IN SITU PERFORMANCE ASSESSMENT AND EVALUATION OF HYDROPHOBIC AND ULTRAVIOLET PROTECTIVE TREATMENTS FOR HISTORIC LOG STRUCTURES

COURTNEY L. MAGILL ✦ FRANK G. MATERO
UNIVERSITY OF PENNSYLVANIA ✦ PHILADELPHIA, PA

✦ ABSTRACT

Beginning in the summer of 2015, research was conducted on protective wood coatings and accelerated weathering testing methods for architectural log and timber. A rack for supplementary natural weathering testing of hydrophobic and ultraviolet protective surface treatments for logs was also erected as a subsequent phase at Grand Teton National Park. This laboratory and field research is part of an ongoing project to develop an appropriate treatment for historic log structures in the region that will preserve their original fabric while maintaining the intended historic appearance of the buildings, i.e., unpainted. The weathering rack will be in place for upwards of five years to verify the lab-based results from Phase I[1] and to determine the long-term durability of the chosen treatments on already aged materials in situ. This report addresses the methods and materials for preparation of the weathering rack and samples as well as the methods being used to monitor their progress and initial results. Readings will be taken yearly to monitor the effects of weathering on each treatment.

✦ INTRODUCTION

This project is part of an ongoing study on the durability of selected traditional and modern sustainable hydrophobic and ultraviolet (UV) resistant penetrating treatments for historic log structures in the Greater Yellowstone Area, such as those found at the Bar BC Dude Ranch in Grand Teton National Park (Figure 1). These treatments are being evaluated using selected criteria including physico-chemical performance under accelerated and natural weathering conditions, ecological sustainability, and impact on aesthetic and heritage character.

Phase I accelerated weathering tests were performed at The Architectural Conservation Laboratory (ACL) at the University of Pennsylvania in cooperation with the National Park Service and the Western Center for Historic Preservation (WCHP). Phase II supplementary natural weathering was begun during the summer of 2015 to verify lab results and develop an environmentally benign treatment protocol for local log structures that will attempt to protect the historic log buildings from UV and water-related deterioration while maintaining the current aged appearance of the wood without environmental or public safety hazards.

Figure 1. The Main Cabin of the Bar BC Dude Ranch with the Teton Mountain Range. Photograph by the author.

[1] Full results of Phase I accelerated weathering testing can be found in the master's thesis, Performance Assessment and Evaluation of Hydrophobic and Ultraviolet Protective Treatments for Historic Log Structures by Courtney Magill (Magill 2015).

Context

While Grand Teton and Yellowstone National Parks have traditionally been known for their natural resources, new management policies recognize the need to preserve and protect the Parks' rich collection of historic buildings and features. A plethora of historic log structures originating from the first wave of settlement during westward expansion and later in the Great Camp Movement survive in both parks ranging in size and complexity from small guest cabins on dude ranches to the Old Faithful Inn, a pinnacle monument in western rustic log construction. These buildings form a rich cultural landscape for the public to explore.

Climate

Grand Teton National Park is in climate zone 7B (Figure 2), a semi-arid mountain climate with mild summers and long, very cold winters; spring and autumn seasons are very brief. According to National Weather Service data compiled from 1958 to 2010 in Moose, Wyoming, located just a few miles south of the Bar BC, average temperatures range from 0.9 ˚F in January to 80.5 ˚F in July, with an extreme low of -63 ˚F in the winter and an extreme high of 97 ˚F in the summer. Daily ranges in these extreme seasons on average span from 1 ˚F to 26 ˚F in the winter and 41 ˚F to 80 ˚F in the summer. The average precipitation for the area is 21.32 inches and the average snowfall is 172.6 inches.

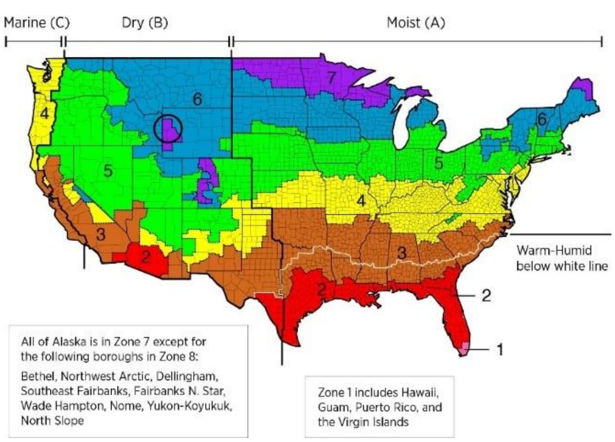

Figure 2. IECC Climate Zone Map with Grand Teton National Park and surrounding area encircled (U.S. Department of Energy 2012).

This data suggests that the climate is very dry with a low relative humidity throughout most of the year and most annual precipitation occurs during winter months. Heavy snow loads from November to April can create problems both with overloading unstable historic structures as well as establishing a prolonged supply of water through daily cycles of freezing and thawing on the lower portions of these structures for months at a time. Summer months can include afternoon thunderstorms that move swiftly up the valley from the southeast, exposing structures to heavy rain and sometimes hail for short periods of time. This rain in an otherwise low-humidity environment results in quick drying of the surface material after such showers, so the wood is additionally stressed by shorter cycles of absorption and desorption which frequently results in checking. These checks occur naturally in wood when stresses occur along the grains created by the fibers of cellulose and are usually not a source for alarm in themselves; however, upward facing checks warrant concern for their ability to gather and hold dirt, debris, and water, creating environments conducive to fungal and insect decay. According to a condition assessment survey of the site conducted by the University of Pennsylvania's Architectural Conservation Laboratory in 2011 (Collins et al. 2011), cabins oriented with their larger elevations facing north and south displayed much worse conditions due to prevailing winds and sun exposure, especially on the southern elevation (Cantu 2012). This demonstrates that the degradation of lignin by UV radiation and the subsequent removal of surface cellulose and other wood material by abrasives carried in the wind or water is one of the major degradation mechanisms of the site. Additionally, some of the structures surveyed show evidence of the deeper penetration of ultraviolet radiation, and thus greater degradation into the end grain than across the grain.[2]

Wood degradation and treatments

Many historic log structures in the American West are exposed to a large amount of UV radiation due to their base elevation. In addition to problems delineated from contact with water, the wood itself is damaged by UV light through degradation of lignin, the component of wood that holds cellulose fibers together (Figure 3). Exposed wooden members are often affected in a matter of days. Small depth of penetration restricts damage to surface area; however, when combined with shrinkage and swelling of water

[2] A study through the Forest Products Laboratory shows that ultraviolet light can more readily penetrate the open pores of the transverse sections of wood exposed in end grain than the tangential section exposed along the length of the tree (Chang et al. 1982).

sorption or abrasion from weathering, surface material delaminates, exposing untreated surfaces for further delignification (Ridout 2000). Additionally, coatings that do not protect against radiation also face polymer degradation from the release of free radicals in the wood caused by substrate surface breakdown, causing them to be rendered ineffective.

Figure 3. Extant Logs found at the Bar BC Dude Ranch displaying a range of coloration due to lignin loss. Photograph by Christine Leggio for the Bar BC Condition Assessment and Report, 2011 by the Architectural Conservation Laboratory.

Alongside durability of treatments for sites that cannot be maintained often, increasing emphasis is being placed on environmentally sustainable solutions for wood coatings. Many past treatments for wood have included large amounts of volatile organic compounds (VOC's), but increasing ecological regulations have driven companies to develop less toxic alternatives. In an effort to collaborate with NPS on utilizing environmentally safe products, low VOC content was a major criterion for treatment selection in this experiment. While Wyoming has no state limits, federal limits may change in the future causing higher VOC products to become illegal and no longer available.

Additionally, treatments should protect against high moisture gradients within the wood substrate to prevent decay. At moisture contents above the fiber saturation point, various agents of decay such as insects, fungi, and water-soluble impurities can begin to degrade the material. The speed of attack of organisms depends on various combinations of moisture content, temperature, relative humidity, and different extractives present in the wood. Most of these decay agents cannot tolerate moisture levels below 18%, some as low as 8% (Ridout 2000). Thus, prevention of moisture content higher than this level can be an effective way to limit wood decay.

Cultures that have traditionally used wood as a building material have developed various techniques for its protection from rot and decay that occurs above the fiber saturation point. The evolution and success of these treatments depends on the environmental conditions of the area as well as the available resources, but most treatments for wood involve regular maintenance and reapplication to ultimately be successful.[3] Wood will last longer if it is regularly treated with finishes that add water repellency and reduce cracking and weathering while inhibiting fungal growth. One such treatment, linseed oil, was commonly used, and still is, for its hydrophobic properties and deep penetration into wood surfaces for protection from water and rot. Even a thin layer can reduce wood movement and cracking by preventing rapid surface absorption and avoiding steep surface moisture gradients. This treatment was utilized historically at the Bar BC according to an account given by Nathaniel Burt, one of the founder's sons (Graham and Associates 1993).[4]

More commercial products were developed by the growing chemical industries, especially after World War II. The desire for exposed wood surfaces continues today, and the wood decking industry especially drives the widespread market for longer-lasting, low-maintenance, UV-resistant stains and coatings. The research conducted for Phase I evaluated a range of commercial products as well as traditional formulations, giving preference to product properties that better met the needs of the site. Many of these commercial products are proprietary with limited access to composition due to trade secrecy clauses, however some key information such as class of coating, solvent type, percent solids by weight, and hazardous materials were available along with other logistical information in technical data and material safety data sheets.

[3] The frequency of reapplication of coatings depends on the product and the conditions of the site. Some film-forming coatings like paints require that the old material is removed before application of a new layer while other treatments, such as pine tar resin, benefit from layering new coatings on top of older treatments.

[4] In an interview Burt does not distinguish what kind of oil was used to treat the cabins. The oil used for the waterproofing and protection of the logs was most likely linseed oil or a similar natural drying oil.

Treatments chosen for Phase I, Accelerated Weathering

Due to the high UV radiation in the Rocky Mountain region, ultraviolet protection for the wood is a significant concern; additionally, due to the decay mechanisms caused by high moisture content, water repellence was also prioritized. Also, because the traditional protective coatings for such regional log structures in the past were clear or only lightly colored, selected products had to be as such with very little visual impact on the aesthetic appearance of the wood. Moreover, low VOC content was considered due to increasingly strict laws on volatile organic compounds. The five modern treatments chosen largely met these criteria. Because an oil finish had been historically applied to the logs on site at the Bar BC Dude Ranch and likely on other buildings in the area, boiled linseed oil was chosen as a traditional finish as well as another historically used treatment for water repellency: paraffin wax melted and dissolved in mineral spirits. Seven treatments in all were chosen for accelerated weathering testing:

1. Armstrong's Wood Stain™ (Natural) (oil-based)
2. DEFY Extreme Exterior Clear Wood Stain™ (water-based)
3. Messmer's UV Plus™ (Natural) (oil-based)
4. TWP® 1500 Series (Natural) (oil-based)
5. Flood CWF UV®5 (Clear) (acrylic emulsion)
6. Allbäck Boiled Linseed Oil™
7. Paraffin Wax in Mineral Spirits

✦ METHODS AND MATERIALS

Summary of Phase I, Accelerated Weathering

Accelerated weathering testing was conducted for 800 total hours in the spring of 2015 using a QUV Weatherometer at the ACL (Figure 4), which simulates weathering by subjecting samples to cycles of UV-B light, heat, condensation, and sprayed water. While artificial weathering occurs in more intense, concentrated cycles than those in nature, results can be a good indicator of longer-term performance of the treatments. In this preliminary testing, treatments were tested on samples of sapwood of Idaho-sourced lodgepole pine (*Pinus contorta latifola*), a common building material in the Greater Yellowstone Region, obtained from Wilmore Lumber Ltd., a supplier in the area. Samples were monitored every 100 hours for weight, surface, and color changes to observe surface degradation alongside extensive evaluations pre- and post-weathering using weight, color, and water repellency changes as well as analysis using Fourier Transform Infrared Spectroscopy (FTIR) to detect lignin loss. As can be seen in Table 1, showing results of Phase I tests, each product displayed strengths and weaknesses after weathering. Treatments such as Armstrong's Wood Stain and DEFY Extreme appeared to perform quite well while other treatments such as the paraffin and minerals spirits mixture or Flood CWF UV5 largely failed. As a result, the two latter treatments were excluded from Phase II natural weathering testing.[5]

Figure 4. The QUV Weatherometer used for accelerated weathering in the Architectural Conservation Laboratory at the University of Pennsylvania. Photograph by the author.

Phase II, Natural Weathering Rack

A natural weathering rack based on those found at industrial weathering sites across the United States (McGreer 2001) was designed and constructed on site at the NPS pit area across from the Jackson Airport. This location allows for full exposure to the sun from the south, limits environmental impact of the weathering bracket on surrounding flora, restricts human interaction with the samples that could potentially cause damage, and allows access to the site even during the heavy snow of winter months. The rack was placed at the edge of the pit area near the gravel mounds. The system is open-backed to allow for air circulation and set at a 45˚ angle facing due south for the greatest exposure to solar radiation.

[5] These treatments were eliminated because they did not meet the criteria of an optimal coating for the site. These criteria include long-term durability, water repellence, UV protection, low impact on aesthetic character, and ecological sustainability.

Eight 8-foot lengths of aluminum strut channel were fastened to 5-foot lengths of strut with zinc-plated steel brackets and high-strength steel cap screws to create a rectangular bracket. This design allows for six rows of samples to be bolted in place on the struts. This rectangular bracket was then inclined by bolting it to 3-foot lengths of strut at both ends and in the center; these were in turn connected and braced to another 8-foot length of strut for stabilization of the setup. Sandbags were laid on the base struts to anchor the bracket in place (Figure 5).

Figure 5. Erected weathering bracket viewed at an angle (above) and from the side (below). Photos by the author.

Samples were randomly dispersed across the face of the setup by independent work associates to eliminate bias and distribute each type of sample across the frame. The pieces were bolted to the struts with steel cap screws and zinc-plated strut-channel nuts in six rows containing either seven or eight samples. The whole assembly was weighted down with seven sandbags.

Treatments chosen for Phase II, Natural Weathering

As previously noted, not all the products used in the accelerated weathering lab tests were selected for the Phase II natural weathering tests. Those products that performed well in the lab testing are being tested alongside a formulation derived from a treatment designed by the Forest Products Laboratory that combines both linseed oil and paraffin wax in mineral spirits. In all, six products are currently being tested alongside a control:

1. Armstrong's Wood Stain™ (Natural) (oil-based)
2. DEFY Extreme Exterior Clear Wood Stain™ (water-based)
3. Messmer's UV Plus™ (Natural) (oil-based)
4. TWP® 1500 Series (Natural) (oil-based)
5. Allbäck Boiled Linseed Oil™
6. Allbäck Boiled Linseed Oil™ – Paraffin Wax – Mineral Spirits formulation

Sample preparation

Log samples for each treatment were prepared according to standard D7787-D7787M – 13 Standard Practice for Selecting Wood Substrates for Weathering Evaluations of Architectural Coatings (ASTM 2011). To observe how these coatings behave on weathered material as well as new wood, sample panels were cut from both newly felled and older logs (Figure 6). Weathered panels were cut from logs salvaged from naturally fallen lodgepole pine sourced on the property of the White Grass Dude Ranch. New panels were created from newly cut, but seasoned, logs of lodgepole pine also from material at White Grass. These logs were sourced by the Western Center for Historic Preservation for use on onsite repairs and replacements. Both new and old log samples were stripped of any remaining bark using a draw knife. The panels were cut tangentially from the outer edges of the chosen logs to give a curved, convex surface to better imitate architectural logs in situ.

Figure 6. Samples were prepared by cutting off tangential sections of both new and weathered logs onsite at the White Grass Dude Ranch. Photograph by the author.

Sample panels were chosen from the pool of cut material to limit the number of knots, cracks, resinous streaks, blue stains, and fungal infections. Each panel is approximately 10 inches long x 8 inches wide x 2 inches thick at its thickest point. Panels were characterized before treatment application to evaluate how much of each treatment was absorbed and to observe any visual changes to the wood substrate caused by the coating application.

Treatments were applied to the panels (Figure 7) according to each manufacturer's instructions. They were applied to the face of the panel with brushes, but not on the end grain or the back to imitate treatment application of stains in the field on architectural logs. Once the treatments properly dried, the end grain of the panels was sealed by dipping each end in satin-finish polyurethane and allowing it to cure.

Each treatment is represented by a cohort of seven test panels: four weathered samples and three new wood samples. Additionally, five controls of untreated wood were included, three weathered and one new sample, totaling forty-six panels on the weathering rack.

Figure 7. Application of stains to cohorts of samples. Photograph by the author.

The panels were bolted to the struts of the natural weathering rack horizontally to mimic the orientation of logs in structures. Small stamped aluminum tags were fastened to the backs of each panel using small tacks to act as long-term labels.

Analytical methods

A variety of methods were utilized to evaluate the samples before treatments and weathering to serve as comparisons for later evaluations in the performance of each treatment over time. These methods include photography, quantitative color measurements, surface inspection, water repellency measurements, and weight measurements. The full range of evaluations will take place yearly to compare to initial measurements taken in August of 2015. At the time of this report, the samples have been evaluated at one year and two years. Initial results of testing will be broadly discussed below.

Color change

Absorption of ultraviolet radiation and the subsequent degradation of lignin in the wood substrate is the primary cause of color change in the weathering of wood. Lodgepole pine tends to darken with the accumulation of lignin degradation products, and, as these product wash away, the wood becomes lighter and more silvered due to the concentration of mostly cellulose fibers at the surface. Perception of color can vary enormously depending on a variety of factors such as the viewer, light source, and surface texture, so two methods are being utilized to monitor these color changes due to weathering as well as the change in the material after treatment application: color-corrected photographs were taken of the samples and quantitative measurements of color were taken with a Konica Minolta Spectrophotometer CM-2500d (Figure 8).

Figure 8. Color measurements of the wood surface taken using a Konica Minolta Spectrophotometer CM-2500d. Photograph by the author.

All samples, both new and old, significantly lightened over the two-year test period and most approached a similar grey and weathered appearance to that of the control panels. The most striking treatment shifts over the two years occurred on the panels treated with TWP (Figure 9). While these panels had a red hue to begin with, the finish became quite orange after one year and irregularly spotted and streaked with grey and orange patches by year two, especially on the new wood panels. The Messmer's product also appeared mottled upon inspection at two years, on the new wood for the most part, but was less striking visually because the treatment appeared more brown. The mottled appearance of TWP and Messmer's indicates that both treatments were likely not absorbed as well by the new wood panels and created more film-like coatings.

Figure 9. Progression of new wood sample N-TWP-2 showing before weathering (top), at one year (middle) and at two years (bottom). Photographs by the author.

The DEFY-treated panels are significantly lighter than the other panels, especially the new wood panels. After one year, these new wood panels were mostly white with light brown streaks, but after two years have more closely approached the grey color of the controls (Figure 10).

Figure 10. DEFY new wood sample N-DEF-3 at one year (above) and two years (below). Photographs by the author.

The linseed oil and mixture treatments had similar effects on the coloring and appearance of their panels (Figure 11). On the new wood panels, each treatment enhanced the grain of the early and late wood after one year, likely due to differential penetration of the product in these areas; however, during the second year the wood surfaces also began to approach the same coloring as the controls, both for new and old wood (Figure 12).

Figure 11. New wood linseed oil panel, N-LIN-3, at one year (above) and two years (below). Photographs by author.

Armstrong panels of both new and old wood were fairly dark brown upon application. After two years samples have lightened significantly and retained a light brown hue with less irregular streaking than seen in other products.

Surface morphology

Many panels, both treated and untreated, experienced macroscopic changes as well such as checking, cracking, and warping in certain cases; these changes were easily noticeable in photographs over time.

Figure 12. Weathered control panel, W-CON-2, progression from before weathering (above) to two years (below). Photographs by the author.

Microscopic changes occurred as well in the form of microchecking and roughening of the surface. Surfaces of each sample were inspected at 70x magnification with a Celestron 5 MP Handheld Digital Microscope Pro to visualize the change in the morphology of the surface of the samples after weathering for an extended period (Figure 13). As the material weathered, many of the finishes began to wear away and loose cellulose fibers separated from the wood substrate, making the surface much rougher. This change is much more visible in the new wood samples, as they previously showed very little deterioration damage before exposure.

All samples accrued microchecks and loose cellulose fibers over the two-year period. All the oil-based treatments appear to have prevented some major damage for the first year, but were ineffective after a period. The DEFY product, being water-based, had little to no conditioning effect on the wood surface and showed checking patterns like that of the control throughout testing.

Figure 13. Surfaces of new wood panel, N-MES-1, treated with Messmer's UV Plus before weathering (top), at one year (middle), and at two years (bottom) (70x magnification). Photographs by the author.

Water repellency

Water repellency of the samples is being evaluated using contact angle measurements. The method for taking such measurements is outlined in ASTM D7334-08 Standard Practice for Surface

Wettability of Coatings, Substrates and Pigments by Advancing Contact Angle Measurement (ASTM 2013) as well as in papers by Woodward (1999) and Lamour et al. (2010). The experiment uses the measurement of the angle of contact when a drop of liquid is applied to a coated surface – water in this experiment. This angle is the interior angle that a drop makes between the substrate and a tangent drawn at the intersection between the drop and the substrate. By measuring the advancing contact angle, the angle immediately after the drop is deposited on the surface, the hydrophobicity of the coating and wood surface can be determined; for water, an angle less than 45˚ indicates a hydrophilic surface, greater than 90˚ indicates a hydrophobic surface, and anywhere between 45-90˚ is intermediate.

A transfer pipette was used to deposit drops of water, termed sessile drops, onto the top (tangential) surface of samples and a camera set up with a mounted concave lens and backlighting was used to record the drop immediately after it was placed on the surface.

These photos were then processed using the plug-in Contact Angle in the open-source software ImageJ to calculate contact angles. Contact angles generated from photos will help to determine the hydrophobicity of the coatings on the wood surface and how weathering may affect the water resistance of the coatings over time.

Many of the weathered wood samples appeared to have retained hydrophobicity longer than the new wood samples, likely because the weathered wood more readily absorbed and retained a significantly greater amount of the treatments.

Samples before weathering, even the new control panel, exhibited fairly high levels of hydrophobicity. However, most lost their water repellency over time with outdoor exposure. At the one-year evaluation, DEFY samples were no longer water repellent, but all the oil-based treatments showed intermediate to strong hydrophobic properties on the surface. The mixture of linseed oil, paraffin wax, and mineral spirits displayed especially good retention of hydrophobicity at one year.

However, at the two-year evaluation, only two products still exhibited intermediate hydrophobicity on all their test panels: Armstrong and TWP (Figure 14). Other panels absorbed the water droplet faster than could be recorded.

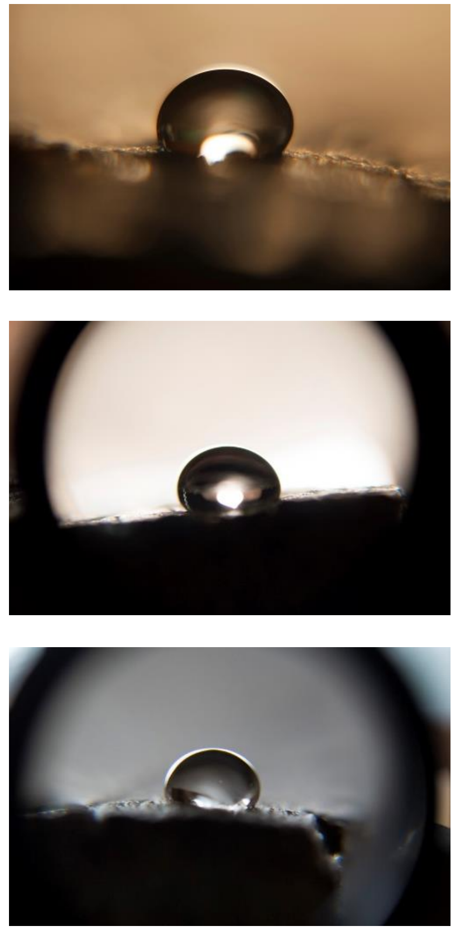

Figure 14. Drops of water deposited on weathered TWP-treated panel, W-TWP-3, before weathering (top), at one year (middle), and at two years (bottom). Photographs by the author.

Weight

With ultraviolet degradation of the lignin and potentially of the treatments, the degraded lignin and cellulose on the surface of the samples become susceptible to removal by abrasion mechanisms such as driving rain or wind laden with abrasive particles. To measure the amount of degradation, samples were weighed to the nearest one-hundredth of a gram with an analytical balance before being weathered and at each evaluation period. Moisture content of each panel was also measured at the time of weighing to inform the influence of water content on measurements.

Over the first year of weathering, the weathered wood control panels lost an average mass of 57 g. While the other treatments on weathered panels lost approximately 50 g, the weathered linseed oil treated panels lost only 38 g on average indicating a greater retention of treatment and wood material.

The new wood control lost approximately 45 g of mass in the first year. All the new treated samples lost a similar amount of mass within 3 grams of the control, perhaps indicating only a small number of treatments deeply penetrated the new wood samples during application and were lost or largely ineffective over the first year.[6]

✦ RESULTS AND DISCUSSION

Preliminary results from the Phase II tests are summarized in Table 2. Many of the treatments fared well for the first year, but declined in their protective ability and visual quality over the second year. Considering the extreme southern exposure of the samples and the manufacturers' recommendations to re-treat every few years, this breakdown is logical. Thus, in evaluation of treatments for potential use, it is essential to note that even though manufacturers' guidelines were followed for application, the panels were only treated once and left unmaintained in the field. If maintained and treated annually or biennially, different results would likely be found.

The traditional finishes (linseed oil and the mixture) may have penetrated deeply and repelled water for the first year, but by the end of the second year appear to have largely weathered out of the wood surface and lost conditioning and hydrophobic properties. Additionally, while their overall appearance generally matched that of the controls during the experiment, neither treatment was designed to prevent UV radiation.

The DEFY product is an interesting development in the field of nanoparticles for UV resistant treatments; however, due to the water-based formula, the treatment appears to have neither penetrated deeply enough in the wood material nor fixed the nanoparticles upon the surface to offer long-term protection in this environment without re-treating often.

Although the TWP product was one of the only products to retain a high level of hydrophobicity over the two-year period of testing thus far, the orange mottled appearance of both new and previously weathered samples would not be ideal for the intended historic appearance of the log structures over time. Similarly, the mottled red-brown appearance of the Messmer's product over the two years is not ideal. This product also did not retain hydrophobicity as well as other treatments of similar coloring.

Armstrong's product retained intermediate hydrophobicity over the two years. While its UV protection derives from metal oxides in the stain and in turn colors the panels a browner tone than the controls, these panels lighten over time and Armstrong was found to be one of the better performing treatments for both new and old wood test panels.

To receive legitimate results from the natural weathering process, samples must undergo an extended period of exposure over multiple years. Natural weathering in the field is a much slower process than artificial weathering in the lab, but it is necessary to be able to follow the real-time degradation of the wood samples and their coatings through numerous weather cycles in the target environment. Samples have been evaluated twice so far and will remain in their positions on the rack for further testing and documentation in the coming years.

Figure 15. Weathering rack with samples at time of installation in August 2015 (top), at one year (middle), and at two years (bottom). Photographs by the author.

[6] During the second year of measurements, the panels were coated with snow during the site visit (Figure 15). Attempts were made to dry them out before measurement, but the moisture levels were higher than previous evaluation and the panels weighed more than the previous year. Therefore, the data was not viable for analysis.

Table 1. Comparison of treatments used in Phase I, accelerated weathering testing in terms of testing properties. Treatments were rated on a 1-10 scale with a score of 1 indicating very poor performance and 10 indicating excellent performance.

	Physical Degradation of Surface (Microscopic Inspection)	Treatment Absorbed (Weight Change)	Material Lost During Weathering (Weight Change)	Color Change - Final Result to Control (Spectroph-otometer)	Lignin Degradation at Surface (FTIR)	Water Repellence (Contact Angle Measurement)	Treatment Retention (FTIR)	Overall Performance (Average)
Control	2	n/a	5	n/a	1	2	n/a	n/a
Linseed Oil	8	9	4	6	2	9	7	6.42
Paraffin and Mineral Spirits	2	1	5	8	1	2	1	2.86
DEFY Extreme	5	8	7	9	5	7	7	6.85
Armstrong's Wood Stain (Natural)	7	10	9	9	4	8	9	8
TWP 1500 Series (Natural)	8	5	4	6	3	10	8	6.14
Flood CWF UV-5 (Clear)	4	3	6	2	2	5	4	3.71
Messmer's UV Plus (Natural)	6	7	5	4	5	8	9	6.28

Table 2. Comparison of treatments used in Phase II, natural weathering testing in terms of testing properties after two years of testing. Treatments were rated on a 1-10 scale with a score of 1 indicating very poor performance and 10 indicating excellent performance.

	Physical Degradation of Surface (Microscopic Inspection)	Material Lost During Weathering (Weight Change)	Overall Appearance and Color Change - Final Result to Control (Spectrophotometer)	Water Repellence (Contact Angle Measurement)	Overall Performance (Average)
Control	2	5	n/a	1	n/a
Armstrong's Wood Stain (Natural)	4	6	7	8	6.25
DEFY Extreme	2	5	8	2	4.25
Linseed Oil	3	7	8	4	5.5
Messmer's UV Plus (Natural)	4	6	4	5	4.75
Mixture of Linseed Oil, Paraffin Wax, and Mineral Spirits	3	4	8	6	5.25
TWP 1500 Series (Natural)	4	6	1	9	5

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✦ LITERATURE CITED

ASTM. 2011. ASTM Book of Standards Volume 06.02. ASTM D7787/D7787M – 13: Standard Practice for Selecting Wood Substrates for Weathering Evaluations of Architectural Coatings. ASTM International, West Conshohocken, PA.

ASTM. 2013. ASTM Book of Standards Volume 06.01. ASTM D7334-08: Standard Practice for Surface Wettability of Coatings, Substrates and Pigments by Advancing Contact Angle Measurement. ASTM International, West Conshohocken, PA.

Cantu, R. J. 2012. Green Roofs for Historic Buildings: Case Study of the Bar BC Dude Ranch at Grand Teton National Park. MS Thesis. University of Pennsylvania, Philadelphia, PA

Chang, S.-T., D. N.-S. Hon, and W. C. Feist. 1982. Photodegradation and photoprotection of wood surfaces. Wood and Fiber 14(2):104-117.

Collins, M. C., M. Diadato, C. Leggio, and N. Youngborg. 2011. Bar BC Dude Ranch: Condition Assessment and Report. University of Pennsylvania, Philadelphia, PA.

Graham, R. E., and Associates. 1993. Bar BC Dude Ranch Grand Teton National Park, Wyoming: Historic Structures Report. U.S. Department of the Interior, National Park Service, Rocky Mountain Regional Office.

Lamour, G., et al. 2010. Contact angle measurements using a simplified experimental setup. Journal of Chemical Education 87(12):1403-1407.

Magill, C. 2015. Performance Assessment and Evaluation of Hydrophobic and Ultraviolet Protective Treatments for Historic Log Structures. MS Thesis. University of Pennsylvania, Philadelphia, PA.

McGreer, M. 2001. Atlas Weathering Testing Guidebook.. Atlas Material Testing Technology, LLC, Chicago, IL.

Ridout, B. 2000. Timber Decay in Buildings: The Conservation Approach to Treatment. Routledge, New York, NY.

Woodward, R.P. 1999. Contact Angle Measurements Using the Drop Shape Method. First Ten Angstroms, Inc., Portsmouth, VA.