Project: USHG #11103

November 17, 2011

Michael Trinkley
Chicora Foundation, Inc.
PO Box 8664
Columbia, SC 29202
Phone: 803-787-6910

EVALUATION OF MORTAR COMPOSITION – ASTM C1324
WHITE PINE CHAPEL, SPRING GROVE CEMETERY, CINCINNATI, OH

INTRODUCTION

Sample consisting of small hardened masonry mortar fragments and dust, was received for analysis on October 21, 2011. The mortar sample was chemically and petrographically analyzed in order to determine composition. The project identification is: USHG #11103.

METHODS OF ANALYSIS

ASTM C1324 - The sample was analyzed according to chemical procedures and petrographic examination methods of ASTM C1324, "Standard Test Method for Examination and Analysis of Hardened Masonry Mortars".

The mortar was examined using a stereomicroscope up to a magnification of 100X. Portions of the binder portion of the mortar were prepared on glass slides in several refractive index oils in the range of 1.30 to 1.71 and examined for identification using a polarizing (petrographic) microscope up to a magnification of 600X. The optical and morphological properties of the phases present were used to identify the various constituents present, including primary and secondary calcium carbonate, hydrated lime, gypsum, brucite, free lime, portland cement, and any other substances.

The chemical analysis was conducted, using wet chemical procedures in ASTM C1324 and X-ray fluorescence spectroscopy (XRF), and thermal analysis.

RESULTS - PETROGRAPHIC EXAMINATION

Mortar Sample - Limestone Block Tomb (circa 1859), White Pine Chapel
Spring Grove Cemetery; Cincinnati, OH, USHG #11103

Paste Properties - The paste appears to consist of hydraulic hydrated lime and buff-colored fragments which are similar in appearance to natural cement. The hydrated lime appears to be an impure, high-calcium type. The paste has a variable color; it is mostly white, but has some areas that are buff-colored. The paste is soft, and is carbonated. The paste-aggregate bond and the mortar firmness could not be determined, since the sample consists mostly of powdered fines. The degree of hydration is advanced. Pockets of hydrated lime, up to several millimeters in size, are present at a moderate amount. Secondary calcium carbonate is present.

Aggregate - The aggregate is a natural sand with a 5.0 mm maximum grain size and a modal (most frequently occurring) grain size of approximately 0.75 mm. The particle grading appears similar to the natural sand grading specified in ASTM C144 (aggregate for masonry mortar). The sand consists of quartz, hornblende basalt, and orthoclase feldspar. Limestone was not detected. The aggregate is in a physically and chemically stable condition.

Air Content - The mortar is not air-entrained, and has a low entrapped air content that could not be quantified, due to sample consisting of mostly fines.

RESULTS - CHEMICAL ANALYSIS

The mortar was chemically analyzed for portland cement content according to the Soluble Silica (SiO_2) method in ASTM C1324, “Standard Test Method for Examination and Analysis of Hardened Masonry Mortars”.

The binder appears to consist of hydraulic hydrated lime and silica flour from natural cement. This binder appears to contain approximately 60.0% calcium oxide (CaO) and 30.0-to-15.0% silicon dioxide (SiO_2). The paste is carbonated. Brucite (magnesium hydroxide) was detected at a low amount, indicating the hydrated lime is an impure, high-calcium type. This binder appears to be a mixture of hydrated lime and natural cement.
The hydrated lime was estimated to contain 65.0 % calcium oxide (CaO), and 10.0% magnesium oxide (MgO), which is equal to 14.5% Brucite ($Mg(OH)_2$). The hydrated lime was calculated based on the amount of Brucite and CaO.
The aggregate content was calculated as the insoluble residue.

The natural cement content was calculated by difference: 100.0% minus the sum of Free Water, Hydrate Water, Hydrated Lime and Aggregate.

RESULTS - CHEMICAL ANALYSIS (continued)

Mortar Sample - Limestone Block Tomb (circa 1859), White Pine Chapel
Spring Grove Cemetery; Cincinnati, OH, USHG #11103

The densities (loose volume basis) of the mortar ingredients were assumed to be those listed in ASTM C270. Eighty lbs. of dry sand was assumed to be equal to one cubic foot of damp loose sand. Lime putty is estimated @ 80 lbs./ft.3, consisting of 50% free water and 50% hydrated lime (calcium hydroxide). The natural cement was assumed to have a bulk density of 90.0 lbs. /ft.3.

This mortar appears to be a hydraulic hydrated lime type, with natural cement.

Constituents:	Mortar Sample: USHG #11103
Natural Cement	1.00 parts
Hydrated Lime NHL 5	1.04 parts
Quartz Sand	5.16 parts
Mortar Type	Type N

Based on the Chemical Analysis results, this mortar sample appears to be chemically similar to a Type N formulation consisting of a mixture of portland cement and hydrated lime. However, based on the Petrographic Examination and Chemical Analysis results, this sample actually appears to be: a mixture of natural cement, hydrated lime, and fine aggregate.

The bulk volume of sand for the sample is: 2.53 times the sum of volume of cement plus hydrated lime, which conforms to the ASTM C270 requirement for sand content. (A summary of the chemical analysis results is given in the attached Table 1.)

Note: This sample is reported to be a historic mortar (circa 1859). Natural cement was in use in the USA from approximately 1815 up to 1900. Portland cement, imported from England, was used in the USA from approximately 1820 to 1870. Eventually portland cement was manufactured in the USA, beginning circa 1870-75. Since this historic mortar sample (circa 1859) appears to contain natural cement, the analysis reported herein was calculated on a natural cement-and-hydrated-lime mixture composition. The hydrated lime may be a hydraulic type, with strength development potential.

REPLICATION OF MORTAR:

Since the hydrated lime in this sample appears similar to a hydraulic lime having strength development properties, NHL 5 and sand mix as currently available materials should be considered as replacement mortar. A typical hydraulic lime formulation consists of 1.00 part hydraulic lime and 2.5 parts sand.

This mortar may be also replicated using portland cement and hydrated lime mix. Ratio of portland cement to lime would depend on current condition of masonry units and may not be the same as found in original mortar. Considering the National Park Service guidelines "the new mortar must be as vapor permeable and as soft or softer (measured in compressive strength) than the historic mortar. (Softness or hardness is not necessarily an indication of permeability; old, hard lime mortars can still retain high permeability.)"

Table 1. Chemical Analysis of Mortar Sample - Limestone Block Tomb (circa 1859), White Pine Chapel

Constituent	**Percent by Mass %**
	Mortar sample USHG # 11103
Silica - SolubleSiO_2	3.31
Calcium Oxide - CaO	14.00
Brucite – $Mg(OH)_2$	1.07
Magnesium Oxide – MgO	1.43
Insoluble Residue	73.59
Loss on Ignition	
At 0-110ºC	0.10
At 110-550ºC	2.91
AT 550-1000ºC	4.25
Calculated Constituents	
Natural Cement	16.04
Hydrated Hydraulic Lime	7.38
Sand	73.59
Volumetric Proportions (according to ASTM C270) **– Loose Volume Ratios**	
Natural Cement: Lime : Aggregate	1.0 : 1.04 : 5.16
Mortar Type	Type N

Respectfully submitted,

U.S. Heritage Group, Inc.

Tom Glab
Laboratory Manager

Nelson Testing Laboratories

Michael F. Pistilli
Chemist, Petrographer

Note:
Loose Volumes of Sand is: 2.53 times the sum of the volume of cement plus hydrated lime, which conforms to the ASTM C270 requirement for sand content.
The total mortar composition is the sum of: Free Water plus Hydrated Water, Natural Cement, Hydrated Lime, and Fine Aggregate.