lime for Masonry Purposes."
9. ASTM C 5, "Standard Specification for Quicklime for Structural Purposes."
10. ASTM C 91, "Standard Specification for Masonry Cement."
11. ASTM C 1329, "Standard Specification for Mortar Cement."
12. *Specification for Masonry Structures* (ACI 530.1-99/ASCE 5-99/TMS 602-99), Masonry Standards Joint Committee.

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