FIELD TECHNIQUES FOR MORTAR REPLICATION

David T. Biggs, P.E[1]
Thomas E. Forsberg, P.E[2]

ABSTRACT

Design professionals involved in rehabilitation, restoration, or historic preservation of a masonry structure must address mortar replication. For many projects, mortar replication is specified as the responsibility of the Contractor (Jones-1985). Mortar replication is usually done by trial-and-error techniques using numerous samples since exact analyses of mortar for constituent materials, strength, and physical properties can be costly. However, there are techniques whereby design professionals and contractors can determine a reasonable mortar replication in the field. These techniques greatly reduce the number of iterations and trial-and-error samples.

This paper will address some of the procedures that can be used in the field to get the proper replication mortar with reduced effort. Examples will be taken from several projects that have used these techniques to address appearance, texture, and physical properties of the replication mortar.

[1]Principal, Ryan-Biggs Associates
291 River St., Troy, New York 12180.,
[2]L. Robert Kimball & Associates
21 W. Washington St., West Chester, PA 19380

INTRODUCTION

Masonry building materials have been in use for thousands of years. Aside from the aesthetic appeal, masonry is selected for its strength and durability. However, masonry structures are only as strong as their weakest link; the mortar. In fact, the mortar is intended to be the weak link, the sacrificial component. Therefore, as the mortar deteriorates with time, it must also be maintained and restored to ensure the original integrity of the structure.

The importance of structural integrity is obvious. To repair and restore masonry structures requires a systematic approach. To repair and restore masonry structures with no visual evidence of that work having been performed is of the utmost importance and should be one of the ultimate goals on any project. Unfortunately, maintaining aesthetic integrity is often neglected. Figure 1 illustrates a brick masonry wall that was repointed with little aesthetic concern. Figure 2 shows a stone wall where the repointing blends so well that it is not perceptible.

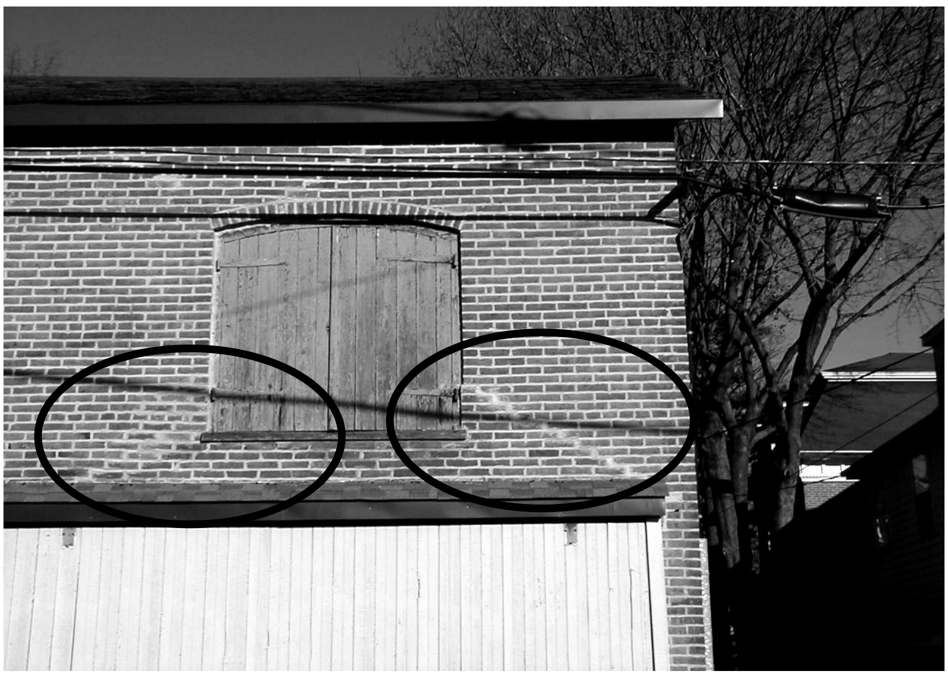

Figure 1

Figure 2

BACKGROUND

More often than not, the Contractor is charged with the responsibility of developing a mortar mix that matches the existing mortar. It is up to the Contractor to obtain the materials and produce sample mixtures for use in comparison to the existing mortar. Traditionally, the Contractor will obtain materials and wet-mix several samples, with various proportions of ingredients, and then compare the cured samples to the original mortar. This trial-and-error method can be very time consuming.

The value of a field procedure to simplify and shorten this trial-and-error method is obvious to saving time and expense. Once the existing mortar has been evaluated, sample mixtures can be put together using only the dry ingredients. The dry-mixed mortar samples can quickly be compared to the existing mortar. As the exterior surface of the mortar is typically weathered and/or stained, the importance of comparing new samples to the “inside mortar” is critical. Final color and texture are a function of age and tooling techniques.

Ideally, once the mortar is evaluated and an accurate description of the aggregate is determined, the Contractor can compare the sample to various sands and procure one that most nearly matches. However, the sand might already be on site for use in the restoration process. In this case, if the sand is a close match, samples can be mixed to produce similar mortars. If the sand does not match, the trial mixes should be put together in proportions that will yield the appropriate mortar type. If the trial mixes do not yield an accurate color match, alternatives such as color admixtures can be used.

The proper mortar must be evaluated and selected on a case-by-case basis. One of the most important steps is to ensure that the new mortar is only as strong as the existing mortar. Installing a Type S or M mortar in an old building that was originally constructed with a lime-sand mortar or a very weak cement mortar can be disastrous.

Mortar analysis is a science that is still evolving. Increasingly sophisticated instrumental and chemical techniques are being adapted to determine compressive strength, constituent materials and proportions, air content, porosity, and bond strength. These instrumental techniques include spectroanalysis, x-ray diffraction, polarized light, thin-section microscopy, scanning electron microscope, and differential thermal analysis (Cliver-1974, Mack and Speweik-1998). The wet chemical methods primarily refer to acid digestion techniques (Cliver-1974, Mack and Speweik-1998).

In the United States, the American Society for Testing and Materials (ASTM) has test method C 1324-96 "Standard Test Method for Examination and Analysis of Hardened Masonry Mortar" which combines wet chemical analysis and thin-section microscopy for evaluating modern cement mortars (ASTM-1996). While useful, these techniques can be costly and unavailable locally. Most important, they may not fit within the time frame of a project.

MORTAR EVALUATION

The primary ingredients of modern mortar are lime, cement, sand, and water. Early mortars had lime, sand, and often included some clay. The physical properties associated with mortar are compressive strength, porosity, water retention, air content, bond strength, hardness, and freeze-thaw durability. The visual characteristics are color, texture, and finish or tooling. Prior to replicating a specific mortar, it is necessary to select which properties and characteristics of the original mortar are essential to determine.

Due to time or budget constraints during the evaluation or construction phase of a project, it may not be possible or necessary to determine every ingredient and property of the original mortar. However, as a minimum, it should include an identification of the type of sand by gradation and color (Mack and Speweik-1998) as well as the texture and finish for the replication mortar. Sand is the dominant ingredient in mortar and is relatively easy to obtain by acid digestion. The texture and finish are determined by visual inspection. Thus, a field method can include both aspects.

Mortar Types

There are essentially two types of mortar, lime mortar and cement-based mortar. Both have different properties, yet both perform similar functions. The primary ingredients of early mortars were a combination of lime and sand. The lime was produced from limestone, and the sand was obtained from natural sources. Lime mortars are low in compressive strength and exhibit lengthy setting times; however, they provide good bond and, as evidenced by their remaining existence today, are quite durable. They are also flexible and tend to be self-healing for minor cracking.

Portland cement, the use of which began in the early 1800s, was originally added to lime mortar in small proportions in order to decrease the setting time of the mortar and increase the compressive strength. Eventually the proportions of Portland cement in mortar became dominant, producing mortars with high compressive strength, excellent freeze-thaw durability, and quick setting times. Lime was still retained in smaller proportions to maintain workability. These mortars have proven to be more brittle than lime mortars; they do not self-heal.

ASTM provides several standards for mortar and its constituent materials. In the United States, ASTM C 270 "Standard Specification for Mortar for Unit Masonry" is the most commonly referenced standard for specifying mortar properties, ingredients, and usage. Within ASTM C 270 are references to other standards for the constituent materials: Portland cement, lime, aggregate, etc.

ASTM C 270 has five basic mortar Types: M, S, N, O, and K. Arranged in descending order of strength, their designations are generally thought of as a derivative of the word "M-a-S-o-N-w-O-r-K." Each mortar type contains the same ingredients but in varying proportions.

There is a specific purpose for each type of mortar. Type M, the strongest, is used in modern applications where high compressive strengths and high durability are required. Types S and N are probably the most widely used for interior and exterior applications in general building construction. Type O is typically used in repointing and restoration applications. Type K is also used in restoration applications, typically where the original mortar was a lime mortar. Older and historic mortars were not developed using any industry standards but are primarily based on a binder-to-aggregate ratio of 1:3 or 1:2. The modern mortars in ASTM use a 1:3 ratio.

One advantage of historic, weak mortars is flexibility. As a structure settles and moves over time, a weak mortar has the flexibility to either remain uncracked or crack in lieu of cracking the masonry units. Hard mortars have little flexibility and can actually force the masonry units to crack with any additional movement.

Evaluation of Existing Mortar

Field evaluation of mortar should begin with a visual observation. It is imperative that the true color be observed inside the joint, below the exterior surface that has been altered over time from dirt, acid rain and the like. The "inside mortar" will reveal the color and physical characteristics of the sand: light or dark, coarse or fine, aggregate size, etc.

Knowing the time at which the building was constructed is also beneficial. Mortar in buildings dating back as far as the late 1800s to early 1900s will likely have some proportion of natural cement or Portland cement in the mixture, while even older buildings will typically have only lime mortars in them. Type N or O mortars are the more common types of mortar found in historic buildings.

Hardness. Hardness is often synonymous with compressive strength. Mortar that can easily be scraped from the joint is considered very low in compressive strength. Mortar that can be scratched and/or partially removed has average compressive strength while mortar that cannot be scratched has high compressive strength. While no precise field method exists for determining mortar hardness, an approximate method uses the Mohs scale. Credited to Friedrich Mohs (1773-1839), the Mohs scale is used to determine the hardness of an unknown mineral relative to minerals of known hardness. The scale, in order of softest to hardest is (1) talc, (2) gypsum, (3) calcite, (4) fluorite, (5) apatite, (6) feldspar, (7) vitreous silica, (8) quartz, (9) topaz, (10) garnet, (11) fused zirconia, (12) fused alumina, (13) silicon carbide, (14) boron carbide and (15) diamond.

To determine the Mohs number for an existing mortar, scratch a mineral of known hardness on the mortar. Do not scratch the tooled surface of the mortar or you will get an indication of the surface hardness from the tooling rather than the hardness of the mortar itself. If the mineral scratches off on the mortar, the Mohs number of the mortar is greater than that of the mineral. If the mineral scratches the mortar, then the Mohs number is lower.

If you can determine an approximate value of hardness based on the Mohs scale, that number can be associated with an approximation of the compressive strength, or type, of the mortar. Based upon personal experience, Mohs numbers up to 3 correspond to Type O mortar; between 3 and 5 correspond to Type N mortar; and above 5 correspond to Type S and M mortars. This is not an exact correlation and is for general guidance only.

Without the Mohs scale, simply scratching the mortar with a screwdriver or chipping away some mortar with a chisel can reveal some approximation of mortar strength. Mortar that is easily scratched from the joint is likely a Type O, while mortar that can be scratched, but not removed, is likely Type N. This procedure forms the basis for the Russack System for Brick and Mortar Description (Ferro-1980). This system classifies mortar hardness numerically from 1 to 10, not by mortar type, and was intended to give conservators and masons a common language for describing mortar hardness.

When attempting to evaluate hardness, it is essential that the mortar be in good, stable condition. Performing the above-described tests on deteriorated mortar will produce inaccurate results.

Ingredients. A simple process for identifying the aggregate is acid digestion which separates the binder from the aggregate by digesting everything except the sand. A solution of hydrochloric acid and distilled water, mixed in a 1:3 proportion, is used as a digestive agent (when mixing this solution, add the acid to the water). This process is a simplified version of ASTM C1324 which can be performed in any workroom or laboratory. It is only applicable to mortars composed of aggregates of siliceous sand since this type of sand will not digest in acid.

First, grind the mortar into a powder or very small granules and place it in a glass beaker. Weigh the beaker by itself and later with the sample. Second, apply the acidic solution to the mortar and observe the reaction. Cement mortars will effervesce rapidly as the acid reacts with the cement; mortars composed of only lime and natural cements are quickly digested and effervesce relatively little. Drain off the liquid and repeat the process until the effervescence stops, indicating the lime and cements are dissolved . Follow-up with a water-wash of the sand. Drain the liquid and dry the sand. Figures 3 through 5 show this procedure. Weighing the remaining material will allow you to determine the amount of ingredients that are acid-soluble.

Figure 3 shows the sample being weighed after being crushed. Figure 4 shows the beaker with the residual sand and the beaker with the filtered fines. Figure 5 has the original mortar in the center and two possible sands above. The large samples are the proposed mortar mixes made with the two sands; the mix on the right was selected.

Once the lime and/or cement has been dissolved, the majority of the remaining material is the sand. The sand sample can be used to visually identify new sand for the restoration mortar. Characteristics such as color, aggregate size, and gradation should be considered.

Figure 3

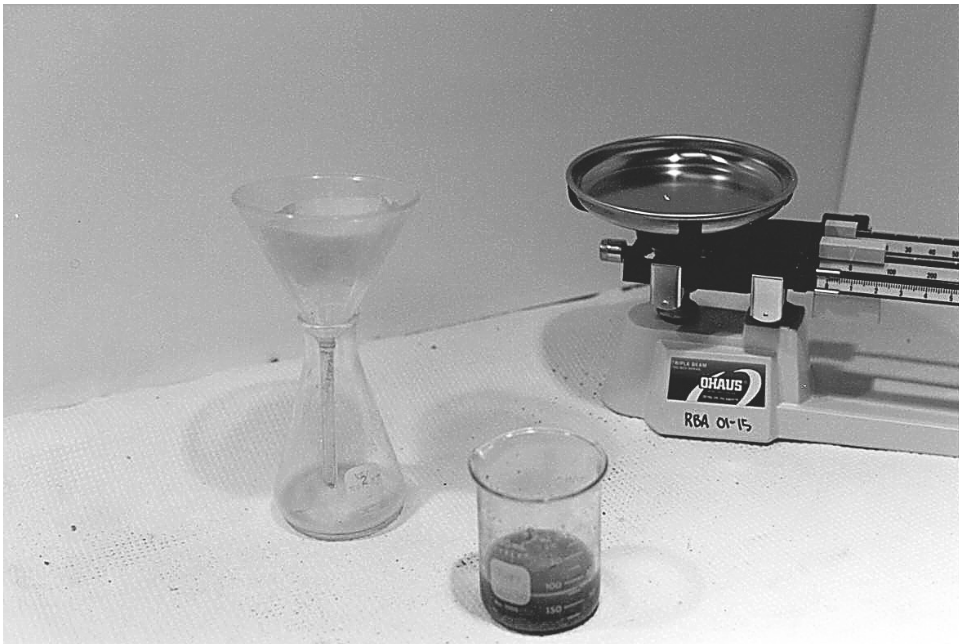

Figure 4

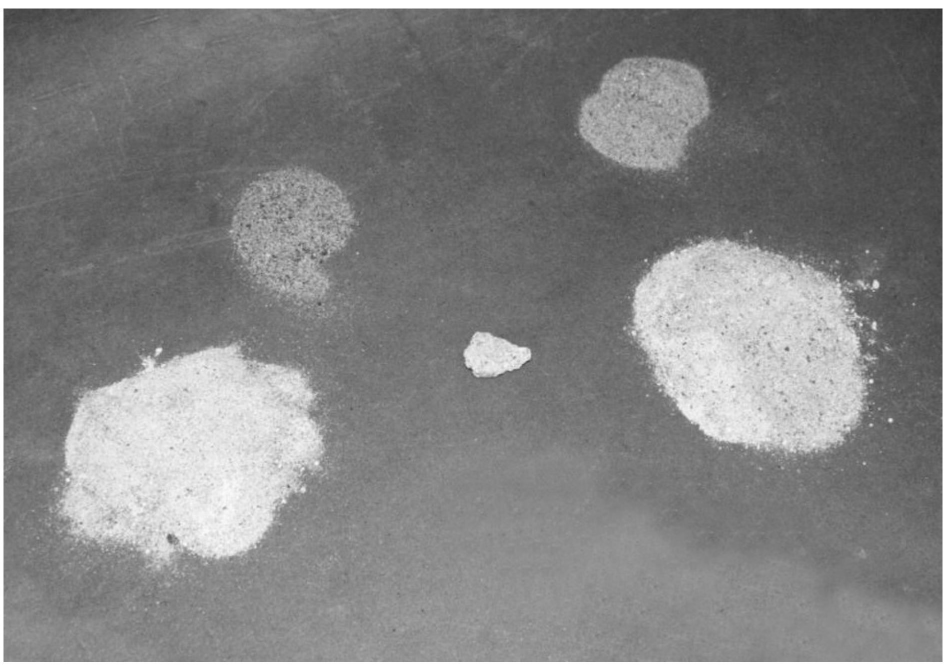

Figure 5

FIELD PROCEDURE - MORTAR REPLICATION

Sampling/Inspection

1. Retrieve at least four samples of the existing mortar, approximately 75 mm long. Place them in plastic bags for handling. The samples can be broken pieces or one intact sample. Use two samples for testing and two for comparison with the dry mixes.
2. Visually observe the tooling finish, color and texture of the existing mortar.
3. Use a magnifying glass to determine if the aggregate is sand or contains some limestone or marble. If there is acid-soluble aggregate in the mortar, the acid digestion procedure will not work.
4. Determine the approximate hardness using the Mohs or Russack methods.

Ingredients

1. Perform the acid digestion procedure. This is best done in a workroom or laboratory.
2. Wash and dry the remaining aggregate, and compare to known sands. A library of available sands in the region is useful. Select a sand which is closest in aggregate size and color.
3. Determine the proportions of acid-soluble material.

Replication

1. Based upon the source, hardness, percent acid soluble, and the use of the mortar, determine the type of mortar to be prepared. Determine if Portland cement is to be used in the mix or if it is to be a lime-based mortar.
2. Mix the new ingredients dry, by proportion, and compare to the original sample. Make several samples varying the proportions slightly within the ASTM ranges for the selected type to try to achieve the desired color. Mixing white and grey cements often works.
3. If the sands, cement and lime cannot achieve the proper color, an admixture may be needed. Once all this work is done, a premixed colored mortar may be possible through the various cement companies.

Sample panel

1. This is the point where the old trial-and-error method began. However, now you have a better understanding of the sand, mortar type and mix proportions.
2. The sample repointing is primarily to allow the mason to adjust the mix for workability and evaluate the finishing techniques to match the original sample. Experience indicates that one to three samples are all that is needed to arrive at a desired solution.

CONCLUSIONS

While not an exact method or science, the field procedure described has been used be many professionals and Contractors to develop replication mortars. It saves time and cost and allows the person doing the tests to achieve a better feel for the mortar. Thus, Contractors generally benefit the most by using these procedures. Even when more sophisticated procedures are used to evaluate and identify ingredients and properties of the original mortar, the procedures for creating the dry replication mortar and the sample panels are still applicable.

REFERENCES

American Society for Testing and Materials (1996). ASTM C 1324-96, Standard Test Method for Examination and Analysis of Hardened Masonry Mortar, Philadelphia, PA.

Cliver, E. Blaine (1974). Tests for the Analysis of Mortar Samples. Bulletin of the Association for Preservation Technology, Vol. 6, No. 1, pp. 68-73.

Ferro, Maximillian L. (Summer 1980). The Russack System for Brick and Mortar Description: A Field Method for Assessing Mortar Hardness. Technology and Conservation, Vol. 5, No. 2, pp. 32-35.

Jones, Larry D. (1985). Specifying Exterior Restoration in the Real World. Bulletin of the Association for Preservation Technology, Vol. 17, No. 2, pp. 43-47.

Mack, Robert C.and Speweik, John P. (1998). Preservation Briefs 2: Repointing Mortar Joints in Historic Masonry Buildings. Heritage Preservation Services, US Department of the Interior, National Park Service, Washington D.C.