Understanding Mortar

by Rochelle Jaffe

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

More important, mortar plays a crucial role in resisting 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. However, it 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

The three most important properties of mortar are workability, bond, and compressive strength.

Workability. Workability is perhaps the most important property of plastic (that is, fresh and not yet hardened) mortar. It refers to 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 other plasticizing ingredients such as hydrated lime or entrained air. Mortar is workable when it:

- spreads easily with the trowel
- supports the weight of the masonry units
- sticks to masonry surfaces
- extrudes readily from the joint when the mason applies pressure to the unit

A mortar with good workability 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). Workability is determined by 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 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 between mortar and masonry unit. Good extent-of-bond exists when the mortar-to-unit contact is complete and intimate. It 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. The laboratory can measure bond strength using bond-wrench equipment in accordance with ASTM C 1072 (Ref. 3) or using the procedures of ASTM C 952 (Ref. 4).

Compressive strength. Seeing the emphasis placed on this property by architects and engineers in most project specifications, you would think that compressive strength is the single most important mortar property. In fact, it's 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's easily measured. Compressive strength is increased with more cement in the mix and decreased with higher ratios of water or 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% (based on tabulated values of compressive strength of masonry in the Masonry Standard Joint Committee's *Specification for Masonry Structures* [Ref.12]).

Mortar Materials

Mortar is a combination of water, aggregate, and cementitious materials. Each ingredient serves an important purpose in the 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. Water is also needed for workability, for absorption by the masonry units, and to account for evaporation — beyond the amount needed to hydrate the cement. Potable water should be used in mortar because water that's safe to drink generally does not contain contaminants that may adversely affect mortar properties.

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Aggregate. Aggregate is the granular material, usually sand, that reduces the required proportion of cementitious materials and resists shrinkage of the cement in the mortar mix. For workability 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 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, as is the total volume of water used in the mix. Lower proportions of cement and water mean less shrinkage. Less shrinkage means less tendency of the mortar to crack.

Cementitious materials. Cementitious materials have adhesive and cohesive properties both when in a plastic state and when hardened. There are three categories of cementitious materials — Portland cement (sometimes combined with other hydraulic cements) and lime, masonry cement, and mortar cement — and mortar must include one of them.

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 less workable, or "harsh."

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

Masonry cement is a proprietary prepackaged mix of Portland cement or blended hydraulic cement combined with plasticizing materials (such as hydrated lime or pulverized limestone) and other ingredients. The standard that governs masonry cement, ASTM C 91 (Ref. 10), places no limitations on what materials may

be used to manufacture a masonry cement. It does, however, state physical requirements — such as fineness, compressive strength, air content, and water retention — for the cement.

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 mortars. According to most building codes, allowable values of bond strength for unreinforced masonry with masonry cement mortar or air-entrained Portland cement mortar are 40% to 50% less than when the masonry uses non-air-entrained Portland cement mortar.

Although research supports the building code reduction in allowable bond 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, others report no difference in water resistance compared to that of masonry with non-air-entrained Portland cement mortar.

Mortar cement is also a proprietary prepackaged blend of materials intended to be mixed with sand and

Table 1. Portland Cement Mortar by Proportion Specification

Mortar Type	Portland	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 and Mortar Cements by Proportion Specification

Mortar Type	Masonry/ Mortar Cement	Portland/ Blended	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	2,500	75	18	12
S	1,800	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 mortar shall be 12%.

water to produce mortar. But 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 that requirement is to produce a mortar equivalent in bond strength to the same type of Portland cement mortar.

Like masonry cement, mortar cement includes an air-entraining additive to give the mix workability. But the ASTM standard for mortar cement limits the volume of entrained air to a lower percentage than 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: proportion or property. It's inappropriate to combine requirements from the two methods. A proportion specification dictates the relative quantities of each ingredient to be included in a 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 bond strength, may be specified by the project architect or engineer if they're considered important to the successful performance of the masonry and 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, it should be based on the best mix for the project and not simply on high compressive strength. Mortar should always be of lower compressive strength than the units that make up the masonry assembly.

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

The mortar mix doesn't have to follow the material proportions exactly as shown because the standard gives a range for those proportions. For example, Type N Portland cement mortar is shown (in Table 1) to consist of 1 part Portland, 1 part lime, and 6 parts sand. In fact, for each part of Portland, between 0.5 and 1.25 parts of lime 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 (previous page) gives the minimum and maximum properties for mortars specified by the property method. These properties are evaluated on a laboratory-prepared mix of mortar, which differs from the field mortar mix in that the amount of water added to the laboratory mix is limited and is based on a standardized measurement of flow.

In the field, the standard doesn't limit the amount of water that a mason can add. 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 can judge the correct amount of water to add 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 won't be able to lay them; if too little water is added, the mortar mix will be unworkable, the mason won't 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 ensure the design and construction of water-resistant and attractive masonry buildings.

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