ASTM International. Designation C270-07. 2007.

…3.3 The compressive strength values resulting from field tested mortars do not represent the compressive strength of mortar as tested in the laboratory nor that of mortar in the wall…

Requirements

5.1 Unless otherwise stated, a cement/lime mortar, a mortar cement mortar, or a masonry cement mortar is permitted. A mortar of known higher strength shall not be indiscrimately substituted where a mortar type of anticipated lower strength is specified….

Note 4: The required properties of mortar in Table 2 are for laboratory prepared mortar….the quantity of water is not sufficient to produce a mortar with a workable consistency suitable for laying masonry units in the field. Mortar for use in the field must be mixed with the maximum amount of water, consistent with workability, in order to provide sufficient water to satisfy the initial rate of absorption (suction) of the masonry units…(*a hydraulic mortar will show diminishing compressive strength as water content increases; an air lime mortar will not, especially if calcareous aggregates are used)*.

Note 5. Air content of non-air-entrained Portland cement-lime mortar is generally less than 8%. *(air content of hot mixed lime mortars between 4-5%; of sand-slaked quicklime, 3-3.5% on test by NRC)*.

(From tables)

Cement-lime 1 portland: between 1 ¼ and 2 ½ air lime: Type O – typical compressive strength after 28 days 350 Psi/ 2.4 MPa

Type S 1 opc: ¼ to ½ air lime. Typical MPa 12.4.

Proportions of both, 1 binder to 'at least 2 ¼ and not more than 3 sand.

6.1.1 When converting volume proportions to batch weights, use the following material bulk densities:

Portland cement 94 lbs per cubic foot
…Lime Putty 80 lbs per cubic foot
Hydrated lime 40 lbs per cubic foot (*difference between putty and hydrate is free water)*
Sand 80 lbs per cubic foot.

Note 7. All quicklime should be slaked in accordance with the manufacturer's directions. All quicklime putty, except pulverised quicklime putty, should be sieved through a No. 20 sieve and allowed to cool until it has reached a

temperature of 80 degrees F (26.7C) *(before mixing and use)*. Quicklime putty should weigh at least 80 lbs per cubic foot. Putty that weighs less than this may be used in the proportion specifications, if the required quantity of extra lime putty is added to meet the minimum weight requirement….

Construction Practices

7.3 *Mixing Mortars* All cementitious materials *(including lime)* and aggregates shall be mixed between 3 and 5 minutes in a mechanical batch mixer with the maximum amount of water to produce a workable consistency…

7.4 *Tempering Mortars* Mortars that have stiffened shall be re-tempered by adding water as frequently as needed to restore the required consistency. No mortars shall be used beyond 2 ½ hours after mixing.

Note 10 *Limitations*. Mortar type should be correlated with the particular masonry unit to be used because certain mortars are more compatible with certain masonry units. The specifier should evaluate the interaction of the mortar type and masonry unit specified, that is, **masonry units having a high initial rate of absorption will have greater compatibility with mortar of high water retentivity.**

Note 13 Where necessary, testing of a wall or a masonry prism from the wall is generally more desirable than attempting to test individual components….

Appendixes

X1 Selection and use of mortar for unit masonry.

X1.2 There is no single mortar mix that satisfies all situations. Only an understanding of mortar materials and their properties, singly and collectively, will enable selection of a mortar that will perform satisfactorily for each specific endeavour.

X1.3 Function

X1.3.1 The primary purpose of mortar in masonry is to bond masonry units into an assemblage which acts as an integral element having the desired functional performance characteristics. Mortar influences the structural properties of the assemblage whilst adding to its water resistance….

(good concrete practice is not the same as good mortar practice)…X1.3.3 A major distinction between the two materials is illustrated by the manner in which they are handled during construction. Concrete is usually placed in non-absorbent metal or wooden forms or otherwise treated so that most of the water is retained. Mortar is usually placed between absorbent masonry units, and as soon as contact is made the mortar loses water to the units. **Compressive**

strength is a prime consideration in concrete, but it is only one of several important factors in mortar.

X1.4 Properties
X1.4.1 Masonry mortars have two distinct, important sets of properties, those of plastic mortars and those of hardened mortars. Plastic properties determine a mortar's construction suitability, which in turn relate to the properties of the hardened mortar and, hence, of finished structural elements. Properties of plastic mortars that help determine their construction suitability include **workability and water retentivity.** Properties of hardened mortars that help determine the performance of the finished masonry include **bond, durability, elasticity and compressive strength.**

…..X1.5.1 Plastic Mortars

X1.5.1 ***Workability*** **– Workability is the most important property of plastic mortar. Workable mortars can be spread easily with the trowel into the separations and crevices of the masonry unit. Workable mortar also supports the weight of the masonry units when placed and facilitates alignment. It adheres to vertical masonry surfaces and readily extrudes from the mortar joints when the mason applies pressure to bring the unit into alignment. Workability is a combination of several properties, including plasticity, consistency, cohesion, and adhesion, <u>which have defied exact laboratory measurement.</u> The mason can best assess workability by observing the response of the mortar to the trowel. (p6)**

X1.5.2 Workability is the result of a ball bearing affect of aggregate particles lubricated by the cementing paste. Although largely determined by aggregate grading, material proportions and air content, the final adjustment to workability depends on water content. This (is)…usually…regulated on the mortar board near the face of the masonry. The capacity of a masonry mortar to retain satisfactory workability under the influence of masonry unit suction and evaporation rate depends on the water retentivity and setting characteristics of the mortar *(hot mixes retain workability the longest, whilst also holding up the joint etc)*. **Good workability is essential for maximum bond with masonry units.**

….For most mortars, and with minor exceptions for all but very low suction masonry units, bond strength increases as flow increases to where detectable bleeding begins. Bleeding is defined as migration of free water through the mortar to its surface *(free water rare in a workable hot mix, uniquely)*.

…X1.5.4
Water retention is a measure of the ability of a mortar under suction to retain its mixing water. This mortar property allows the mason time to place and adjust a masonry unit without the mortar stiffening *(hot mixes do this optimally)*. Water retentivity is increased through higher lime or air content, addition of sand fines

within allowable gradation limits, or use of water retaining materials *(such as wood ash, historically)*.

X1.5.5 *Stiffening Characteristics*. Hardening of plastic mortar relates to the setting characteristics of the mortar, as indicated by resistance to deformation…Too rapid stiffening of the mortar before use is harmful. Mortar in masonry stiffens through loss of water and hardens through normal setting of cement (*including air lime*)….a consistent rate of stiffening assists the mason in tooling joints.

X1.6 *Hardened Mortars*.

X1.6.1 *Bond*.
Bond is probably the most important single physical property of hardened mortar. It is also the most inconstant and unpredictable. **Bond actually has three facets: strength, extent and durability.** Because many variables affect bond, it is difficult to devise a single laboratory test for each of these categories that will yield reproducible results and which will approximate construction results. These variables include air content and cohesiveness of mortar, elapsed time between spreading mortar and laying masonry unit, suction of masonry unit, water retentivity of mortar, pressure applied to masonry joint during placement and tooling, texture of masonry unit's bedded surfaces, and curing conditions. *Lists out various standard tests etc and procedures)*.

…X1.6.1.3
The tensile and compressive strength of mortar far exceeds the bond strength between the mortar and masonry…A lack of bond at the interface of mortar and masonry unit may lead to moisture penetration through those areas. **Complete and intimate contact between mortar and masonry unit is essential for good bond. This can best be achieved through the use of a mortar having proper composition and good workability and being properly placed….**Because of mortar workability *(not part of laboratory testing),* it has been found that Type S mortar (typically with ½ as much lime as cement and 12.4 MPa) generally results with the maximum tensile bond strength that can be practically achieved in the field *(1:1:6, in effect – 10 MPa)*.

…X1.6.3 *Compressive Strength*…is sometimes used as a principal criterion for selecting mortar type, **since it is relatively easy to measure,** and it commonly relates to some other properties, such as tensile strength and absorption of the mortar…..(X1.6.4) The compressive strength of mortar depends largely upon the cement content and the water-cement ratio…

X1.6.3.2….the importance of compressive strength of mortar is overemphasized. Compressive strength should not be the sole criterion for mortar selection. Bond strength is generally more important, as is good workability and water retentivity, both of which are required for maximum bond….Flexural strength is also important because it measures the ability of a

mortar to resist cracking *(Note the addition of animal hair or other fibres to air lime plaster and pointing mortars to enhance flexural strength – resisting both initial and possible later cracking)*….Often overlooked is the size/shape of mortar joints in that the ultimate compressive load-carrying capacity of a typical 9.5mm bed joint will probably be well over twice the value obtained when the mortar is tested as a 2 inch cube *(even more so than a 100mm cube)*….It is frequently desirable to sacrifice some compressive strength of the mortar in favour of improved bond….

X1.6.4 *Durability.* **The durability of a relatively dry masonry which resists water penetration is not a serious problem.** The coupling of mortars with certain masonry units, and design without exposure considerations, can lead to unit or mortar durability problems. It is generally conceded that **masonry walls, heated on one side, will stand many years before requiring maintenance…Parapets, masonry paving, retaining walls, and other masonry exposed to freezing whilst saturated represent extreme exposures and thus require a more durable mortar. (p7).**

X1.6.4.1 Mortar, when tested in the laboratory for durability is subjected to repeated cycles of freezing and thawing. **Unless a masonry assemblage is allowed to become nearly saturated, there is little danger of substantial (*or any)* damage due to freezing.**

X1.7.2 ….Portland cement contributes to strength and durability. Lime, in its hydroxide state, provides workability, water rettentivity and elasticity. Both Portland cement and lime contribute to bond strength….

X1.7.3 Mortar should be composed of materials which will produce the best combination of mortar properties for the intended service conditions.

X1.7.4 Straight Portland cement mortars are not used because they lack plasticity, have low water retentivity, and are harsh and less workable than Portland cement-lime or masonry cement mortars.

X1.7.4.1 Masonry cement is a proprietary product usually containing Portland cement and fines, such as ground limestone or other materials in various proportions, plus additives such as air entraining and water repellency agents *(and should therefore be treated with great caution – see below)*.

X1.7.5 *Cementitious materials based on Carbonation.*
Hydrated lime contributes to workability, water retentivity and elasticity. Lime mortars carbonate gradually under the influence of carbon dioxide in the air, a process slowed by cold, wet weather. Because of this, the complete hardening occurs slowly over time. This allows healing, the recementing of small hairline cracks *(until carbonation is complete)*.

X1.7.5.1 Lime goes into solution when water is present *(although hot mixes resist this lest there be no weathering detail)* and migrates through the masonry where it can be deposited in cracks and crevices as water evaporates. This could also cause some leaching, especially at early ages. Successive deposits may eventually fill the cracks. Such autogenous healing will tend to reduce water permeanace.

X1.7.5.2 Portland cement will produce approximately 25% of its weight in calcium hydroxide at complete hydration. This calcium hydroxide performs the same as lime during carbonation, solubilizing and redepositing.

,,,Sand acts as an inert filler, providing economy, workability and reduced shrinkage, while influencing compressive strength…

X1.7.6.1
Well-graded aggregate reduces separation of materials in plastic mortar, which reduces bleeding and improves workability. Sands deficient in fines produce harsh mortars, while sands with excessive fines produce weak mortars and increase shrinkage. **High lime or high air content mortars can carry more sand, even with poorly graded aggregates and still provide adequate workability.**

X1.7.7.1 Water content is perhaps the most misunderstood aspect of masonry mortar, probably due to the confusion between mortar and concrete requirements…**Mortars should contain the maximum amount of water consistent with optimum workability. Mortar should also be re-tempered to replace water lost by evaporation.**

X1.7.8. *Admixtures.* ….Some chemical additions are essential in the manufacture of basic mortar materials. **The inclusion of an additive is also necessary for the production of ready-mixed mortars.** Undoubtedly, there are…some special situations where the use of admixtures may be advantageous when added at the job site mixer. **In general, however, such use of admixtures is not recommended. Careful selection of the mortar mix, use of quality materials, and good practice will usually result in sound masonry. Improprieties cannot be corrected by admixtures, some of which are definitely harmful.**

X1.7.8.1
Admixtures are usually commercially prepared products and their compositions are not generally disclosed *(a big problem in conservation)*. Admixtures are functionally classified as agents promoting air entrainment, water retentivity, workability, accelerated set, and so on. Limited data are available regarding the effect of proprietary admixtures on mortar bond, compressive strength, or water permeaence of masonry. **Field experience indicates that detrimental results have frequently occurred.** For these reasons, admixtures should be used in the field only after it has been established by laboratory test under conditions duplicating their intended use, and experience, that they improve the masonry.

X1.8.8.3
The uncontrolled use of air entraining agents should be prohibited. At high air levels, a definite inverse relationship exists between air content and tensile bond strength of mortar as measured in the laboratory. In general, any increase in air content is accompanied by a decrease in bond as well as compressive strength *(and elimination of capillarity)*….Most highly air entrained mortar systems can utilize higher sand contents without losing workability, which could be detrimental to the masonry if excessive sand were used.

….X1.8.2 *Portland Cement-Hydrated Lime (mortars)*
Cement-lime mortars have a wide range of properties. At one extreme, a straight Portland cement and sand mortar would have high compressive strength and low water retention. A wall containing such a mortar would have lower strength, particularly early strength, **but greater resistance to cracking and rain penetration.** Between the two extremes, various combinations of cement and lime provide a balance with a wide variety of properties, the **high strength and early setting characteristics of cement modified by the excellent workability and water retentivity of lime….**

X1.9 *Related Items that Have an Effect on Properties*

X1.9.1 The factors influencing the successful conclusion of any project with the desired performance characteristics are the design, material, procedure and craftsmanship selected and used…

X1.9.3 Masonry units are absorptive by nature, with the result that water is extracted from the mortar as soon as the masonry unit and the mortar come into contact. The amount of water removal and its consequences effect the strength of the mortar, the properties of the boundary between the mortar and the masonry units, and thus the strength…of the masonry assemblage….

X1.9.3.2 Mortar generally bonds best to masonry units having moderate initial rates of absorption, from 5 to 25 g/min 30 inch squared, at the time of laying…
X1.9.3.3….A loss of too much water from the mortar can be caused by low water retentivity mortar, high suction masonry units or dry, windy conditions….

X1.9.3.4 Mortars having higher water retentivity are desirable for use in summer or with masonry units having high suction. Mortars having lower water retentivity are desirable for use in winter or with masonry units having low suction.

…X1.9.4.4 Since all mortar is not used immediately after mixing (*hot mixes can be and frequently were),* evaporation may require the addition of water, retempering the mortar, to restore its original consistency. The addition of water to mortar within specified time limits should not be prohibited. **Although compressive strength of the mortar is reduced slightly by re-tempering, bond** strength is usually increased. …Because re-tempering is harmful only after

mortar has begun to set, all site prepared mortar should be placed in final position as soon as possible, **but always within 2 ½ hours after the original mixing, or the mortar discarded.**

X1.9.4.5
Weather conditions should be considered when selecting a mortar. During warm, dry, windy, summer weather, mortar must have a high water retentivity to minimize the effect of water lost by evaporation. In winter, a lower water retentivity has merit because it facilitates water loss from the mortar units prior to a freeze. To minimize the risk of reduced bond in cold weather, the masonry units being used as well as the surface on which the mortar is placed should both be brought to a temperature at least above 32 degrees F (0 degrees C) before any work commences *(a hot mixed mortar used hot will achieve both and will lose excess water to evaporation as well as to suction to resist freezing)*.

X1.9.5 *Workmanship*.
Workmanship has a substantial effect on strength and extent of bond. The time lapse between spreading mortar and placing masonry units should be kept to a minimum because the flow will be reduced through suction of the unit on which it is first placed. This time lapse should not exceed one minute. Reduce this time lapse for hot, dry and windy conditions, or with use of highly absorptive masonry units….

X1.9.5.1 Once the mortar between adjacent units has begun to stiffen, tapping or otherwise attempting to move masonry units is highly detrimental to bond and should be prohibited. The movement breaks the bond between the mortar and the masonry unit, and the mortar will not be sufficiently plastic to re-establish adherence….

….Striking joints….Finishing is not only for appearance, but to seal the interface between mortar and masonry unit, while densifying the surface of the mortar joint.

X1.9.5.4 With very rapid drying under hot, dry and windy conditions, very light wetting of the in-place masonry…can improve its quality. **Curing of mortar by the addition of considerable water to the masonry assemblage, however, could prove to be more detrimental than curing of mortar by retention of water in the system from its construction. *(NHLs demand such wetting, hot mixes do not).*** The addition of excess moisture might saturate the masonry, creating movements which decrease the adhesion between mortar and masonry unit.

X1.10 *Summary*.

….X1.10.2
Bond is probably the most important single property of a conventional mortar. Many variables affect bond. To obtain optimum bond, use a mortar with properties that are compatible with the masonry units to be used. To increase

tensile bond strength in general, increase the cement content of the mortar; keep air content of the mortar to a minimum; use mortars having high water retentivity; mix mortar to the water content compatible with workability; allow re-tempering of the mortar; use masonry units having moderate initial rates of absorption when laid; bond mortar to a rough surface rather than to a die skin surface; minimize time between spreading mortar and placing masonry units; apply pressure in forming the mortar joint; and do not subsequently disturb laid units. (p11)