Durability of Traditional and Modified Limewashes

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Increased knowledge of recipes and additives could improve the performance of limewash applied to historic materials.

Introduction

The National Center for Preservation Technology and Training (NCPTT) recently completed a study of the durability of traditional and modified limewash formulations. The study tested a variety of limewash recipes for possible use on historic structures located in the Cane River Creole National Historical Park, located in central Louisiana.

Limewashes have long been used as surface finishes on buildings and other structures, on both the interior and the exterior. As limewash slowly dries, it reacts with the carbon dioxide in the air, carbonating and creating a tough finish. During the height of limewash's popularity, prior to the industrial age, the knowledge and skills needed for effective application were passed on from craftsman to craftsman. The basic ingredients, lime and water, were readily available in every community. Additives used were commonly available and often varied from place to place.

As the popularity of limewash waned in the U.S. and modern paints began to be used widely, experience with limewash recipes and their application began to fade. Today, instead of every community having someone knowledgeable in limewash, experienced craftsmen are spread thinly across the country. The waning popularity of limewash did not result solely from the rise in popularity of modern paints; other factors were the increased cost of labor and creation of more durable, inexpensive materials that did not need a finish for protection.

Fig. 1. Outbuildings at Oakland Plantation, part of Cane River Creole National Historical Park, located in the Bermuda Community south of Natchitoches, Louisiana. Many of these buildings date back to the nineteenth century, and their existence today is a reflection of the physical completeness of the site. Numerous outbuildings at Oakland Plantation are clad with wood siding that has weathered over time. All images by Sarah Jackson.

The Scope of the Study

Cane River Creole National Historical Park (CARI) represents more than 200 years of plantation life. It is home to more than 42 historic vernacular structures. The park consists of Oakland Plantation and the outbuildings of Magnolia Plantation (Figs. 1 and 2). The buildings are constructed of wood, low-fired brick, and, in some cases, *bousillage* — clay or mud mixed with moss and hair, which is packed around sticks that have been placed between wood timbers.

Park superintendent Laura Soulliere Gates explains the early use of limewash at CARI thus: "Historically nearly all of the buildings at this park were coated with limewash, and that material served multiple purposes in much the same way as the finish coating on adobe in the Southwest. Limewash provided a layer of protection from the onslaught of wind and water that weathered buildings' exteriors. Limewash gave a layer

Fig. 2. Brick slave cabins at Magnolia Plantation, part of Cane River Creole National Historical Park, located near the Magnolia community south of Natchitoches, Louisiana. These cabins date to the mid-ninteenth century and are significant because they are built of brick. Brick was an expensive alternative to the more commonly used wood.

of hardness to both interior and exterior walls that protected softer materials underneath, such as *bousillage* or handmade brick."[1]

In 2003 CARI considered applying limewash to many of the historic structures at the park. NCPTT partnered with CARI to determine the durability of traditional and modified limewash recipes within certain criteria. CARI wanted to identify a lasting, low-cost limewash that could be applied in approximately three layers and would last three to five years. Quality Finish, a local paint contractor, joined the project to ensure that local craftsmen would gain the experience and knowledge to apply limewash outside of a laboratory setting.

In collaboration with these partners, NCPTT designed a program for testing limewash on weathered wood, rough-sawn wood, historic handmade brick, and modern brick. The historic bricks were handmade, low-fired bricks; the modern bricks were newer, factory-produced bricks that had been salvaged locally from twentieth-century buildings. CARI supplied the materials for the substrate to which the limewash would be applied from supplies they had at the park. Epoxy was later added to the study to take into account its use in preserving the wooden structures at the park. Quality Finish assisted with historical research and prepared many of the samples. The firm researched possible limewash recipes used locally by interviewing community members. Unfortunately, they were unable to identify recipes used in the community and therefore turned to historic and modern published limewash recipes, including a limewash included in the National Park Service's contracting schedules.[2]

Given the scope of the study, NCPTT researchers identified several questions to be addressed through testing:

- Does the source of the lime affect the durability of the limewash?
- Does the type of lime (e.g., hydrated lime or lime putty) affect the durability of the limewash?
- Does the surface material, or substrate, affect the adhesion or the resistance to abrasion of limewashes?
- How do various additives and modifications affect the performance of limewashes?
- Can acrylic-emulsion additives improve or hinder the performance of limewashes?
- How do limewashes behave after long-term exposure to ultraviolet light and temperature?

Background

Historically, applying a sacrificial surface finish to buildings became more widespread in European countries after the seventeenth century as good hardwoods became scarce, necessitating the use of poorer quality building materials.[3] In the United States, a much younger and less populated country, limewash came into widespread use during the ninteenth century. Limewash continued to be used on plaster and more informal areas even after the advent of oil-based paints.[4]

Traditionally limewash was prepared on-site by skilled craftsmen and applied in the spring or fall to take advantage of optimal temperatures. The basic ingredients in limewash are lime and water, although other ingredients were sometimes included to provide additional chemical or physical properties. The use of additives required careful consideration due to the possible adverse affects. For example historic recipes often called for adding tallow during slaking in order to increase water-shedding capabilities. The tallow did increase water shedding, but it also decreased breathability and the ease of applying successive layers.

Pigments were often added to limewash to vary the color of the finish. Earth-based pigments were used historically to maintain consistent color and limit changes from the alkalinity of the limewash. It was necessary to add pigments in moderation to limit the weakening effect of excessive amounts of additives.

In order to maintain consistency sufficient limewash to complete the project was mixed and agitated throughout application.[5] After the limewash was prepared, the surface to be treated was brushed down to remove loose dirt and then dampened to prevent the wash from drying too quickly. If the limewash dried too quickly, carbonation would be disrupted, resulting in a weak, cohesionless finish that tended to crack and powder.

Limewash was applied in thin layers, constantly maintaining a wet edge to create a more conformal coat. Multiple layers were applied, leaving sufficient time for drying between applications. Drying times were 24 hours or longer, depending on exterior conditions such as humidity and temperature. When first applied, the limewash appeared transparent, but as it carbonated and layers built up, it was transformed into a solid,

Table 1. Limewash Recipes Showing Ingredients Used

		Lime	Part A	Part B Mix
Wash A	Graymont Ivory Hydrated Lime	1lb. table salt, .5 oz alum, ⅓ cup unsulfured molasses, 1⁄12 tsp. laundry bluing. Mix in 2½ c. hot water.	Mix 4¼ c. hydrated lime with 4½ c. hot water. Let stand 12 hours	Mix parts A & B in equal parts. Viscosity 17 seconds at 70 degrees in #4 Ford cup.
Wash B	Graymont Niagara Lime Putty	1lb. table salt, .5 oz alum, ⅓ cup unsulfured molasses, 1⁄12 tsp. laundry bluing. Mix in 3 c. hot water.	Mix 8½ c. Niagara putty with 4 c. hot water. Let stand 12 hours.	Mix parts A & B in equal parts. Viscosity 17 seconds at 70 degrees in #4 Ford cup.
Wash C	Virginia Limeworks Lime Putty	1lb. table salt, .5 oz alum, ⅓ cup unsulfured molasses, 1⁄12 tsp. laundry bluing. Mix in 2½ c. hot water.	Mix 8½ c. Virginia Limeworks with 4.75 c. hot water.	Mix parts A & B in equal parts. Viscosity 17 seconds at 70 degrees in #4 Ford cup.
Wash D	Graymont Ivory Hydrated Lime	⅓ cup unsulfered molasses, 1⁄12 tsp. laundry bluing, ¼ tsp. clove oil. Mix with 1.5 c. hot water.	Mix 4¼ c. hydrated lime with 2½ c. hot water. Let stand 12 hours.	Mix together A & B. Viscosity same as A. Add 4 tsp. Schmincke Casein Binding Medium per 1 cup limewash.
Wash E	Graymont Niagara Lime Putty	⅓ cup unsulfered molasses, 1⁄12 tsp. laundry bluing, ¼ tsp. clove oil. Mix with 2½ c. hot water.	Mix 8½ c. putty with 2¼ c. hot water. Let stand 12 hours.	Mix together A & B. Viscosity same as A. Add 4 tsp. Schmincke Casein Binding Medium per 1 cup limewash.
Wash F	Virginia Limeworks Lime Putty	⅓ cup unsulfered molasses, 1⁄12 tsp. laundry bluing, ¼ tsp. clove oil. Mix with 1½ c. hot water.	Mix 8½ c. Virginia Limeworks putty with 2¼ c. hot water. Let stand 12 hours.	Mix together A & B. Viscosity same as A. Add 4 tsp. Schmincke Casein Binding Medium per 1 cup limewash.
Wash G	Graymont Ivory Hydrated Lime	4¼ c. hydrated lime mixed with 7½ c. hot water. Let stand 12 hours.		Check viscosity 17 seconds at 70 degrees. For each 1 cup of limewash, add 2 tbsps. of Edison.
Wash H	Graymont Niagara Lime Putty	8½ c. Niagara lime putty mixed with 5 c. hot water. Let stand 12 hours.		Check viscosity 17 seconds at 70 degrees. For each 1 cup of limewash, add 2 tbsps. of Edison.
Wash I	Virginia Limeworks Lime Putty	8½ c. Virginia lime putty with 5 c. hot water. Let stand 12 hours.		Check viscosity 17 seconds at 70 degrees. For each 1 cup of limewash, add 2 tbsps. of Edison.
Wash K	Virginia Limeworks Lime Putty	8½ c. Virginia lime putty with 5 c. hot water. Let stand 12 hours		Check viscosity 17 seconds at 70 degrees in #4 Ford cup.
Wash L	Graymont Ivory Hydrated Lime	4¼ c. hydrated lime mixed with 4½ c. hot water. Let stand 12 hours.	Add sufficient water to achieve mix requirements. (We added 2½ c. of water)	Check viscosity 12 seconds at 70 degrees in #4 Ford cup.
Wash M	Graymont Niagara Lime Putty	8½ c. Niagara lime putty mixed with 5 c. hot water. Let stand 12 hours.	Add sufficient water to achieve mix requirements. (We added 15 c. of water)	Check viscosity 12 seconds at 70 degrees in #4 Ford cup.
Wash N	Mississippi Lime Company Lime Putty	8½ c. Mississippi Lime Co. lime putty with 5 c. of hot water. Let stand 12 hours.	Add sufficient water to achieve mix requirements. (We added 21 c. of water)	Check viscosity 12 seconds at 70 degrees in #4 Ford cup.

(white)	Applied to handmade brick, modern brick, weathered wood, and rough-sawn new wood with primer.
(dark gray)	Applied to handmade and modern brick with primer.
(light gray)	Applied to handmade brick and weathered wood without primer.

matte finish.[6] Three or more applications were recommended for the initial limewashing. Annual reapplication was necessary to counter weathering from exposure. Successive limewashings required fewer layers.[7]

It was only after the Civil War that ready-made paint began to gain popularity in the U.S.[8] Beginning in the 1900s limewash was used less often in urban areas, although its popularity continued in rural settings until as late as the mid-twentieth century. Urban areas were the first to be affected by an increase in the use of modern, long-lasting building materials and the rising cost of labor needed to apply limewash. The time needed to apply multiple thin layers and for carbonation may also have contributed to the waning popularity of limewash, as ready-made paint was less time- and labor-intensive.

Limewash is now beginning to see renewed interest, because its vapor per-

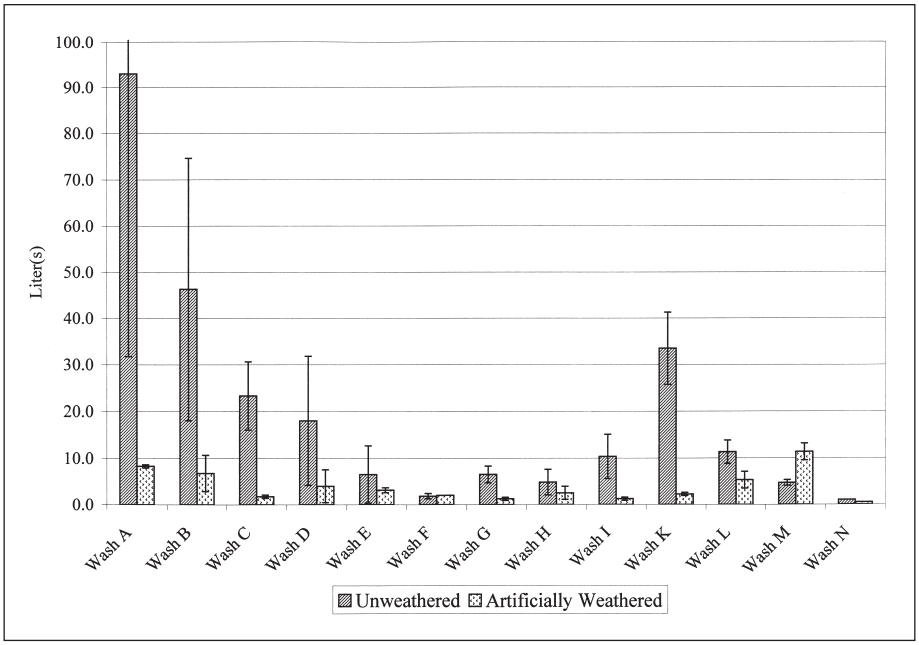

Fig. 3. Abrasion test on handmade brick. Brick samples performed much better on the abrasion test before artificial weathering. Washes A and B, containing salt additive and Graymont limes, performed significantly better before artificial weathering, but there was a significant decrease in performance after artificial weathering. For washes A, B, and C this loss in performance may be a result of the salt migration from the limewash through the samples during artificial weathering. However, wash M, containing lime and water only, performed almost twice as well after artificial weathering, possibly indicating continued carbonation. I-bars indicate standard deviation.

meability allows for greater water transfer than most modern finishes. This property is very important when considering finishes for historic structures where dampness is often a problem. The increased interest may also be attributed to historical accuracy, aesthetic qualities, and environmental concern (limewash produces very small quantities of volatile organic compounds).

Laboratory Testing

NCPTT tested limewashed samples using artificial weathering and adhesion and abrasion tests that were based on published standard methods. Samples were photographed before and after each test and monitored for color change. A solids test was also performed to determine how much limewash was applied to the samples.

In 2004 the testing began after preparation of samples of handmade brick, modern brick, weathered wood, and rough-sawn new wood provided by CARI. The samples were cored with a drill press using a saw bit with a 1⅜-inch hole so that they would fit in the sample holders. NCPTT later purchased 105 Epoxy Resin, 207 Special Coating Hardener, and 405 Filleting Blend, manufactured by West Systems, the epoxy product used at the historic site. The components were mixed following the instructions supplied by the manufacturer and then cast and cored to the same dimensions as the other materials. The surfaces of the epoxy samples were sanded to remove any remaining chemical residue. Limewash was applied once the samples were prepared.

The limewashes were prepared following instructions shown in Table 1. After the limewash was mixed and screened, the viscosity was determined by dipping a #4 Ford cup into the limewash until overflowing and recording the time for the limewash to run completely through, a process that follows ASTM D 1200-94.[9] After checking the viscosity, the samples were dampened and limewash was applied. They were allowed to dry for a minimum of 24 hours before they were redampened and the next coat of limewash was applied.

Quality Finish chose to apply two coats of Edison Coatings Primer #342 to consolidate brick surfaces and assist in adhesion to wood samples for washes A through K.[10] Washes A through I were applied to the handmade brick, modern brick, weathered wood, and rough-sawn new wood. Wash K was applied to the handmade and modern brick. An NCPTT intern applied the primer and the best performers from the wood test — washes D, E, and G — to the epoxy following the same instructions used with the wood. NCPTT staff applied washes L, M, and N to the handmade brick and weathered wood without a primer.

Table 2. Testing Results for All Materials and Washes.
The overall rating for each wash was the sum of rankings from each test.

	Handmade Brick		Modern Brick		Weathered and Rough-sawn New Wood		Epoxy
Best 13	Wash A	*Best* 9	Wash B	*Best* 12	Wash E	*Best* 3	Wash E
12	Wash K	8	Wash D	11	Wash G	2	Wash D
11	Wash M	7	Wash A & K	10	Wash D	*Worst* 1	Wash G
10	Wash D	6		9	Wash A & I		
9	Wash C	5	Wash E	8			
8	Wash B	4	Wash F & M	7	Wash B & H		
7	Wash G	3		6			
6	Wash L	2	Wash G	5	Wash F		
5	Wash I	*Worst* 1	Wash C & I	4	Wash C		
4	Wash H			3	Wash L		
3	Wash F			2	Wash M		
2	Wash E			*Worst* 1	Wash N		
Worst 1	Wash N						

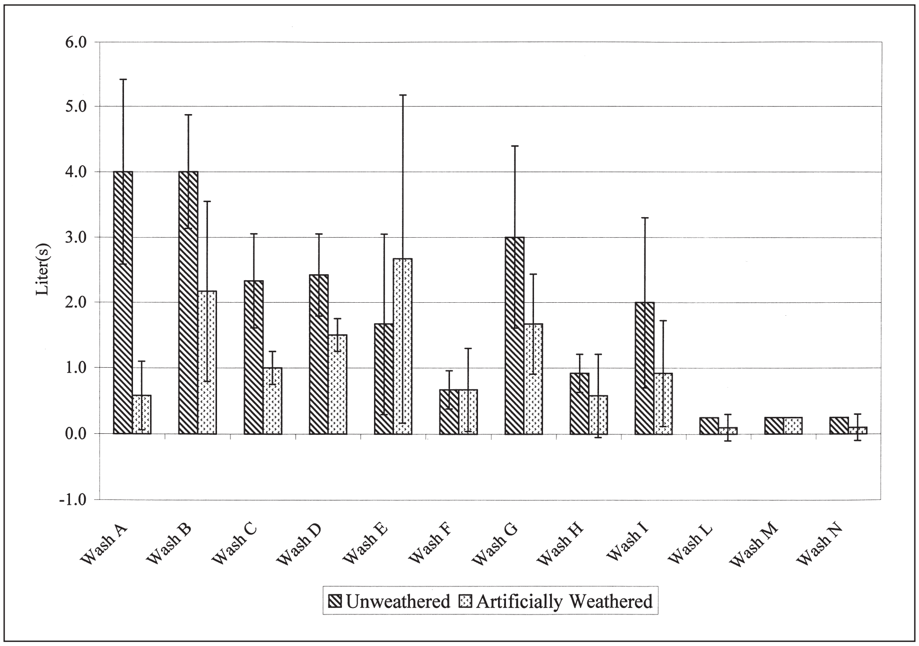

Fig. 4. Abrasion test on wood. All wood samples performed poorly on the abrasion test, both before and after artificial weathering. Limewash began to fail, flaking off on samples from washes C, D, and E before testing began. Washes L, M, and N performed the worst, both before and after artificial weathering. After weathering, several samples from these washes retained insufficient limewash to perform abrasion testing. I-bars indicate standard deviation.

The tests were performed in triplicate for each limewash on each sample material. The samples were photographed before and after each test to maintain a visual record throughout the study. A Minolta colorimeter was used to record color data for all samples using the CIE standard; results from before and after the weathering, adhesion, and abrasion tests were compared for color changes.

The solids test followed a simple gravimetric method to determine the total mass of the limewash applied to the samples. Masses were taken of the samples before limewash was applied and after the final coat had dried. The mass differences before initial and after final application were averaged for each sample, giving the amount of solids deposited. Depending on the limewash applied, the solids deposit would be either lime or a mixture of lime and additives, such as the salt additive in washes A, B, and C.

Abrasion testing, based on ASTM D 968-93, was used to rank how a limewash might stand up over time when subjected to abrasion from wind- and rain-borne particles.[11] The testing apparatus was a funnel fitted over a guide tube and supported vertically. The samples were mounted in a holder positioned 45 degrees from vertical exactly 1 inch below the outlet tube. Sand was loaded into the funnel in 1-liter increments and discharged over the sample until the limewash began to wear away and the substrate was visible. As the substrate became visible, the amount of sand was decreased to 250-milliliter increments until a patch 4 millimeters in diameter was exposed. The amount of sand needed to remove the limewash was recorded. The test was performed on three samples from each wash for each sample material and the results averaged. The best performers were those samples that required the highest amount of sand, indicating that they had formed a harder, more cohesive finish.

Adhesion testing evaluated how firmly the limewash bonded to the samples, following ASTM D 3359-95. An X cut was made with a sharp blade through the limewash to the substrate using a template with the smallest angle of the intersection between 30 and 45 degrees. Pressure-sensitive tape was applied over the cut and smoothed down with a rubber eraser, and the tape was removed in a quick, non-jerking motion. Each limewash was rated on a scale of 5A (best) to 0A (worst), and the results were averaged.[12] The best performers were the samples with the least

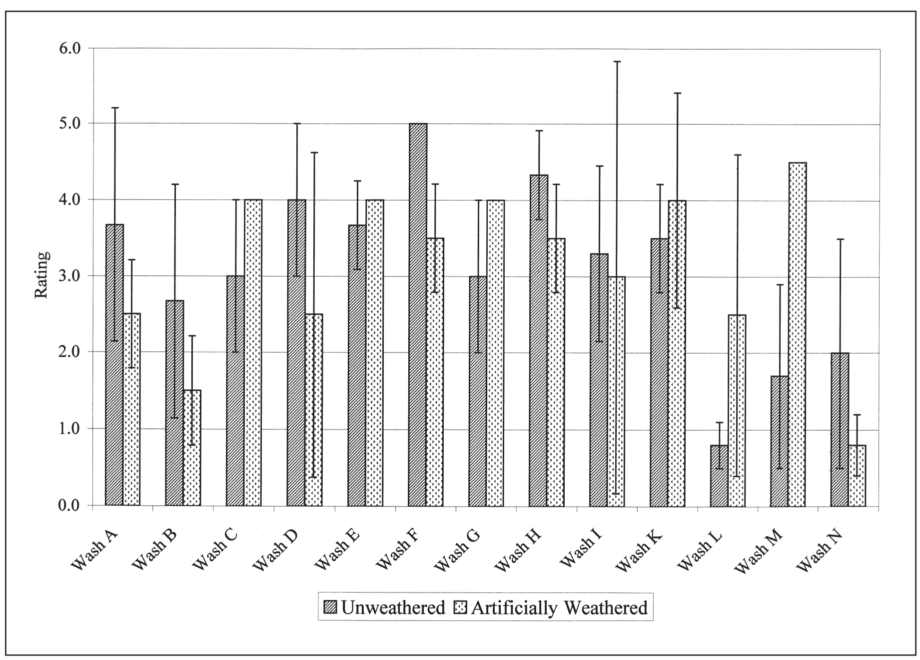

Fig. 5. Adhesion test on handmade brick. All washes performed similarly before and after artificial weathering on handmade brick, except for wash M. After artificial weathering, wash M performed significantly better, possibly because of continued carbonation. Washes applied to modern brick experienced similar results. I-bars indicate standard deviation.

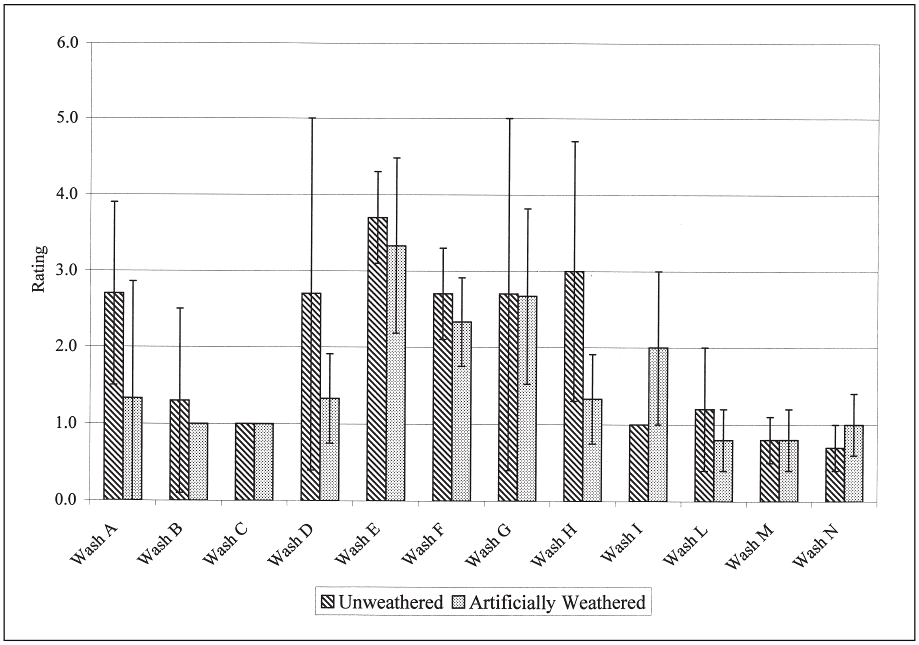

Fig. 6. Adhesion test on wood. All washes performed similarly before and after artificial weathering on weathered and rough-sawn new wood. Washes E, F, and G were the best performers before and after artificial weathering. Wash I performed better after artificial weathering, due to the powdery nature of the limewash. The powdering led to inaccurate results due to the tape's difficulty adhering to the limewash. Washes applied to epoxy samples ranked similarly to wood samples with the same washes. I-bars indicate standard deviation.

limewash loss, indicating the limewashes that bonded most tightly to the material.

Artificial weathering was performed on samples using a Q-Lab QUV Weathering Tester following a procedure based on ASTM D 4587-91. The controlled conditions of this test cannot correlate directly to outdoor exposure but do give an idea of how the limewashes might weather comparatively over time. The samples were mounted in holders with silicone adhesive and placed in the QUV. They were subjected to four hours of ultraviolet light at 140°F (60°C), followed by four hours of condensation and dark at 122°F (50°C) for 100 cycles, for a total of 800 hours of exposure.[13] The sample locations within the weatherometer were rotated daily to ensure even exposure and eliminate any instrumental irregularities. Artificially weathered samples were rated on a scale of 5A (best) to 0A (worst), similar to that used in the adhesion-rating system. The samples were evaluated visually based on the overall appearance and the amount of limewash remaining on the samples. The results from each limewash were averaged to determine the best performers. Mass differences are commonly used to determine loss from weathering, but the final masses of this test were affected by the silicone that had been used to mount the samples and adhered to the edges of the samples after testing.

Results of the Study

The results of the abrasion and adhesion testing before and after artificial weathering are presented in this section. Solids tests were compared for each of the limewash samples. In addition, changes in appearance of the limewashes were recorded by colorimetry and photographic documentation. Test results were represented as an unweighted average of the results from the individual samples for each wash.

For each test except the artificial weathering, three replicates were prepared of each wash and the results averaged. Due to space limitations in the QUV, the artificial weathering was performed in duplicate. A ranking system was devised to evaluate the results of each test, and each limewash was ranked from best to worst for relative change in appearance, adhesion, and abrasion for samples both before and after weathering. Depending upon the number of limewashes for the sample, the rankings varied from 1 (worst) to 10 to 13 (best) (Table 2). The ranking was based on the unweighted averages of the

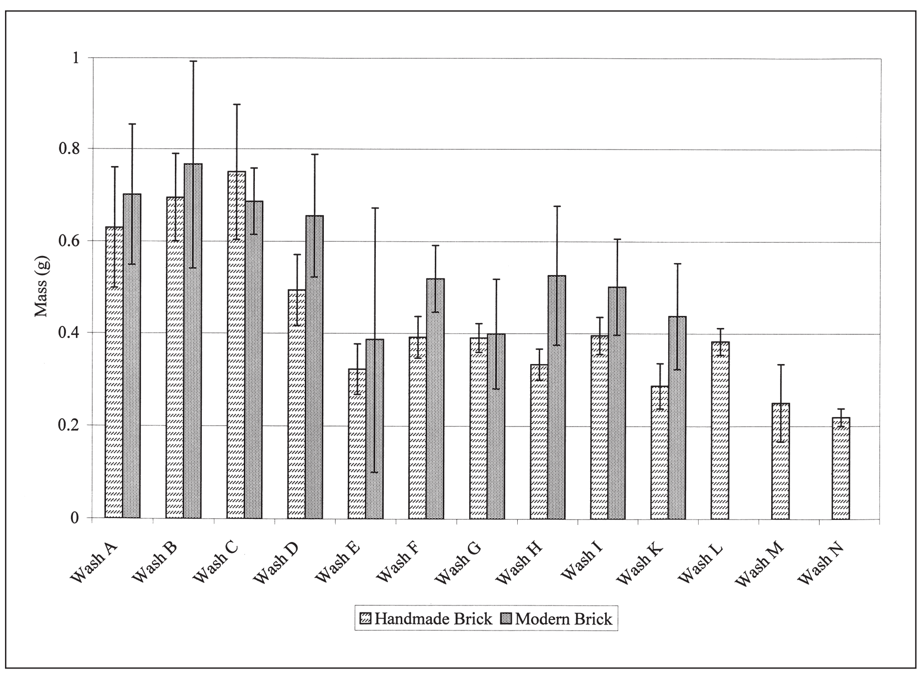

Fig. 7. Solids deposit on brick. Washes containing a salt additive had the highest solids deposit on brick samples. The washes from the same recipes had similar solids deposit, regardless of the lime type or producer. The wood and epoxy samples had similar results. I-bars indicate standard deviation.

result from each test. The ratings where two washes are grouped together are representative of washes with the same overall rating.

The results of abrasion testing on all limewashed samples of handmade brick are presented in Figure 3. These results compare abrasion testing before and after artificial weathering. In all cases the limewash performed better before artificial weathering except for wash M, which performed better after artificial weathering. Washes that include a salt additive required the most volume of sand to abrade through to the substrate before artificial weathering. After artificial weathering, all limewashes performed markedly worse, with the exception of wash M, which performed more than twice as well. Washes A, B, L, and M required similar volumes of sand abrasion after artificial weathering. Limewashed modern-brick samples performed similarly to handmade brick.

The results of abrasion testing on limewashed wood samples, including both weathered and rough-sawn new wood, are presented in Figure 4. It should be noted that limewash was flaking off samples of washes C, D, and E before testing began. All limewashes were poor performers on wood substrates both before and after artificial weathering. None of the washes withstood more than 5 liters of sand abrasion. Several samples from washes L, M, and N retained insufficient limewash after artificial weathering to perform abrasion testing. The samples that were tested from washes L, M, and N took less than 250 milliliters to abrade to the wood substrate. Epoxy samples had results similar to the wood in the abrasion tests.

Figure 5 presents adhesion results on historic handmade brick. All limewashes performed similarly before and after artificial weathering except wash M, which performed better after artificial weathering. Before artificial weathering washes D, F, and H were well rated. After artificial weathering, wash M was the best rated, followed closely by washes C, E, G, and K. Washes D through G had powdering surfaces that made it more difficult to perform adhesion tests. In many of these adhesion tests there was little consistency between replicates, leading to a large standard deviation.

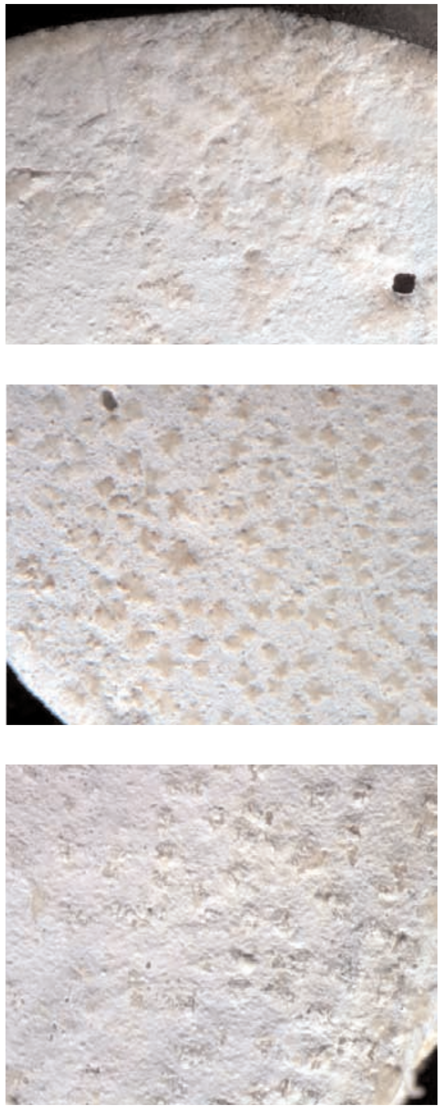

Fig. 8. Photographs taken with Leica MZ 8 stereomicroscope showing crystallization on the surface of limewash samples that included salt. The top photograph is of a handmade brick sample; the middle is a modern brick sample; and the final photograph is of a weathered wood sample. After drying, the crystallization became visually evident and was examined further under stereomicroscope.

On the wood samples all washes performed similarly in the adhesion testing before and after artificial weathering. On most samples the limewash was beginning to flake off before testing, and there was not a solid, cohesive coat to remove with the tape. The best performers, washes E, F, and G, had a rating average in the middle of the scale and experienced between 1/16 inch and 1/8 inch of loss along the incision. Before artificial weathering wash A received an average rating and ranked with the best performers. After artificial weathering wash A was rated significantly lower, near the bottom of the group. The rest of the washes averaged a rating between 0A and 1A both before and after artificial weathering. The migration of salt through the brick samples during artificial weathering is one likely cause for the poor performance of wash A in tests after artificial weathering.

Handmade-brick and modern-brick samples performed exceptionally well during artificial weathering. All recipes on brick samples were rated 4A or 5A, the top rankings, and had an excellent appearance after artificial weathering. However, a marked difference could be seen in the performance of all washes on the adhesion and abrasion tests before and after artificial weathering.

There was a noticeable failure of the limewash on numerous weathered-wood and rough-sawn new wood samples during artificial weathering (Fig. 6). Washes D, E, and I were the only recipes that had a rating average above 4A. Washes F and G had the next highest average ratings but a large standard deviation. For all recipes applied to wood samples, artificial weathering generally removed limewash from the peaks of the grain on the weathered samples, leaving limewash remaining in the valleys. This may be a result of the valleys in the grain being created by the less dense spring growth that erodes faster than the harder, denser summer growth.[14] The lower density wood in the valleys in the grain or the valley itself may have provided assistance in the adhesion of the limewash.

On all materials washes A, B, and C showed the highest solids deposit, which may be a result of the salt additive (Fig. 7). Washes from the same recipe tended to have similar solids deposit regardless of the lime used. Washes G, H, and I, with the acrylic-emulsion additive, showed the lowest solids deposit. Washes D, E, and F, with the casein binder, had the second-highest solids deposit. Washes L, M, and N, which did not have additives, had solids deposits similar in amount to washes G, H, and I.

The total color difference was calculated based on data from the Minolta colorimeter before and after artificial weathering.[15] Results were similar for all samples where limewash remained after

Fig. 9. Unexposed back of modern brick samples after artificial weathering. White residue was identified by Keymaster TRACer III Portable XRF as chlorine. The residue is evidence of salt migration through brick samples from the limewash in response to artificial weathering.

testing. Samples where limewash remained after artificial weathering often showed lighter results than before weathering. One sample from wash G on the wood substrate had a drastic color change that was the result of a tan spot that developed during artificial weathering. It is unclear whether the tan spot was the result of tannins in the wood migrating through the limewash or a reaction of one of the additives.

During the visual inspection and documentation of samples before testing, crystallization was observed on washes A, B, and C. These washes had a salt additive. Samples were examined under a Leica MZ 8 stereomicroscope to confirm the crystallization (Fig. 8). In the stereomicroscope photographs, the crystals are readily apparent as raised, discolored material differing in composition from the limewash itself. These crystals could be either salt or sugar (from the molasses additive), since those were the only constituents capable of such crystallization. Their presence suggests that the additive did not become a cohesive part of the limewash matrix upon drying. Furthermore, since both salt and sugar are highly soluble, the crystals would be lost upon exposure to water, disrupting the matrix significantly and weakening the limewash.

During the artificial weathering, a white residue began to appear on the unexposed back of the modern brick samples from washes A, B, and C (Fig. 9). Using a Keymaster TRACer III Portable XRF for X-ray fluorescence analysis, the residue was studied. The results showed that the residue contained chlorine. The limewash on the surface, which was tested after artificial weathering, had almost no trace of chlorine. Thus, the chlorine on the backside of the samples suggests that the salt migrated from the limewash through the modern brick samples.

Discussion

The results of the study are compiled here to respond to the questions proposed by the partners of the study and listed in the scope of study.

Does the source of the lime affect the durability of the limewash? On both the wood and brick samples the limewashes prepared using Graymont hydrated lime and lime putty (washes A, B, D, L, and M) performed better than the limewashes prepared with the high-calcium lime from the Mississippi Lime Company or Virginia Lime Works (washes C, F, I, K, and N). The limewashes prepared with an acrylic-emulsion additive had less notable difference in the performance between lime sources (washes G through I). This result could be due to the powdery surface that was noted in the adhesion tests on both brick and wood samples.

Does the type of lime (e.g., hydrated lime or lime putty) affect the durability of the limewash? The type of lime seemed to have less of an effect on the durability of limewash in the test results of unweathered wood samples. Taking into account the standard deviation of the test results, all wood samples performed in the same range for each recipe. Wash E, with the casein additive and Graymont Niagara lime putty, performed slightly better overall than the other limewashes on wood samples.

The limewashes prepared from putty performed better than those prepared with hydrated lime on the brick samples tested before and after artificial weathering. For the handmade-brick samples the limewashes prepared with putty and applied without a primer performed better than other limewashes.

Does the surface material, or substrate, affect the adhesion or the resistance to abrasion of limewashes? Limewash performed better on brick samples than on either epoxy or wood samples, indicating that the substrate does make a difference. On the wood samples the limewash began flaking off as soon as it dried, indicating poor adhesion, which could have resulted from either the closed-cell matrix or the expansion and contraction of the wood. The limewash on the epoxy samples performed statistically similar to the wood samples of the same washes. Pits created from the filler being loosened during surface sanding of the epoxy may have improved adhesion.

How do various additives and modifications affect the performance of limewashes? Limewashes prepared with salt, alum, molasses, and laundry bluing had the greatest solids deposit and performed well in tests on unweathered samples of all materials. These formulations were also slightly darker in appearance than the other limewashes, which could have been a result of the salt or the molasses individually or the interaction of the two. After weathering, however, these limewashes (washes A through C) performed significantly worse on all materials. This poor performance was markedly noticeable on the brick samples and could have been a result of salt migration through the samples.

The limewashes prepared without additives (washes K, L, M, and N) and applied either with or without a primer performed better than the limewashes prepared with an acrylic or casein additive on brick samples. On brick samples the limewashes prepared without additives or primer (washes L, M, and N) performed best in tests after weathering. The enhanced performance of the limewashes prepared with no additives suggests that these formulations continued to carbonate during artificial weathering. The decrease in performance of limewashes that included additives indicates that the limewashes lost durability during artificial weathering, suggesting that the additives may have affected the limewash matrix or carbonation. On the wood samples the limewashes applied after a primer performed better than those applied without a primer.

Can acrylic-emulsion additives improve or hinder the performance of limewashes? The limewashes prepared with an acrylic-emulsion additive (washes G, H, and I) had a good appearance on all materials. However, they also had the least amount of solids deposited on all samples. In both the adhesion and abrasion tests before and after weathering the limewash had a powdering surface. The powdering and poor test results could indicate disrupted or incomplete carbonation.

How do limewashes behave after long-term exposure to ultraviolet light and temperature? On the wood samples the limewashes deteriorated during artificial weathering. Samples from washes A, F, H, and I were too deteriorated after weathering to continue with the abrasion test. By way of contrast all brick samples showed little visual change from artificial weathering. For almost all samples in washes A through K the colorimetry revealed lightening of the limewashes after artificial weathering. As stated in the discussion of additives, the limewashes prepared without additives and applied without a primer to the handmade brick (washes L, M, and N) performed better after artificial weathering. They were the best performer in tests after artificial weathering. However, limewash prepared with salt additive (washes A, B, and C) experienced a drastic decrease in performance after artificial weathering.

Conclusions

The purpose of the study was to test a variety of limewash recipes for possible use on historic brick and wooden structures located in CARI. The immediate goal was to identify lasting, low-cost limewash that could be applied in approximately three layers and would last three to five years. NCPTT partnered with CARI to determine the durability of traditional and modified limewash recipes within certain criteria. In collaboration with the project partners, NCPTT designed a program of testing for limewash on weathered wood, rough-sawn wood, handmade brick, and modern brick.

A variety of limewash recipes was tested on multiple sample materials for possible use at CARI. Based on the results, the most important distinction among the recipes tested was the additives used, rather than the type of lime. The recipes fell into four different categories: salt and molasses additives, casein binder, acrylic binder, and no additives. The adhesion of the limewash was greatly affected by the substrate to which it was applied. The more porous material, brick, allowed for a better adhesion of the limewash, creating a more cohesive coat and increasing durability.

On porous materials such as brick, soluble salts can be very detrimental, contributing to spalling or flaking and micro-fissures in the pore walls, increasing drying times, and changing the porosity of the brick.[16] Therefore, limewash prepared with a salt additive may be detrimental to porous materials. Such formulations did not perform significantly better than limewash prepared without additives after artificial weathering and actually experienced a significant decrease in performance on both abrasion and adhesion tests after artificial weathering. However, on the handmade brick wash M performed almost twice as well on all tests after artificial weathering. The porous structure of handmade brick makes a primer unnecessary to assist in the adhesion of limewash to the surface. For application on handmade or historic brick wash M (Graymont Niagara lime putty and water) would likely provide the best results in field applications.

None of the limewashes tested were long-lasting on the wood samples, which could be attributed to using only three layers of limewash on the wood samples. The wood itself has been unfinished for numerous years, which most likely contributed to the poor adhesion and would have affected any finish applied to it. However, there was a noticeable difference performance between the washes applied after Edison Coatings Primer #342 and those that were applied to bare wood. The limewashes applied to wood samples after primer performed better during study. In applications where an acrylic primer is deemed an inappropriate treatment on wood, wash E with Graymont Niagara lime putty and casein would likely be a good choice for use. The epoxy samples experienced results that were comparable to the same recipes on the wood samples, indicating they would have a similar durability. Wash E (the Graymont Niagara lime putty, water, molasses, clove oil, and laundry bluing) was the best performer on the wood and epoxy samples.

Future Research Questions

Additional research is needed on the physical and chemical properties of limes available commercially in the United States and Europe in order to gain a clearer understanding of their role in limewash. Application of a greater number of thin coats of the wash, as well as investigation of the effects of temperature and humidity on carbonation, may provide greater insight into the durability of limewash. The use of Pozzalonic additives and the interaction between the minerals in the brick and the limewash should be studied for historical accuracy and possible increased durability. The reversibility of primer and its effect on historic materials should be researched more thoroughly before considering it for use.

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