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DURABILITY
OF
MORTAR AND MASONRY

Factors Influencing Mortar Durability
Durability Experience with Mortars

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Preface

Over the years considerable research has been conducted on masonry mortar, some of which has been obscure or forgotten . . . and much of it contradictory in its conclusions and/or interpretation of the findings . . . and there is often disagreement among the researchers on the significance of tests, etc. Yet, preponderant or majority opinions on this collective research is often possible to glean. To this end the National Lime Association's staff has made a study of what appears to be the most significant research in the mortar field.

The results of this study are being summarized in a series of articles categorized into the principal properties and considerations of mortar, such as durability, efflorescence, bond, volume change, strength, and workability, along with selected bibliographies. The first of this series of consolidated research digests is Mortar Durability.

One inescapable general conclusion from this study is that an overwhelming majority opinion among the independent authorities consistently substantiated the need for *both* lime and portland cement in a well balanced, all-purpose mortar. The lime referred to is either hydrated lime or lime putty made from quicklime and may be either dolomitic or high calcium types. This should never be confused with pulverized limestone (calcium carbonate) that is sometimes erroneously called "lime", and which is inert in mortar and has none of the properties inherent with burned lime products. So, whether a conventional lime-cement mortar or a prepared one-bag mortar is used, be sure the mortar contains a bonafide lime that meets ASTM Specification C 207—and enough of it.

Durability of Mortar

Durability refers to the ability of a structure to maintain substantially its original appearance, strength, and soundness for many years. In masonry the two prime requisites for durability are a dimensionally stable unit and a mortar that forms a permanent and complete bond, thereby making the structure watertight.

In recent years some engineers have erroneously attempted to correlate "durability" of masonry to laboratory cycles of freezing and thawing. If the mortar disintegrates in a few cycles, they declare it lacks durability. In general, lime-cement mortars that do not contain air entrainment are in this category. Such proponents either overlook or unfairly minimize the centuries-old successful durability experience of lime-based mortars. "Father Time" is obviously a much more realistic measure of performance than artificial, accelerated laboratory tests.

The subject of durability in mortars embraces the following interrelated considerations:

Empirical- based solely on history, observation and experience with mortars.

Statistical—also empirical but based on a statistical analysis of the mortar practices that have been both successful and unsuccessful.

Autogenous healing—the ability of a mortar to reknit or reconstitute itself after cracking or in filling up original mortar voids.

Efflorescence—how the permanent forms of efflorescence contribute to mortar and masonry disintegration.

Air content—the effect of entrained air in improving the weatherability of mortars.

Effect of freezing—its effect on mortars.

Permeability—absorption of moisture through pores in mortar and units and by leaks through voids and cracks in mortar joints.

A selected bibliography covering the principal researchers and authorities in these various aspects of mortar durability is included.

Empirical—Lime's long history in mortar dating back to antiquity is practically axiomatic. Surprisingly, many of these ancient mortars were made with the crudest types of lime (that could not possibly meet present day lime specifications) and with dirty, poorly graded sand; and they were poorly mixed.

In the United States straight lime-sand mortar prevailed until about 1890, when portland cement became commercially available in quantities. (See Fig. 1.) Some of the limes were quite impure, approximating hydraulic limes in their reaction; and the sands of this period were generally unwashed, containing clay loam that reacted with the free lime, lending possibly a faint pozzolanic effect to the mortar. However, regardless of the purity of the lime or quality of the sand, these mortars were uniformly of a low strength as compared to modern mortars. Generally they were used to "bed" the masonry units, with the result that the mortar joints were much thinner than in modern masonry. This helped to compensate for the seeming lack of compressive strength, but most important the mortar developed a tenacious bond at the mortar-unit interface due to intimate contact. The upshot was often a hundred years or more of water resistant masonry and remarkable longevity records without tuckpointing.

Visualize the widespread slum clearance and urban modernization construction programs that have prevailed in most U.S. cities since World War II. Countless of these old masonry buildings have been leveled to make space for freeways, slum clearance programs, and modern buildings. Although

FIG. 1. Massachusetts Hall, Harvard University, built in 1720 with straight lime mortar, has never been tuckpointed.

many of these old buildings were hopelessly antiquated and obsolescent in layout, generally the masonry was still sound and watertight. When these wall structures were knocked down by the drop ball, the mortar almost invariably ruptured in the middle of the joint instead of at the mortar-unit interface, indicating a strong, adhesive bond.

A learned exposé on masonry and mortars of yesteryear was a study by the Swedish scientist, Kreuger, which was translated into English and discussed in a formal paper by Palmer. Kreuger was not just interested that buildings 100—400 years old were still standing in well-preserved condition, but also in analyzing *why* this occurred. He pointed out (as other writers have) that too often the tuckpointing of joints with dense cement mortar of some century-old buildings may only endure for 5-15 years in contrast to 50—500 years of life for the old porous lime mortar. He observed that the porous mortars and units tend to dry out rapidly after soaking rain. By drying out, they are less prone to freeze. He noted that the more porous, weaker mortars were less subject to volume change and shrinkage cracking; that dense mortars tend to expand on wetting, narrowing openings of shrinkage cracks, thereby impeding drying. The retained moisture in the wall is then a vehicle for internal efflorescense to develop, which causes disintegration and decay of mortar joints and induces spalling of units.

In modern day tuckpointing, Newman, for 45 years a specialist in the restoration of old masonry structures, concludes similarly to Kreuger, although he expresses his opinion in a less academic but more practical manner. (See Fig. 2.) Regarding Kreuger's, and other British studies, Palmer states: "After 10 years of research in the field of unit masonry problems, the writer (Palmer) concludes that (they) have hewed to the line, and his own conclusions, reached by a different approach (laboratory) to the problem, are in good agreement with theirs."

Voss was substantially in accord with these views and impressed with the empirical evaluation of mortars. He frequently pointed out that portland cement lacked this old history. Both Voss and Palmer felt that the empirical approach to mortar durability is of the greatest significance—far more so than accelerated laboratory tests.

Statistical—Another empirical but statistical study was conducted by Connor, who examined 100 buildings of his company's properties (New Jersey Bell Telephone Company) that were six to 23 years old. These buildings were laid with nine different mortars of varying lime-cement ratios, straight cement, and masonry cement brands and 55 different makes of brick of widely divergent degrees of moisture absorption. Fifty-two of the buildings were watertight. The four factors he found almost invariably present with the watertight buildings were:

1. Use of lime-cement mortars of 1:1:5 or 1:1:6
2. Protected coverings for parapet walls
3. Use of moderate absorption brick
4. Concave tooled joints

Statistically the masonry cement and high cement mortars did not measure up to the 1:1:6 mortar. Leakage occurred mainly as a result of shrinkage separation cracking at the mortar-unit interface—a failure of the mortar bond. Cracking in some cases led to mortar disintegration, necessitating tuckpointing.

FIG. 2. Stanley Newman examining original lime mortar at Massachusetts Hall, after 240 years of exposure in severe New England climate.

Autogenous Healing—The phenomenon of high lime mortar having the capacity to reconstitute (reknit) slight cracks or small voids in mortar was researched and reported by Voss. Microscopic thin sections of mortar were offered as proof that mortar reconstitution can be achieved slowly over a period of time as seen in Figs. 3 and 4. Rainwater is absorbed into the mortar, dissolving minute

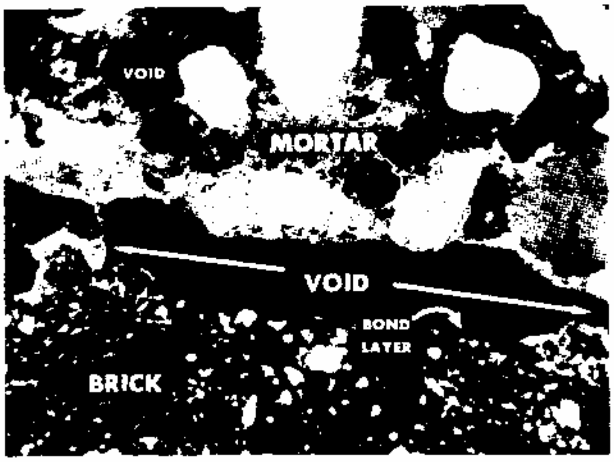

FIG. 3. Photomicrograph of joint interface of dense brick and high cement mortar, 21 years old (magnification 60 times). Note that the bond is not continuous.

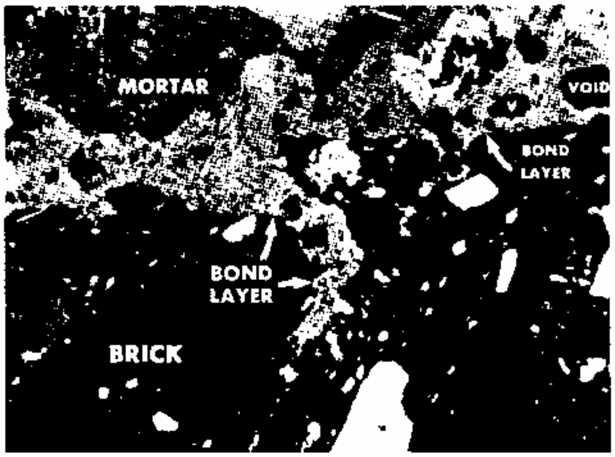

FIG. 4. Photomicrograph of joint interface of moderately dense brick and high lime mortar, 4 years old. Note that the plastic mortar has created a continuous bond. The filling of the irregular cavity is an example of the autogenous healing characteristic of a high lime mortar.

amounts of uncombined lime (calcium hydroxide) which penetrates into the crack or void and soon carbonates and precipitates, thereby filling or plugging the interstices. This is demonstrated by the following chemical equation:

$$Ca(OH)_2 + H_2O + CO_2 \rightarrow CaCO_3 + 2H_2O$$

(Hyd. Lime) + (water) + (carb. dioxide) →
(cal. carbonate + (water)

Such reconstitution might occur with hairline, cracks, caused by deflection or settlement, located within the mortar . . . or it might gradually fill minute voids or occlusions at the mortar interface, thereby increasing the intimacy and extent of bond.

Voss claims this phenomenon is only likely to occur with high lime mortars since high cement mortars have so much less lime for dissolution. Because calcium hydroxide has such faint solubility, this reaction can only occur slowly—in months or years, depending upon the size of the crack or void, climatic conditions, etc. Cold, rainy weather interspersed with warm, dry spells will stimulate this reaction since solubility of lime increases as the temperature decreases. Solubility is further catalyzed by the presence of CO_2.

Efflorescence—According to Palmer and Newman, the most pernicious type of efflorescence is the permanent type that initially is often not seen, since it develops in the interior of a wall. This type is most prevalent with dense mortar and masonry units in which the bond has broken at the mortar interface. Rain easily penetrates through the cracks, but after saturation, this masonry resists drying since water is trapped and cannot evaporate as readily as it can through the pores of porous masonry materials. This retained moisture dissolves and attracts soluble alkali sulfates which tend to collect in these damp areas. The salts eventually work out to the masonry face, but also hasten the decomposition of the mortar that is already weakened by shrinkage cracks. Newman claims the porous masonry materials can "breathe" and by drying out, this disruptive form of efflorescence does not develop. Porous masonry materials are characterized by absorptive types of brick, concrete block, and high lime mortars.

Air Content—It has been proven conclusively that additions of small amounts of entrained air to concrete improve weatherability and durability. Most masonry cements contain air entraining agents in varying amounts to provide mortar plasticity. Those producers who add no lime to their prepared mortars generally use the highest air contents in order to obtain workability, but in so doing the air content is excessive—as high as 25%. Zemaitis claims vastly superior durability for masonry cements having high air contents over lime-cement mortars with little or no air. His research is solely based on accelerated laboratory tests of 2- x 2-in. mortar cubes subjected to repeated cycles of both wetting and drying and freezing and thawing. In effect, the lime-cement mortars started disintegrating after a few cycles, whereas some of the masonry cement mortars went over 100 cycles without distress. Because of this research, Zemaitis and some cement producers claimed that lime-cement mortars or mortars without air are unsafe to use in cold climates, completely ignoring lime's centuries of successful use. It is true that lime-based mortars without air may erode slightly over a long period of time, but this does not affect its tight bond, so the walls remain sound and watertight.

Palmer, as long ago as the early 30's completely discredited this same accelerated mortar test, claiming it was misleading and unrealistic. He contended, in fact, that the most frost resistant materials are usually the most dense, but that they tend to remain excessively wet in the wall. He claims "the most weather-resistant wall is one that remains relatively dry even though the materials composing it have poor records in laboratory freezing and thawing tests." However, Palmer's comments preceded the advent of air entrainment in concrete and mortar. Palmer and Voss were more concerned with watertight masonry than with the weathering of joints.

The Zemaitis theory has been attacked by other independent groups, like Structural Clay Products Institute and National Concrete Masonry Association. First, what good is improved weatherability if the mortar develops a poor extent of bond that shrinks and cracks? Second they are adamant that there should be limitations on the maximum amount of air permitted, such as 10-15% air. In reinforced masonry and in high level apartment buildings, they want less air than this and are recommending only lime-cement mortars for such purposes. The Swedes, who were pioneers in the use of air entrainment, favor lower percentages of air than that used in most American masonry cements—15% maximum; and some Swedish authorities, like Rune Hedin, internationally known cement and lime technologist, favor a maximum of 5-6%. Hedin claims that this small amount of air is ample for improving weatherability and is not high enough to impair bond strength. Thus, the current trend is for lower air contents, but there seems to be no doubt that a small amount of air enhances mortar weatherability (probably in the 5-10% range). Above this air content, durability will be increasingly adversely affected by poor extent of bond due to the myriad of microscopic air bubbles at the interface that interferes with intimacy of bond. This small amount of air can readily be obtained in lime-cement mortars by the use of either an air-entrained portland cement or hydrated lime.

Effect of Freezing—Authorities agree that masonry rarely freezes, regardless of climatic conditions and types of units and mortar used. For freezing to commence the masonry assemblage would have to become saturated, a condition that is virtually impossible, even with the most dense units and mortars which have the lowest moisture absorption capacity. A high lime mortar (1:2:9) has a porosity of 30 to 35%, about 50% higher than a straight cement mortar. It is doubtful that the latter would ever become saturated even in a hard driving rain, much less the high lime mortar. This fact makes the accelerated laboratory freeze-thaw test on saturated mortar cubes meaningless.

The test is also unrealistic since the cubes are frozen from six directions simultaneously, whereas freezing of a wall would be unidirectional only. In the latter case, as the ice forms, the expansion would cause the water to move inward toward the warm side of the structure, but no damaging pressure would be created since the resistance to flow of water in a porous mortar is relatively low. With mortar cubes, on the other hand, great internal pressures are built up as the ice front moves inward from all six sides. Thus, the analogy between a freezing saturated mortar cube and a monolithic wall structure is ridiculous.

Permeability—There seems to be considerable disagreement among the researchers on the effect of porosity and permeability on watertightness of masonry walls. Voss, Palmer and Newman prefer the more porous masonry materials and discount their greater moisture absorption, mainly because they dry out so rapidly. They feel the principal criteria for watertightness are good bond and lack of separation cracks, but not permeability.

McBurney, on the other hand, reported that a brick panel made with dense brick laid in dense mortar (1:¼:3) was the most impervious to water penetration. He also found out that the quality of brick, based on the degree of absorption, had a greater bearing on permeability of masonry than mortar. He further reported that permeability of masonry increased with increased lime content. Wetting of absorptive brick before laying reduced water penetration and permitted successful use of dense mortar (good bond reported). Anderegg found that masonry durability and imperviousness was enhanced by brick of medium water absorption; his comments on mortar were inconclusive. Connor empirically agreed with Anderegg on moderate absorptive brick.

Ritchie's views tend to be nearer Voss and Palmer. He found in testing brick panels that the amount of moisture penetration was less with 1:1:6 and high lime mortars as against high cement or masonry cement mortars. He attributes this to tighter joints and better extent of bond. However, in panels made with concrete masonry, the advantage of high lime mortars was not evident; generally the influence of different mortars with the masonry on permeability was inconclusive.

Conclusion—Based on the extensive background of research and experience, it can be concluded that the use of lime in mortar contributes to watertight walls and durable masonry structures.

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