Practice Points NUMBER 21

Specifying Mortars under *ASTM C1713: Standard Specification for Mortars for the Repair of Historic Masonry*

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In an era defined by frequent innovations in new building materials and construction technologies, preservation professionals who help care for the past can take solace in the fact that as innovation has marched forward, it has also looked back. Over the past several decades, there has been a resurgence in masonry materials that closely replicate their historic counterparts, and they are becoming available with increasing frequency. As an ever-widening number of "historic" binder materials has been brought back to market, the need for an ASTM mortar standard that embraces this array has become evident (Fig. 1).

Until the introduction of *ASTM C1713*: *Standard Specification for Mortars for the Repair of Historic Masonry* in 2010, the only codified standard that covered the formulation of mortars in the United States was *ASTM C270: Standard Specification for Mortar for Unit Masonry* issued in 1951. This standard is limited to the use of portland cement and hydrated lime blends traditionally used in the twentieth century. However, the Type K air lime and sand blend was removed from the body of the standard and put into the appendix because of infrequent use.

As more and more nontypical yet traditional formulations have been utilized in the preservation of historic masonry assemblies, *ASTM C1713* was created in response to the need for an applicable specification. *ASTM C1713* addresses the design and specification of mortar formulations that include binders and aggregates that are now available.

Fig. 1.
Mortar failure at Pine Bank Mansion, Boston, Massachusetts, 2004. This mass brick masonry was set with lime mortar that has failed due to decades of water infiltration and freezing and thawing. It is an example of the type of sacrificial-joint softening failure that occurs with older, lower-strength mortar binder materials. All figures by author.

Beyond *ASTM C1713*'s main document, there is an appendix ("X1") that is a helpful, abbreviated compendium of information and advice regarding not only the use of the standard but also how it relates to the selection of preservation-purposed mortars in general. It is certainly worth reading.

The Need for Compatibility

In the restoration of historic masonry, no matter whether the work involves reconstruction, back filling, or repointing, it is critical that the mortars act as components that are compatible to the masonry assembly of which they are a part. In order to ensure compatibility, one must fully understand the properties of the other components of the assembly. One must also consider the performance of the overall assembly of which the mortar is a contributing part—not only the structural loading on the assembly but also the microclimatic environment that surrounds it, along with seasonal variations. It is usually assumed that materials that would have been used originally are compatible materials; however, with what may be subtle differences between yesterday's materials and today's manufactured equivalents, compatibility must still be considered even when seemingly similar materials are being used.

In most instances, mortar should behave sacrificially to the masonry units of the assembly, typically being weaker and more breathable than the masonry units but still being sufficiently strong and durable to resist structural and climatic loads. For example, if a pointing mortar is stronger or harder than the stone units it is pressed between, it can act like a sharp knife or wedge between the outer edges of the bricks and stones and cause them to split, chip, or spall as structural loads concentrate themselves on the hard points that are created by the repointing. If the mortar is weaker or softer than the stones, it acts like a soft bed or pad that evens out the bearing loads and eliminates the load concentrations that could otherwise cause damage.

It is also critical that a bedding mortar be weaker than the masonry units it is bonding together so that the mortar yields before the units under heavy loads. Mortars typically have lower elastic moduli than most stone and brick units and deform laterally (Poisson deformation) at the same time they deform longitudinally. This lateral deformation can exert splitting stresses on the masonry units, causing them to fail prematurely. An appropriately lower-strength mortar will plastify or yield before significant splitting stresses can develop, thus sacrificing itself for the longevity of the units.

In addition, a restoration mortar should have about the same strength as the original mortar that remains, assuming that the remaining mortar is sufficiently sound. The combined padding effect between new and old masonry units should provide an even distribution of stress, rather than an uneven or eccentric one. There are many cases where an unyielding pointing mortar combined with a lower-strength bedding mortar has allowed the inside face of the masonry to compress while the outside face splits off (as described above) or even bellies outward.

Mortar should always be more breathable than the masonry units. During a rainstorm, mass masonry commonly absorbs and temporarily stores water from its surrounding environment. After the rain stops, the water then evaporates out in the form of a vapor. In the case of an enclosed structure, the interior is kept dry by the ability of the enveloping masonry to intercept and gather the water before it passes all of the way through it, and the enveloping masonry must be able to evaporate the stored water back out through its exterior surface before the next inundating event.

The repeating absorption and evaporation process occurs by the transport of pore water into and vapor out of the assembly, both through the masonry units and the mortar in competing proportions. The mortar is typically the best avenue for the outward transport, as it surrounds the masonry units and accelerates their drying by wicking away the moisture. If the mortar joints are less breathable than the masonry units, the units will not dry and may succumb to long-term freeze-thaw damage from the perennial wetness or surface shaling and salt crystallization from moisture flow. This eventuality is often a "cubbyhole" effect, where the mortar joints stand proud of the eroded stone units that are recessed between them. Also, stronger mortars tend to be more brittle, and when they crack, they allow water to enter the masonry assembly. Because of the lower breathability of the stronger mortar, this water tends to remain trapped (Fig. 2).

Compressive and flexural strength and breathability are determined by binder type, aggregate type (such as dense versus lightweight and porous aggregates) and gradation, binder-to-aggregate ratio, and, for hydraulic materials, binder-to-water ratios. Compressive strength and breathability generally vary in inverse proportion to each other. Porosity can also be governed by the way the materials are mixed and by using additives.

Binder Options

Mortar consists of a binder plus an aggregate and, in the pre-hardened state, water. Historically, mortar proportions tended to be richer in binder than what is used today. Today, binders most commonly comprise between a quarter to a third of the total volume of the mortar, with aggregate comprising the remaining two-thirds to three-fourths. In some formulations, however, such as those using natural cement, the ratio can be as high as half binder to half aggregate. The amount of water varies with the binder, the aggregate ratio, and the application.

There are generally four families of binders that have been used traditionally.

Dry hardening binders. These consist of non-chemically-hardened binders, such as clay, which hold the aggregate together in a hardened state by simply drying (Fig. 3). Sometimes clay is used with no aggregate at all. Examples of such binders are found in adobe construction and in early wall mortars and plasters, in flues and fireplace pargings, and in kilns. Currently there is no ASTM standard for such binders, but their use is permitted.

Carbonating binders. The next family in the development of binders was made by firing limestone taken from the ground and then slaking it to a traditional putty or modern powdered consistency. The resulting lime binders are hardened and chemically cured through a process called carbonation. This is a slow-acting process, since it is entirely dependent upon the wet- and dry-state transport of atmospheric carbon dioxide into the mortar matrix. Shallow applications, such as surface pointing, cure much more rapidly than deeper applications, such as wall reconstructions where the carbon dioxide has to move a long distance. Sometimes, due to buffering in very thick masonry assemblies, lime-putty mortar at the center of the assembly never fully carbonates and retains the same, cream cheese–like consistency with which it was laid.

Lime can be obtained as a lime putty (*ASTM C1489: Standard Specification for Lime Putty for Structural Purposes*) or as a dry powder, hydrated lime (*ASTM C207: Standard Specification for Hydrated Lime for Masonry Purposes*), the latter with just enough hydrating water to stabilize it. These binders are classified as Type L in the *ASTM C1713* specification.

Fig. 2.
Brick failure at Saint Paul's Church, Cranston, Rhode Island, 2002. This mass brick masonry was set with a portland-cement mortar that has failed due to decades of water infiltration and freezing and thawing. It is an example of the type of non-sacrificial global assembly failure that occurs with more modern, higher-strength mortar binder materials.

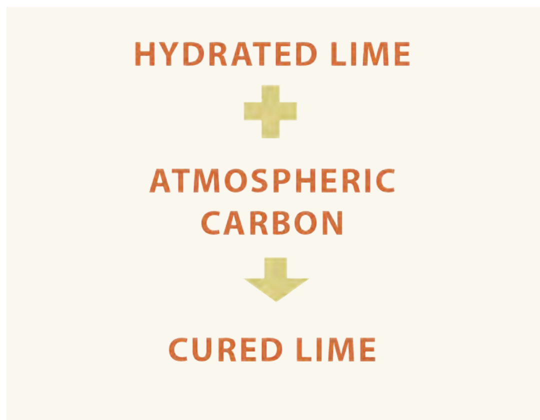

Fig. 3.
Diagram depicting hardening of hydrated lime.

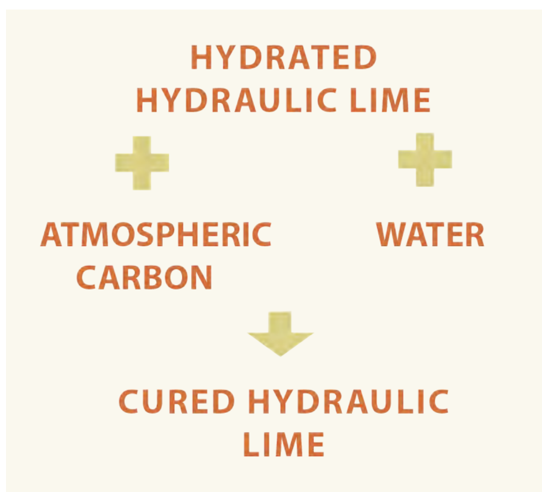

Fig. 4.
Diagram depicting hardening of hydrated hydraulic lime.

Hydraulic carbonating binders. Limestone used to make hydraulic lime must contain significant amounts of alumina and silica. In the natural state, this can occur when the limestone contains significant amounts of alumina- and silica-bearing clay. These stones, when fired and slaked, create a lime that does not only carbonate; it simultaneously cures by a hydraulic reaction that is enabled by the pozzolanic effect of the silica/alumina (Fig. 4). A binder made from these naturally occurring stones is called "natural hydraulic lime," or "NHL."

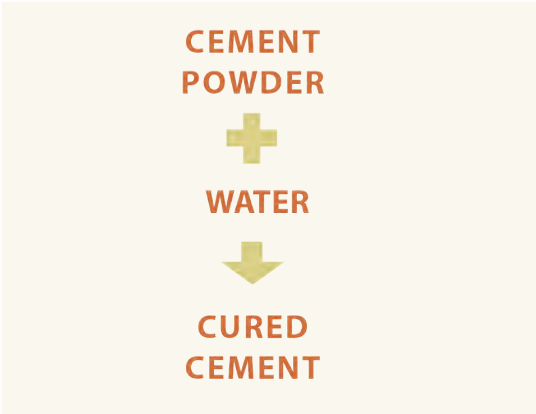

Fig. 5.
Diagram depicting hardening of cement.

Hydraulic lime can also be made artificially by blending air (non-hydraulic) lime and a natural or manufactured material that contains silica and alumina, causing the resultant blended product to behave in a similar manner, curing both by carbonation and hydration. This silica- and alumina-bearing material is called a pozzolan, which is a generally non-cementitious material on its own but that reacts with calcium hydroxide (lime) in water to give it hydraulically cementitious properties. Such pozzolanic materials include ground granulated blast furnace slag; desulfated pulverized fuel ash; fumed silica; and metakaolins, among others. The end product is a binder that we call a "pozzolanic hydraulic lime" or "pozzolan-lime" for short.

Hydraulic carbonating binders, which include hydrated hydraulic lime (*ASTM C141: Standard Specification for Hydraulic Hydrated Lime for Structural Purposes*) and pozzolanic hydraulic lime (*ASTM C1717: Standard Specification for Pozzolanic Hydraulic Lime for Structural Purposes*), are classified as Type HL in the *ASTM C1713* specification.

Hydraulic binders. During the eighteenth century, a form of limestone was discovered that was so argillaceous that after being fired and slaked, it remained in a solid, rock-like form that had to be ground to a powder before use. When this ground material was mixed with water, it hardened hydraulically without the need for any carbon dioxide from the atmosphere, yielding what is now called natural cement. In the early nineteenth century, a competing artificial binder called portland cement was developed; it had properties that surpassed those of natural cement in both strength and rapidity of cure, establishing itself as the predominant binding material, which is used today in modern-day mortars and concrete. Both natural cement (*ASTM C10: Standard Specification for Natural Cement*) and portland cement (*ASTM C150: Standard Specification for Portland Cement*) are available in a dry powder form (Fig. 5).

Other available binders include masonry cement (*ASTM C91: Standard Specification for Masonry Cement*), which is a modified blend of portland cement and inert, non-calcined ground limestone, and blended hydraulic cement (*ASTM C595: Standard Specification for Blended Hydraulic Cements*), which is hydraulic cement blended with pozzolan and/or lime. Mortar cement (*ASTM C1329: Standard Specification for Mortar Cement*) and performance hydraulic cement (*ASTM C1157: Standard Performance Specification for Hydraulic Cement*) are also referenced in *ASTM C1713*. All of these hydraulic binders are classified as Type HC in the *ASTM C1713* specification.

Carbonating binders tend to produce mortars that are of relatively low strength, are slow to set, and have high breathability, while hydraulic binders tend to produce mortars that are of relatively high strength, are fast to set, and have low breathability. Not surprisingly, hydraulic carbonating binders tend to produce mortars that are of relatively low to moderate strength, have a moderate setting time, and have moderate to high breathability.

Tested Properties

Because binders harden at different rates, *ASTM C1713* considers several standard minimum curing times (CT) at which to test for different binder combinations at proportional levels of maturity. They are as follows:

- "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."[1]

The above times were determined based upon the consideration that the tested sample will have achieved at least 85 percent of its ultimate maturation by the specified CT under strictly defined curing regimens (Fig. 6).

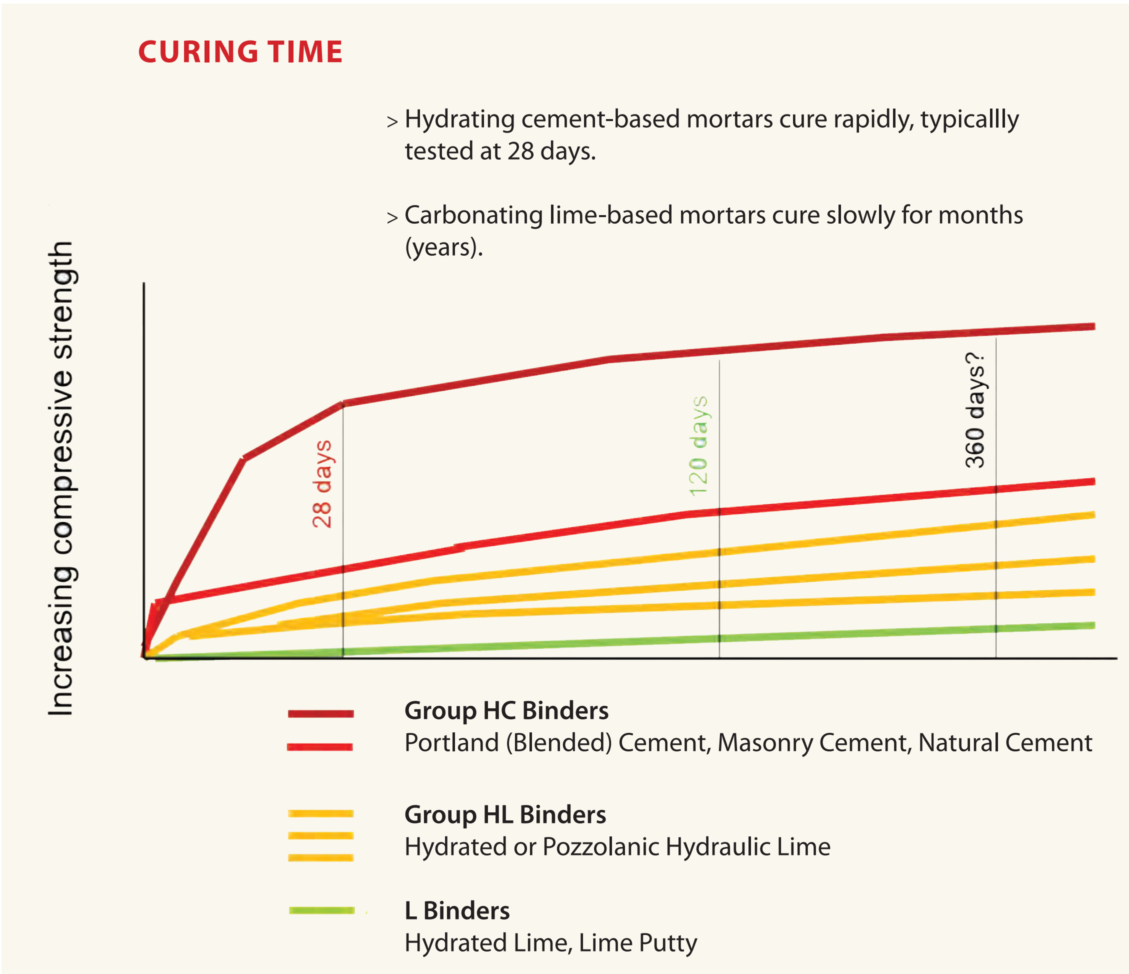

Fig. 6.
Diagram depicting relative rates of cure for various binder materials.

The following properties are considered in *ASTM C1713*:

- Absorption rate (AR), which is the "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 [*Standard Test Method for Rate of Water Absorption of Masonry Mortars*] and evaluated at the specified curing time (CT)."[2] This basically measures the affinity of a mortar to take up water during wetting cycles and should be appropriate for the masonry units that also need to be tested alongside mortars.

- Air content (AC), which is the "cumulative volume of air in a mortar, as a percentage of the total volume of mortar in its plastic state."[3] The entrainment of air achieved by additives, porous aggregates and mixing regimes in certain mortar applications can increase durability; however, *ASTM C1713* includes specified mandatory limits in AC to avoid significant reduction in bond strength.

- Flexural bond strength (FBS), which is the "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)."[4] This measures the mortar's adhesive strength, which tends to be improved by the presence of lime.

- Maximum compressive strength (Fcmx), which is the "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)."[5] This measure is used to ensure that a mortar is not of too high a strength and that it will be compatible with the remaining masonry.

- Minimum compressive strength (Fc), which is the "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)."[6] This measures whether the mortar is of sufficient strength.

- Total porosity (TP), which is the "volume percentage of all pores or void space in the mortar at the specified curing time (CT)."[7] To quote *ASTM C1713*'s commentary, this relates to "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."[8] This measure requires evaluation of the existing substrate mortar, if any, as its own porosity, along with the masonry units.
- Water retention (WR), which is defined via references to *ASTM C1180: Standard Terminology of Mortar and Grout for Unit Masonry* as "the measured physical property of a plastic mortar indicating its ability, under suction, to retain its mixing water." Per *ASTM C1713*, the test shall be conducted on a sample in its plastic state. *ASTM C1713* specifies a lower limit to this property to avoid overly porous masonry units from sucking all of the water out of the mortar.
- Water vapor permeability (WVP), which is the "ability of a mortar to pass water through it in vapor form at the specified curing time (CT)."[9] This is a way of measuring a mortar's relative breathability.

Specifying Mortars under *ASTM C1713*

There are two methods of specifying mortars under *ASTM C1713*—by proportion or by property.

Proportion specification. Using the proportion-specification method, the specifier states the specific materials to be used and their proportions. In addition to the specific mandatory AC and WR property limits in the *ASTM C1713* specification, the specifier can also list properties that should be verified by testing to confirm the performance of the as-supplied formulation.

For example, what would have been called a Type N mortar in *ASTM C270*, might be specified as follows according to *ASTM C1713*:

> 1 part portland cement, 1 part hydrated lime, and 6 parts bulked sand meeting the requirements of *ASTM C1713* and the following additional tested properties at CT = 28 days: Fc = 1,200 psi and Fcmx = 1,800 psi.

Interestingly, the following alternative mortar would also meet *ASTM C270*, Type N:

> 1 part Type N masonry cement and 3 parts sand, with Fc = 750 psi.

Note that this second formulation contains no hydrated lime (using instead ground limestone as a porous soft aggregate) and has no upper limit on compressive strength. Because *ASTM C270* specifies only lower limits on strength, some masonry-cement producers may supply products that simultaneously meet the much higher strength levels of Type S and Type M while still satisfying the Type N specification requirements of *ASTM C270* (by actually meeting all three). This illustrates the strength of *ASTM C1713* versus *ASTM C270*, which has always been more appropriate for new construction.

One can also specify mortars with materials not included in *ASTM C1713*, along with additional property requirements—for example:

> 1 part lime putty, 1/2 part natural cement, and 4 1/2 parts bulked sand that matches the color blend and gradation of that of the existing, in situ mortar, meeting the requirements of *ASTM C1713*.

The proportion-specification method is often most appropriate for site-batched and custom plant-batched formulations. Because of the total control that the proportion specification gives the specifier in the creation of a formulation, the specifier must be mindful to develop formulations that not only are available, practical, and appropriate to the application but also be expected from experience to yield the material properties that are specified or desired.

Property specification. Using the property-specification method, the specifier states the overall type of mortar and the required properties but not the actual proportions. *ASTM C1713* requires that Fc, Fcmx, FBS, and AR be specified; WVP be reported; and the limits on WR and AC be met. For example, the same Type N equivalent can be specified as follows:

> A hydrated lime, portland cement, and sand blend meeting *ASTM C1713* with the following properties at CT = 28 days: Fc = 1,200 psi, Fcmx = 1,800 psi, and FBS = 20 psi. WVP shall be reported.

Another example might be:

> A natural cement, hydrated lime, and sand blend meeting *ASTM C1713* with the following properties

at CT = 120 days: Fc = 500 psi, Fcmx = 750 psi, and FBS = 10 psi. WVP shall be reported.

The property-specification method is often most appropriate for larger site-batched and plant-produced projects where a sufficient amount of a specific mortar formulation is produced so that the production budget can support the additional incremental cost of trial testing for specific properties; it is required by default for plant mass-produced and marketed mortars where publication of the tested material properties is mandatory.

Future Revisions and Additions

ASTM C1713 undergoes periodic review by the ASTM task group and revisions every several years. Most commonly, these revisions consist of updating cross-references to other specifications and miscellaneous updates and improvements. Beyond these reviews, there is the potential for some significant revisions and additions in the future.

One of my personal hopes for the standard is to someday publish target values in a table of likely properties of various mortar formulations in the form of another appendix to the master document. While *ASTM C270* provides minimum properties for the standard Types M, S, N, or O formulations in the body of the document, the wide range of possible formulations allowed under *ASTM C1713* would make such an in-body reference a significant challenge, and such an effort would need to be mirrored with a similar study of masonry units in order to give the mortar properties relative significance. The question has been raised by committee members as to whether ASTM is the proper body to conduct such testing for reference values. As task group chair, I believe that if ASTM could find another organization that would agree to be a partner, such an endeavor could revolutionize the industry.

Conclusion

ASTM C1713 was purposefully written for use by preservation practitioners. While officially the mandatory code of reference in more than 60 countries, it has not been adopted quickly, mainly because many people do not know about it; others might not know how to use it; and the cost might dissuade potential users who are looking for free references online.

ASTM C1713 is a work-in-progress and the first of its type worldwide. While the authors of the specification have attempted to address and define the specific scientific aspects of mortar selection, we have attempted to do this in such a way that we have at least laid the groundwork for future research and the sharing and furthering of knowledge in the public domain. I encourage fellow practitioners to get involved in ASTM, which is a welcoming and well-run organization that gives its members a voice in the development of the standards that define many everyday materials. The Historic Mortars Task Group, C12.03.03, also welcomes new members.

John Wathne is a structural engineer and the president of Structures North Consulting Engineers, Inc., and of VoidSpan Technologies, LLC. VoidSpan produces historic masonry restoration products and its patented “Port Anchor” system, which simultaneously ties and bonds distressed masonry back together. Wathne is chair of the ASTM task group that authored *ASTM C1713*. He can be reached at jwathne@structures-north.com.

Notes

1. *ASTM C1713-17, Standard Specification for Mortars for the Repair of Historic Masonry* (West Conshohocken, Pa.: ASTM International, 2017), 4.

2–7. *ASTM C1713-17*, 2.

8. *ASTM C1713-17*, 10.

9. *ASTM C1713-17*, 2.

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