Designation: C1713 – 17

Standard Specification for Mortars for the Repair of Historic Masonry[1]

This standard is issued under the fixed designation C1713; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers mortar for the repair of masonry that was constructed with methods and materials that pre-date the origination of current standards of construction that are compatible with it. The mortar may be used for non-structural purposes such as repointing of the masonry, or for structural purposes such as, but not restricted to, reconstruction or repair of mortar joints that contribute to the structural integrity of the masonry.

1.2 Masonry includes the following units laid in mortar: (*1*) cast stone, (*2*) clay masonry unitsbrick and clay tile, (*3*) concrete masonry units, (*4*) natural stone, and (*5*) terra cotta.

1.3 This specification may be used to pre-qualify mortar for a project.

1.4 Mortars tested using this specification are laboratory-prepared mortars and do not represent in-place, site mortars.

1.5 Use of this specification should be based on a thorough understanding of the function, maintenance, and repair requirements for the preservation and continued performance of the masonry in the context of the building structure and long-term performance. The user of this specification is responsible for examining all criteria and selecting the appropriate mortar formulation and properties required.

1.6 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.8 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C5 Specification for Quicklime for Structural Purposes
C10 Specification for Natural Cement
C61 Specification for Gypsum Keene's Cement
C91 Specification for Masonry Cement
C109/C109M Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)
C110 Test Methods for Physical Testing of Quicklime, Hydrated Lime, and Limestone
C136 Test Method for Sieve Analysis of Fine and Coarse Aggregates
C141 Specification for Hydraulic Hydrated Lime for Structural Purposes
C144 Specification for Aggregate for Masonry Mortar
C150 Specification for Portland Cement
C207 Specification for Hydrated Lime for Masonry Purposes
C216 Specification for Facing Brick (Solid Masonry Units Made from Clay or Shale)
C270 Specification for Mortar for Unit Masonry
C305 Practice for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency
C511 Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes
C595 Specification for Blended Hydraulic Cements
C780 Test Method for Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry
C948 Test Method for Dry and Wet Bulk Density, Water Absorption, and Apparent Porosity of Thin Sections of Glass-Fiber Reinforced Concrete
C979 Specification for Pigments for Integrally Colored Concrete

[1] This specification is under the jurisdiction of ASTM Committee C12 on Mortars and Grouts for Unit Masonry and is the direct responsibility of Subcommittee C12.03 on Specifications for Mortars.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

C1072 Test Methods for Measurement of Masonry Flexural Bond Strength
C1093 Practice for Accreditation of Testing Agencies for Masonry
C1157 Performance Specification for Hydraulic Cement
C1180 Terminology of Mortar and Grout for Unit Masonry
C1329 Specification for Mortar Cement
C1384 Specification for Admixtures for Masonry Mortars
C1400 Guide for Reduction of Efflorescence Potential in New Masonry Walls
C1403 Test Method for Rate of Water Absorption of Masonry Mortars
C1489 Specification for Lime Putty for Structural Purposes
C1506 Test Method for Water Retention of Hydraulic Cement-Based Mortars and Plasters
C1707 Specification for Pozzolanic Hydraulic Lime for Structural Purposes
E96/E96M Test Methods for Water Vapor Transmission of Materials
E2260 Guide for Repointing (Tuckpointing) Historic Masonry

3. Terminology

3.1 The terms used in this specification are identified in Terminology C1180.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *aggregate, n*—material as defined in Terminology C1180, but limited to the material groups listed under Section 4 of this specification.

3.2.2 *binder, n*—material as defined in Terminology C1180, but limited to the cementitious material groups listed under Section 4 of this specification to be mixed with potable water.

3.2.3 *curing, n*—process by which a mortar gains its long-term, final-state properties.

3.2.4 *curing time (CT), n*—number of days in which a hardened state sample is cured before testing.

3.2.5 *historic masonry, n*—masonry that may have been constructed with methods and materials that pre-date the origination of current standards.

3.3 *Properties*, as determined by Section 8 of this specification:

3.3.1 *absorption rate (AR), n*—a measure of the hardened mortar's ability to absorb water from a dry condition, measured as the initial flow of water into the mortar, as defined under Test Method C1403 and evaluated at the specified curing time (CT).

3.3.2 *air content, n*—cumulative volume of air in a mortar, as a percentage of the total volume of mortar in its plastic state.

3.3.3 *flexural bond strength (FBS), n*—maximum flexural tensile stress that causes failure of the bond between the mortar and masonry unit in a tested assembly at the specified curing time (CT).

3.3.4 *maximum compressive strength (Fcmx), n*—upper allowable limit on the ultimate strength of a hardened mortar sample subjected to compression measured as force per unit area at the specified curing time (CT).

3.3.5 *minimum compressive strength (Fc), n*—lower allowable limit on the ultimate strength of a hardened mortar sample subjected to compression measured as force per unit area at the specified curing time (CT).

3.3.6 *total porosity, n*—volume percentage of all pores or void space in the mortar at the specified curing time (CT).

3.3.7 *water retention, n*—as defined in Terminology C1180. Test shall be conducted on a sample in its plastic state.

3.3.8 *water vapor permeability (WVP), n*—ability of a mortar to pass water through it in vapor form at the specified curing time (CT).

4. Constituent Materials

4.1 *Binder Materials* shall be classified into the following groups:

4.1.1 *Group L*—Lime (non-hydraulic) shall conform to the following specifications:

4.1.1.1 Hydrated Lime shall conform to Specification C207, Types S or SA. Types N and NA hydrated limes are permitted if soaked or shown by test or performance record to be not detrimental to the mortar.

4.1.1.2 Lime putty shall conform to Specification C1489.

NOTE 1—Specification C5, Appendix 1, may be used, and the resulting putty should meet the requirements of Specification C1489.

4.1.2 *Group HL*—Hydraulic Lime shall conform to the following specifications:

4.1.2.1 *Hydraulic Hydrated Lime*—shall conform to Specification C141.

4.1.2.2 *Pozzolanic Hydraulic Lime*—shall conform to Specification C1707.

4.1.3 *Group HC*—Hydraulic Cements shall conform to the following specifications:

4.1.3.1 *Blended Hydraulic Cement*—shall conform to Specification C595.

NOTE 2—Blended hydraulic cement may not be appropriate for structures built before the second half of the 20th century.

4.1.3.2 *Performance Hydraulic Cement*—shall conform to Specification C1157.

NOTE 3—Performance hydraulic cement may not be appropriate for structures built before the second half of the 20th century.

4.1.3.3 *Masonry Cement*—shall conform to Specification C91.

4.1.3.4 *Mortar Cement*—shall conform to Specification C1329.

4.1.3.5 *Natural Cement*—shall conform to Specification C10.

4.1.3.6 *Portland Cement*—shall conform to Specification C150.

NOTE 4—For interior gypsum mortar based systems requiring gypsum cement refer to Specification C61 and consult with the product manufacturer regarding exposure suitability.

4.2 *Aggregates*—Aggregate shall conform to Specification C144. Aggregates that conform to all aspects of Specification C144 except for the gradation limits are permitted if demonstrated by their history of performance under equivalent conditions and mortar formulation to be non-detrimental to the mortar. To determine aggregate gradation, use Test Method C136.

NOTE 5—The need to aesthetically match the color and texture of an existing mortar may be justification for deviating from the gradation limits of Specification C144.

4.3 *Water*—Water shall be clean and free of oils, acids, alkalies, salts, organic materials, or other substances that are deleterious to mortar or any metal used in the masonry.

4.4 *Admixtures:*

4.4.1 *Admixtures*—shall meet the requirements of Specification C1384. Calcium chloride is not permitted. Other admixtures that are outside the scope of Specification C1384 are permitted if they contain no more than 0.3 % water-soluble alkali and if demonstrated by their history of performance under equivalent conditions and mortar formulation to be non-detrimental to the mortar and items in contact.

4.4.2 *Pigments*—Pigments shall meet the requirements of Specification C979. Pigments which are not described by Specification C979 are permitted if demonstrated by their history of performance under equivalent conditions and mortar formulation to be non-detrimental to the mortar. Pigment addition shall not exceed 10 % by weight of the binder materials except for carbon black which is limited to 2 % unless otherwise demonstrated by history of performance under equivalent conditions and mortar formulation to be non-detrimental to the mortar.

5. Mortar Proportioning

5.1 *Binder/Aggregate Ratio:*

5.1.1 Combine the mortars in volume ratios of 1 part total binder materials to 2 to 3½ parts aggregate.

5.1.2 Mortars specified outside volume ratios of 1 part total binder materials to 2 to 3½ parts aggregate shall be permitted if shown by history of use or by mortar testing per this specification to be not detrimental to the mortar.

NOTE 6—Most common mortars have total binder to aggregate ratios of 1 part total cementitious materials to 2½ to 3 part aggregate, whereas some earlier mortars may have ratios as high as 1 to 1.

5.2 *Air Entraining Binders*—Air entraining binders shall not be used in combination with other air entraining binders or with a separate air entrainment admixture.

6. Requirements

6.1 *Establishing Mortar Proportions:*

6.1.1 Specify mortars by (*1*) proportion specification, constituent materials and their respective volume proportions, or (*2*) property specification, constituent materials (or proprietary products names) and required properties, in accordance with Table 1.

6.1.1.1 Specifiers using the proportion specification shall select binder and aggregate proportions based upon an established history of performance or testing that documents satisfactory performance of the combinations and proportions specified, and in conformance with Section 5 of this specification.

NOTE 7—WVP of the mortar should be greater than that of the masonry units, and equal to or greater than that of the substrate mortar where present.

NOTE 8—Vapor permeability will generally decrease with increasing hydraulic constituents; however, aggregate gradation and admixtures can greatly influence the value.

7. Test Samples and Preparation

7.1 *Material Proportioning*—Laboratory mixed mortar specified by volume proportions shall contain the mortar materials as indicated in the mortar specification. Volume proportions shall be converted to weights using the batch factor calculated as follows:

7.1.1 *Material Proportioning for Test Batches of Mortar:*

7.1.1.1 Batch factor = 1440/ [1280 kg/m^3 (bulk density of aggregate) times total aggregate volume proportion].

NOTE 9—A batch size using 1440 g of aggregate will typically result in enough mortar for water retention testing and one set of three 2-in. cubes for compressive strength testing. Several batches with the same water to binder ratio may be necessary to complete all tests.

7.1.1.2 Oven dry and cool to room temperature all aggregate used for test mortars. Mortars preblended with aggregate require no proportioning.

7.1.2 Constituent materials shall have the bulk densities as noted in Table 2.

7.2 *Masonry Units for Use in Water Vapor Permeability and Bond Strength*—Masonry units shall be the actual masonry units to be used in the field, or if unavailable, a brick meeting Specification C216, Grade SW with absorption properties similar to the in-situ masonry units, if known.

7.3 *Mortar Mixing*—Mix the mortar in accordance with Practice C305 with the exception that for Group L and Group HL mortars and those combined mortars at or greater than 45 % lime by binder volume the initial (low speed) mixing time is extended to up to 2 minutes, the resting time is extended to 1.5 minutes, and the final (medium speed) mixing time is extended to up to 8 minutes, as best suits the formulation for complete intermixing of components without segregation or over entrapment of air.

NOTE 10—These time extensions allow for the full wetting of the mortar constituents.

7.4 *Mortar Test Sample Molding:*

7.4.1 For total porosity, absorption rate and compressive strength testing, mold the 2-in. (50-mm) cubes in accordance with Test Method C109/C109M, subsections on Specimen Molds and Molding Test Specimens. For mortars to be used as unit bedding, add enough water to obtain flow of 110 ± 5 %. For mortars to be used as repointing mortars, add enough water to obtain a Vicat Cone Penetrometer value (Test Method C780, Annex A1, Consistency by Cone Penetration Test Method) of 15 mm ± 5 %.

7.4.2 For vapor transmission and bond strength testing mold the samples according to Test Method C1072, with the exception that for the vapor transmission the specimen is two brick, and cheese cloth is to be used as a bond break, and mortar is to have flow values of 120 ± 5%. If the binder material to aggregate volume ratio has not been specified, use a value of 1:3 binder to aggregate ratio measured by volume with sand meeting Specification C144.

7.5 *Sample Demolding*—Table 3 summarizes the demolding time required for different binder combinations.

7.6 *Specimen Storage and Curing*—The storage and curing conditions in Table 3 shall be maintained both before and after demolding, for the duration of the specified Curing Time (CT).

TABLE 1 Specification Requirements

Requirement	Proportion Specification	Property Specification
Water Retention (%)—Water retention value shall not be less than 75 %.	Mandatory requirement for all mortar formulations in their plastic states	Mandatory requirement for all mortar formulations in their plastic states
Air Content (%)—When an air entraining admixture is used, the air content of the mortar shall not exceed 12 %, with the exceptions of mortar cement which shall not exceed 17 % and masonry cement mortar which shall not exceed 21 %.	Mandatory requirement for all mortar formulations	Mandatory requirement for all mortar formulations
Curing Time (CT, days)—Laboratory Test Samples shall be cured according to Section 7. The minimum CT for mortars with Group L and Group HL as binders, and those that combine Group HC with greater than or equal to 45 volume % Group L shall be 120 days. The minimum CT for mortars with Group HC as binder and those that combined Group HC with Group L with less than 45 volume % Group L shall be 28 days. Longer CTs or multiple CTs may be required at the discretion of the specifier. The above is for Laboratory Sample Testing Only.	Mandatory minimum curing requirement for all hardened state mortar test samples	Mandatory minimum curing requirement for all hardened state mortar test samples
Total Porosity (TP, %)—Where a target value has been established by the specifier or the manufacturer, the total porosity % shall not range more than 0.75 to 1.25 times the target value.	Report if specified.	Mandatory if specified. Previously determined TP values obtained using this specification within the last five years from at least five same mortar formulations are permitted to be used.
Water Vapor Permeability (WVP, perms)—Where a target value has been established by the specifier or the manufacturer the water vapor permeability value shall not range more than ±25 % of the target value.	Report if specified.	Mandatory to report. Previously determined WVP values obtained under this specification within the last five years for at least five samples from the same mortar formulation are permitted to be used.
Minimum Compressive Strength (Fc, psi)[A]	Report if specified.	Mandatory requirement.
Maximum Compressive Strength (Fcmx, psi)—Where needed to establish material quality control. Where minimum compressive strength is specified, the value shall not be more than 100 ± 20 % greater than the minimum compressive strength.[B]	Report if specified.	Mandatory if specified.
Flexural Bond Strength (FBS, psi)—Where bond strength of the mortar to masonry unit is critical. In mortars containing more than 50 % of Group HC binder, the FBS average shall be not less than 29 psi.	Report if specified.	Mandatory if specified.
Absorption Rate (AR, g/min/30 in.^{2}) , shall be appropriate for the masonry units employed.	Report if specified.	Mandatory if specified.

[A] This property can be critical to physical compatibility with the surrounding construction, and the structural safety and/or stability of the system.
[B] This property can be critical to physical compatibility with the surrounding construction, as limited by structural safety and/or stability of the system.

7.6.1 Test specimens stored at 70 ± 5 % RH shall be placed in a cabinet or environmental chamber where the relative humidity and ambient CO_2 level can be maintained and documented.

7.6.2 Test specimens stored at 100 % RH shall be placed in a moist room or cabinet following Specification C511.

8. Test Methods

8.1 *Water Retention*—Determine water retention in accordance with the Test Method C1506.

NOTE 11—Water retention cannot be determined for repointing mortars at low flow values. Enough water must be added to obtain a flow of 110 ± 5 %.

8.2 *Air Content*—Determine air content in accordance with Specification C270 or with the air meter technique of Test Method C110.

8.3 *Total Porosity*—Determine total porosity in accordance with Test Method C948, on a set of three 2-in. samples.

8.4 *Absorption Rate*—Determine absorption rate in accordance with Test Method C1403 using three 2-in. cubes, performing weight measurements at 1 and 3 min in addition to the times specified therein, with reported units converted to g/min/30 in.^{2}.

8.5 *Water Vapor Permeability*—Determine in accordance with Test Method E96/E96M. The mortar shall be prepared

TABLE 2 Bulk Density of Constituent Materials

Binder/Aggregate	Material	Bulk Density
Group L Binder	Hydrated Lime	40 pcf (640 kg/m^3)
	Lime Putty	80 pcf (1280 kg/m^3)
Group HL Binder	Hydrated Hydraulic Lime	Obtain from manufacturer
Group HC Binder	Pozzolanic Hydraulic Lime	Obtain from manufacturer
	Portland Cement	Obtain from manufacturer
	Masonry Cement	Obtain from manufacturer
	Mortar Cement	Obtain from manufacturer
	Natural Cement	Obtain from manufacturer
	Blended Hydraulic Cement	Obtain from manufacturer
	Hydraulic Cement	
Pre-blended Binder	Any or all of the above	Obtain from manufacturer
Aggregate		80 pcf (1280 kg/m^3)^A

^{A}The sand is oven dried for laboratory testing to reduce the potential of variability due to sand moisture content and to permit better accounting of materials used for air content calculations. It is not necessary for the purpose of this specification to measure the unit weight of the dry sand. Although the unit weight of dry sand will typically be 85 to 100 pcf (1360 to 1760 kg/m^3), experience has shown the use of an assumed unit weight of 80 lb (1280 kg/m^3) for dry sand will result in a laboratory mortar ratio of aggregate to binder that is similar to that of the corresponding field mortar made using damp loose (bulked) sand.

TABLE 3 Storage Time in Molds

Binder Type	Time in Molds	Specimen Storage Conditions
Group L and Group HL only and combined mortars with 45 % or more lime by binder volume	Minimum 5 days or until the sample is sufficiently stable to demold	70 ± 5 % RH for Group L 90 ± 5 % RH for Group HL
Group HC only and combined mortars with less than 45 % lime by binder volume	2 to 5 days as needed	100 % RH

according to 7.3. At the time of testing, samples will be cut to fit over a testing cup measuring 50 ± 2.5 mm on a side, in a manner so as not to adversely affect the result.

8.6 *Compressive Strength*—Determine in accordance with Test Method C109/C109M (using 2-in. or 50-mm cube specimens), except that samples shall be cured in accordance with 7.6 of this specification.

8.7 *Flexural Bond Strength*—Determine in accordance with Test Method C1072 using masonry units as described in 7.2. Assembly shall be cured in accordance with 7.6 of this specification.

9. Quality Assurance

9.1 Compliance of volume specified mortars to this specification shall be verified by:

9.1.1 Confirmation that the materials in Section 4 of this specification are used shall be verified by letters of certification or mill reports from the manufacturer.

9.1.2 Proportions of material shall be verified by weigh scale certificates or described procedures for proportioning and mixing the approved materials.

NOTE 12—The testing laboratories performing the testing specified herein should be evaluated in accordance with Practice C1093.

10. Keywords

10.1 absorption rate; air content; compressive strength; flexural bond strength; hydrated lime; hydraulic cement; hydraulic lime; lime putty; masonry; natural cement; portland cement masonry cement; preservation; repointing; total porosity; water retention; water vapor permeability

APPENDIXES

(Nonmandatory Information)

X1. EVALUATION, SELECTION AND USE OF MORTAR FOR REPAIR OF HISTORIC MASONRY

X1.1 *Scope*—This specification covers mortar for the repair of masonry that was constructed with methods and materials that pre-date the origination of current standards of construction. The mortar may be used for non-structural purposes such as repointing of the masonry, or for structural purposes such as, but not restricted to, reconstruction or repair of mortar joints that contribute to the structural integrity of the masonry. This appendix is a guide to the use of this specification and provides additional information for use in evaluating and specifying mortars for the repair of historic masonry. Repeated reference is made to the Appendix X1 of Specification C270, which provides nonmandatory information that can be used as a supplement to this appendix. The reader is encouraged to read all of Appendix X1 and X2 in Specification C270 as well as the other appendices in Specification C270 as they will provide helpful information beyond what is specifically referenced herein.

X1.2 *Significance and Use*—Masonry mortar is a versatile material capable of satisfying a variety of diverse requirements and significantly influences the performance of the masonry assembly as a whole. In the repair of existing masonry, it is critical that the mortar being used in the repair is both aesthetically and physically compatible with the existing mortar, as well as the masonry assembly as a whole. In many cases, this may be achieved with nearly equal success by a variety of different mortar types that all satisfy the same requirements. A thorough understanding of both existing mortar materials and those used in the repair and their properties, and their relation to the historic masonry assembly being repaired will enable selection of a mortar that will perform satisfactorily.

X1.3 *Specifying Mortars for Repair of Historic Masonry*:

X1.3.1 *Understanding the Existing Masonry Assembly and Functional Requirements of Mortar for Repair*—In order to properly specify a mortar that is appropriate for the repair of an historic masonry assembly, the user of this specification (specifier) must first understand the materials and functional requirements of the existing masonry assembly, the way in which the assembly has and will behave, how well it has performed, and how appropriate the existing mortar and masonry units have been for the assembly's usage requirements and environment. Based upon this understanding, the specifier must then determine what materials and mortar properties are most appropriate for the mortar that will be used for the repairs.

X1.3.2 *Proportion vs. Property Specification*—This specification provides two ways of specifying mortars: (*1*) by proportion and (*2*) by property, whichever better suits the requirements of the work. The specifier may also designate or restrict allowed material types to be used in a property-specified mortar, and require verification of expected properties on a proportion-specified mortar. In all cases, the proportion-specifier must have a thorough understanding of the available materials, which include binders (cementitious materials), aggregate, water and sometimes admixtures, and their role in the mortar properties that will result. The property-specifier must have a thorough understanding of the properties that are required, as well as the properties that can be achieved with the available materials. The specifier is cautioned not to intermix the requirements of the proportion specification and the property specification in such a way as creates unachievable requirements for given formulations, but must rather, base the use of all overlapping requirements on a thorough understanding of the properties that will result from the specified proportions.

X1.3.3 *Proportion Specification* can be useful for projects where manufactured property-specified mortars are not available or may not best suit the requirements of the work, or where the size of the project is such that it is not expedient for a contractor or manufacturer to produce a pre-tested, prequalified mortar for the specific requirements of the job, as well as in cases where mortar formulations have been developed by the specifier for mixing on site.

NOTE X1.1—It is the intent of this specification to encourage the growth of a public domain repository of mortar formulations and their correlated properties that will be helpful in guiding the process for selection of mortar formulations that must satisfy the specific needs of the project.

X1.3.3.1 *Examples of Proportion Specification*—When using proportion specification, the specifier must list the constituent materials in the mortar with their relative proportions by volume. For example:

> "Mortar A and its constituents shall meet the requirements of ASTM C1713, and shall consist of 1 part portland cement, 3 parts hydrated lime and 12 parts bulked sand by volume."
> or:
> "Mortar B and its constituents shall meet the requirements of ASTM C1713 and shall consist of 2 parts natural cement, 1 part hydrated lime and 7 parts bulked sand by volume with an air content of 8 % plus or minus 2 %."
> or:
> "Mortar C and its constituents shall meet the requirements of ASTM C1713, and shall consist of 2 parts lime putty and 5 parts bulked sand by weight."

X1.3.3.2 Additional requirements can be put into the specification regarding sand gradation, additives and pigments for exposed applications, such as:

> "For architecturally exposed mortar, the aggregate type and gradation shall match the existing exposed original mortar sand and, where necessary, mineral oxide pigments may be added by up to ten percent by weight of binder to adjust the paste color to match the original."

X1.3.3.3 The specifier may also require certain properties to be attained or reported as verification of the formulation (but must allow a mechanism for adjustment of the proportions in order to meet required properties if the original formulation does not), such as:

"Mortar A shall have an Fc of 750 psi and an Fcmx of 1500 psi subject to verification by test in accordance with ASTM C1713. Constituent proportions may be adjusted by up to 25 percent to meet these property requirements, but only with written authorization of the [specifier]."
or:
"The water vapor permeability (WVP) of Mortars B and C shall be determined in accordance with ASTM C1713 and shall be reported in writing."

X1.3.4 *Property Specification* can be useful in projects where pre-blended mortars are available to suit the requirements of the work, or where the size of the project is such that it is expedient for a manufacturer or contractor to produce a pre-tested, prequalified mortar for the specific requirements of the job, as well as cases where the performance requirements of the project are so critical that the specific property requirements drive the design.

X1.3.4.1 *Example of Property Specification*—When using property specification, the specifier should state the allowed constituent types but not the proportions, leaving the determination of proportions to the contractor or manufacturer, to be verified by test (tests shall be batch specific in the case of custom designed mortars or where permitted from previous tests within the last five years for pre-manufactured pre-blended standardized mortars). For example:

"Mortar A and its constituents shall meet the requirements of ASTM C1713, and shall consist of a mix of Group HC and L binders and sand with the following properties as determined in accordance with ASTM C1713 at the required CT: air content of 8 % plus or minus 2 %, Fc=750 psi, Fcmx=1500 psi. The WVP shall be determined in accordance with ASTM C1713 and shall be reported in writing."

or, if more specificity is desired:

"Mortar B and its constituents shall meet the requirements of ASTM C1713 and shall consist of a mix of natural cement and hydrated lime binders and sand following properties as determined in accordance with ASTM C1713 at the required CT: Fc=2500 psi, FBS>50 psi. The WVP shall be determined in accordance with ASTM C1713 and shall be reported in writing."
or:
"Mortar C and its constituents shall meet the requirements of ASTM C1713 and shall consist of a mix of lime putty and sand with an Fc of 350 psi as determined in accordance with ASTM C1713 at the required CT. The WVP shall be determined in accordance with ASTM C1713 and shall be reported in writing."

X1.3.4.2 Additional requirements can be put into the specification regarding sand gradation, additives and pigments for exposed applications, such as:

"For architecturally exposed mortar, the aggregate type gradation shall match that of the existing exposed original mortar and where necessary, up to 10 percent mineral oxide pigment may be added to adjust the paste color to match the original."

X1.3.5 *Binder Materials and Historical Context*—The specification allows a wide range of binder materials because of the many time periods of construction it covers. Lime putty and, to a lesser extent, clay, hydraulic lime, and lime hydrate were the predominent binder materials used up until the mid- to late-19th century. Natural cement was first used in England in 1756 and then North America in 1818, and then became increasingly common throughout duration of the 19th century, particularly in large urban centers and in significant public works, transportation and industrial projects. Portland cement production began in England in the 1820s and began to be exported shortly thereafter, not being produced in North America until the 1870s. By the beginning of the 20th century, portland cement had gained market dominance, becoming one of the primary building materials of the modern industrialized world. Masonry cement was first introduced as a patented product in 1918 and generic masonry cements gained sufficient use in the marketplace to warrant issuing of ASTM , Tentative Specification for Masonry Cement in 1932. Much of this more recent, modern-era construction that was built during the first half of the 20th century, is now old enough that it too can be considered "historic".

X1.3.6 *Differences in Curing Times* in the specification were developed to account for the differences between carbonation-curing, which takes place in Group L and to some extent HL binders, and hydration curing which takes place in Goup HC and HL binders. In simplistic terms, carbonation-curing generally starts from the exposed surface of a mortar and slowly works its way inward (requiring sample testing at up to 120 days), while hydration curing takes place from within (requiring sample testing at only 28 days).

X1.3.6.1 The curing times in hydrating laboratory samples are generally analogous to the curing times that might be experienced in the field, whereas curing times in carbonating samples are usually not analogous to field curing times, because the actual time that it takes to cure a carbonating mortar is dependent upon the mode and pathway of carbon transport from the atmosphere. For example, mortar that is in the core of a granite faced wall with tight joints will carbonate more slowly than the same mortar used in pointing the exposed surfaces of the joints because it takes longer for sufficient carbon to reach the wall's core than the surface. Carbonation is promoted through repeated cycles of wet and dry where care is taken in the early stages to ensure the mortar is not allowed to completely dry out. The unit material, construction sequencing and joint detailing in a masonry assembly along with wetting and drying frequency of the completed work will affect the curing time. The geometric relationship of the mortar, the masonry units and the free air surface, however, will often have an even bigger effect on the in-situ curing time of the mortar, this being a function of the unexposed mortar volume multiplied by the distance from the surface divided by the surface-exposed area.

X1.4 *Function of Mortar in Historic Masonry Assemblies*:

X1.4.1 The purposes of mortar in historic masonry are to bond masonry units together, provide for load-bearing support, weather resistance, vapor transport, architectural expression, and constructability as an integral element having the desired functional performance characteristics. Mortar influences the performance of the assembly in many ways.

X1.4.2 *Functional Requirements*—A masonry assembly may be subjected to numerous external conditions under which it must successfully perform. These include structural loading, induced strains and forced displacements, environmental abrasion, wetting and drying, freezing and thawing, and salt transport. The ability of an historic masonry assembly to perform under these conditions must be maintained or, if needed improved, with the proper selection of materials that will be used in their repair.

X1.4.2.1 *Structural Loading* includes the combined weight of built-in, stationary elements (dead loads), and non-built-in often non-stationary elements (live loads) and the weight of the masonry itself. Moving structural loads, such as vehicles or swinging bells, can also cause dynamic impact live loads. Other structural live loads include wind forces, earthquake forces, and even in rare cases bomb blasts. The masonry assembly, of which mortar is a key component, must be sufficiently strong to support such loads without failure or excessive deformation. The minimum strength (Fc, Fbs) of the mortar must be adequate to properly stabilize and support the masonry units within the loaded assembly whereas the maximum strength (Fcmx) must be less than the units in order to maintain strain compatibility within the assembly (see X1.4.2.2). Generally, mortars with greater quantities of group HC binder materials have higher compressive strengths than those without. Bond strength is a property of mortars in combination with masonry units. Selection and combination of mortar binders can significantly affect bond strength (FBS), however this is also a function of workability, water retentivity, air content, workmanship, curing, and unit properties. Reference may also be made to Appendix X1 of Specification C270, which provides additional information that is useful in understanding the development of strength properties in portland cement and hydrated lime-based mortars.

X1.4.2.2 *Induced Strains and Forced Displacements*—can be caused by heating and cooling cycles where the masonry thermally expands and contracts, as well as moisture growth where some types of masonry units expand upon absorbing water. Strains and forced displacements can also be caused by external structural influences such as lintel deflections, foundation settlements and rust jacking. A masonry assembly will deform elastically until a level of deformation is reached where either plastic yielding occurs, or the assembly fails and a crack is formed. Both the mortar and the masonry units undergo elastic deformation, however when elastic limits are exceeded, then the weaker of the two materials responds. Mortar, the more easily replaceable component, is the preferred sacrificial respondent and must be weaker than the masonry units for this to occur. At equal binder-to-aggregate ratios, lower strength mortars, such as those containing greater amounts of Group L binders, have lower moduli of elasticity, exhibit greater plastic flow, and are therefore more flexible and able to deform plastically than those with higher concentrations of Group HC binders. The properties of mortars with Group HL binders fall in between. When the mortar can no longer deform plastically and a crack occurs, this crack may be within the mortar (joint failure), between the mortar and the masonry unit (bond failure), or through the masonry unit (unit failure). Upper limits on maximum compressive strength (Fmx) help prevent unit failure from occurring. Optimization of flexural bond strength (FBS) helps the masonry assembly withstand higher tensile stress without premature bond failure. Extensibility is the maximum unit tensile strain just prior to rupture, indicative of the maximum elongation under tensile forces, and is discussed in Appendix X1 of Specification C270. Depending upon the location and geometry, where joint failure does occur, hydrated lime provided by Group L and HL binders or released during hydration of Group HC binders can sometimes autogenously heal hairline cracks as the lime migrates to the crack location and carbonates.

X1.4.2.3 *Environmental Abrasion* occurs where wind, water flow, or other environmental dynamics tend to wear away the surface of the masonry. In such cases a harder mortar, such as one containing higher amounts of Group HC binders and the stronger of the HL binders, will be more resistant than mortars with lesser amounts of the same.

X1.4.2.4 *Wetting and Drying* occurs during normal weather cycles, rising dampness and day-to-day functioning of a building. Unlike modern building assemblies, which are designed as impenetrable barriers to water, historic masonry assemblies were intended to depend upon their mass to protect the interiors of structures, as they would absorb and store water that entered them before it could reach the interiors, and then allow the water to drain and evaporate out before the next wetting. The assembly must be able to dry in order to have storage capacity for the next cycle of wetting; and it is usually critical that most of this take place through the mortar joints. Maintaining the ability for sufficient drainage and evaporation through porosity and water vapor permeability (WVP) is thus necessary for the success of the masonry assembly and protection of the structures' interior. Mortars that have greater concentrations of Group L and HL binders tend to higher porosity and WVP.

X1.4.2.5 *Freezing and Thawing*—Damage can occur when expansive forces induced by absorbed water turning to ice exerts pressure within the masonry assembly; and after many ratcheting cycles can begin to cause cracks. Effective drying of the masonry assembly (described in X1.4.2.4) helps minimize the volume of water that can freeze within it. When air entrained mortars are used, the entrained air bubbles in the mortar help give expanding water a place to go.

X1.4.2.6 *Salt Transport*—occurs when there is a flow of water through the mortar created by the wetting and drying process, and dissolved solids, such as salts, are transported in solution within the water. These solids can come from contaminated rainwater runoff or salt-spray, from wicking groundwater or seawater, or even from the masonry itself. When this water evaporates at the surface of the masonry mass, salts are deposited on the surface and evidence themselves as efflorescence. When this water evaporates under the surface of the masonry, damage can occur through cryptoflorescence, where expanding crystals form within the outer shell of the masonry and cause it to unavoidably flake off. It is generally helpful to protect masonry assemblies from environment conditions that can inundate them with salts. Given the fact that there are some situations where the transport of soluble compounds is unavoidable, it is critical that the mortar, which is intended to be replaceable, act sacrificially to the masonry units, which are not. A higher water vapor transmission rate (WVT) in the mortar compared to the masonry units will channel the evaporating water through the joints; and a lower strength (Fcmx, FBS) of the mortar than the units will allow the mortar to spall without damaging the units. Air entrainment within the mortar mass will postpone surface mortar failure by giving the solids, at least for a while, a place to grow. In cases of significant flow, efflorescing salts can also come from within the masonry assembly. This effect is reduced with lower alkali contents in the binder constituents. Refer to Guide C1400 as well as Appendix X2 in Specification C270 for additional information.

X1.4.3 *Constructability*—A masonry assembly must be readily constructible within the limits of time, economy and scale. Earlier mortars containing primarily Group L-based binders and to a lesser extent Group HL binders had limited strength and took a long time to cure. This limited the heights and spans of structures that could feasibly be built, both due to the resulting lower strengths of the masonry assemblies, and the impractical timeframe that would be required in more heavily loaded construction. The development of Group HC binders during the 19th century allowed for larger and higher strength construction which could be built with ever increasing speed.

X1.4.4 *Workability* is the degree by which the physical properties of a mortar in its plastic state aid or hinder the efficiency or quality of the work, and is determined by the binder and aggregate combinations and ratios, the aggregate type and gradation, and the water content. Appendix X1 in C270 provides additional helpful information regarding workability as well as other plastic properties.

X1.4.5 *Architectural Integrity*—Until the Modern Era of the late 20th century, mass masonry served as both the structure and the architectural feature, with many structural components such as flying buttresses, pinnacles, and arches performing critical load-carrying functions while at the same time serving as ornamental features. For example, during the mid-to-late 19th century pigments and multi-colored aggregates were often carefully blended to provide the desired aesthetic effects on exposed surfaces of mortar joints that were part of structural load carrying elements, sometimes with two intentionally distinct colors appearing in the same inter-unit joint. The aesthetic and environmental demands that were placed upon historic masonry assemblies were specific to each structure's developmental and architectural time period and locality.

X1.5 *Selection and Function of Mortar for Repair of Historic Masonry*:

X1.5.1 Many historic materials that were used in the construction of masonry structures, such as natural and portland cement, hydrated lime and lime putty, hydraulic lime, and clay are presently available in the market today in replicated form, and many of these have ASTM specifications. Mortar used for the repair of historic masonry is typically used for re-setting masonry units or for repointing joints, and often for both simultaneously. Rebuilding is done using basically the same methods that the original builders used, methods that are still used today; and repointing should be done as described in Guide E2260. Beyond aesthetics and in-situ performance, application methods, curing requirements, environmental conditions, and speed of construction will be affected by the mortar selection.

X1.5.2 *Selection of Mortar for Repair*—Mortar that is used for the repair of historic masonry should (*1*) be functionally compatible with the existing masonry assembly and maintain or improve the longevity and performance of the assembly, (*2*) be aesthetically appropriate and consistent with the existing mortar, (*3*) have the ability to be installed properly and within the timeframe available for the work, and (*4*) where possible, be authentic to the history of the structure.

X1.5.3 *Functional Compatibility*—When selecting the most appropriate mortar for a repair, there is the option of simply using the same formulation as the original or the option of matching all of the properties of the original mortar that was used. In the case of existing masonry that has performed poorly or prematurely failed, there also is the need to investigate the cause of the failure, and to consider improving upon the properties of the original mortar in order to enhance the longevity and performance of the assembly. Every historic structure has its own history of performance, and most older structures that still survive do so either because they were appropriately constructed and performed well, or because they served an important function and were painstakingly repaired and maintained, or maybe a combination of both. Just because an historic masonry structure exists does not mean that it was necessarily the most suited for the conditions that it has endured. The best way to evaluate the level appropriateness of an existing structure or assembly is to evaluate how successfully it has performed or how often it needed to be repaired.

X1.5.3.1 *Matching Formulations*—Many in the preservation field believe that simply using the same materials as the original is the best way to ensure compatibility and continued successful performance of a well-performing masonry assembly. Although this is logically consistent, the reality is that materials produced today may not have the same performance characteristics as the original materials they are trying to match. The specifier should be aware of and understand these differences and the effects they will have on the masonry assembly, and may need to deviate from the historical proportions accordingly.

X1.5.3.2 *Matching Properties*—Matching the properties of the existing mortar is an effective way of maintaining the same level of performance of a successfully performing assembly. This specification was written so that the tested hardened mortar properties listed in Table 1 can also be applied to the evaluation of the existing mortar, with the intent of allowing comparison. The specifier should be cautioned, however, regarding the potential for deviations in test results between in-situ or retrieved specimens, and laboratory specimens that are indirectly representative of mortars that will be used and cured in the field. While every attempt should be made to reduce these deviations as much as possible through effective sampling and testing techniques, some level of deviation will always exist.

X1.5.3.3 *Improving Properties*—The prospect of successfully "improving" properties of mortar to enhance the performance of the assembly should be tempered with the caution that the specifier should be certain which specific properties actually need to be improved and the consequences of doing so. One classic example was the predominant use of intentionally dense and impervious pointing mortars starting the early to mid-20th century. Common knowledge at the time was that these "improved" mortars would prevent water from entering the masonry; however the reality was that water entered the masonry anyway but could not evaporate back out, resulting in damage.

X1.5.4 *Aesthetic Appropriateness*—Mortar used in the repair of exposed masonry must be aesthetically appropriate for the application. Most commonly, this means color- and texture-matching an existing mortar. In the case of complete repointing or reconstruction this would typically mean matching the original. In the case of partial repointing or rebuilding of elements that were earlier repointed with a non-matching mortar, the difficult decision must be made as to whether it is better to match the inappropriate repointing mortar so that repairs are less visible or to match the original mortar so the historical integrity of the work is maintained but repairs stand out. Also, there are many cases where the historic mortars' pigments and aggregate gradations that did not fall within the limits of currently accepted standards. Such deviations as replicated in the mortar for repairs may be acceptable per this specification as long as it can be demonstrated that the original in-situ mortar performed satisfactorily.

X1.5.5 *Ease and Speed of Construction*—Appropriate plastic properties are critical to ensuring high quality results in the repair work, along with stiffening time and strength gain, which determine how quickly the work can be considered serviceable. Much of the work involving the repair of historic masonry is done in a retrofit situation where the work schedule is driven by the fact that and existing structure has been opened or partially dismantled while in service or temporarily out of service, and needs to be restored to a fully functioning condition as quickly as possible. In the case of structural repairs, there may be damage at the bottom of a structure that requires reconstruction while the upper portion of the structure is still bearing upon it. This can require that the work is done in a sequential, multi-step process and that the work reach its required strength before the next sequential operation is started. In these cases the more rapid strength development ability of mortar with Group HC binders and to a lesser extent Group HL binders, must be weighed against other requirements affecting the selection of mortar.

X1.6 *Important Properties of Mortar for Repair of Historic Masonry*:

X1.6.1 *Plastic Properties* per this Specification include curing time, air content and water retention.

X1.6.1.1 *Curing Time* determines how soon mortar samples can be tested but also affects how quickly mortar can be put into service . The specifier should be cautioned that in mortars with Group L, and to a lesser extent HL binders, the amount of time for an in-place mortar to be considered fully cured will relate to but not be the same as the minimum CT values given in Table 1, with pointing applications sometimes close but re-setting applications usually longer.

X1.6.1.2 *Air Content* is measured while the mortar is in its plastic state. It will ultimately affect the ability of the mortar to withstand freezing and thawing cycles and cryptoflourescing salts, and improves workability. Excessive air content in mortar may lead to decreased compressive strength.

X1.6.1.3 *Water Retention* is the ability of a mortar to retain mixing water when subject to the "suction" of a masonry unit, which is the capillary action in masonry units that draws water out of the freshly placed mortar. Appendix X1 in Specification C270 provides additional helpful information on this subject.

X1.6.2 *Other Plastic Properties to Consider* include workability, flow, water retentivity, and stiffening characteristics will all affect the quality of the construction, and are discussed in Appendix X1 of Specification C270.

X1.6.3 *Hardened Properties* per this Specification include total porosity, water vapor permeability (WVP), minimum compressive strength (Fc), maximum compressive strength (Fcmx), flexural bond strength (FBS) and absorption rate (AR).

X1.6.3.1 *Total Porosity and Absorption* reflect the mortar's ability to absorb, hold and release water. These properties in a mortar used for repair should be equivalent to or greater than those of the existing mortar, and greater than that of the masonry units.

X1.6.3.2 *Water Vapor Permeability* is the ability of the mortar to allow water vapor transport. This property in a mortar used for repair should be equivalent to or greater than that of the existing mortar, and greater than that of the masonry units.

X1.6.3.3 *Minimum Compressive Strength* is the lower allowable limit to be placed on a mortar and directly contributes, along with unit strength, to the strength of the masonry assembly, which must be able to support required loads within code-mandated factors of safety.

X1.6.3.4 *Maximum Compressive Strength* is the upper allowable limit on compressive strength of the mortar. This should always be less than the strength of the masonry units to ensure that the mortar sacrificially fails before the masonry units.

X1.6.3.5 *Flexural Bond Strength* is a good indicator of the bond strength between mortar and a masonry unit and is usually less than the internal tensile strength of the mortar, and therefore a safe measure of the perpendicular-to-plane tensile strength of the mortar joint. This value should always be less than the tensile strength of the masonry units.

X1.6.3.6 *Absorption Rate* is the affinity of a mortar to take up water during wetting cycles and should be appropriate for the masonry units.

X1.6.4 *Other Hardened Properties to Consider* include extensibility, plastic flow, and durability are discussed in Appendix X1 of Specification C270.

X2. SAMPLING, LABORATORY TESTING AND USE

X2.1 It is the intent of the task group to write a second Appendix to this specification with the purpose of providing supplemental guidance for testing and evaluation of new and existing mortars, and later to provide an Annex with public domain target values of common mortar formulations to act as a guideline for use.