MASONRY INFORMATION

Masonry Mortars

Centuries ago, combinations of sand and lime were used as mortar. These combinations took months and even years to harden, as the lime slowly combined with carbon dioxide from the air to form calcium carbonate. Because it took so long for these mortars to harden and gain strength, it was necessary to use very thin joints. In many instances the joints were so thin that adjacent masonry units would bear on each other in direct contact. This type of construction required an excessive amount of labor to carefully fit and place each masonry unit. However, sand-lime mortars were adequate for the then massive construction and slow-paced construction procedures.

The development of mortars that harden and gain strength rapidly made it possible to place masonry units quickly. Also, thicker joints provided cushions for dimensional variations in the masonry units. The stronger mortars were first obtained by "sweetening" the lime with a small amount of portland cement. Later, the ratio of portland cement was progressively increased until the process involved sweetening the *cement* with a small amount of lime.

In the later 19th century, the advancement of strong mortars with controlled setting characteristics was a major step forward for masonry construction. Another important step was the development of masonry cements in the 1930s.

Masonry cement is factory-prepared hydraulic cement primarily used to produce masonry mortar or portland cement plaster (stucco). Masonry cement consists of a mixture of portland or blended hydraulic cement and plasticizing materials (such as limestone, hydrated, or hydraulic lime) together with other materials introduced to enhance one or more properties such as setting time, workability, water retention, and durability. White masonry cement and colored masonry cements containing premixed mineral oxide pigments are also available in many areas. All are mixed and packaged under factory conditions, increasing quality control.

Fig. 1. Mortar of proper workability is soft, but with good body; it spreads readily and extrudes without smearing or dropping away. (IMG13629)

Today, most mortars are made with masonry cement due to the ease of use and consistent performance. These mortars are a combination of a masonry cement, clean and well-graded sand, and enough clean water to produce a plastic, workable mix. Masonry cements are designed to ease the mixing operation at the construction site. Their use produces color and batch uniformity. Masonry cements that meet the requirements of American Society for Testing and Materials (ASTM) designation C 91 or Canadian Standards Association (CSA) standard A3002 ensure workable, sound, and durable mortar.

In the 1990s, increased use of masonry in demanding structural applications and high seismic areas resulted in the development of a new product, mortar cement. Mortar cement is similar to masonry cement in that it is a factory-prepared hydraulic cement primarily used to produce masonry mortar. However, ASTM C 1329, the Standard Specification for Mortar Cement, places lower maximum air content limits on mortar cement than permitted for masonry cements, and ASTM C 1329 is the only ASTM masonry material specification that includes bond strength performance criteria.

Mortar for masonry is designed not only to join masonry units into an integral structure with predictable performance properties, but also to: (1) effect tight seals between units against the entry of air and moisture; (2) bond with steel joint reinforcement, metal ties, and anchor bolts, if any, so that they perform integrally with the masonry; (3) provide an architectural quality to exposed masonry structures through color contrasts or shadow lines from various joint-tooling procedures; and (4) compensate for size variations in the units by providing a bed to accommodate tolerances of units.

Masonry mortar is composed of one or more cementitious materials; clean, well-graded masonry sand; and sufficient water to produce a plastic, workable mixture. Modern specifications call for proportions by volume ranging from one part of cementitious material to 2¼ to 3½ parts of damp, loose mortar sand. The choice of cementitious material—masonry cement, mortar cement, a portland cement and lime combination, or a portland cement and masonry cement or mortar cement combination—is largely a matter of economics and convenience. Any of these combinations will produce mortar with acceptable properties as long as applicable specifications are met and appropriate design procedures are followed.

Desirable Properties

Good mortar is necessary for good workmanship and proper structural performance of masonry construction. Since mortar must bond masonry units into strong, durable, weathertight walls, it must have the properties described below.

Workability. Probably the principal quality of plastic masonry mortar is workability, because of its influence on other important mortar properties in both the plastic and the hardened states. Workability is difficult to define because it is a combination of a number of interrelated properties. The properties considered as having the greatest influence on workability are consistency (flowability), water retentivity, setting time, weight, adhesion, and cohesion.

An experienced mason judges the workability of mortar by the way it adheres to or slides from his trowel. Mortar of good workability should spread easily on the masonry unit, cling to vertical surfaces, extrude readily from joints without dropping or smearing, and permit easy positioning of the unit without subsequent shifting due to its weight or the weight of successive courses. A mortar's consistency should be compatible with the units and weather conditions. For example, under hot summer conditions when using a high-absorption unit, a softer mortar having a higher water content is needed, compared to that used with a dense unit during cold winter construction.

Water retentivity. Mortar having this property resists rapid loss of mixing water (prevents loss of plasticity) to the air on a dry day or to an absorptive masonry unit. Rapid loss of water causes the mortar to stiffen quickly, making it practically impossible to obtain weathertight joints.

Water retentivity is an important property and is related to workability. A mortar that has good water retentivity remains soft and plastic long enough for the masonry units to be carefully aligned, leveled, plumbed, and adjusted to proper line without danger of breaking the intimate contact or bond between mortar and unit. When low-absorption units such as split block are in contact with a mortar having too much water retentivity, they may float. Consequently, the water retentivity of a mortar should be within tolerable limits. Water adds workability to the mortar; entrained air or extremely fine aggregate or cementitious materials not only add workability or plasticity to the mortar, they also increase its water retentivity.

Consistent rate of hardening. The rate of hardening of a mortar due to hydration (chemical reaction) is the speed at which it develops resistance to an applied load. Rapid hardening may interfere with the use of the mortar by the mason. Very slow hardening may impede the progress of work, because the mortar will extrude from the completed masonry. During winter construction, slow hardening may also subject mortar to early damage from frost. A well-defined, consistent rate of hardening assists the mason in laying the masonry units and in tooling the joints at the same degree of hardness.

Uniform color of masonry joints reflects proper hardening and consistent tooling times. Hardening is sometimes confused with a stiffening caused by rapid loss of water, as when low-water retention mortar is used with highly absorptive units. Also, in very hot, dry weather, mortar may tend to stiffen more rapidly than usual. In this case, the mason may find it advisable to lay shorter mortar beds and fewer units in advance of tooling. See also "Hot-weather construction" of this publication.

Durability. The durability of masonry mortar is its ability to endure exposure conditions. Mortar joints can deteriorate from exposure to freeze-thaw cycles when saturated, from exposure to aggressive chemical environments, or from the use of unsound materials.

Damage by frost action—either to mortar joints or to mortar bond—has not been a problem in most masonry wall construction above grade. In order for frost damage to occur, the hardened mortar must first be water-saturated or nearly so. Although mortar is saturated when first placed, the mixing water is absorbed by units and chemically combined with cement compounds as the mortar hardens. The saturated condition does not readily return except when the masonry is in continuous contact with saturated soils, when downspouts leak, when there are heavy rains, or when horizontal ledges are formed. Under these conditions, the masonry unit and mortar may become saturated, which can lead to freeze-thaw deterioration if temperatures drop to freezing or below.

High-compressive-strength mortars usually have good freeze-thaw durability. Because air-entrained mortar will withstand hundreds of freeze-thaw cycles, its use provides good protection against localized freeze-thaw damage. Masonry cement and mortar cement mortars have higher air contents than non-air-entrained portland cement and lime mortar and therefore have better freeze-thaw resistance. Mortar joints that have deteriorated due to freezing and thawing present a maintenance problem that usually requires tuckpointing.

Sulfate attack provides an example where deterioration of mortar results from exposure to an aggressive chemical environment. Sulfate resistance is usually not a concern for masonry above ground; however, in some parts of the country, masonry can be exposed to sulfate from soil, ground water, or industrial processes. Sulfate-resistant masonry materials should be used when they are going to be in contact with soils containing more than 0.1% water-soluble sulfate (SO_4) or water solutions containing more than 150 ppm of sulfate. Without the use of sulfate-resistant masonry units and mortar or use of a protective treatment, sulfates would attack and deteriorate masonry. Masonry cement, sulfate-resistant portland cements (Types II or V) or hydraulic cements (Types MS or HS), or sulfate-resistant blended cements should be used in mortar exposed to sulfates. One study demonstrated that masonry cement is significantly more sulfate resistant than a Type II portland cement and lime mortar when tested in accordance with ASTM C 1012 (at 13 weeks, portland cement-lime mortars exhibited expansions of 0.16% to 0.37% compared to 0.03% to 0.12% for masonry cement mortars). For additional information see Dubovoy (1990).

Expansion in mortars due to unsound ingredients can cause serious disintegration of masonry. Soundness of a hydraulically cementitious material is measured by the autoclave expansion test (ASTM C 151). This test produces reactions in unsound ingredients (particularly free lime and periclase) and simulates a long period of in-place exposure. ASTM specifications for masonry cement (ASTM C 91), mortar cement (ASTM C 1329), and portland cement (ASTM C 150) limit acceptable changes in length of the test specimen to ensure that no serious expansion of the hardened mortar will occur in a wall. While a method for measuring soundness of hydrated lime has been developed, correlation of results to field performance has not yet been established. Thus, soundness is generally assured by limiting the unhydrated oxide content of the hydrated lime to a maximum of 8%.

Absorption of mortar is a measure of how much water the hardened mortar will take in. Low absorption mortars will be less susceptible to saturation, freeze-thaw deterioration, and staining. Absoprtion is reduced by increasing cement content, using air-entrained mortars, and using water repellent admixtures.

Compressive Strength. The principal factors affecting the compressive strength of masonry structures are the compressive strength of the masonry unit, the proportions of ingredients comprising the mortar, the design of the structure, the workmanship, and the degree of curing. Although the compressive strength of masonry may be increased with a stronger mortar, the increase is not proportional to the compressive strength of the mortar. Tests have shown that compressive strengths of concrete masonry walls increase only about 10% when mortar cube compressive strengths increase 130%. Composite wall compressive strengths increase 25% when mortar cube compressive strength increases 160% (Fishburn 1961).

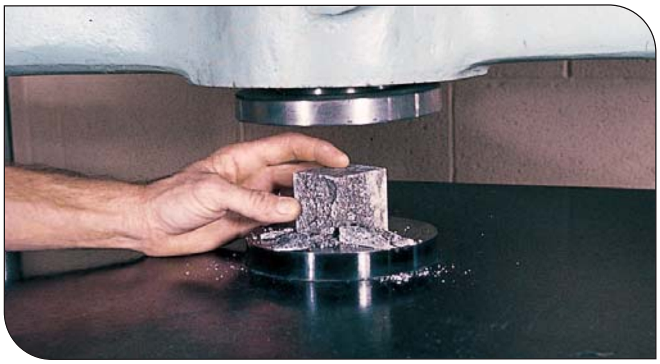

Fig. 2. Cube compressive-strength test. (IMG14091)

Compressive strength of mortar is largely dependent on the type and quantity of cementitious material used in preparing the mortar. It increases with an increase in cement content and decreases with an increase in air entrainment, lime content, or water content. Portland cement requires a period in the presence of moisture to develop its full strength. To obtain optimum curing conditions, the mortar mixture should contain the maximum amount of water compatible with acceptable workability. Lean, oversanded mixtures should be avoided as they will have poor water retentive characteristics. Freshly laid masonry should be protected from the sun and drying winds. With severe drying conditions, it may be necessary either to wet the exposed mortar joints with a fine water spray daily for about 3 days or to cover the masonry with a plastic sheet, or both.

Bond. The term *bond* refers to a specific property that can be subdivided into: (1) extent of bond, or degree of contact of the mortar with the masonry units; and (2) bond strength, or force required to separate the units. A chemical and a mechanical bond exist in each category.

Fig. 3. Tensile bond test. (IMG14591)

Good extent of bond (complete and intimate contact) is important to watertightness and tensile bond strength. Poor extent of bond at the mortar-to-unit interface may lead to moisture penetration through the unbonded areas. Good extent of bond is obtained with a workable and water-retentive mortar, good workmanship, full joints, and masonry units having a medium initial rate of absorption (suction). Bond strength is usually measured as tensile or flexural bond strength. In determining direct tensile bond strength, specimens representing unit and mortar are pulled apart (Fig. 3). Test methods for measuring flexural (more properly termed "flexural-tensile") bond strength place a more complex load on the mortar-to-unit interface, but can be applied to full-sized specimens.

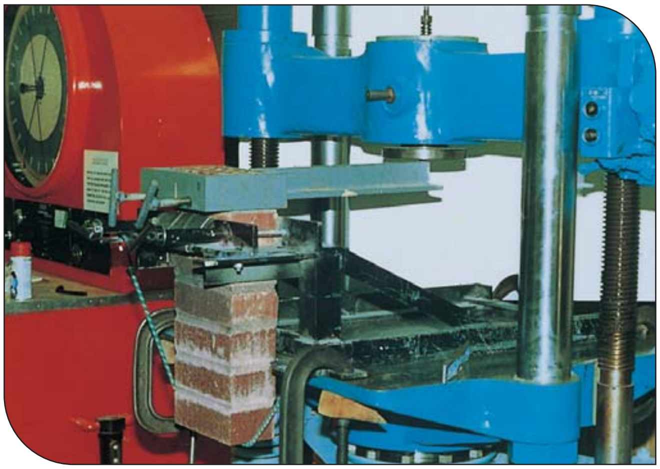

Fig. 4. ASTM C 1072 bond wrench apparatus. (IMG13317)

For example, ASTM Method C 1072 (Fig. 4) utilizes a bond wrench apparatus and loading configuration to induce failure of prisms constructed from full-sized masonry units. Other standard methods used to measure bond strength of masonry include ASTM E 518, ASTM C 952, and ASTM E 72. While bond strength is an important property of masonry, current methods of test for determining bond strength are considered impractical as a basis for material specifications or quality control at the jobsite, due to the high variability of results inherent in the testing methods.

Many variables affect bond, including (1) mortar ingredients, such as type and amount of cementitious materials, water retained, and air content; (2) characteristics of the masonry units, such as surface texture, suction, and moisture content; (3) workmanship, such as pressure applied to the mortar bed during placing; and (4) curing conditions, such as temperature, relative humidity, and wind. The effects of some of these variables on bond will be briefly discussed.

All other factors being equal, mortar bond strength is related to mortar composition, especially the cement content. The bond strength of the mortar increases as the cement content increases (Melander and Conway 1993).

Bond strength tends to decrease as air contents increase. However, excellent bond strengths can be achieved using air-entrained mortars. An extensive study of over 20 different masonry cements representing a cross section of producers throughout the United States confirms that masonry cements yield excellent flexural bond strengths (Dubovoy and Ribar 1990). Seventy-five percent of these masonry cement mortars tested with a brick unit having an IRA* (initial rate of absorption) of 9 yielded bond strengths in excess of 100 psi (690 kPa). None produced values lower than 65 psi (450 kPa). The bond strength criteria for mortar cements were established to assure comparable bond strength performance to non-air-entrained portland cement-lime combinations of equivalent type designation (Melander and Ghosh 1996).

Bond strength is low on smooth, molded surfaces, such as glass or die skin surfaces of clay brick or tile. On the other hand, good bond is achieved on concrete block or on wire-cut or textured surfaces of clay brick. For high absorption clay brick, bond strengths can be increased by wetting the units prior to laying them. However, surfaces of wetted brick should not be saturated. Concrete masonry units should not be wetted before use.

There is a distinct relationship between mortar flow (water content) and bond strength. For all mortars, bond strength increases as water content increases, within reasonable limits. The optimum bond strength is obtained by using a mortar with the highest water content compatible with workability, even though mortar compressive strength may decrease (Isberner 1974a, Ritchie and Davison 1963).

Workmanship is paramount in determining bond strength. The time lapse between the spreading of mortar and the placing of the masonry units should be kept to a minimum because the water content of the mortar will be reduced through suction of the masonry unit on which it is first placed. If too much time elapses before the upper unit is placed, the bond between the mortar and that unit will be reduced. The mason should not realign, tap, or in any way move units after initial placement, leveling, and alignment. Movement disrupts the bond between unit and mortar, after which the mortar will not reestablish good bond with the masonry units.

Volume change. As available water in mortar is absorbed by the masonry units and lost through evaporation, some drying shrinkage occurs. Though generally not a problem in masonry construction, extreme drying shrinkage can result in development of cracks in the mortar. Since drying shrinkage is related to the amount of water lost by the mortar, factors that increase water content of a mortar tend to increase its drying shrinkage. For example, air-entrained mortars tend to have a lower water demand than non-air-entrained mortars at an equivalent flow and thus exhibit less drying shrinkage. However, this principle should not be misinterpreted to mean that water content of a mortar should be arbitrarily reduced. As previously noted, workability and bond are directly related to the flow of the mortar and should be given priority in determining the water content of field mixed mortar.

On projects where it is desirable to minimize drying shrinkage, masonry cement mortar should be considered. The shrinkage of mortar can be tested in accordance with ASTM C 1148. In a study using this test, masonry cement mortar had half the shrinkage of cement-lime mortar (0.07% at 25 days for masonry cement mortar versus 0.12% to 0.14% for cement-lime mortar (Dubovoy 1990).

Appearance. Uniformity of color and shade of the mortar joints greatly affects the overall appearance of a masonry structure. Atmospheric conditions, admixtures, and initial rate of absorption (suction) of the masonry units are some of the factors affecting the color and shade of mortar joints. Others are uniformity of proportions of the mortar mix, water content, and time of tooling the mortar joints.

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* IRA is measured in g/min•30 in.^{2} (g/min•194 cm^2)

Careful measurement of mortar materials and thorough mixing are important to maintain uniformity from batch to batch and from day to day. Control of this uniformity becomes more difficult with the number of ingredients to be combined at the mixer. Pigments, if used, will provide more uniform color if premixed with a stock of cement sufficient for the needs of the whole project. In many areas, colored masonry cements are available; they provide better control over color uniformity. Tooling of mortar joints at like degrees of setting is important to ensure a uniform mortar shade in the finished structure. If the joint is tooled when the mortar is relatively hard, a darker shade results than if the joints are tooled when the mortar is relatively soft. Some masons consider mortar joints ready for tooling after the mortar has stiffened but is still thumb-print hard, with the water sheen gone. Tooling white cement mortar with metal tools may darken the joint. A glass or plastic joint tool should be used.

Table 1. Proportion Specifications for Mortar

A. United States – ASTM C270

Mortar type	Parts by volume: Portland cement or blended cement	Masonry cement or mortar cement type M	S	N	Hydrated lime or lime putty	Aggregate
M	1	--	--	1	--	4½ to 6
	--	1	--	--	--	2¼ to 3
	1	--	--	--	¼	2¹³⁄₁₆ to 3¾
S	½	--	--	1	--	3⅜ to 4½
	--	--	1	--	--	2¼ to 3
	1	--	--	--	Over ¼ to ½	*
N	--	--	--	1	--	2¼ to 3
	1	--	--	--	Over ½ to 1¼	*
O	--	--	--	1	--	2¼ to 3
	1	--	--	--	Over 1¼ to 2½	*

B. Canada – CSA A179

Mortar type	Parts by volume: Portland cement or blended cement	Masonry cement or mortar cement type M	N	Hydrated lime or lime putty	Aggregate
S	--	1	--	--	2¼ to 3
	½	--	1	--	3½ to 4½
	1	--	--	½	3½ to 4½
N	--	--	1	--	2¼ to 3
	1	--	--	1	4½ to 6

*The total aggregate shall be equal to not less than 2¼ and not more than 3 times the sum of the volumes of the cement and lime used.

Notes: 1. Under both ASTM C270, Standard Specification for Mortar for Unit Masonry, and CSA A179, Mortar and Grout for Unit Masonry, aggregate is measured in a damp, loose condition and 1 ft^3 of masonry sand by damp, loose volume is considered equal to 80 lb of dry sand (in SI units 1 m^3 of damp, loose sand is considered equal to 1280 kg of dry sand).

2. Mortar should not contain more than one air-entraining material.

Specifications and Selection of Types

Specifications. ASTM C 270, Standard Specification for Mortar for Unit Masonry, and CSA Standard A179, Mortar and Grout for Unit Masonry, are the main specification documents in North America. ASTM C 270 covers four types of mortars (Type M, S, N, or 0) while CSA A179 defines two types of mortars** (Type S and N). Current specifications for mortars for nonreinforced and reinforced unit masonry are shown in Tables 1 and 2. Mortar types are to be identified by either proportion or property specifications, *but not by both. An interplay of property and proportion specifications is not intended or recognized by the specifications.*

The proportion specifications (Table 1) identify mortar type through various combinations of portland or blended cement with masonry cement, masonry cement singly, and combinations of portland or blended cement and lime. The proportion specifications govern when ASTM C 270 or CSA Standard A179 are referred to without noting which specification—proportion or property—should be used.

** Information on the traditional requirements for Type M, 0, and K mortars and a description of their uses is given in the nonmandatory appendix A of CSA A179.

Fig. 5. Flow test. (IMG14093)

Mortar type classification under the property specifications (Table 2) is dependent on the compressive strength of 2-in. (50-mm) cubes, water retention, and air content, using standard laboratory tests per ASTM C 270 or CSA A179. These test requirements of the property specifications for laboratory mortar do not apply to job-made mortar. Laboratory mortars are prepared with less water than will be used on the job. The standard consistency for laboratory mortars is determined using a laboratory flow table (Fig. 5). In this test, a truncated cone of mortar is subjected to twenty-five ½-in. (12.7-mm) drops of a laboratory flow table plate. The diameter of the disturbed sample is compared to the original diameter of the conical sample. Allowable initial flow ranges from 105% to 115% for ASTM and 100% to 115% for CSA. This consistency is not suitable for laying masonry units in the field. Rather, it is intended to approximate the flow and properties of field mixed mortar after it has been placed in contact with absorptive masonry units. Flow values of 130% to 150% are common for the initial consistency of mortar used in actual construction.

In the laboratory, the water retention limit is measured by a flow-after-suction test, which simulates the action of absorptive masonry units on the plastic mortar. The test is described in C 1506, Standard Test Method for Water Retention of Hydraulic Cement-Based Mortars and Plasters and CSA A3004, Physical Test Methods for Cementitious Materials for Use in Concrete and Masonry Cement. Upon performing a flow test before and after absorptive suction on the mortar, the flow after suction must equal or exceed 75% or 70% of the original flow for ASTM or CSA, respectively.

Once the proportions of cement, lime, and aggregate have been established in the laboratory for mortar meeting Table 2 property specifications, the same proportions must be used in the field.

Mortar should be evaluated in the field according to ASTM C 780, Standard Test Method for Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry, or CSA A179, Mortar and Grout for Unit Masonry. The standard provides test methods to ensure that the field mortar meets the recipe that was selected from ASTM C270 or CSA A179 specifications. The test methods are equally effective whether specifications were chosen based on proportions or properties (C 270 Table 1 or Table 2, respectively). Field quality control is based on the mortar aggregate ratio test and the mortar water content test. The mortar aggregate ratio test provides a means to identify, measure, evaluate, and control differences which may be expected to exist between laboratory and jobsite mortars. The water content test provides information needed to calculate the mortar aggregate ratio. Used together, they enable effective quality control of field mortars. Results are rapidly available and allow for changes to procedures to correct non-conforming mortars during the construction process.

When ASTM C 780 is to be used for quality control testing, preconstruction testing using procedures described in the standard must be conducted to develop data that can serve as a benchmark for evaluation of test results obtained during construction (see PCA (1997) for further information on field testing of masonry mortar). Unlike ASTM C 270, CSA A179 also has compressive strength requirements (not shown in Table 2) for job-prepared mortar proportioned according to property specifications.

ASTM C 780 provides guidance for compressive strength testing. It should be recognized, however, that compressive strength values determined on field mortars are generally lower than those for laboratory prepared mortars, and are not required or expected to meet the property specification requirements of Table 2. Compressive strengths of mortar cube specimens molded under field test conditions do not represent the strength of the mortar in place, nor are they indicative of the compressive strength of the masonry.* In addition, test results are usually determined at 7 and 28 days, too late to enact construction procedures that might correct the situation. For these reasons, compressive strength testing is not recommended for quality control in the field.

For the designer seeking data representative of the in-place masonry, the most effective procedures are masonry assembly tests such as ASTM C 1314, the Standard Method for Constructing and Testing Masonry Prisms Used to Determine Compliance with Specified Compressive Strength of Masonry. These assembly tests indicate the interaction between mortar and unit, quality of workmanship, mortar consistency, and numerous other characteristics of the masonry.

The ratio of cementitious material to aggregate in the mixture under the property specifications may be less than under the proportion specifications. This is to encourage preconstruction mortar testing; an economic reward is possible if less cement is required for a mix to meet the strength requirement of the property specifications. In both the property and proportion specifications, the amount of water to be used on the job is the maximum that will produce a workable

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* Mortar in the wall is much stronger than the tested strength of the cube because the joint has a smaller aspect ratio than the cube and in-place mortar has a lower water-cement ratio. Compressive strength of masonry is a function of both the unit strength and the mortar strength.

Table 2. Property Specifications for Laboratory-Prepared Mortar[*]

A. United States

Mortar specification	Mortar type	Minimum 28-day compressive strength, psi, (MPa)		Minimum water retention, %	Maximum air content, %	
					Masonry cement	Mortar cement or cement-lime
ASTM C 270	M	2500	(17.2)	75	18	12
	S	1800	(12.4)	75	18	12
	N	750	(5.2)	75	20[**]	14[†]
	O	350	(2.4)	75	20[**]	14[†]

B. Canada

Mortar specification	Mortar type	Minimum compressive strength, MPa		Minimum water retention, %
		7-day[††]	28-day	
CSA A179	S	7.5	12.5	70
	N	3	5	70

[*] The total aggregate shall be equal to not less than 2¼ and not more than 3½ times the sum of the volumes of the cement and lime used.

[**] When structural reinforcement is incorporated in masonry cement mortar, the maximum air content shall be 18%.

[†] When structural reinforcement is incorporated in mortar cement or cement-lime mortar, the maximum air content shall be 12%.

[††] If the mortar fails to meet the 7-day requirement but meets the 28-day requirement, it shall be acceptable.

consistency during construction. This is unlike conventional concrete practice where the water-cement ratio must be carefully controlled.

Selection. Once the design loads, type of structure, and masonry units have been determined, the mortar type can be selected. No one mortar type will produce a mortar that rates the highest in all desirable properties. Adjustments in the mix to improve one property often are made at the expense of others. For this reason, the properties of each mortar type should be evaluated, and the mortar type chosen that will best satisfy the end-use requirements. See PCA (1998) for additional guidance on selecting and specifying mortars.

The Masonry Standards Joint Committee documents—ACI 530/ASCE 5/TMS 402, *Building Code Requirements for Masonry Structures (MSJC Code)*, and ACI 530. I/ASCE 6/TMS 602, *Specification for Masonry Structures (MSJC Specification)*—have been adopted by the *International Building Code* and by the last published editions of the *BOCA National Building Code and the Standard Building Code*. As a result, many areas of the country now have similar requirements. Specifiers should be familiar with both the design requirements of the *MSJC Code* and the provisions of the *MSJC Specification*. The *MSJC Code* makes several distinctions in the structural characteristics of masonry constructed using Type N mortar compared to that of masonry constructed using Type S or M mortar. In addition, for masonry design that takes into consideration the flexural tensile resistance of masonry, allowable flexural tensile stresses are different for non-air-entrained portland cement-lime or mortar cement mortars than for air-entrained portland cement-lime or masonry-cement mortars. The Uniform Building Code (UBC) has similar provisions, *except that air-entrained portland cement-lime mortars are not specifically addressed.* Mortar cement mortars are used on an equivalent basis as cement-lime mortars. The specifier should confirm that mortar types and materials indicated in project specifications are consistent with structural design requirements of the masonry.

In the United States, mortar is selected based on the (desired) compressive strength of the masonry, type of masonry unit, type and location of building segment, and conditions of the loading, soil, and exposure. Table 3, adapted from ASTM C 270, provides guidelines for selecting mortar for plain (nonreinforced) masonry. For example, the guide recommends Type 0 mortar for non-load-bearing walls, Type N for load-bearing walls and exterior walls above grade, and Type S for exterior walls and masonry applications at or below grade. Alternate mortar types are also presented.

Special attention to mortar selection must be given when severe exposure conditions, special masonry applications, or reinforced masonry applications are considered. Type 0 mortar should not be used in saturated freezing conditions. For severe frost action or heavy loading, Type M mortar should be considered. Air-entrainment should

Table 3. Guide for the Selection of Masonry Mortars (United States)*

Location	Building segment	Mortar type Recommended	Mortar type Alternative
Exterior, above grade	Load-bearing walls	N**	S or M
	Non-load-bearing walls	O	N or S
	Parapet walls	N†	S
Exterior, at or below grade	Foundation walls, retaining walls, manholes, sewers, pavements, walks, and patios	S	M or N†
Interior	Load-bearing walls	N	S or M
	Non-load-bearing partitions	O	N

*Adapted from ASTM C 270. This table does not provide for specialized mortar uses, such as chimney, reinforced masonry, and acid-resistant mortars.

**Type 0 mortar is recommended for use where the masonry is unlikely to be frozen when saturated or unlikely to be subjected to high winds or other significant lateral loads. Type N or S mortar should be used in other cases.

†Masonry exposed to weather in a nominally horizontal surface is extremely vulnerable to weathering. Mortar for such masonry should be selected with due caution.

be used to improve freeze-thaw durability, although it may reduce bond and compressive strengths.

Mortar should also be compatible with the masonry unit. For example, a masonry unit with a high rate of absorption is compatible with a mortar having a high water retentivity. Mortar strength should never be greater than the masonry unit's strength. It is not always necessary to use Type M mortar for high-strength masonry, because Type S can provide comparable strength of masonry. Moreover, Types S and N generally have greater workability, water retention, and extensibility.

In Canada, Types S or N mortars are permitted for masonry designed on the basis of engineering analysis and for masonry designed according to empirical procedures. As previously noted, Types M, 0, and K are not included in the body of the current edition of CSA A179 but are described in the nonmandatory Appendix A of that document. Types 0 and K are not allowed where the masonry is to be (1) directly in contact with soil, as in a foundation wall, or (2) exposed to the weather on all sides, as in a parapet wall, balustrade, chimney, or steps and landings. CSA (1997), CSA (1996), and NRCC (1995) provide more information on mortar selection in Canada.

White and Colored Mortars

White and colored mortars can provide a color contrast or harmony between masonry units and joints to create pleasing architectural effects. White mortar is made with white masonry cement, or with white portland cement and lime, and white sand. For colored mortars, the use of white masonry cement or white portland cement instead of the normal gray cements not only produces cleaner, brighter colors, but is essential for making pastel colors such as buff, cream, ivory, pink, and rose.

Integrally colored mortar may be obtained through the use of pigments, colored masonry cements, or colored sand. Brilliant or intense colors are generally not attainable in masonry mortars. The color of the mortar joints will depend not only on the pigment, but also on the cementitious materials, aggregate, water-cement ratio, and tooling.

Pigments must be thoroughly dispersed throughout the mix. To determine if mixing is adequate, some of the mix is flattened under a trowel. If streaks of color are present, additional mixing is required. For best results, the pigment should be premixed with the cement in large, controlled quantities. Alternately, colored masonry cement is available in many areas in a range of stock colors, and alleviates the need for measuring and blending cements with pigments on the job. Custom colors may be available from some producers as well.

As a rule, pigments should be of mineral oxide composition and contain no dispersants that will slow or stop the portland cement hydration. Iron, manganese, chromium, and cobalt oxides have been successfully used. Zinc and lead oxides should be avoided, because they may react with the cement. Carbon black may be used as a coloring agent to obtain dark gray or almost black mortar, but lampblack should not be used. Carbon black should be limited to 1% or 2% by weight of the cement for masonry cement or portland cement-lime mortars, respectively, since durability of this mortar may be lowered. In addition, the color of mortar using carbon black pigment rapidly fades with exposure to weathering.

Use only those pigments that have been found acceptable by testing and experience. The following is a guide to the selection of coloring materials:

Red, yellow, brown, black, or gray . . . . .Iron oxide

Green . . . . .Chromium oxide
Blue . . . . .Cobalt oxide

Only the minimum quantity of pigment that will produce the desired shade should be used. An excess of pigment, more than 10% of the portland cement or 5% of the masonry cement by weight, may be detrimental to the strength and durability of the mortar. The quantity of water used in mixing colored mortar should be accurately controlled. The greater the water content, the lighter the color of the mortar. As such, retempering or adding water to colored mortar should be done cautiously. Mortar stiffness while tooling also has an effect on color.

Variations in the color of materials are such as to make a color formula only approximate. Best results are obtained by experiment. Test panels should be made with the same materials and proportions intended for use in the actual work and stored for about 5 days under conditions similar to those at the jobsite. Panels will have a darker shade when wet than when dry.

Discoloration of colored mortar joints may be caused by efflorescence, the formation of a white film on the surface. The white deposits are caused by soluble salts that have emerged from below the surface, or by calcium hydroxide, which is liberated during the setting of the cement, that subsequently combines with atmospheric carbon dioxide to form carbonate compounds. Good pigments do not effloresce or contribute to efflorescence. Efflorescence is more visible on a colored surface and may be removed with water, stiff-bristle brush, a light sandblasting, or acid wash. See PCA (2002a) for more information.

Mortar Components

Cementitious materials. Foremost among the factors that contribute to good mortar is the quality of the mortar ingredients. The following material specifications of ASTM or CSA are applicable:

- Masonry cement—ASTM C 91 (Types M, S, or N); CSA A3002 (Types S or N)
- Mortar cement—ASTM C 1329 (Types M, S, or N); CSA A3002 (MCN, MCS)
- Portland cement—ASTM C 150 (Types I, IA, II, IIA, III or IIIA); CSA A3001 (Types GU, MS, HS, HE)
- Blended hydraulic cement—ASTM C 595 (Types IS, IS-A, IP, IP-A, I(PM), or I(PM)-A)*
- Hydraulic cement—ASTM C 1157 (Types GU, MS, HS, HE)
- Hydrated lime for masonry purposes—ASTM C 207 (Types S, SA, N, or NA)**
- Lime putty—ASTM C 1489

Masonry sand. Since the quantity of sand required to make 1 cu ft (0.0283 m^3) of mortar may be as much as 0.99 cu ft (0.0280 m^3), the sand has considerable influence on mortar properties. Masonry sand for mortar should comply with the requirements of ASTM C 144, Standard Specification for Aggregate for Masonry Mortar, for

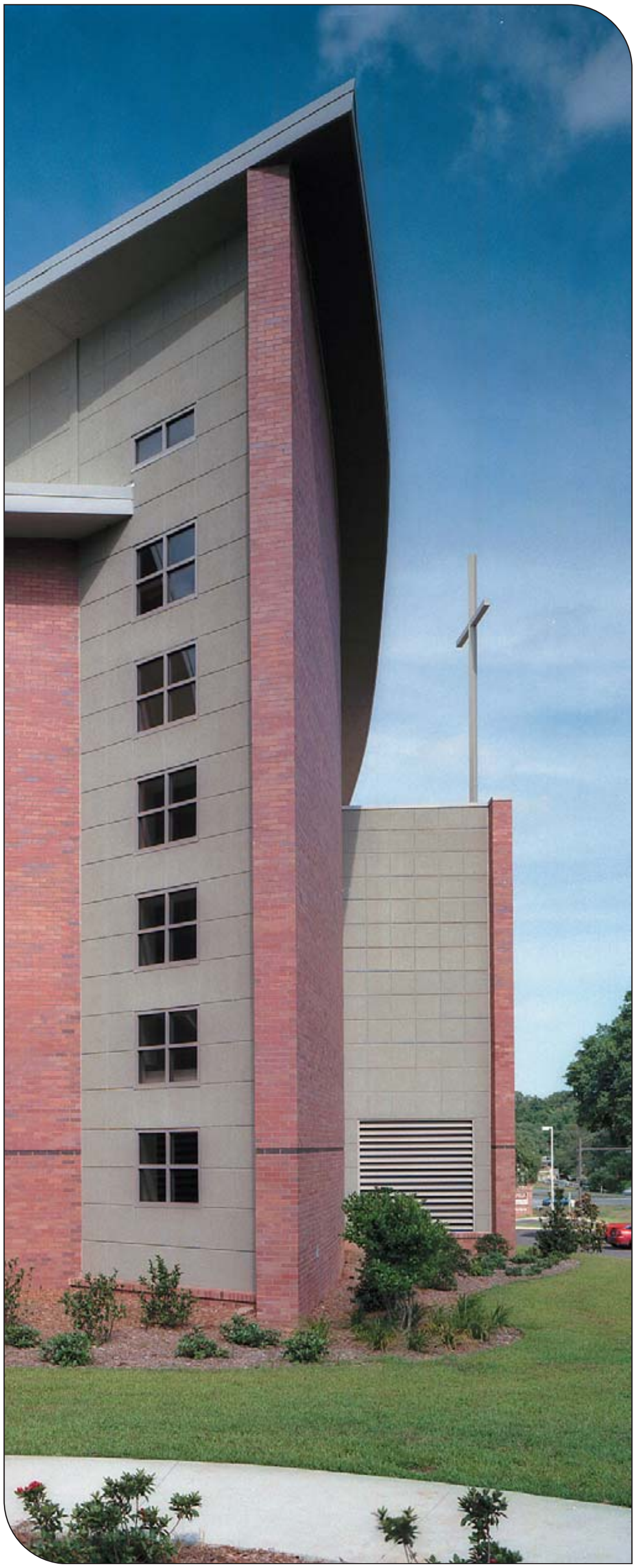

Fig. 6. A colored mortar made with light red masonry cement picks up the earth tones of this brick, while a standard gray mortar, also made with masonry cement, complements the concrete masonry units that it joins. (IMG14575)

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* Slag cement Types S or SA can also be used but only according to the property specifications.

** Types N and NA lime may be used only if tests or performance records show that these limes are not detrimental to the soundness of mortar.

construction within the United States and CSA A179 within Canada. These specifications include both natural and manufactured sands. Sand should be clean, well graded, and meet the gradation requirements listed in Table 4.

Sands with less than 5% to 15% passing the Nos. 50 (300 µm) and 100 (150 µm) sieves generally produce harsh or coarse mortars, which possess poor workability and result in mortar joints with low resistance to moisture penetration. On the other hand, sands finer than those permitted by the above specifications may yield mortars with excellent workability, but they may be weak and porous.

For mortar joints that are less than the conventional ⅜ in. (10 mm) thickness, 100% of the sand should pass the No. 8 (2.36 mm) sieve and 95% the No. 16 (1.18 mm) sieve. For joints thicker than ⅜ in. (10 mm), the mortar sand selected should have a fineness modulus* approaching 2.5 or a gradation within the limits of concrete sands (fine aggregate) shown in ASTM C33, Standard Specification for Concrete Aggregates, or CSA A23.1, Concrete Materials and Methods of Concrete Construction.

Table 4. Aggregate Gradation for Masonry Mortar

		Gradation specified, percent passing	
Sieve size no.		ASTM C144**	
U.S.	(Metric)	Natural sand	Manufactured sand
4	(4.75 mm)	100	100
8	(2.36 mm)	95 to 100	95 to 100
16	(1.18 mm)	10 to 100	70 to 100
30	(600 µm)	40 to 75	40 to 75
50	(300 µm)	10 to 35	20 to 40
100	(150 µm)	2 to 15	10 to 25
200	(75 µm)	0 to 5	0 to 10

** Additional requirements: Not more than 50% shall be retained between any two sieve sizes, nor more than 25% between No. 50 and No. 100 (300 µm and 150 µm) sieve, sizes. Where an aggregate fails to meet the gradation limit specified, it may be used if the masonry mortar will comply with the property specification of ASTM C 270 (Table 2).

All cementitious materials and aggregates should be stored in such a manner as to prevent wetting, deterioration, or intrusion of foreign material. Brands of cementitious materials and the source of sand supply should remain the same throughout the entire job.

Water. Water intended for use in mixing mortar should be clean and free of deleterious amounts of acids, alkalies, and organic materials. Some potable waters contain appreciable amounts of soluble salts such as sodium and potassium sulfate. These salts may later contribute to efflorescence. Also, a water containing sugar would retard the set. Thus, the water should be fit to drink, but investigated if it contains alkalies, sulfates, or sugars.

Admixtures. Although water-reducers, accelerators, retarders, and other admixtures are used in concrete construction, their use in masonry mortar may produce adverse effects on the normal chemical reaction between cement and water, especially during the early periods after mixing when water is needed for hydration of the portland cement. Hardened properties are also affected. ASTM C 270 indicates that admixtures should not be used in masonry mortar unless specified. When they are specified and used, they should meet the requirements of ASTM C 1384, Standard Specification for Admixtures for Masonry Mortars. ASTM C 1384, which classifies admixtures by their effect on performance characteristics, recognizes the following classifications: bond enhancers, workability enhancers, set accelerators, set retarders, and water repellents.

Because there is no current standard test method for determining corrosion potential of mortars toward embedded and attached materials, a limit on chlorides is set. The *MSJC Specification* limits the chloride content of admixtures to a maximum of 0.2%. In Canada, CSA A179 does not permit the use of salts or chlorides in any masonry containing connectors or reinforcement. ASTM C 1384 establishes that the mortar admixture not add more than 65 ppm (0.0065%) water-soluble chloride or 90 ppm (0.0090%) acid-soluble chloride to the mortar's overall chloride content.

Set-controlling admixtures have been reliably used to produce extended life mortar (see "Extended Life Mortar" section of this publication). Regular retarders, as used in concrete, are undesirable, because they reduce strength development and increase the potential toward efflorescence.

Air-entrainment increases workability and freeze-thaw durability. However, addition of an air-entraining admixture at the mixer on a jobsite is not recommended, due to the sensitivity of the admixture and the likelihood of poor control in monitoring air content. Materials with factory controlled amounts of air-entraining agent such as masonry cement, mortar cement, air-entraining portland cement, or air-entraining lime, should be used if air-entrainment is desired. Also see "Cold-Weather Construction" and "Modified Mortars" sections of this publication.

Whenever admixtures are considered for use in masonry, and experience or performance records are not available, it is recommended that the admixture be laboratory-tested in the construction mortars at the temperature extremes expected during their use, and then jobsite-inspected to ensure their satisfactory performance under the prevailing conditions.

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* Fineness modulus equals the sum of the cumulative percentages retained on the standard sieves, divided by 100. The higher the fineness modulus, the coarser the sand.

Measuring Mortar Materials

Measurement of masonry mortar ingredients should be completed in a manner that will ensure the uniformity of mix proportions, yields, workability, and mortar color from batch to batch. Aggregate proportions are generally expressed in terms of loose volume, but experience has shown that the amount of sand can vary due to moisture bulking.

Fig. 7 shows how loose sand with varying amounts of surface moisture occupies different volumes. Fig. 8 has the same data in another form for fine sand and shows the density of the sand. While dry sand or saturated sand typically has a unit weight of over 100 lb/ft^3 (1600 kg/m^3), damp loose sand generally contains approximately 80 lb/ft^3 (1280 kg/m^3) of dry sand plus the weight of the water. ASTM C 270 and CSA A179 procedures for proportioning mortar ingredients are based on the premise that sand will be used in a damp and loose condition at the construction site. Thus, to conform with specification requirements and to assure consistent volume batching, sand stock should be maintained in a damp, loose condition. The sand pile at the construction site should be covered to reduce evaporation and provide protection from rain or snow.

Ordinary sands will absorb water amounting approximately to 0.4% to 2.3% of the weight of the sand. In the field, damp sands usually have 4% to 8% moisture, so most of the water is on the surface of the sand.

Mortar ingredients other than sand are often sold in bags labeled only by weight. Since mortar is proportioned by volume, it is necessary to know the following data:

	Unit weight, lb/ft^3 (kg/m^3)	
Portland cement	94	(1500)
Masonry cement*	70 to 90	(1120 to 1440)
Hydrated lime (dry)	40	(640)
Lime putty (wet density)	80 to 90	(1280 to 1440)

*See printed net weight on bag.

Sand is commonly added to the mortar mixer using a shovel. However, some positive control should be established to assure that the proper volume of sand is used. That can be accomplished by periodically checking the required shovel count with a box of known volume, using that measuring box to add the sand to the mixer, or using calibrated buckets to measure sand added to the mixer. (A cubic foot box is a common and practical size.) When a measuring box is used, a hinged attachment to the mortar mixer can be constructed to facilitate one-man operation. When buckets are used, they should be calibrated to determine actual volume capacity. For example: if it is determined that buckets being used for proportioning have a volume capacity of exactly five gallons, then, since 1 cu ft is equal to 7.48 gal, 3 cu ft of sand is 22.44 gal or 4½ five-gallon buckets of sand. To obtain a mortar having a 3 to 1 volume proportion of sand to cementitious materials, 4½ buckets of sand would be added to the mixer for each bag of masonry cement or cubic foot of cement plus lime used in the mortar batch.

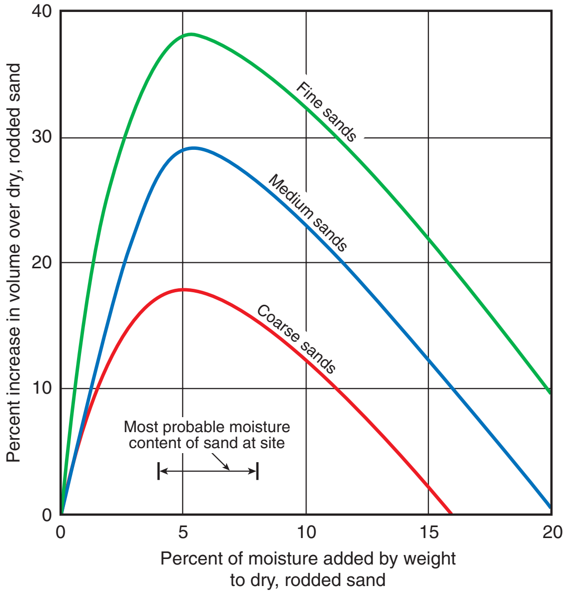

Fig. 7. Volume of loose, damp sand.

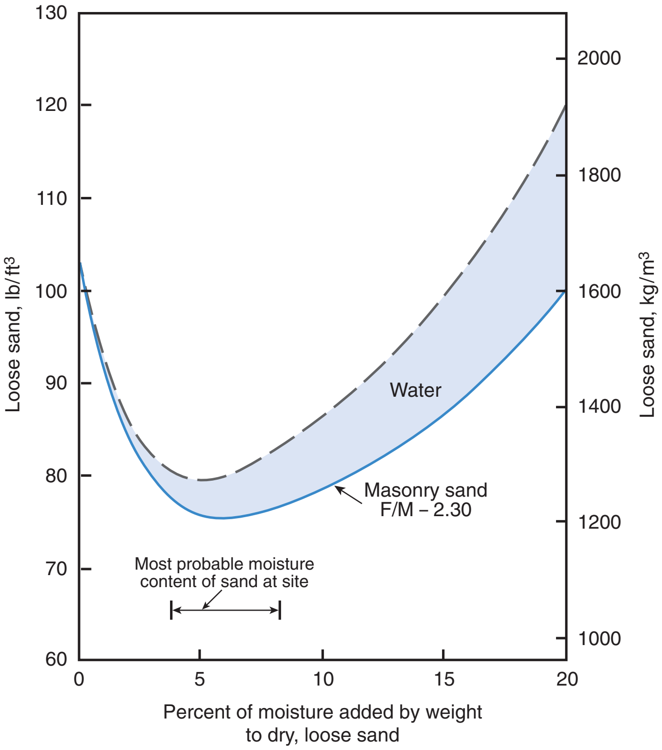

Fig. 8. Weight of loose, damp sand.

Fig. 9. For best results, the mortar should be mixed with a power mixer. (IMG14592)

Mixing

To obtain good workability and other desirable properties of plastic masonry mortar, the ingredients must be thoroughly mixed.

Mixing by machine. With the possible exception of very small jobs, mortar should be machine-mixed. A typical mortar mixer (Fig. 9) has a capacity of 4 cu ft to 7 cu ft (0.1 m^3 to 0.2 m^3). Conventional mortar mixers are of rotating-spiral or paddle-blade design with tilting drum. After all batched materials are together, they should be mixed from 3 to 5 minutes. A shorter mixing time may result in non-uniformity, poor workability, low water retention, and less-than-optimum air content. Longer mixing times may adversely affect the air contents of mortars containing air-entraining cements, particularly during cool or cold weather. Longer mixing times may also reduce the strength of the mortar.

Batching procedures will vary with individual preferences. Experience has shown that good results can be obtained when about three-fourths of the required water, one-half of the sand, and all the cementitious materials are briefly mixed together. The balance of the sand is then charged and the remaining water added. The amount of water added should be the maximum that is consistent with satisfactory workability.

Mixing is carried out most effectively when the mixer is charged to its design capacity. Overloading can impair mixing efficiency and mortar uniformity. The mixer drum should be completely empty before charging the next batch.

Mixing by hand. When hand-mixing of mortar becomes necessary, as on small jobs, all the dry materials should be mixed together by hoe, working first from one end of a mortar box (or wheelbarrow) and then from the other. Next, two-thirds to three-fourths of the required water is mixed in with the hoe and the mixing continued as above until the batch is uniformly wet. Additional water is carefully mixed in until the desired workability is attained. The batch should be allowed to stand for approximately 5 minutes and then thoroughly remixed with the hoe.

Retempering. Fresh mortar should be prepared at the rate used, so that its workability remains fairly consistent throughout the day. Mortar that sits unused for long periods of time tends to dry out and stiffen. Loss of water by absorption and evaporation on a dry day can be reduced by wetting the mortarboard and covering the mortar in the mortar box, wheelbarrow, or tub.

If necessary to restore workability, mortar may be retempered by adding water; thorough remixing is then necessary. Although small additions of water may slightly reduce the compressive strength of the mortar, the result is acceptable. Masonry built using plastic mortar has a better bond strength than masonry built using dry, stiff mortar.

Fig. 10. To restore workability, mortar may be retempered. (IMG13630)

Mortar that has stiffened because of hydration should be discarded. Since it is difficult to determine by sight or feel whether mortar stiffening is due to evaporation or hydration, the most practical method of determining the suitability of mortar is on the basis of time elapsed after mixing. Mortar should be used within 2½ hours after mixing.

Retemper colored mortar cautiously to avoid color changes. Water content and stiffness of mortar during tooling can also affect color.

All-Weather Construction

The key to successful construction of masonry in any weather —hot or cold—lies in advanced planning and careful preparation. All-weather construction involves some change in procedures and additional equipment and supplies. Both hot and cold weather significantly influence the entire masonry construction industry. Hot-weather problems often have been encountered but not recognized, resulting in some sacrifice of quality or increase in construction costs. On the other hand, greater extension of the construction season into the winter months in recent years has resulted in better utilization of manpower and encouraged innovative construction techniques.

Hot-weather construction. Hot weather poses some special problems for masonry construction. These arise, in general, from higher temperatures of materials and equipment and more rapid evaporation of the water required for cement hydration. Other factors contributing to the problems include wind velocity, relative humidity, and sunshine.

As the temperature of mortar increases, there are several accompanying changes in its physical properties:

- Workability is lessened; or, for a given workability, more water is required.
- A given amount of air-entraining agent yields less entrained air.
- Initial set and final set occur earlier, and evaporation rates are generally faster.
- Depending on the surface characteristics, temperature, and moisture content of the masonry units, their absorption of moisture from the mortar may be faster.

The *MSJC Specification* defines hot weather construction as occurring when ambient temperature exceeds 100°F or 90°F with a wind velocity greater than 8 mph (38°C or 32°C at 13 km/h in CSA A371). Under such conditions masonry units are to be set within one minute of spreading mortar and open mortar beds are to be limited to no more than 4 ft (1.2 m). Additional measures such as storing masonry materials and equipment in cool shaded areas, constructing wind breaks, cooling mixing water, and controlling evaporation rates by covering or fogging masonry may be helpful. High absorption clay masonry units should be wetted before use to reduce initial rates of absorption. Concrete masonry units should not be wetted before use.

Cold-weather construction. Ideal temperature for the placement and curing of masonry mortar is in the range of 70°F ± 10°F (21.1°C ± 5.5°C). In cold weather, defined as 40°F (4.4°C) and below, mortar materials need to be heated; otherwise, the mortar is likely to exhibit slower setting times and lower early strengths.

Water acts as a lubricant in the plastic mortar and is required for hydration of the portland cement contained in the mortar. While mortar stiffens as water is absorbed by units and evaporates, the hardening of mortar is a result of the reaction between the portland cement and water. This reaction rate is temperature dependent and is slowed or stopped when the cement paste temperature is below 40°F (4.4°C). When masonry construction is carried on during periods of cold weather, proper facilities should be available for preparing the mortar and protecting the fresh masonry work during the critical early curing stages, when the free water content of mortar is high (above 6%), to avoid disruptive expansion in the mortar due to freezing. Sufficient heat must be provided to ensure hydration of the cement. After combining all ingredients, mortar temperature is required to be within the range of 40°F to 120°F (United States), or 20°C to 50°C (Canada). Mortar temperatures in excess of 120°F (50°C) may cause excessively fast hardening, with resultant loss of compressive and bond strength. Table 5 shows requirements at various cold-weather temperatures for heating of materials and

Figs. 11a, b. Warm sand and a continuous supply of hot water may be needed when cold weather arrives. Sand can be heated over fire in a pipe (above) and water can be heated in metal drums (below). (IMG12506, IMG12507)

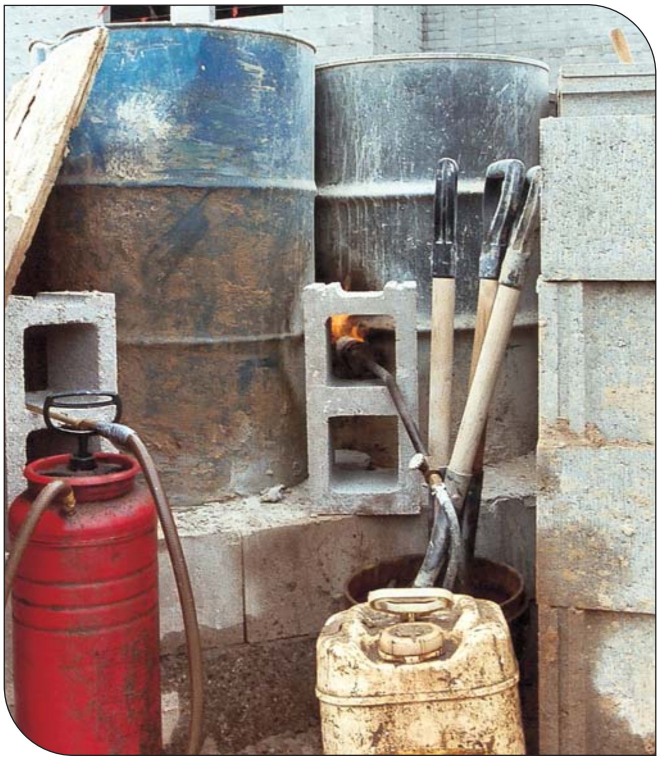

Table 5a. Cold Weather Construction Requirements for Work in Progress (United States)*

Temperature (ambient)	Cold weather procedures
Above 40°F (4.4°C)	No special requirements.
Below 40°F (4.4°C)	Do not lay glass unit masonry.
32°F to 40°F (0 to 4.4°C)	Heat sand or mixing water to produce mortar temperature between 40°F and 120°F (4.4°C and 48.9°C) at the time of mixing. Heat materials for grout only if they are below 32°F (0°C).
25°F to 32°F	Heat sand or mixing water to produce mortar temperature between 40°F and 120°F (4.4°C and 48.9°C) (-3.9°C to 0°C) at the time of mixing. Keep mortar above freezing until used in masonry. Heat materials to produce grout temperature between 70°F and 120°F (21.1°C and 48.9°C) at the time of mixing. Keep grout temperature above 70°F (21.1°C) at the time of placement.
20°F to 25°F (-6.7°C to -3.9°C)	In addition to requirements for 25°F to 32°F (-3.9°C to 0°C), heat masonry surfaces under construction to 40°F (4.4°C) and use wind breaks or enclosures when the wind velocity exceeds 15 mph (24 km/h). Heat masonry to a minimum of 40°F (4.4°C) prior to grouting.
20°F (-6.7°C) and below	In addition to all of the above requirements, provide an enclosure and auxiliary heat to keep air temperature above 32°F (0°C) within the enclosure.

*Adapted from recommendations of the International Masonry Industry All-Weather Council and requirements of Masonry Standards Joint Committee (MSJC) *Specification for Masonry Structures* (ACI 530.1-02/ASCE 6-02/TMS 602-02).

Table 5b. Protection Requirements for Newly Completed Masonry (United States)*

Temperature (minimum for grouted; mean daily for ungrouted)	Cold weather procedures
Above 40°F (4.4°C)	No special requirements.
25°F to 40°F (-3.9°C to 4.4°C)	Cover newly constructed masonry with a weather-resistive membrane for 24 hours after being completed.
20°F to 25°F (-6.7°C to -3.9°C)	Cover newly constructed masonry with weather-resistive insulating blankets (or equal protection) for 24 hours after being completed. Extend the time period to 48 hours for grouted masonry, unless the only cement used in the grout is Type III portland cement.
20°F (-6.7°C) and below	Keep newly constructed masonry above 32°F (0°C) for at least 24 hours after being completed. Use heated enclosures, electric heating blankets, infrared lamps, or other acceptable methods. Extend the time period to 48 hours for grouted masonry, unless the only cement used in the grout is Type III portland cement.

*Adapted from recommendations of the International Masonry Industry All-Weather Council and requirements of Masonry Standards Joint Committee (MSJC) *Specification for Masonry Structures* (ACI 530.1-02/ASCE 6-02/TMS 602-02).

Table 6a. Cold Weather Construction Requirements for Work in Progress (Canada)*

Air temperature	Cold weather procedures
0°C to 4°C	Heat sand or mixing water to a minimum of 20°C and a maximum of 70°C.
-4°C to 0°C	Heat sand or mixing water to a minimum of 20°C and a maximum of 70°C.
-7°C to -4°C	Heat sand or mixing water to a minimum of 20°C and a maximum of 70°C. Provide heat on both sides of walls under construction. Use windbreaks when wind exceeds 25 km/h.
-7°C and below	Heat sand or mixing water to a minimum of 20°C and a maximum of 70°C. Provide enclosures and supplementary heat to maintain air temperature about 0°C. The temperature of the unit when laid should not be less than 7°C.

Note: Grout should be placed at a minimum temperature of 20°C and a maximum temperature of 50°C, then maintained about 0°C for 24 hours following placement of the grout.

*Source: Canadian Standards Association (CSA 1994).

Table 6b. Protection Requirements for Newly Completed Masonry (Canada)*

Mean daily air temperature	Cold weather procedures
0°C to 4°C	Protect masonry from rain of snow for 24 hours.
-4°C to 0°C	Completely cover masonry for 24 hours.
-7°C to -4°C	Completely cover masonry for 24 hours with insulating blankets.
-7°C and below	Maintain masonry above 0°C for 24 hours by enclosure and supplementary heat.

Note: The amount of insulation required to properly cure masonry in cold weather shall be determined on the basis of the expected air temperature and wind velocity (wind-chill factor) and the size and shape of the structure.

*Source: Canadian Standards Association (CSA 1994).

protection of construction. Table 6 shows the same information for masonry in Canada.

The use of Type III portland cement or non-chloride based accelerators may be helpful to increase rates of early-age strength development of masonry mortar. Accelerators normally used include soluble carbonates, silicates and fluosilicates, aluminous cements, calcium aluminate, and some organic compounds such as triethanolamine. Calcium chloride, a common accelerator for use in concrete, can have adverse side effects such as corrosion of embedded metal. Therefore, the *MSJC Specification* prohibits its use as an admixture for mortar.

Admixtures are not effective in lowering the freezing point of mortars to any appreciable degree. The quantity of such materials would be so large that mortar strength and other desirable properties would be seriously impaired. Therefore the use of accelerators does not eliminate the need to observe recommended cold weather practices or the need to protect newly constructed masonry from freezing.

Fig. 12. Enclosure and heating of a work area protects materials, workers, and installed masonry from severe weather. (IMG12508)

Fig. 13. The storage bin/batcher at this central plant stores individual mortar ingredients (masonry cement, portland cement, lime, and sand) in separate compartments. The computer controlled plant batches the dry ingredients by weight and dry blends them prior to discharge into the silos. (IMG14081)

Special Mortar Production Techniques

Packaged Dry Mortar Materials. Packaged, combined, dry mortar ingredients have been available since 1936. The bag of dry mortar contains cementitious materials and dry sand accurately proportioned and blended at a manufacturing plant. Only water and mixing are required at the project. The mortar is available in Types M, S, and N. Packaged dry mortar is very useful on small jobs, such as projects needing 1 cu ft to 5 cu ft (0.03 m^3 to 0.14 m^3) of mortar, or jobs with limited space to store mortar ingredients. This mortar should meet the requirements of ASTM C 387, Specification for Packaged, Dry, Combined Materials for Mortar and Concrete. ASTM C 387 contains property specifications similar to those in Table 2.

Dry-batching. In dry-batching, the cementitious materials and dried sand are accurately weighed and blended at a central plant before delivery to the site in a sealed truck, where the mixture is conveyed into a sealed, weathertight hopper. When the mason contractor is ready for mortar, he has only to add the water and mix. In a variation of this basic concept, the premixed dry mortar materials may be delivered to the jobsite in bulk-pack bags. The process of dry-batching mortar ingredients alleviates the need to adjust the mix for moisture content of the sand and ensures consistent portions of sand and cementitious materials.

Silo-Mixed Mortar. Silo mixers consist of a screw (auger) mixer that is fed dry mortar ingredients for a silo. Single bin silos use preblended mortar ingredients, whereas multi-compartment silos house mortar ingredients separately. For example, two compartment silos have one compartment for sand and one compartment for cementitious materials.

The silo is filled with mortar ingredients at a central plant, delivered to the jobsite by truck, and erected. Mortar ingredients are accurately weighed and preblended as needed at the plant to meet the specific project requirements. On site, the unit needs only to be connected to a pressurized water source and electricity. Mixing at the project is controlled by a computer, so the contractor merely presses a button when mortar is needed. The mortar is usually deposited into a portable tub or wheelbarrow for distribution at the jobsite.

As with the dry-batching techniques mentioned previously, silo mixed mortars provide accurate batching of mortar materials, reduce jobsite waste, and require very little jobsite space.

Fig. 14. When connected to electricity and water at the jobsite, the silo mixer is ready to produce mortar as needed. (IMG14096)

Extended Life Mortar. Extended life mortar, also known as ready-mixed mortar, is batched at a central location, usually a ready mixed concrete or mortar batch plant, mixed in the plant, and delivered to the jobsite in trowel-ready condition. Extended life mortar is made with essentially the same ingredients as conventional mortar, except that the mortar contains a special retarding, set-controlling admixture that keeps the mortar plastic and workable for a period of more than 2-½ hours, usually 24 to 36 hours. Conventional mortar ingredients (cement, lime, and sand) in conventional proportions are combined with a retarding, set-controlling admixture and enough water to provide the desired field consistency. The ingredients are mixed at a central location, using either stationary mixers or truck mixers. An important advantage of extended life mortar is that the ingredients are accurately measured by mass (weight) or by metering devices, thereby producing more uniform mixes closely meeting design specifications. The volumetric methods used for conventionally prepared field mortar can be less accurate.

Table 7. Property Specifications for Extended Life Mortar*

Mortar type	Average compressive strength at 28 days, minimum psi (MPa)**	Minimum water retention, %	Maximum air content, %†
RM	2500 (17.2)	75	18
RS	1800 (12.4)	75	18
RN	750 (5.2)	75	18
RO	350 (2.4)	75	18

*Adapted from ASTM C 1142.

**The strength values are standard 2-in. (50-mm) cube strength values. Intermediate values may be specified in accordance with project requirements. Cylindrical specimens (2x4 in. or 3x6 in., [50x100mm or 75x150mm]) can also be used as long as their strength relationship to cube strength is documented by the producer with test data. The 28-day time period starts when the specimens are cast, not when the mortar is initially mixed.

†When structural reinforcement is incorporated in mortar, the maximum air content shall be 12% or bond strength test shall be provided to justify higher air content.

The design of extended life mortar is usually based on a performance specification and, therefore, proper preliminary laboratory testing is required to determine ingredient proportions. Once proportions are established, they should not be changed throughout the job except for admixture adjustments required to compensate for temperature changes to maintain a consistent setting period or board life.

Extended life mortar should meet the requirements of ASTM C 1142, *Specification for Extended Life Mortar for Unit Masonry*. The mortar types are designated as Type RM, RS, RN, and RO. Table 7 lists the property specifications for these mortars.

Trowel-ready mortar is delivered to the jobsite in ready mix trucks, mortar transports, mortar containers, or hoppers (see Fig. 15). The mortar is stored in a protected metal or plastic container (¼ to ⅓ cubic yard or cubic meter) to minimize evaporation and avoid temp-erature extremes. The retarding, set-controlling admixture delays the initial hydration of the cement, causing the mortar to remain plastic and workable for 24 to 36 hours.

Extended life mortar is used the same way as conventional mortar in reinforced and nonreinforced masonry. If the mortar stiffens due to evaporation or absorption of water, the mortar can be retempered with additional water to restore workability. However, the mortar should not be used beyond its predetermined life expectancy.

When the mortar is placed between masonry units, the units absorb water from the mortar, thereby removing the set-controlling admixture from solution, at which time the extended life mortar proceeds to set like normal mortar. Therefore, masonry walls can be constructed at the same rate as walls with normal mortar. Like normal mortar, sufficient water should be present in the mortar to develop proper strength gain; however, special precautions should be taken to reduce evaporation on hot and windy days.

Extended life mortar should be used with caution with nonabsorbent units such as glazed units and glass block. Extended life mortar should be retarded for no more than 10 hours for non-absorbent units.

The cautions and concerns of using conventional mortar are also applicable to extended life mortar. Special information about the use of extended life mortar, including jobsite storage requirements, useful life, and allowable extent of retempering, should be provided by the producer.

Specific controls and procedures must be carefully followed in order to obtain a successful mortar mix with an extended plastic life. Among these are careful mix design and careful batching controls.

Fig. 15. Extended life, or ready-mixed, mortar is often delivered in mortar containers (tubs) or a flatbed truck. The mortar-filled containers are unloaded and left at the jobsite. (IMG14082)

Table 8. Modifiers–Benefits and Concerns

Modifier	Primary benefits	Possible Concerns
Air-entraining	Freeze-thaw durability, workability	Effect on compressive and bond strengths
Bonding	Wall tensile (and flexural) bond strength	Reduced workability, bond strength regression upon wetting, corrosive properties
Plasticizer	Workability, economy	Effect on hardened physical properties under field conditions
Set accelerator	Early strength development	Effectiveness at cold temperatures, corrosive properties, effect on efflorescence potential of masonry
Set retarder	Workability retention	Effect on strength development, effect on efflorescence potential of masonry
Water reducer	Strength, workability	Effect on strength development under field conditions with absorptive units
Water repellent	Weather resistance	Effectiveness over time
Pozzolanic	Increased density and strength	Effect on plastic and hardened physical properties under field conditions, adequate curing
Color	Aesthetic versatility	Effect on physical properties, color stability over time

To maintain quality and consistent behavior of the mortar, sources of supply for the original mix ingredients should not deviate. Bond and compressive strength, water permeance, and other properties of extended life mortar are generally equivalent to the properties of conventional mortar. The applicable laboratory, batch plant, and field quality assurance tests in ASTM C 1142 and C 780 or CSA A179 should be used and a qualified inspector should be present to perform the tests. Specimens for comp-ressive strength tests should be moved from the field to the laboratory after the mortar has undergone final set and the specimens are four or more days old.

Masonry walls built with extended life mortar can be loaded at about the same time as walls built with normal mortar, except when used with low absorptive units or wet units. If the loading period is of concern, ASTM C 1314 prism tests can be performed to determine proper loading time.

Modified Mortars. Occasions arise when modified masonry mortar may be considered beneficial. Modified mortars are conventional masonry mortars altered by either the addition of an admixture at the mixing location or the replacement of one of the basic mortar ingredients. Benefits are appraised from laboratory testing of comparative mortars and testing of walls containing comparative mortars.

ASTM C 270 recognizes admixtures when specified, but the present specification does not provide guidance toward accept/reject criteria. Some of the concerns with respect to the indiscriminate use of admixtures are discussed in the appendix to ASTM C 270.

Modifiers considered for use in the masonry industry are essentially similar to those used in the concrete industry. Concrete technology, however, must be tempered for masonry industry applications and assessment of benefits. Modifiers having varying degrees of acceptance in the masonry industry are classified in Table 8.

Selection and use of a mortar modifier should be based on field performance and laboratory testing. Manufacturers of mortar modifiers should be asked to provide data supporting their claims as to the performance of their products under the anticipated climatic conditions that will prevail during use. Modifiers, be they admixtures or replacements, must not be used indiscriminately.

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C 91-03a Standard Specification for Masonry Cement

C 144-03 Standard Specification for Aggregate for Masonry Mortar

C 150-02a Standard Specification for Portland Cement

C 151-00 Standard Test Method for Autoclave Expansion of Portland Cement

C 207-91(1997) Standard Specification for Hydrated Lime for Masonry Purposes

C 270-03 Standard Specification for Mortar for Unit Masonry

C 387-00e1 Standard Specification for Packaged, Dry, Combined Materials for Mortar and Concrete

C 595-03 Standard Specification for Blended Hydraulic Cements

C 780-02 Standard Test Method for Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry

C 952-02 Standard Test Method for Bond Strength of Mortar to Masonry Units

C 1012-02 Standard Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution

C 1072-00a Standard Test Method for Measurement of Masonry Flexural Bond Strength

C 1142-95(2001) Standard Specification for Extended Life Mortar for Unit Masonry

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C 1157-02 Standard Performance Specification for Hydraulic Cement

C 1314-02a Standard Test Method for Compressive Strength of Masonry Prisms

C 1329-03a Standard Specification for Mortar Cement

C 1384-02a Standard Specification for Admixtures for Masonry Mortars

C 1489-01 Standard Specification for Lime Putty for Structural Purposes

C 1506-03 Standard Test Method for Water Retention of Hydraulic Cement-Based Mortars and Plasters

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PCA R&D Serial No. 2226

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