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Mortars for Brickwork

Abstract: This *Technical Note* addresses mortars for brickwork. The major ingredients of mortar are identified. Means of specifying mortar are covered. Mortar properties are described, as well as their effect on brickwork. Information is provided for selection of the appropriate materials for mortar and properties of mortars.

Key Words: hardened mortar properties, mortar, plastic mortar properties, specifications, Types of mortar.

SUMMARY OF RECOMMENDATIONS:

General

- Use mortar complying with ASTM C270
- For typical project requirements, use proportion specifications of ASTM C270
- Per ASTM C270, the proportion specifications are the default if not specified
- Select mortar Type using recommendations of *Technical Note* 8B
- Use Type N mortar for normal use, including most veneer applications
- Avoid combining two air-entraining agents in mortar

Mortar Materials

- Cementitious:
  - Use cement complying with ASTM C150 (portland cement), ASTM C595 (blended hydraulic cement) or ASTM C1157 (hydraulic cement) in combination with either hydrated lime complying with ASTM C207, Type S, or lime putty complying with ASTM C1489
  - Use mortar cement complying with ASTM C1329
  - Use masonry cement complying with ASTM C91
- Aggregate:
  - Use natural or manufactured sand complying with ASTM C144
- Water:
  - Use potable water free of deleterious materials
- Preblended dry mix:
  - Use materials that comply with ASTM C1714
  - Per ASTM C1714, the property specifications of ASTM C270 are the default if not specified

Mortar Admixtures

- Use admixtures complying with ASTM C1384
- When using a bond enhancer admixture, do not use an air-entraining agent
- Do not use water-repellent admixtures

Pigments

- Use pigments complying with ASTM C979
- Use as little pigment as possible
- For metallic oxide pigments, limit quantity to 10 percent of cement content by weight
- For carbon black pigment, limit quantity to 2 percent of cement content by weight
- When using metallic oxide or carbon black pigments for mortar cement and masonry cement, reduce the above pigment percentages by half
- Avoid using pigments containing Prussian blue, cadmium lithopone, and zinc and lead chromates
- Premix cement and coloring agents in large, controlled quantities
- Do not retemper colored mortar

INTRODUCTION

Mortar is the bonding agent that integrates brick into a masonry assembly. Mortar must be strong, durable and capable of keeping the masonry intact, and it must help to create a water-resistant barrier. Also, mortar accommodates dimensional variations and physical properties of the brick when laid. These requirements are influenced by the composition, proportions and properties of mortar ingredients.

Because concrete and mortar contain the same principal ingredients, it is often erroneously assumed that good concrete practice is also good mortar practice. In reality, mortar differs from concrete in working consistencies, methods of placement and structural performance. Mortar is used to bind masonry units into a single element, developing a complete, strong and durable bond. Concrete, however, is usually a structural element in itself.

Mortar is usually placed between absorbent masonry units and loses water upon contact with the units. Concrete is usually placed in nonabsorbent metal or wooden forms, which absorb little if any water. The importance of the water–cement ratio for concrete is significant, whereas for mortar it is less important. Mortar has a high water–cement ratio when mixed, but this ratio is reduced as water is drawn into pores of the absorptive masonry units upon contact with mortar.

Mortar is usually specified to conform to ASTM C270, *Standard Specification for Mortar for Unit Masonry* [Ref. 1]. This *Technical Note* contains information on specifying and using mortar. It uses ASTM C270 as a basis and addresses the materials, properties and means of specifying mortars. Refer to *Technical Note* 8B for information on the selection and quality control of mortars and to *Technical Note* 7B for information on placement of mortar and tooling of mortar joints.

MATERIALS

Historically, mortar has been made from a variety of materials. Burned gypsum and sand were used to make mortar in ancient Egypt, while lime and sand were used extensively in the United States before the 1900s. Currently, the basic dry ingredients for mortar include some type of cement, a plasticizer and sand. Hydrated lime usually serves as the plasticizer, but ground limestone is a common plasticizer for masonry cement and mortar cement–based mortars. Each of these materials makes a definite contribution to mortar performance.

Cementitious Materials

Portland Cement. Portland cement, a form of hydraulic cement, is the principal cementitious ingredient for cement-lime mortar. It contributes to durability, high strength and early setting of the mortar. Portland cement used in masonry mortar should conform to ASTM C150, *Standard Specification for Portland Cement* [Ref. 1]. Of the 10 portland cement Types covered by ASTM C150, seven (I, IA, II, IIA, III, IIIA and V) are permitted for use in mortar per ASTM C270. Of the seven Types listed in ASTM C270, three are preferred for use in masonry mortars:

- **Type I:** for use when the special properties of Type II and Type III are not required
- **Type II:** for general use, especially when moderate sulfate resistance is desired
- **Type III:** for use when high early strength is desired

In many cases, the locally available cement may be designated Type I/II, indicating that the cement meets the requirements of both Type I and Type II. Type I/II should be acceptable where Type I or Type II are required. Although Types IA, IIA and IIIA are permitted for use in mortar specified in accordance with ASTM C270, these cements are not preferred because of the air entrainment present in the cement. If air-entrained cements are used, they should not be combined with any other air-entraining admixture.

Hydraulic Cement. ASTM C270 permits the use of other hydraulic cements in mortar. Some of these materials may slow the strength gain or may affect the color of mortar. Hydraulic cements should conform to one of the following standards: ASTM C595, *Standard Specification for Blended Hydraulic Cements*, or ASTM C1157, *Standard Performance Specification for Hydraulic Cement* [Ref. 1]. The use of blended hydraulic cements, which can include portland blast-furnace slag cement, portland-pozzolan cement or slag cement, is not recommended unless the mortar containing such cements meets the property specifications of ASTM C270.

Masonry Cements. Masonry cements are proprietary cementitious materials for mortar. They are widely used because of their convenience and good workability. ASTM C91, *Standard Specification for Masonry Cement* [Ref. 1], defines masonry cement as “a hydraulic cement, primarily used in masonry and plastering construction, consisting 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.” ASTM C91 provides specific criteria for physical requirements and performance properties of masonry cements. The constituents of masonry cement may vary depending on the manufacturer, local construction practices and climatic conditions.

Masonry cements are classified into three Types by ASTM C91: Types M, S and N. ASTM C91 requires a minimum air content of 8 percent (by volume) and limits the maximum air content to 20 percent for Type N masonry cement and 18 percent for Types S and M masonry cements. When structural reinforcement is incorporated in a Type N masonry cement mortar, the maximum permitted air content is 18 percent. Mortar prepared in the field will typically have an air content that is 2 to 3 percent lower than mortar tested under laboratory conditions.

In the model building codes, allowable flexural tensile and modulus of rupture stress values for masonry built with masonry cement mortar are lower than those for masonry built with non-air-entrained portland cement-lime or mortar cement mortar. Therefore, the use of masonry cement should be based on the requirements of the specific application.

Mortar Cements. Mortar cements are hydraulic cements, consisting of a mixture of portland or blended hydraulic cement, plasticizing materials such as limestone or hydrated or hydraulic lime, and other materials intended to enhance one or more of the properties of mortar. In this respect, mortar cement is similar to masonry cement. However, ASTM C1329, *Standard Specification for Mortar Cement* [Ref. 1], includes requirements for minimum flexural bond strength that are not included in other cement specifications. The intent of this material is to provide a level of performance similar to that of a portland cement-lime mortar with the ease of use and workability of a masonry cement. Three Types of mortar cements are specified in ASTM C1329: Types M, S and N. Physical requirements vary depending upon mortar cement Type. Air content for all three Types must be a minimum of 8 percent. The maximum air content is 18 percent for Types M and S and 20 percent for Type N. When structural reinforcement is incorporated in a Type N mortar cement mortar, the maximum permitted air content is 18 percent. Flexural bond strength, as measured by the test method in ASTM C1072, *Standard Test Method for Measurement of Masonry Flexural Bond Strength* [Ref. 1], is also specified in ASTM C1329. Per that standard, the minimum flexural bond strength for these mortar cements is 115 psi (0.8 MPa) for Type M, 100 psi (0.7 MPa) for Type S and 70 psi (0.5 MPa) for Type N.

Because of the strict controls on air content and the minimum strength requirement, mortar cement and portland cement-lime mortars are treated similarly in the *Building Code Requirements for Masonry Structures* (TMS 402) [Ref. 5].

Hydrated Lime and Lime Putty

Hydrated lime is a derivative of limestone that has been through two chemical reactions to produce calcium hydroxide. Lime contributes to workability, water retention, elasticity and extent of bond.

Hydrated lime in ASTM C207, *Standard Specification for Hydrated Lime for Masonry Purposes* [Ref. 1], is available in four Types: S, SA, N and NA. BIA recommends that only Type S hydrated lime be used in mortar for masonry. ASTM C270 permits both Type S and Type SA lime in all applications; however, Type SA lime is air-entrained, and its use is discouraged in many cases, as discussed previously. ASTM C270 permits the use of Type N or Type NA lime only when shown by testing or performance record to not be detrimental to the soundness of the mortar. Type N and Type NA hydrated limes contain no limits on the quantity of unhydrated oxides and are not recommended for use in masonry mortar.

Lime putty products made from hydrated lime are discussed in ASTM C1489, *Standard Specification for Lime Putty for Structural Purposes* [Ref. 1]. Products covered under this specification are often used in restoration projects for historic structures that were originally constructed without cement in the mortar.

Because lime hardens only upon contact with carbon dioxide in the air, hardening occurs over a long period of time. However, if small hairline cracks develop, water and carbon dioxide that penetrate the joint will react with calcium hydroxide from the mortar and form calcium carbonate. The newly developed calcium carbonate will seal the cracks, limiting further water penetration. This process is known as autogenous healing.

Aggregates

Aggregates (sand) act as a filler material in mortar, providing for an economical mix and controlling shrinkage. Either natural sand or manufactured sand may be used. Gradation limits are given in ASTM C144, *Standard Specification for Aggregates for Masonry Mortar* [Ref. 1].

Gradation can be easily and inexpensively altered by adding fine or coarse sands. Sometimes the most feasible method requires proportioning the mortar mix to suit the available sand, rather than requiring sand to meet a particular gradation. In cases where the sand does not meet the grading requirement of ASTM C144, it can comply through the gradation alternate in ASTM C144, which permits the sand to be used if the mortar prepared using the sand complies with the aggregate ratio, water retention, air content and compressive strength requirements noted in the property specifications of ASTM C270. Note that the gradation alternate does not supersede compliance with the fineness modulus requirement of ASTM C144.

The sand should also be free of organic contaminants and contain no more than 50 parts per million of chloride ions.

Water

Water that is clean, potable and free of deleterious acids, alkalis, salts or organic materials is suitable for masonry mortars.

Admixtures

Admixtures are sometimes used in mortar to obtain a specific mortar color, increase workability, decrease setting time, increase setting time, increase flexural bond strength or act as a water repellent [Ref. 2]. Admixtures to achieve a desired color of the mortar are the most widely used. Although some admixtures are harmless, some are detrimental to mortar and the resulting brickwork. Because the properties of both plastic and hardened mortars are highly dependent on mortar ingredients, the use of admixtures should not be considered unless their effect on the mortar and the masonry is known.

Admixtures should be evaluated for their effect on the mortar. ASTM C1384, *Standard Specification for Admixtures for Masonry Mortars* [Ref. 1], provides methods to evaluate the effect of admixtures on mortar properties. The evaluation will compare the mortar with the admixture with the properties required for mortar per ASTM C270. The admixtures represented in ASTM C1384 are as follows:

- **Bond enhancers:** Bond enhancers improve flexural bond strength, surface density and freeze-thaw resistance. They are typically used to increase bond strength to smooth dense surface units and applications such as copings and pavers. Bond enhancers should not be used with air-entraining agents.
- **Set accelerators:** Set accelerators shorten the time required for cement hydration to occur and typically reduce the setting time by 30 to 40 percent. They are typically used to reduce the time required for cold-weather protective measures. Set accelerators typically increase short-term compressive strengths and may affect color.
- **Set retarders:** Set retarders increase the board life of fresh mortar by increasing the time required for cement hydration to occur. They are typically used in conjunction with hot-weather protective measures or to aid in reducing the rapid suction associated with high initial rate of absorption (IRA) brick. Mortar with set retarders may require moist curing to maintain hydration. Set retarders typically reduce short-term compressive strength and may affect color.
- **Water repellents:** Water-repellent admixtures are typically used in conjunction with concrete masonry units where the admixture is added to both the mortar and to the concrete masonry units. When water-repellent admixtures are used in mortar alone, they may inhibit bond and are not recommended for use with brick.
- **Workability enhancers:** Workability is a combination of several properties, including plasticity, consistency, cohesion, adhesion, water retentivity, setting characteristics and response to unit suction. All of these properties allow for easier placement of mortar on masonry units. Air-entraining admixtures would fall within this category. The benefits of workability enhancers are subjective, as these properties are not readily measurable in the lab. As a result, the use of workability enhancers is more to suit the liking of the mason. Workability enhancers should be reviewed to ensure that there are no deleterious effects on the mortar.

In addition to the effect on the mortar, admixtures should also be evaluated for their effect on the masonry, masonry units and any embedded items in the brickwork. Any admixtures containing chlorides will promote corrosion of embedded metal anchors and joint reinforcing and therefore are not recommended. If admixtures containing chlorides are specified by the designer, the admixture should not add more than 65 ppm water-soluble chloride or 90 ppm acid-soluble chloride to the mortar's overall chloride content as determined by the test methods described in C1384.

Air Entrainment of Mortar Materials

ASTM C270 places limits on the percentage of air content in masonry mortar because research has historically shown that high air entrainment can significantly reduce the bond between the mortar and brick or reinforcement. Consequently, most building codes have lower allowable flexural tensile stress values for mortar made with air-entrained cementitious materials. A cement-lime mortar prepared with no air-entraining components will typically contain approximately 8 percent air and is permitted to have a maximum of only 12 percent air. As a result, the use of air-entrained cementitious materials, air-entrained lime or air-entraining admixtures is not recommended for this mortar formulation. Mortar cement and masonry cement mortars are permitted to contain a higher percentage of air content per ASTM C270; therefore, there is more leeway for the inclusion of air-entrained materials within the mortar ingredients.

Recent research on Type S mortar [Ref. 7] evaluated the bond strength and water penetration resistance of mortar cement mortars with low and high air content. The performance of a Type S portland cement-lime mortar with low and high air content was also evaluated. In both cases, the high air content values exceeded the current limits permitted in ASTM C270. The research found that mortar cement mortar with a high air content did not correlate with increased water penetration, whereas the portland cement-lime mortar with high air content performed significantly worse for water penetration resistance out of the mortar Type/air content combinations tested. While high bond strengths were achieved with the high air content mortar cement mortar, the evaluation was limited to concrete masonry units, not clay masonry units. While the study demonstrates that high air content does not always correlate with increased water penetration in clay brick masonry construction, it does highlight the significance of compatibility between the brick and mortar. More research is recommended to confirm whether similar effects can be achieved using Type N mortar as it relates to water penetration resistance. In addition, testing should be conducted to evaluate the effect on bond strengths when Type S and Type N mortars are used with clay masonry units.

Being cognizant of the amount of air that will be introduced into the mortar is critical to selecting the correct materials for the application. BIA recommends limiting the combination of air-entrained ingredients, as an adverse combination of materials can significantly impact the mortar.

Colored Mortar

Colored mortars may be obtained through the use of colored aggregates or suitable pigments. The use of colored aggregates is preferable to pigments when the desired mortar color can be obtained through the use of aggregates. Sand, ground granite, marble or stone usually have permanent color and do not weaken the mortar. For white joints, the use of white sand, ground limestone, or ground marble combined with white cementitious materials and lime is recommended.

Most pigments that conform to ASTM C979, *Standard Specification for Pigments for Integrally Colored Concrete* [Ref. 1], are suitable for mortar used in brick masonry. Mortar pigments must be sufficiently fine to disperse throughout the mix, capable of imparting the desired color when used in permissible quantities, and must not react with other ingredients to the detriment of the mortar. These requirements are generally met by metallic oxide pigments. Carbon black and ultramarine blue also have been used successfully to color mortar. Avoid using organic colors and, in particular, colors containing Prussian blue, cadmium lithopone, and zinc and lead chromates. Also, paint pigments are not suitable for mortars, as they do not conform to ASTM C979.

Use as little pigment as is needed to produce the desired results; an excess may seriously impair the strength and durability of the mortar. The maximum permissible quantity of most metallic oxide pigments is 10 percent of the cement content by weight for cement-lime mortars and 5 percent for either masonry or mortar cement mortars. When a combination of pigments is used to produce the desired color, the total combined dosage rate of all pigments should not exceed any of the individual maximum dosage rates of the component pigments. Although carbon black is a very effective coloring agent, it will greatly reduce mortar strength when used in greater proportions. Therefore, the amount of carbon black should be limited to 2 percent of the cement content by weight for cement-lime mortars and 1 percent for masonry or mortar cement mortars.

Incorporating color into mortar can be achieved in three ways: adding color pigments to the mortar mix separately in the field, using a colored cement or using a colored mortar mix. Colored cement and colored mortar mixes are prepared at the manufacturing plant and delivered to the site in bags. These products are available in portland cement, mortar cement or masonry cement formulations. For best results, use cement and coloring agents premixed in large, controlled quantities. Premixing large quantities will ensure more uniform color than can be obtained by mixing smaller batches in the field. Specifying a colored cement or colored mortar mix can help achieve uniform color, as large-scale premixing occurs at the manufacturing plant. For all colored mortar products, a consistent mixing sequence is essential for color consistency when mixing mortar batches in the field. Further, use the same source of mortar materials throughout the project. Do not add additional pigment to premixed colored mortar unless specifically directed to by the mortar manufacturer.

Color uniformity varies with the amount of mixing water, the moisture content of the brick when laid and whether the mortar is retempered. It is generally recommended to not retemper colored mortar, as it will dilute the intended color. To compensate for this, mixing of smaller batches is recommended. The time and degree of tooling and cleaning techniques also will influence final mortar color. Color permanence depends upon the quality of pigments and the weathering and efflorescing qualities of the mortar.

SPECIFYING MORTAR

Mortar specified for use in masonry must comply with the requirements of ASTM C270. Use of a preblended dry mortar mix conforming to ASTM C1714, *Standard Specification for Preblended Dry Mortar Mix for Unit Masonry* [Ref. 1], is permitted to prepare an ASTM C270–compliant mortar. Masonry mortars are classified by ASTM C270 into four Types: M, S, N and O. Each mortar Type consists of aggregate, water, and one or more of the four cementitious materials (portland or hydraulic cement, mortar cement, masonry cement and lime) listed in the previous section.

There are two methods of specifying mortar by Type in ASTM C270: proportion specifications and property specifications. Per ASTM C270, the requirements for the proportion specifications are the default if neither is specified. However, in cases where the mortar uses a preblended dry mortar mix per ASTM C1714, the property specification requirements in ASTM C270 are the default. Unless otherwise required, a cement-lime mortar, a mortar cement mortar or a masonry cement mortar is permitted.

From a practical standpoint, the number of mortars used on a job should be minimized. However, some projects may require different mortars for various masonry applications. Project specifications often include all the permitted mortar ingredients without sufficient direction regarding the intended mortar constituents for each application. It is recommended that the designer specify the desired cementitious material(s), selecting cement-lime mortar, mortar cement mortar or masonry cement mortar, as well as the mortar Type for each masonry application used on the project. Consider a mortar schedule to avoid confusion.

Proportion Specifications

The proportion specifications require that mortar materials be mixed according to given volumetric proportions. If mortar is specified by this method, no laboratory testing is required, either before or during construction. Table 1 lists proportion requirements of the various mortar Types. Note that masonry cement and mortar cement should be used alone with sand, without lime, to produce Type M, S, N or O mortars. Additionally, Type N mortar cement or masonry cement may be combined with portland cement to produce a Type M or Type S mortar.

TABLE 1

Proportion Specification Requirements[a]

Note: Two air-entraining materials shall not be combined in mortar.

Mortar	Type	Proportions by Volume (Cementitious Materials)								Aggregate Ratio (Measured in Damp, Loose Conditions)
		Cement[a]	Mortar Cement			Masonry Cement			Hydrated Lime or Lime Putty	
			M	S	N	M	S	N		
Cement-Lime	M	1	—	—	—	—	—	—	¼	Not less than 2½ and not more than 3 times the sum of the separate volumes of cementitious materials
	S	1	—	—	—	—	—	—	over ¼ to ½	
	N	1	—	—	—	—	—	—	over ½ to 1¼	
	O	1	—	—	—	—	—	—	over 1¼ to 2½	
Mortar Cement	M	1	—	—	1	—	—	—	—	
	M	—	1	—	—	—	—	—	—	
	S	½	—	—	1	—	—	—	—	
	S	—	—	1	—	—	—	—	—	
	N	—	—	—	1	—	—	—	—	
	O	—	—	—	1	—	—	—	—	
Masonry Cement	M	1	—	—	—	—	—	1	—	
	M	—	—	—	—	1	—	—	—	
	S	½	—	—	—	—	—	1	—	
	S	—	—	—	—	—	1	—	—	
	N	—	—	—	—	—	—	1	—	
	O	—	—	—	—	—	—	1	—	

a. Includes cements that comply with the requirements of ASTM C150/150M, C595/C595M and C1157/C1157M.

The volumetric proportions given in Table 1 can be converted to weight proportions using assumed weights per cubic foot (cubic meter) for the materials as follows:

- **Portland cement:** varies, use weight printed on bag
- **Masonry, mortar and blended cements:** varies, use weight printed on bag
- **Hydrated lime:** 40 lb (641 kg)
- **Lime putty:** 80 lb (1281 kg)
- **Sand, damp and loose:** 80 lb (1281 kg) of dry sand

Property Specifications

The property specifications require a mortar mix of the materials to be used for construction to meet the specified properties under laboratory testing conditions. If mortar is specified by the property specifications, then compressive strength, water retention and air content tests must be performed prior to construction on mortar mixed in the laboratory with a controlled amount of water. The material quantities determined from the laboratory testing are then used in the field with the amount of water determined by the mason. Materials with different characteristics from those tested under laboratory conditions should not be used in the mortar unless compliance with the property specifications has been reestablished. Table 2 lists property requirements of the various mortar Types.

Properties of field-mixed mortar cannot be compared with the requirements of the property specifications because of the different amounts of water used in the laboratory mortars compared with the field mortars, the use of different mixers and the different curing conditions. Field mortar will generally be wetter and have a lower compressive strength than laboratory mortar. This is because additional mixing water is needed to account for the amount lost when laid with units. Field sampling of mortar, where specified, is typically performed for tracking project consistency from beginning to end. It is not to be used for compliance with property specifications. Additional information about this type of quality assurance testing can be found in *Technical Note* 8B.

TABLE 2

Property Specification Requirements[a]

Mortar	Type	Average Compressive Strength at 28 Days, Min. psi (MPa)	Water Retention, Min. %	Air Content, Max %[b]	Aggregate Ratio (Measured in Damp, Loose Conditions)
Cement-Lime	M	2500 (17.2)	75	12	Not less than 2¼ and not more than 3½ times the sum of the separate volumes of cementitious materials
	S	1800 (12.4)	75	12	
	N	750 (5.2)	75	14[c]	
	O	350 (2.4)	75	14[c]	
Mortar Cement	M	2500 (17.2)	75	18	
	S	1800 (12.4)	75	18	
	N	750 (5.2)	75	20[d]	
	O	350 (2.4)	75	20[d]	
Masonry Cement	M	2500 (17.2)	75	18	
	S	1800 (12.4)	75	18	
	N	750 (5.2)	75	20[d]	
	O	350 (2.4)	75	20[d]	

a. Laboratory-prepared mortar only.

b. Air content of non-air-entrained portland cement-lime mortar is generally less than 8 percent.

c. When structural reinforcement is incorporated in cement-lime, the maximum air content shall be 12 percent.

d. When structural reinforcement is incorporated in masonry cement mortar or mortar cement mortar, the maximum air content shall be 18 percent.

Proportion vs. Property Specifications

The specifier should indicate in the project specifications whether the proportion or the property specifications are to be used. If the specifier does not indicate which should be used, then the proportion specifications govern by default. The specifier also should confirm that the mortar Types selected and the materials indicated in the project specifications are consistent with the structural design requirements of the masonry. For instance, if a particular mortar strength is required for structural elements within the project, this should be specified and identified for that application. The same mortar is not required to be used throughout the project.

Mortar prepared by the proportion specifications is not to be compared with mortar of the same Type prepared by the property specifications. A mortar that is mixed according to the proportion specification will have a higher laboratory compressive strength than that of the corresponding mortar of the same mortar Type and made of the same cementitious materials that is mixed according to the property specification [Ref. 8].

PHYSICAL PROPERTIES OF MORTAR

Mortars have two distinct, important sets of properties: those in the plastic state and those in the hardened state. The plastic properties help to determine the mortar's compatibility with brick and its construction suitability. Properties of plastic mortar include workability, water retention, initial flow and flow after suction. Properties of hardened mortars help determine the performance of the finished brickwork. Hardened properties include flexural bond strength, durability, extensibility and compressive strength. The properties of plastic mortar are more important to the mason, while the properties of hardened mortar are more important to the designer and owner.

Workability

Workability is the most important physical property of plastic mortar. A mortar is workable if its consistency allows it to be spread with little effort and if it will readily adhere to vertical masonry surfaces. This results in good extent of bond between the mortar and the brick, which provides resistance to water penetration. Although experienced masons are good judges of the workability of a mortar and have developed various methods to determine suitability, there is no standard laboratory or field test for measuring this property. A mason can best judge the workability of mortar by observing its response to the trowel.

Workability is affected by many properties, including but not limited to water retention, flow and resistance to segregation. In turn, these are affected by properties of the mortar ingredients. Because of this complex relationship, quantitative estimates of workability are difficult to obtain. Until a test is developed, the requirements for water retention and aggregate gradation must be relied upon to provide a quantitative measure of workability.

Water Content

Water content is possibly the most misunderstood aspect of masonry mortar, probably due to the similarity between mortar and concrete materials. Many designers mistakenly base mortar specifications on the assumption that mortar requirements are similar to concrete requirements, especially with regard to the water/cement ratio.

Many specifications incorrectly require mortar to be mixed with the minimum amount of water consistent with workability and prohibit retempering of the mortar during construction. Mortar mixed and placed following such specifications typically exhibits higher compressive strengths but lower bond strengths. Mixing mortar with the maximum amount of water consistent with workability will provide maximum bond strength within the capacity of the mortar. As a result, water content normally should be determined by the mason or bricklayer to produce the best workability. Retempering is permitted to replace water lost by evaporation. This is usually controlled by the requirement that all mortar be used within 2½ hours after initial mixing, or 2 hours after initial mixing in hot-weather construction. Mortar should not be used once it has begun to set.

Water Retention/Water Retentivity

Water retentivity is the ability of a mortar to hold water when placed in contact with absorbent masonry units. The laboratory value of water retention is the ratio of flow after suction to the initial flow, expressed in a percentage. Flow after suction, as described in ASTM C91, is determined by subjecting the mortar to a vacuum and remeasuring the flow of the mortar. The vacuum suction in this test simulates the suction of the brick, also referred to as IRA. The water content of the mortar will need to be adjusted to accommodate higher or lower absorption values of the brick. A mortar that has low water retention will lose moisture more rapidly and should be used with a low-IRA brick. A mortar that has high water retention will keep moisture and should be used with a high-IRA brick.

In general, the following will increase mortar water retention:

1. Addition of sand-fines within allowable gradation limits
2. Use of highly plastic lime (Type S lime)
3. Increased air content
4. Use of hydraulic cement containing very fine pozzolans

Refer to *Technical Note* 7A for a more detailed discussion regarding the water retention properties of mortar and the IRA of brick.

Initial Flow

Initial flow is essentially a measure of the mortar's water content. It can be measured by either of two methods: ASTM C109, *Standard Test Method for Compressive Strength of Hydraulic Cement Mortars*, or ASTM C780, *Standard Test Method for Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry* [Ref. 1].

In ASTM C109, a truncated cone of mortar is formed on a flow table, which is then mechanically raised ½ in. (12.7 mm) and dropped 25 times in 15 seconds. During this test, the mortar will flow, increasing the diameter of the mortar specimen. The initial flow is the ratio of the increase in diameter from the initial 4 in. (102 mm) cone base diameter, expressed in a percentage. Flow rates are laboratory tests.

In ASTM C780, a 3½ in. (89 mm) high hollow cylinder is filled with mortar, and a cone-shaped plunger, whose point is placed at the top of the cylinder, is dropped into the mortar. The depth of the cone penetration into the mortar is measured in millimeters. The greater the penetration of the cone into the mortar, the greater its flow or water content. Cone penetration can be measured in the laboratory or in the field.

Construction mortars generally require higher initial flow rate values than laboratory mortars to produce adequate workability. Laboratory mortars are mixed to have an initial flow of only 105 to 115 percent, whereas construction mortars normally have initial flows in the range of 130 to 150 percent (sometimes higher in hot weather) to produce workability satisfactory to the mason. Requirements for laboratory-prepared mortar should not be applied to field-prepared mortar. Test results of laboratory-prepared mortar should not be compared with test results of field-prepared mortar without considering the initial flow of each. The lower initial flow requirements for laboratory mortars were set to allow for more consistent test results on most available laboratory equipment, and to compensate for water absorbed by the units during construction.

Extensibility and Plastic Flow

Extensibility is another term for maximum tensile strain at failure. It reflects the maximum elongation possible under tensile forces. High-lime mortars exhibit greater plastic flow than low-lime mortars. Plastic flow, or creep, acting with extensibility will impart some flexibility to the masonry, permitting slight movement. Where greater resiliency for movement is desirable, the lime content may be increased while still satisfying other requirements.

Flexural Bond Strength

Flexural bond strength is perhaps the most important physical property of hardened mortar. For veneer applications, the bond strength of mortar to brick units provides the ability to transfer lateral loads to veneer anchors. For loadbearing applications, the bond influences the overall strength of the wall for resisting lateral and flexural loads. Variables that affect the bond strength include texture of the brick, suction of the brick, air content of the mortar, water retention of the mortar, pressure applied to the joint during forming, mortar proportions and methods of curing.

Brick Texture. The texture of brick affects the mechanical bond between the brick and mortar [Ref. 9]. Mortar bond is greater to roughened surfaces, such as wire-cut surfaces, than to smooth surfaces, such as die-skin surfaces. Sanded and coated surfaces can reduce the bond strength depending upon the amount and type of material on the surface and its adherence to the surface.

Brick IRA (Suction). The laboratory-measured initial rate of absorption (IRA) of brick indicates the brick's suction and whether it should be considered for wetting before use. It is the IRA at the time of laying that influences bond strength. In practically all cases, mortar bonds best to brick with an IRA of 30 g/min/30 in.^{2} (30 g/min/194 cm^2) or less when laid. If the brick's IRA exceeds this value, then the brick should be wetted 3 to 24 hours before laying. Wetted brick should be surface dry when they are laid in mortar.

Several researchers have shown that IRA appears to have little influence on bond strength when the appropriate mortar is used [Ref. 3, Ref. 4 and Ref. 10].

Air Content. Most available information indicates an inverse relationship between air content and bond strength of mortar. Provided that other parameters are held constant, as air content is increased, compressive strength and bond strength are reduced, while workability and resistance to freeze-thaw deterioration are increased [Ref. 12].

Water Content. Mortar with a high water content, or flow, at the time of use is beneficial because it can satisfy the suction of the brick and allow greater control of the mortar for the bricklayer. For all mortars, and with minor exceptions for all brick suction rates, bond strength increases as flow increases. However, excessive water can reduce both workability and bond strength.

The time lapse between spreading mortar and placing brick will affect mortar flow, particularly when mortar is spread on brick with high suction rates, or when construction takes place during hot, dry weather. In such cases, mortar will have less flow by the time brick are placed than when it was first spread. Conceivably, bond to brick placed on this mortar could be reduced. For highest bond strength, reduce the time interval between spreading the mortar and laying brick on top of it to a minimum. Mixing batch sizes that can be used in a timely manner can help to maintain mortar flow.

Because not all mortar is used immediately after mixing, some of its water may evaporate while it is on the mortar board. The addition of water to mortar (retempering) to replace water lost by evaporation should be encouraged, when necessary. Although compressive strength may be slightly reduced and mortar color lightened if mortar is retempered, bond strength may be lowered if it is not. ASTM C270 requires that all mortar be used within 2½ hours after mixing, since the mortar will begin to set. This time may be affected by hot or cold weather, as discussed in *Technical Note* 1.

Materials and Proportions. There is no precise combination of materials that will always produce optimum bond. Mortars made with cement-lime and mortar cement cementitious materials typically have higher flexural bond strengths than do masonry cement mortars [Ref. 3, Ref. 4 and Ref. 6]. Building codes prescribe the same bond strength values to Type S and M mortars [Ref. 5].

Test Methods. Because many variables affect bond, it may be desirable to achieve reproducible results from a small-scale laboratory test. The bond wrench test method discussed in ASTM C1072, *Standard Test Method for Measurement of Masonry Flexural Bond Strength* [Ref. 1], appears to fulfill this need. This testing method evaluates the flexural bond strength of each joint in a masonry prism. The apparatus shown in Figure 1 consists of a stack-bonded prism clamped in a stationary frame. A cantilevered arm is clamped to the top brick over the joint to be tested. The free end of the cantilevered arm is loaded until failure, which occurs when the clamped brick is "wrenched" off.

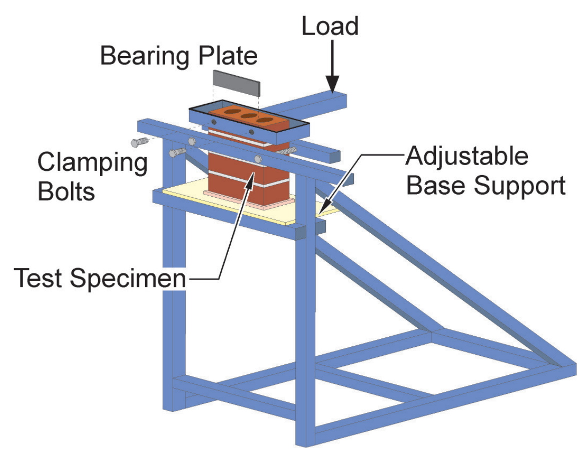

Figure 1
Bond Wrench Test Apparatus

In general, to increase the flexural bond strength:

1. Bond mortar to a wire-cut or roughened surface rather than a die-skin surface.
2. Wet brick with an IRA greater than 30 g/min/30 in.² (30 g/min/194 cm²) when laid.
3. Use Type S cement-lime mortar, Type S mortar cement or Type S masonry cement mortar with air content in the low to middle range of ASTM C91 limits.
4. Mix mortar to the maximum flow compatible with workmanship. Use maximum mixing water, and permit retempering.

Compressive Strength

Because of the similar components used in portland cement concrete and masonry mortar, some designers mistakenly attempt to apply the principles for achieving high-quality concrete to masonry mortar. Unlike concrete, compressive strength is not the primary consideration for brick mortar selection, especially mortar used in brick veneer. Bond strength, workability and water retention are more important than compressive strength in most applications and should be given principal consideration during the mortar design/selection process. The water–cement ratio is also a primary concern for concrete, yet a lesser concern in masonry mortar. The water–cement ratio in plastic mortar is generally higher than the accepted water–cement ratios for concrete. This is because the masonry units laid into the mortar will absorb the mix water, thereby lowering the water–cement ratio of the mortar.

Proportions. Compressive strength increases with an increase in cement content of mortar and decreases with an increase in water content, lime content or over-sanding. Occasionally, air entrainment is introduced to obtain higher flows with lower water content. The reasoning here is that lower water–cement ratios will provide higher compressive strengths. However, this generally proves futile, since compressive strength decreases with an increase in air content.

Test Methods. Compressive strength can be measured by laboratory or field testing that uses 2 in. (51 mm) mortar cubes or 2 in. (51 mm) or 3 in. (76 mm) diameter cylinders. Laboratory procedures for molding and testing mortar cubes appear in ASTM C109, whereas field testing using either mortar cubes or cylinders is discussed in ASTM C780.

Durability

The durability of mortar in unsaturated masonry is not a serious problem. The durability of mortar has been demonstrated by the number of masonry structures that have been in service for many years.

The mortar Types recommended for various applications inherently increase in durability for more severe applications. With respect to resistance to freeze-thaw damage, some professionals may advocate for including air-entrainment ingredients in the mortar mix to increase durability, similar to recommendations for concrete. However, mortar generally contains sufficient entrapped and entrained air to resist freeze-thaw damage in unsaturated applications [Ref. 10]. Though increasing air content may theoretically increase the durability of masonry mortar, a decrease in bond strength, compressive strength and other properties can result. For this reason, air-entraining admixtures to increase air content should be used with caution.

Volume Change

Volume changes in mortars can result from four causes: chemical reactions in hardening, temperature changes, wetting and drying, and unsound ingredients that chemically expand. Differential volume change between brick and mortar in a given wythe has no significant effect on performance. However, total volume change can be significant.

Volume change caused by cement hydration (hardening) is often termed “shrinkage” and depends upon curing conditions, mix proportions and water content. Mortars hardened in contact with brick exhibit considerably less shrinkage than those hardened in nonabsorbent molds. An increase in water content will cause an increase in shrinkage during hardening of mortar if the excess water is not removed. Change in temperature will lead to expansion or contraction of mortar. Thermal expansion and contraction of masonry and means to accommodate the expected movement are discussed in the *Technical Note* 18 Series.

Mortar swells as its moisture content increases and shrinks as it decreases. Moisture content changes with normal cycles of wetting and drying. The magnitude of volume change due to this effect is smaller than that from shrinkage. Unsound ingredients or impurities such as unhydrated lime oxides or gypsum can cause significant volume change and are thus limited by ASTM C207.

Efflorescence

Efflorescence is a crystalline deposit of water-soluble salts on the surface of masonry. Three simultaneous conditions are necessary for efflorescence to occur: a source of soluble salt compounds, moisture to dissolve those compounds and a driving force/evaporation. Limiting water intrusion into masonry construction through proper design and construction helps reduce or prevent efflorescence, as described in ASTM C1400, *Standard*

Guide for Reduction of Efflorescence Potential in New Masonry Walls [Ref. 1]. Mortar may be a major contributor to efflorescence, since it is a primary source of calcium hydroxide. This chemical can produce efflorescence on its own and can react with carbon dioxide in the air or solutions from the brick to form insoluble compounds. Mortar can contain other soluble constituents, including alkalis, sulfates and magnesium hydroxide.

Currently there is no standard test method to determine the efflorescence potential of mortar or of a brick-and-mortar combination. Researchers have concluded that mortars may effloresce under any standard test.

RECOMMENDED MORTAR USES

Selection of a particular mortar Type and materials is usually a function of the needs of the finished masonry element. When selecting a mortar, evaluate properties of each Type and materials and choose the combination that is compatible with the selected brick and will best meet the particular end-use requirements. No single mortar Type is best for all brick units or applications. Refer to *Technical Note* 8B for more information on selection of mortar Type.

GREEN BUILDING/SUSTAINABILITY

Sustainability or "green building" is a movement to use resources efficiently, create healthier environments and enhance the quality of buildings while minimizing social and environmental impacts. For further information about the sustainability of brick masonry, refer to *Technical Note* 48.

While materials used to make mortar are readily abundant and produce a durable material, sustainability can be improved further by using 1) masonry cements that incorporate natural materials, such as ground limestone, as a plasticizer, 2) recycled products such as blast furnace slag cement, and 3) cements with fly ash in the mortar to partially replace portland cement. Blast furnace slag is a byproduct from the production of iron. The waste from the production is processed to produce slag cement. When slag cement is used in mortar, it typically makes the cement hydration process more efficient, increases long-term compressive strength, produces a tighter pore structure and increases workability of mortar during placement. Fly ash comes from coal-fired plants used in generating electrical power. It can replace a portion of the cement in mortar materials. Fly ash increases strength and durability by increasing density. As noted in the Cementitious Materials section, mortars that incorporate these cement materials must be tested to verify compliance with the property specifications of ASTM C270.

SUMMARY

Mortar requirements differ from concrete requirements, principally because the primary function of mortar is to bond masonry units into an integral element. Properties of both plastic and hardened mortars are important. Plastic properties determine construction suitability; hardened properties determine performance of finished elements. When selecting a mortar, evaluate all properties, and then select the mortar providing the best results overall for the particular requirements.

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Volume 4.01

C91/C91M	Standard Specification for Masonry Cement
C109/C109M	Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)
C150/C150M	Standard Specification for Portland Cement
C207	Standard Specification for Hydrated Lime for Masonry Purposes
C595/C595M	Standard Specification for Blended Hydraulic Cements

C1157/C1157M	Standard Performance Specification for Hydraulic Cement
C1329/C1329M	Standard Specification for Mortar Cement
C1489	Standard Specification for Lime Putty for Structural Purposes

Volume 4.02

C979/C979M	Standard Specification for Pigments for Integrally Colored Concrete

Volume 4.05

C144	Standard Specification for Aggregate for Masonry Mortar
C270	Standard Specification for Mortar for Unit Masonry
C780	Standard Test Method for Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry
C1072	Standard Test Method for Measurement of Masonry Flexural Bond Strength
C1384	Standard Specification for Admixtures for Masonry Mortars
C1400	Standard Guide for Reduction of Efflorescence Potential in New Masonry Walls
C1714/ C1714M	Standard Specification for Preblended Dry Mortar Mix for Unit Masonry

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