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A Performance Evaluation and Assessment of Mineral Silicate Coatings for the Restoration of the Exterior Concrete at Jackson Lake Lodge

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Abstract

This thesis focuses on the evaluation of the durability of potassium silicate coating on concrete surfaces, in particular the exterior concrete walls at Jackson Lake Lodge located in Grand Teton National Park, Wyoming. The main building on the site, the Central Lodge, is a large 61 year old structure that is in need of a new architectural coating to prolong its service. This structure, once dubbed the ugliest building in America, is now cherished and appreciated for its significance in ushering in a new era of Modernist-style buildings constructed within National Parks. Because the pH of the concrete walls has fallen to 7, the original architectural coating—acid stains—is not a viable option to recoat the structure. New coatings must be explored such as mineral silicates.

Comprised of a waterglass solution and inorganic pigments, mineral silicate coatings impart a durable colored finish to cementitious and silica-rich substrates. Developed in Europe, mineral silicate paints and stains have been around for over 150 years. Recently this coating system has gained traction in the United States for its durability and performance enhancing properties. This testing program used a variety of analytical methods (such as accelerated weathering, spectrophotometry, water vapor transmission rate tests, water immersion tests, RILEM tube tests, contact angle measurements, and pH readings) to evaluate the color durability, water vapor permeability, and liquid water repellency characteristics of potassium mineral silicate coatings. This evaluation was conducted to determine if potassium silicate coatings can be viable alternative architectural finish to restore the original appearance of the Central Lodge, while improving the performance of the concrete.

Keywords

concrete, Jackson Lake Lodge, potassium silicate stains, Mid-Century Modern, coating duriability

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A PERFORMANCE EVALUATION AND ASSESSMENT OF MINERAL SILICATE COATINGS FOR THE RESTORATION OF THE EXTERIOR CONCRETE AT JACKSON LAKE LODGE

Araba Prah

A THESIS

in

Historic Preservation

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Chapter 1: Introduction

Concrete has been and continues to be one of the most popular building materials. Many twentieth century buildings utilized exposed ‘fair faced’ or board marked concrete for structural and decorative purposes. Early and mid-twentieth century concrete structures are reaching the point where they will need some form of remedial or preventive intervention to continue their service life. Finding appropriate restoration techniques that can prolong the lifespan of these structures is critical. This thesis seeks to examine the dual role mineral silicate coatings can play in both restoring the original aesthetic intent of colored historic concrete buildings while improving the performance of the concrete itself.

In order to exam this duality, this thesis will evaluate and assess the use of mineral silicate coatings to recreate the original exterior acid-stained concrete of the Central Lodge at Jackson Lake Lodge. The site is located in Grand Teton National Park, Moran, Wyoming whose climate can be characterized as humid continental climate according to the Köppen classification. In order to convey a rustic wooden appearance using a structural, fireproof material, architect Gilbert Stanley Underwood constructed the Central Lodge using poured in place concrete that was textured and colored with acid stains to resemble redwood paneling. The staining technique used three colors to create a slightly variegated and semi-transparent finish on the concrete.

The finish on the exterior walls has changed significantly, and the current coating on the Central Lodge is now an opaque synthetic resinous brown stain that has obscured the original concrete surface. This brown coating is now in poor condition and the exterior surface of the Central Lodge (approximately 40,000 square feet) requires a complete renovation. Even though mineral silicates were not the original coating, they may be one of the few viable options for restoring the building’s appearance. Prior to this thesis, it was determined that the reapplication of acid stains will not create a reliable or durable finish due to acid stain’s dependence on fresh concrete’s high alkalinity. When first cured, concrete is highly alkaline (with a pH of around 13), but over time due to the carbonation of the material the pH is lowered. Such is the case of the Central Lodge, where after 61 years of exposure to the elements, the pH of the walls has dropped to 7 or neutral. Now, alternatives to acid staining must be examined. It is important that the alternative coating be durable, vapor permeable, reduce water absorption, and be able to replicate the dynamic color of the original finish. Ease of application, cost, and low to no toxicity are also important considerations.

Mineral silicate paints and stains have been in use for over 150 years— first in Europe, and more recently in the United States (within the past 20-25 years). There is growing interest in using these products for the renovation and restoration of cultural heritage. Mineral silicate paints have been used on a variety of prominent structures, many of which are listed on the National Register of Historic Places such as the Pemaquid Point Lighthouse in Bristol Maine; the Wayne-Gordon House in Savannah Georgia; and the Fort Hill Tower in Boston, Massachusetts. Mineral silicate coatings have also been used in the renovation of modernist-style buildings such as I.M. Pei’s Bushnell Tower in Hartford Connecticut and the 1970’s residential towers (Harnwell, Rodin, and Harrison College Houses) on the University of Pennsylvania’s campus. In all of these examples the mineral silicate coating was not the same type of finish originally used on the structure.

In order to confirm the viability of using mineral silicate stains, an assessment and evaluation of the performance and functional characteristics of the coating was conducted. Mineral silicates paints and stains use the following binders: sodium silicate, lithium silicate, and potassium silicate. This thesis focused on potassium silicate coatings. The testing program included: creating various shaped concrete coupons (that are similar in composition to the concrete mix used in the Central Lodge); applying two coats of KEIM Concretal® Lasur potassium mineral silicate stain to the surface of the coupons; and testing the coating's durability through various tests —water vapor transmission rate test; water repellency tests; and accelerated weathering to test color durability.

Figure 1: Jackson Lake Lodge with the Grand Teton Mountains in the background. Image Credit: Grand Teton Lodge Company

Chapter 2: A Brief History of Jackson Lake Lodge

Located near the eastern foothills of the Teton Mountain Range, Jackson Lake Lodge serves as reminder of the changing attitudes of the National Park Service (NPS). The 144 acre site was designated a National Historic Landmark in 2003, and is comprised of the large concrete Central Lodge and approximately 60 smaller guest cabins, staff dormitories, and service facilities. Jackson Lake Lodge was designed to be a dramatic departure from the Rustic-style buildings that the National Park Service had long promoted throughout the 1920s and 1930s, especially in western parks (Reed and Wallace, 13). The buildings on the site, particularly the Central Lodge, were designed to emphasize the natural beauty of the surrounding landscape; not by the imitation of natural materials but through massing, height, color, and texture. Jackson Lake Lodge not only provided an escape into a scenic wilderness, but also represented a modern version of that experience which included the automobile as a primary factor for access.

During the mid-twentieth century the NPS was in the grips of transition as the agency strived to cater to the surging number of visitors to national parks. This surge was the result of increased wealth and optimism after World War II. From this dilemma federal programs such as Mission 66 (which began in 1955 and ended in 1966) were created to better accommodate visitors and improve experiences in national parks. One way this was achieved was through the creation of lodges that accommodated the automobile. Through the fusion of rustic architecture and the modernistic ideals of the International Style, a new architectural style was embraced. Jackson Lake Lodge was the first to implement this fusion within the park system, and the project would have a significant impact on the standards for infrastructure for the Mission 66 program soon thereafter. Because of this, Jackson Lake Lodge can be viewed as the prototype of this new style and instrumental to the notion of how to design for the modern age in a park setting.

2.1. The Establishment of the Grand Teton Nation Park

Jackson Lake Lodge has been described as “bringing bold ideas of modernism and the International style to Wyoming” (Architecture of the Tetons). The development of Jackson Lake Lodge began as a vision of John D. Rockefeller Jr (1874-1960), one of the wealthiest men of the twentieth century. Rockefeller was involved in the preservation and expansion of the park since his first visit to Yellowstone National Park as an adult in 1924. It was during this visit that Rockefeller would meet Horace Albright, the superintendent of Yellowstone National Park, and their friendship would lead to the creation and expansion of Grand Teton National Park (GTNP) and the construction of Jackson Lake Lodge.

When Rockefeller returned to the area with his family in 1925, Albright led the group through the Jackson Hole valley to a bluff overlooking the majestic Tetons (Engle, 9). Soon after this experience, Rockefeller wrote in a letter pledging to purchase “the entire Jackson Hole Valley with a view to it being ultimately turned over to the [federal] government for joint or partial operations by the Department of Parks and the Forestry Department” (Righter, 48). He, along with Albright, wanted to protect the area from the ravages of commercialism, and they felt that the best way to preserve the area would be to turn it into a national park. GTNP was established by executive order on February 26, 1929 by President Calvin Coolidge. The order was supported primarily by wealthy Jackson Hole residents, and established 96,000 acres of park land (Besser, 35). Even though many residents supported the creation of the park, there was a large percentage of the local public against it.

Albright and Rockefeller wanted to expand the park, but they knew that they would receive resistance from ranchers if they openly purchased land. In an effort to be discrete, Rockefeller created a shadow company –the Snake River Land Company– to acquire properties in the valley. He feared that once landowners knew that a wealthy Eastern millionaire was purchasing the land, prices would skyrocket or landowners would be less inclined to sell.

By April 1930, Rockefeller's involvement in purchasing land was uncovered and by that point the Snake River Land Company "had acquired 25,000 acres of land at the base of the Tetons" (Engle 10). Once the secret was out, livid ranchers rallied against what they saw as an "invasion of Eastern millionaires led by national park officials". For these ranchers this was "a fight for the West" (Gerling). This led to court hearings and protests against Rockefeller and the NPS. Fiery slogans such as "IF YOU LOVE FREEDOM, then help us fight our bureaucratic form of government, such as the creation of the Jackson Hole National Monument…YOUR FRONT YARD MAY BE NEXT" could be found throughout the town (Engle, 10). Court hearings in the early 1930s found that the Snake River Land Company, and Rockefeller by extension, had done nothing illegal and had purchased (at that point) 36,000 acres at fair market rate from willing sellers. This did not quench the fiery opponents, and the land owned by Rockefeller's company sat in limbo for ten years as politicians fought over how it should be incorporated into the park system. It was decided to turn the land into a national monument, signed into law by President Franklin Delano Roosevelt on March 15, 1943 through Executive Order 2578. By September 17, 1950 the monument was designated a national park and finally incorporated into the Grand Teton National Park (Engle, 10). Once the issue of Rockefeller's land acquisitions had been resolved, work could begin on how to accommodate the vast number of visitors coming to the park.

Figure 2: Mr. and Mrs. John D. Rockefeller, Jr. on a boat ride on Jenny Lake, 1931. Image Credit: Jackson Hole Historical Society, BC.0224

2.2. Addressing the Dilapidated and Sparse Accommodations

With the extra land incorporated into the park, the number of visitors to the area skyrocketed. According to Engle, "in 1950, 189,286 visitors entered Grand Teton National Park. By 1952, due to a growing middle class and postwar prosperity, that number had risen by nearly 600,000 to 785,343, while accommodations were still limited to around 150 units" (27). The lack of accommodations forced many of the visitors to camp out in tents or sleep on the side of the road in their vehicles (Ibid). The management for the park knew that this would have to be addressed. Problems concerning the facilities were a subject of much debate, even in the 1940s. Kenneth Chorley, the trustee and president of Jackson Hole Preserve, wrote about the sad state of GTNP's accommodations to Lawrence Rockefeller (Rockefeller Jr.'s son) saying "it is unfortunate, but nevertheless true, that the people to whom the Lodges were leased had let the properties run down in some cases to a deplorable condition"(Chorley). It was estimated that it would take as much as $700,000 to get the existing facilities in running order, but there were many that did not believe that saving the facilities would be worth the time and expense (Engle 23). The question was not if new facilities would be needed, but how to pay for them and where they should be located. One of the sites proposed for a new hotel/lodge would be close to the spot where the Rockefellers and Albright picnicked so many years ago; in the vicinity was an old, rundown lodge from the 1920s.

On the site of the current Jackson Lake Lodge was an inn of the same name. Built in 1922 by Eugene Amoretti of Lander, Wyoming, the lodge was comprised of a series of cabins. At its prime, the lodge could accommodate around 125 guests. It was considered to be the first modern lodge in the valley, having cabins with hot and cold running water, baths, and toilets. The site was purchased by the Snake River Land Company in 1930, like other properties in the area. It remained in operation until 1953 when the cabins were removed to make way for a larger more modern lodge (Daugherty). When the time came to design this modern lodge, the NPS turned to a well-known architect, Gilbert Stanley Underwood, with ties to the NPS as well as the Rockefeller family.

Figure 3: Original Jackson Lake Lodge built by Eugene Amoretti in 1922. Image Credit: Jackson Hole Historical Society & Museum (www.jacksonholehistory.org/jackson-lake-lodge/).

2.3. Underwood's Association with the NPS

Underwood helped to set the tone for contextual rustic architectural styles used by the National Park Service (Wheaton). The Rustic style had become so synonymous with the NPS during the first half of the twentieth century that it often referred to as "Parkitecture" (PARKitecture in Western National Parks…). "For his part, Underwood helped define the "rustic style" that used native rock, massive timbers, and steeply pitched roofs to many of the national park lodges built during the 1920s and 1930s" (National Parks Traveler). Also the first director of the National Park Service, Stephen Mather, had a great influence on the use of the rustic style throughout the park system. Mather and many of his assistants had "strong ideas about the types of structures to be built in areas under the agency's jurisdiction. Deeply concerned with protecting the natural beauty of the lands, [they] felt it vital that all construction be non-intrusive and in harmony with the natural surroundings" (National Parks Traveler).

The features of rustic architecture –stone, wood, steeply pitched roofs, and earthy colors like greens, browns, and greys— were designed to create a woodsy appearance. This characteristic was found in the majority of Underwood's lodges for the NPS such as: the Old Faithful Lodge in Yellowstone National Park; the Grand Canyon Lodge in Grand Canyon National Park; and Ahwahnee Hotel in Yosemite National Park. Although considered to be the quintessential "rustic" lodge, the Ahwahnee Hotel incorporated modern materials such as concrete in areas visible to guests due to its fireproof qualities.

Built in 1927, this lodge (now known as the Majestic Yosemite Hotel) used concrete that was formed, textured, and stained to look like timbers and planks. Approximately 23-years later, Underwood would use this material and method again, this time in a more abstract and less literal reference to wood construction at Jackson Lake Lodge. He would later call this technique "Shadowood", and it was used extensively on the Central Lodge. The Central Lodge interpreted the European based International Style with a nod toward the long tradition of the rustic in the National Parks, thus helping to move NPS into the modern era.

Figure 4: Contemporary Photo of the Majestic Yosemite Hotel (formally known as the Ahwahnee Hotel) built by Underwood in 1927. Image Credit: Management (www.tripadvisor.com)

2.4. Underwood's Fusion of Old and New Architectural Styles

There were a number of reasons why the use of rustic architecture began to diminish towards the middle of the twentieth century. New materials and building techniques were changing the way that structures were being designed and built. The International Style which begun in Europe during the early twentieth century, had made its way to the United States by the 1930s. This new style was changing attitudes towards design. The rustic style was becoming less appealing, portraying an outmoded "Hansel-and-Gretel" presence (Harrison). An exhibition led by Philip Johnson and Henry-Russell Hitchcock called *Modern Architecture: International Exhibition* opened at New York City's Museum of Modern Art on February 9, 1932, showcasing avant-garde modernist buildings from Europe and the U.S. This exhibition is often cited as the catalyst bringing the International Style into the U.S. mainstream. Furthermore, with funding for relief programs and workers diminishing towards World War II, labor-intensive aspects of rustic construction such as the use of large logs and rubble stone made the style less appealing. By the time the war was over "the design ethic of rustic architecture had seen its heyday" (Harrison).

Even though Underwood was known as a leader in the rustic architecture movement, towards the latter part of his career he embraced a range of other styles such as: Art Deco (i.e. Union Station in Omaha Nebraska and the Seattle Federal Courthouse) and the International Style (i.e. South Boston's United States Post Office Garage). Underwood combined the philosophies of the International Style and a new focus on the automobile, with the basic values of the rustic style to create a new kind of lodge. This lodge was meant to not only bring harmony between the building and the landscape, but also convey the new and modern experience that the NPS wanted to showcase. This led to the first International Style building to be built in a national park- Jackson Lake Lodge (Engle 3). As defined by Johnson and Hitchcock, the main principles of the International Style were:

> "[an] emphasis upon volume – space enclosed by thin planes or surfaces as opposed to the suggestion of mass and solidity; regularity as opposed to symmetry or other kinds of obvious balance; and, lastly, dependence upon the intrinsic elegance of materials, technical perfection, and fine proportions, as opposed to applied ornament" (29).

Underwood incorporated these same principles into the design of Jackson Lake Lodge.

Figure 5: (on left) Image of Gilbert Stanley Underwood. date unknown Image Credit: www.nationalparkstraveler.com

Figure 6: (on right) The William Kenzo Nakamura U.S. Courthouse in Seattle, Washington. Completed in 1940, the concrete and terracotta building was the first single-purpose federal courthouse in the western United States (William Kenzo Nakamura…). Image Source: National Archives

2.5. Design and Construction

Approximately 350 by 150 feet, Underwood designed the Central Lodge to be the focal point of the Jackson Lake Lodge complex. The overall form of the main building can be described as a series of rectangular massings connected by an elongated rectangular central spine. By incorporating a single plane slope into the roof line of these massings, Underwood broke away from the rigid orthogonal characteristic of the forms. There was also a strong emphasis on the automobile with a motor court-style layout for most of the site, and a large porte cochère to invite guests into the Central Lodge. The emphasis on the automobile demonstrated the change from tourists arriving to the area by train, to the personal vehicle becoming the primary mode of transportation.

"Jackson Lake Lodge had all the hallmarks of the [International] style; it was cubic in form, and featured clean lines, large expanses of glass and steel, cantilevered overhangs, simple shed roofs, and was free of ornamentation" (Gilmore, 9). By designing the structure to be primarily horizontal in form, Underwood made the three story Central Building appear low on the landscape. The architect's use of a simple grid pattern also helped emphasize this horizontality and dispel any notions of structural wood construction. The grid pattern was also incorporated into various aspects of the design such as locations of the windows and v-shaped expansion joints, and to help break up the structure's overall mass. The windows were not only used for light and ventilation, but also to allow the surrounding landscape to be an ever present feature for guests; even when they were indoors. The lack of ornamentation helped to make various details —such as the wood grain texture of the exterior concrete walls and the large windows— more prominent.

Initially, John D. Rockefeller Jr. was hesitant about financing such a large and expensive hotel in the park. Also various issues with the NPS shelved the project for a short period, but with mounting pressure from tourists for better accommodations the project was revived. In 1952, Underwood presented the final drawings of Jackson Lake Lodge to the client (Rockefeller, members of the NPS, and Jackson Hole Preserve, Inc.) (Engle, 27). After seeing how the new International Style lodge would revolutionize the visitor experience in the park, Rockefeller was impressed and agreed that the project should be implemented. Rockefeller put up $5.5 million for the hotel (Engle 46), and “ground was broken on May 25, 1953, and construction began under the leadership of Morrison-Knudson contractors” (Engle, 31). The announcement the new lodge even made the front page of the *New York Times*.[1] One of the characteristics that connected the International Style building to the rustic style of traditional lodges was Underwood’s use of “Shadowood”.

The Central Lodge was Underwood’s first NPS lodge to use exposed form-finished (fair-faced) concrete on the majority of the building’s exterior. To tie the International Style building to the rustic style of traditional lodges, the architect texturized the concrete, a modern material, to resemble wood. He called this technique Shadowood. The use of a wood grained concrete to emulate timber construction was also used at the Ahwahnee Inn, but not in the same way as at the Central Lodge. Here the concrete surface was gridded and textured by using sandblasted plywood sheets[2] to create a raised wood grain texture (Gilmore 3). Sandblasting removed the softer areas of wood, leaving the denser sections intact. These plywood sheets were then coated with mineral oil, and used as formwork for the cast-in-place concrete walls. Once the concrete had cured, the surface could be cleaned and coated with acid stains to create a reddish-brown finish.

The use of acid stains along with the Shadowood texture and grid pattern of the v-joints, were used to make the concrete walls look as though if it were made of redwood panels – a feature that connected the modernist style building with the traditional rustic style of the past. According to Gilmore, “very little documentation about how the stains were applied to the

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[1] The ground breaking of Jackson Lake Lodge was announced in both local and out of state newspapers. Even the *New York Times* published an article on June 4, 1950 titled “Expanding the Jackson Hole Monument.”, written by Jack Goodman.

[2] Specifications from the architect state that these sheets could be either Douglas fir or Redwood plywood (Underwood, 6-3).

concrete exists, as there were no specifications for the acid-stain finish. Therefore how the finishes looked immediately after application is unknown" (31). Two sources that provide some insight into the finish's appearance are from a letter between Underwood and the company that provided the stain, Rohloff and Co., and a 1956 advertisement by Kemiko, the original manufacturer of the acid stains.

The letter written in 1954, vaguely explains the complications that arose when the painters used three coats of Kemiko Colorado Brown on a test area to achieve a finish that would allow the concrete to show through the stain. Here Underwood states that using the three coats of Colorado Brown did not match the sample card provided by Rohloff and Co. He also states that due to the budget concerns they would only be able to afford two coats of stain. It is at this time that the suggestion of using a black coat of stain over the brown to achieve a darker finish is mentioned (Gilmore 31). A couple years later, a Kemiko advertisement was published that revealed slightly different information.[3] The colored advertisement describes how three colors-Malay Tan, Colorado Brown, and Black- were used to "harmonize with the natural beauty of the setting" in addition to allowing for the "natural beauty" of the concrete to show through (Kemiko Advertisement). These two sources demonstrate that great care was taken to achieve the appropriate reddish-brown hue that would resemble redwood. It was this care that helped to make the exterior finish one of the character defining elements of the site.

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[3] See section: Kemiko Jackson Lake Lodge Advertisement in the Appendix

Figure 7: Bird's eye illustration showing massing and grid pattern on the Central Lodge at Jackson Lake Lodge. Image Credit: Rockefeller Archives Center

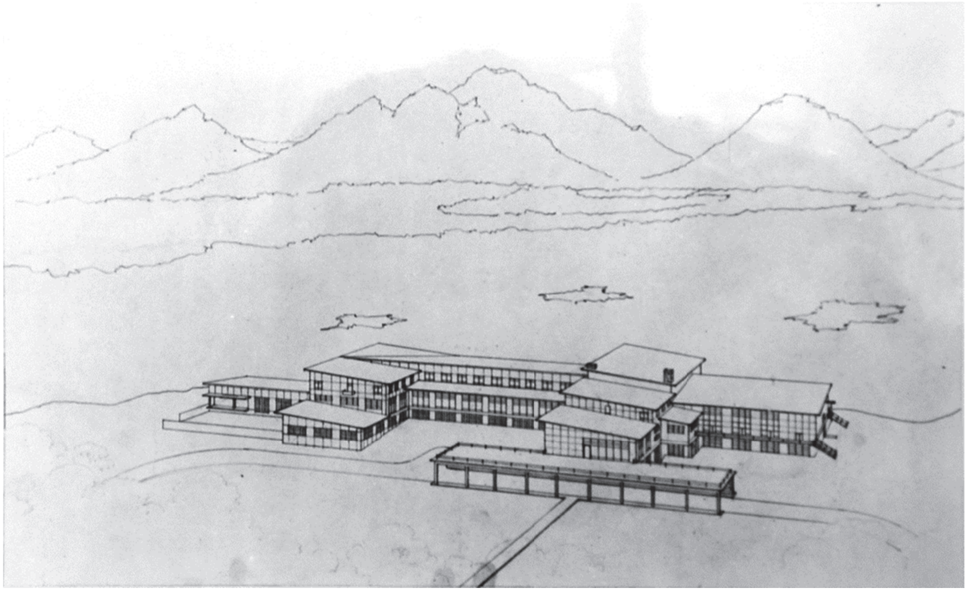


Figure 8: Bird's eye sketch of the Jackson lake Lodge site and surrounding area. Sketch shows the influence of the automobile in the design of the site. Image Credit: Rockefeller Archives Center

Figure 9: Construction workers pour concrete. Image Credit: Jackson Hole Historical Society

Figure 10: Plywood boards used in formwork to create the Shadowood texture of the walls. . Image Credit: Jackson Hole Historical Society

Figure 11: Windows were used to frame and bring the surrounding landscape into the Central Lodge. This allowed for the visitors to always be surrounded by the beauty of the Tetons. Image Credit: Joe Elliott

2.6. Reactions to the New Lodge

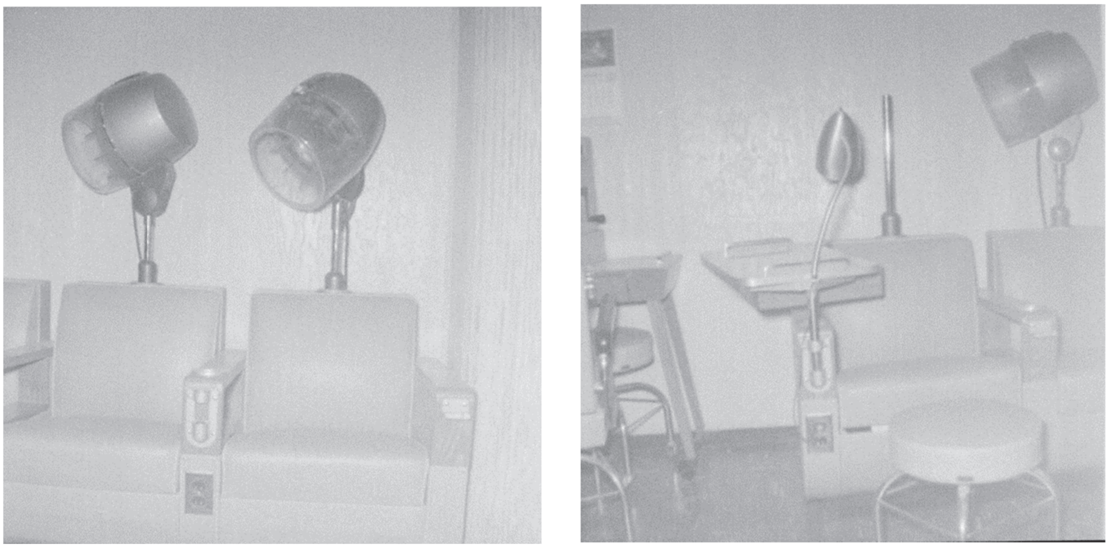
After approximately two years of construction, Jackson Lake Lodge held its grand opening celebrations on June 11-12 of 1955. Reactions to the site, and more specifically the Central Building, were mixed. There were many accolades to Rockefeller and his son Laurance – who had taken a greater role in the project due to his father's advancing years– "thanking them for this wonderful gift to the American people" (Engle 45). Newspapers published articles on the "handsome new Jackson Lake Lodge" that was "modern in architecture, having been designed to take full advantage of the site above gem-like Jackson Lake without obtruding on the landscape." (Goodman XX39). The lodge quickly became a favorite spot for tourists.

Although most approved of the much needed lodge, the building had many critics. Devereaux Butcher, a National Parks Association board member labeled Jackson Lake Lodge as "the ugliest building in the park and monument system", and equated the main building to

Alcatraz (Butcher 166). Others followed suit calling the lodge a "concrete monstrosity" (Engle 48) and more colorfully "surely one of the ugliest buildings in Wyoming. Shit brown in color and as slab-sided as Menor's outhouse, it looks like something the Nazis built to fortify their Siegfried." (Swift 173). The feelings of these naysayers were probably best described by Jack Goodman in his 1955 *New York Times* article in which he wrote, "Those who bitterly deride the appearance of the fifty room main lodge building and its 250 adjacent guest cottages level their aesthetic barbs at the mammoth central structure chiefly because it does not look "rustic"." (XX39). The lodge soon became a popular destination for visitors to the area that wanted to experience the beauty of the surrounding area, while enjoying the comforts of modern amenities and comforts.

Figure 12: President John F. Kennedy visited Jackson Lake Lodge in September 1963. Image Credit: Rockefeller Archives Center

Figure 13: The Central Lodge has many modern amenities to cater to guests such as a beauty parlor.
Image Credit: Rockefeller Archives Center



2.7. Conclusion

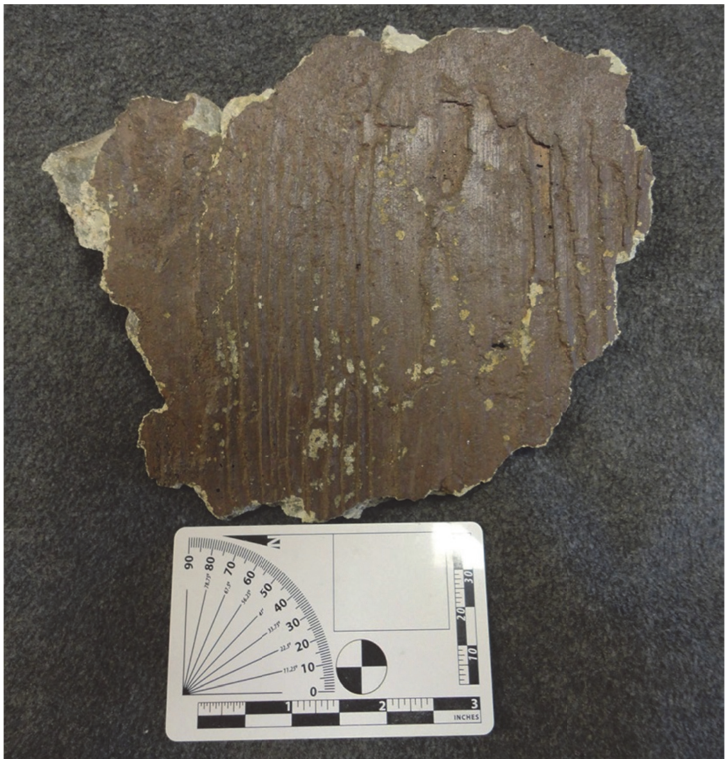
Once built Jackson Lake Lodge attracted both positive and negative comments, but one could not deny that the building did not fulfill its intended purpose. As the years past, more buildings were added to the site in order to accommodate the growing numbers of visitors. Modifications were made to the Central Lodge such as the construction of the Blue Heron Bar in 1988 on the west elevation, which deviated from the strict orthogonality of the original 1955 building. Also “nearly all of the windows [were] changed, in size, glazing type, or both” (The Architectural Conservation Laboratory, 45). One of the most evident changes to the building was its color.

When construction was completed in 1955, the Central Lodge was a reddish-brown color, created by the three acid stains to produce a dynamic variegated appearance. Today the building is coating with a monochromatic resinous brown stain that lacks the transparency and subtlety of the original finish. Furthermore, the brown stain has reached the end of its service life, and a new protective coating is needed for the building. Even though there have been many changes to the Central Lodge over the past 61 years, the structure still contains much of its original fabric and 1955 appearance. To fully restore the Central Lodge to its original appearance, a new surface coating system is needed. This system should reestablish the original color of the exterior finish, be durable, and also help to extend the service life of the reinforced concrete walls.

Figure 14: Appearance of the west elevation of the Central Building ca. 1960. Notice the red-brown hue of the stain and the variegation that allows the concrete to show through. Image Credit: Rockefeller Archives Center

Figure 15: Appearance of the west elevation in 2014, with the current coating. Image Credit: Joe Elliott

Figure 16: Close-up of spalled piece of concrete with current coating. Image Credit: Julianne Wiesner-Chianese



Chapter 3: Coating Information

Architectural surface finishes are an important component of historic structures. These finishes can come in a range of colors, textures, transparencies, and sheens, and are often characterized as either a continuous or discontinuous film on the surface of a substrate. Architectural coatings are considered to have two primary functions: protective and decorative. The decorative element is often the most perceived aspect of a coating, and gives aesthetic value to a building. The decorative element also allows the substrate to take on different appearances, such as in the case of the Central Lodge where the concrete was stained to resemble wood. Even though it is often overlooked, the protective aspect of coatings is of great importance. Protective aspects are especially important for exterior concrete surfaces, because they can help to extend the life of the material.

With advancements in technology the term “functional coating” has become more common. This term refers to paints and stains that possess additional functions beyond the standard decorative and protective characteristics. These functions are diverse ranging from self-cleaning to antibacterial to intumescent. “The typical expectations of functional coatings include: durability, reproducibility, easy application and cost effectiveness, tailored surface morphology, and environmental friendliness” (Ghosh, 3). With the wide range of coating options and a desire to reduce maintenance time and costs, the functional aspect of coatings are having a greater influence on what is applied on buildings today. This is particularly important for historic structures because prolonging the longevity of materials and improving their performance is a constant issue.

3.1. Architectural Coating Systems Basics

In *Historic Concrete: From Concrete Repair to Concrete Conservation*, Herdis Heinemann cites that there are three reasons for treating the surface of concrete: “first, to protect the concrete from the elements, second to prevent concrete from wear and tear [and] third, to make the concrete surface prettier” (214). The type and quality of the architectural coating is just as important as the quality of the substrate it covers. For concrete surfaces there are a wide range of coatings that can be applied to protect the substrate while imparting a decorative element. In spite of this wide range, all architectural coatings are comprised of two main components: pigments or colorants and a vehicle/medium. The components can be from organic and inorganic sources. Even though both categories are known to impart protective, decorative, and functional characteristics, inorganic coatings are mainly used for protective purposes (Ghosh, 1).

Pigments are the main source of color within coatings, and are suspended as distinct particles within the vehicle. In addition to color, pigments impart other properties such as opacity, pH sensitivity, dispersion, light-fastness, and drying time. Colorants fall into two broad categories: organic and inorganic. According to Pylam, a leading supplier of dyes, pigments, and colorants, “when it comes to deciding whether to use an organic or inorganic pigment, the following must be determined: (1) if the opaqueness of the pigment is a driving attribute, (2) the vibrancy of color is the key criteria, and (3) if its ability to withstand light and weather is paramount” (Difference Between Organic & Inorganic Pigments).

Organic pigments contain carbon and are sourced from either natural products from animals and plants, or synthetically made. These pigments tend to be brighter and more saturated in color than inorganic pigments. Also, organic pigments tend to be more expensive. A significant disadvantage of organic pigments is that they can be unstable; often degrading quickly when exposed to extreme temperatures and ultraviolet light for extended periods of time (Racusin and McArleton, 363). This would not be ideal for exterior use in an area such as Moran, Wyoming. Inorganic pigments on the other hand have a wide range of characteristics that makes them better suited for exterior environments.

Inorganic pigments like organics can be from natural and synthetic sources. Common sources include clay products (i.e. yellow ochres and raw sienna) and minerals (i.e. iron oxide, azurite, and orpiment), in addition to synthetic varieties containing metallic compounds (i.e. manganese violet, cobalt blue, and chrome green). Inorganic pigments are good for exterior use because they have: a strong chemical resistance to acids and alkalies; greater control over opacity; more durable in regards to the effects of weathering–color, ultraviolet (light), and infrared (light) stable; heat resistant; low oil absorption; and compatible with a range of organic or inorganic vehicle solutions.

It is important to remember that “pigments are designed to interact with light”, and inorganic pigments are often cited as being more stable. These pigments are

> …optimized to the size that optimizes opacity, or provides the strongest absorption as to minimize the amount of pigment needed. For a pigment to be highly effective at [interacting with light and opacity strength], it must be of a size similar to that of the wavelength of light. The wavelength of visible light ranges between 0.4 and 0.7 µ, and pigment particles generally range in particle size between 0.1 and 10 µ. (Pigments (Inorganic)).

It is important to note that the use of an inorganic pigment can create transparent coatings with the appropriate dilution of the pigment within a vehicle.

The options for the vehicle or medium of the coating system is just as variable and important as the pigments. The vehicle is referred to as “the liquid component of the paint system which acts as the carrier of the pigment allowing it to be applied to the surface… [and gives] the paint it's cohesive and adhesive film-forming properties” (Weaver and Matero, 218).

An important component of a coating's performance is how the film is created, and how a coating system solidifies to create a film depends on the type of vehicle used. The type of solidification for architectural coatings can be classified into four main categories: crystal formation, coalescence, cross-linkage, and evaporation (Ibid, 220-221). Vehicles are a two component system made of a binder and a solvent. The binder is the non-volatile portion of the system and falls into two broad categories: aqueous (water based) and non-aqueous (typically oil-based). Like pigments, the binder can be made from natural or synthetic compounds. For aqueous coatings, "the solvent aids in the initial application and penetration of the system and later evaporates during film formations". Together the solvent and the binder influence various properties of the coating system such as: ease of application, viscosity, color, consistency, shrinkage/tension, elasticity, and reversibility of the coating (Ibid, 218).

When choosing an architectural coating it is critical to take into account the substrate that it will be covering. This will help prevent adverse effects from occurring. Since the application will be to the exterior of the Central Lodge, it is important that the coating material be durable (does not flake, delaminate, or crumble over time) and can resist the effects of weathering (i.e. being colorfast and stable when exposed to ultraviolet light). Since the substrate is concrete, which is a porous and tends to absorb water, it is also important that the system have a high vapor transmission rate, which will allow the wall to dry out quickly in the event of liquid water penetration. According to A. Barbucci et al., "Protective coatings for concrete should have a high vapor transmission rate to permit the drying process of the concrete without problems such as adhesion loss and subsequent detachment of the coating. Therefore, every protective coating for concrete has to be investigated to verify its properties of liquid water and water vapour permeability" (293).

Having a coating that significantly reduces the vapor transmission of the wall is not only detrimental to the coating itself, but can lead to deterioration of the concrete. Types of deterioration conditions that can result from this include but are not limited to: cracks, spalls, and biological growth—mold and mildew. Because of this, coating products that form continuous, non-breathable films on the surface should not be used on concrete. Rather, breathable integral coating systems that chemically react with the concrete and penetrate past the surface such acid stains, mineral silicate products, and reactive polymer products, are good candidates. Acid stains were the original finish on Jackson Lake Lodge's main building. Stains are particularly beneficial because they enhance rather than hide the surface of concrete, allowing the material to show through.

3.2. Acid Stains

"Although today acid stains are most frequently associated with the decoration of concrete floors, they have been used to color concrete since at least the early twentieth century" (Wiesner-Chianese, 58). Acid stains are an integral finish that imparts a permanent, durable color to concrete through a chemical reaction between transition metals solubilized in hydrochloric acid (HCl). This creates metallic salts and hydrogen gas. According to Gilmore, hydrochloric acid is "the most common acid used in concrete staining, however phosphoric acid (H_3PO_4) can also be used" (23). Gilmore also explains that because phosphoric acid is a weak acid, it does not completely deprotonate when mixed with a solvent, thus creating variable results when used as an acid stain. It was confirmed that HCl was used at Jackson Lake Lodge for the original 1955 acid stain treatment (23-24).

Gilmore's 2016 thesis examined the feasibility of retreating the original reddish-brown acid stain finish of the Central Building using the same products. The manufacture of the acid stains used in 1955, Kemiko Products a subsidiary of Empar Corporation, is still producing the product. Another thesis by Julianne Wiesner-Chianese confirmed that the current formulation of the stains (Malay Tan, Cola, and Black) matched that of the 1950s. The transitional metals that form the pigments in these strains were confirmed using ED-XRF analysis. The pigments in the stains are as follows:

- the Malay Tan was colored with ferrous chloride
- the Cola stain was colored with manganese chloride and ferrous chloride
- the Black stain was sodium dichromate and manganese chloride

Through a range of analytical tests Gilmore concluded that the reuse of acid stains on the original concrete walls of the Central Lodge may not create a durable finish because the product requires a high pH for the transition metals and acid solution to precipitate and color the substrate. The pH of a concrete sample extracted from the Central Lodge was tested in 2015 and results revealed that the pH was neutral (approximately 7). Gilmore did note that preliminary tests showed that it may be possible to retreat concrete with acid stains with a pH as low as 6, but it may be worth looking into other integral finish coating systems. One of the alternatives she mentioned was mineral silicate paints (62-64).

3.3. Mineral Silicate Paints

Mineral silicate paints are considered to be an environmentally friendly, durable, and economical means of imparting permanent color and protection to mineral surfaces. This system has been available for over a century, and was and continues to be a popular application technique in Europe. “There are reports of some original applications still surviving over a hundred years later” (Racusin and McArleton, 358). Examples of these archaic wall applications can be found on the exterior of the Schwyz Town Hall in Switzerland (painted in 1891), and

Neuschwanstein Castle in Schwangau, Germany (c. 1886). The original three major mineral silicate paint manufactures are based in Latvia and Germany— Silacote, Silin, and KEIM (Parker). Within the past twenty years, mineral silicate paints have gained in popularity in the United States. Many professionals feel that mineral silicates may be a good solution to achieving a durable architectural finish; particularly for concrete structures. The following sections will focus on the development of mineral silicates paints, the material's chemistry, and its composition.

Figure 17: Neuschwanstein Castle, southwest Bavaria, in Germany. Image Credit: www.castlesandforts.blogspot.com

Figure 18: Schwyz Town Hall located in Schwyz Switzerland. "The murals are among the first examples of use of KEIM Mineral Silicate paints and have been retouched only twice since."(Townhall and Murals in Schwyz, Switzerland). Image Credit: www.keim-usa.com

3.4. The Development of Mineral Silicate Paint

According to KEIM Mineral Coatings Ltd —one of the largest and oldest mineral coating manufacturers— the first practical use of applying a mineral silicate paint to a cementitious surface was patented by their founder Bavarian scientist Adolf Wilhelm Keim (1851-1913) in 1878.[4] This discovery can be attributed to King Ludwig I of Bavaria and his love of Italian frescos (History of Silicate Mineral Paints). Also during period (the mid to late 19th century) there was an explosion of decorative mural painting in Germany (Art Notes from the Continent: Germany).

After his travels to Italy, Ludwig I wanted beautiful wall frescos for his own palaces. This great admiration was also shared by his son who became king after his father's abdication in 1864. The problem was that traditional methods employing pigments to lime in Italy were not as effective in the harsh German climate. The king assembled a group of scientists to create a

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[4] Other sources such as *The Natural Building Companion: a Comprehensive Guide to Integrative Design and Construction* by Jacob Racusin and Ace McArleton and many online building trade website have also cited Adolf Wilhelm Keim as the inventor of mineral silicate paints.

durable means of imparting bright colorants to plaster surfaces (KEIM History).[5] While the exact date of this group's formation is unknown, it most likely occurred in the 1860s. Keim—a member of this group— decided to take a closer look at a material known as liquor silicium, or waterglass.

Waterglass had been known since the Middle Ages, but had limited use. According to Kurt Wehite, a noted art restorer, the development of waterglass began as a pursuit by alchemists to find the Philosopher's Stone. In the fourteenth century Basililius Valentinus discovered that combining and heating quartz sand and potash produced liquid quartz, also known as waterglass or liquor silicum. At the time there was little practical use for the material, and its use as a coating had not been discovered. It was not until 1818 that liquor silicum was rediscovered by Professor Nepomuk Fuchs. By 1850, he along with professors from the Munich Academy developed a new silicate based painting technique, which they called stereochromy (Wehlte 238).

Fuchs' development of waterglass used as a coating was published in a short treatise that was issued and privately circulated by the command of the king (Robertson, 83). According to the literary magazine, *Art, Pictorial, and Industrial* published in 1871, the treatise was translated into English by Cave Thomas. The article states that Thomas' translation helped to spread the early use of mineral silicate paint outside of Germany and was considered a great service to the art world (Ibid 82-83).

Cave Thomas' translation states that:

> Waterglass solution, a solution of silicate of soda or potassa in water, first prepared by the late Prof. Fuchs at Munich, has been used in France since about fifteen years, for a great many purposes—subsequently specified, and its application has since become very general. In Germany its use has been very limited till lately. (Hauser, ed., 3).

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[5] KEIM

He goes on to describe how "by order of the king" the newly constructed theater in Munich was coated with soluble glass for fire protection. But this particular compound did not have wide application until a letter by chemist Justus von Liebig was published in newspapers.[6] The letter describes Justus von Liebig's travels to a French chemical factory, where a colleague promised to astonish him with a new coating system discovered by the celebrated Fuch in Munich and further developed at his factory. During this visit it was revealed to Liebig that the mineral silicate paint safeguards the substrate from "destruction by fire or atmospheric agencies, putrefaction, [and] corrosion" (Hauser, 3-4). Furthermore, "the use of water glass solution for painting walls (comprised of mortar or stone) is of the highest importance, as it answers fully as well as oil paint, but being cheaper and more durable" (Hauser, 9). The translation by Cave Thomas shows that during the early years of its use, the performance and functional benefits of silicate coatings were understood.

Fuch may have been the first to develop a silicate based paint, but Keim is often considered to be the creator of the mineral silicate system used today. "His flair for experimentation, refined stereochromy and developed it into a dependable technique for artists and house painters" (Wehlte 238). Keim's work created one of the most durable mural painting techniques known (Wehlte 213).

With the advancements of the Industrial Revolution, Keim was able to analyze liquor silicium in ways that had not been previously possible.[7] Building upon the work of Fuch, Keim understood that when silicified, liquor silicum produced a clear stable coating that permanently

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[6] The text does not go into detail on what newspapers published the letter by Justus von Liebig.

[7] It is important to note that the refinements made by Keim would not have been possible without the industrial manufacture of liquor silicium by Vincent van Baerle and later Henkel & Cie., Dusseldorf who brought consistency to the product and made the material more cost effective so it could be used to cover larger areas. (Wehlte 238)

bonded with silica-rich materials (Hauser, 9). He believed that this material could be an effective vehicle to transport and permanently bond a mineral-based colorant to a plaster substrate to produce durable, colorful murals to meet the needs of the time period. After many tests, Keim developed a two part system where he combined the liquid waterglass with mineral pigments to create a resilient paint that could be applied not only on plaster, but also on stone, brick, and other silica rich substrates. It took Keim nearly twelve years to perfect his invention (Stratham). In 1878, he patented his paint system and it became the backbone of his company Keimfarben (KEIM History).

3.5. Chemistry and Composition

Structures are continuously exposed to weathering elements such as water, UV radiation, air pollution, extremes of temperature and fouling by micro-organisms. Due to these deterioration methods, protective coatings are often applied to the exterior of a structure. It is widely accepted that one of the most important functions of a coating is to protect the surface from deterioration. As mentioned under Section 3.1.: *Architectural Coating System Basics,* coatings can also impart thermal protection. According to Kolokotsa et al. “silicate minerals can behave as cool coatings and contribute to a significant reduction of the cooling demand” particularly in warm and sunny climates (3).

Modern coatings on masonry structures are typically water-based or aqueous (Ibid 3). Aqueous coatings (like mineral silicate paints) use water as a solvent to disperse a binder. “This makes the coating eco-friendly and relatively easy to apply. In most cases, waterborne coatings contain up to 80% water with small quantities of other solvents” (Thomas). Since waterborne paints typically contain less than the minimum amount of VOC [volatile organic compounds] concentration, these paints or often labeled as ecologically-friendly and low/zero VOC.

According to the United States Environmental Protection Agency the maximum content to be classified as low VOC is 200 grams per liter and 5 grams per liter for zero VOC paints/stains (Non-Toxic Paints). In the case of mineral silicate paints such as KEIM's Concretal Lasur line, the VOC content is less than 1 gram per liter, classifying it as zero VOC (KEIM Concretal Lasur Specification, 1).

Mineral silicate coatings use one or a combination of the following binders: sodium silicate, potassium silicate, and lithium silicate. According the director of Silacote USA LLC:

> When applied to inorganic substrates such as concrete, cement plaster, lime plaster, marble, natural stone, and other similar material, the silicate coating bonds to the substrate chemically forming an insoluble compound of paint and substrate [known as silification]. This chemical bonding ensures that the colored coating will not peel, chip or flake off as would happen with traditional [film forming] organic paints. (Parker)

For this testing program a potassium silicate based binder was chosen because it is the most widely used type of mineral silicate coating for exterior architectural purposes. Even though it is typically cheaper, sodium based waterglass solutions have a higher chance of producing efflorescence on the surface of building materials than the potassium silicates. The sodium-based waterglass has also been known to darken the surface of some materials (Racusin and McArleton, 344). Lithium silicate waterglass is cited as having the lowest efflorescence potential but is the most costly of the three. Furthermore, the lithium variety is often used on concrete floors, because the "smaller molecules of lithium make the silicate reaction more even and consistent, creating a denser surface" (Why Lithium?). This may reduce the vapor permeability of the substrate as well.

Mineral silicate paints/stains consist of two main components: the liquid mineral silicate and a mineral pigment. According to PQ Corp, a manufacturer of inorganic chemicals such as soluble silicates, the following materials are needed to create potassium-silicate waterglass:

quartz sand, an alkali carbonate such as potash, water, fuel/energy to power furnaces, and sometimes natural filter aids (Sodium and Potassium Silicate). The contemporary method of creating waterglass begins by producing silicate glass lumps.

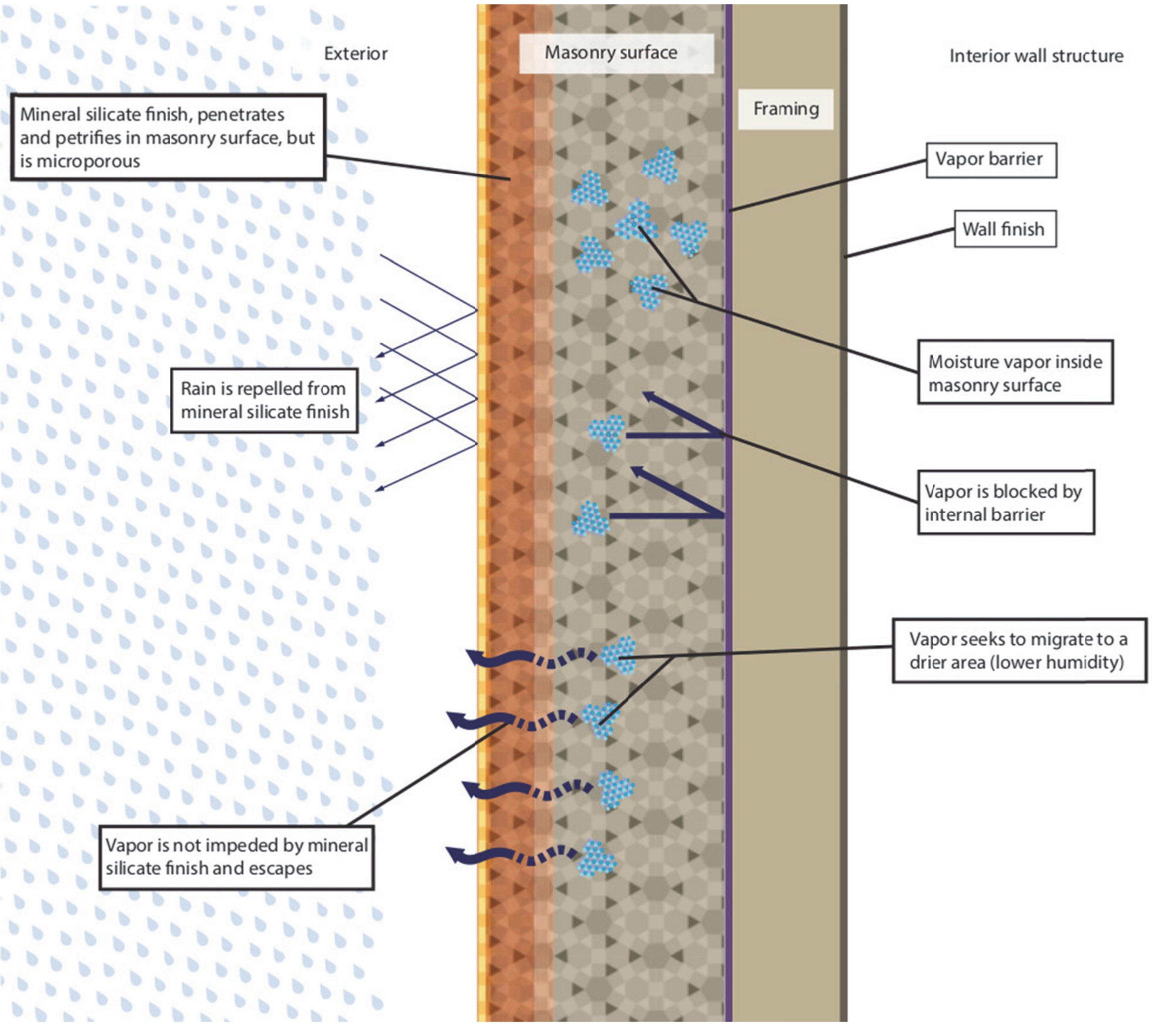
The lumps are formed "by the direct fusion of precisely measured portions of pure silica sand (SIO_2) and potash (K_2CO_3), in oil, gas, or electrically fired furnaces at temperatures above 1000°C, according to the following reaction: $K_2CO_3 + xSiO2 \Rightarrow K_2O \, . \, xSiO_2 + C0_2$". After the lumps are formed they are dissolved at elevated temperatures and pressures in a solution of an alkali hydroxide solution according to the following equation: $2KOH + xSiO_2 \Rightarrow K_2O. \, xSiO_2 + H_2O$ (Ibid). This produces the potassium waterglass solution. Concerning the mineral pigment component of the paint system, these are made from inorganic minerals. As previously mentioned, inorganic minerals are often considered superior to organic pigments because the latter tends to "deteriorate prematurely because of their poor lightfastness, [which can worsen] the state of the conservation of historical buildings" (Sudipto Pal et al., 6).

The mineral silicate paints chemically bonds to substrates (such as concrete) to form a permanent bond. This silification forms at ambient temperatures with the air and moisture.

> The curing process [of mineral silicate paints] involves various basic reactions with the atmospheric carbon dioxide, with the constituents of the substrate [the calcium hydroxide in the concrete] and of the paint itself. The complete silification leads to the formation of an insoluble silica gel, which is converted into solid, amorphous silicate structures by evaporation of water. The physicochemical bonds induced between the insoluble silica gel and the substrate, are very strong and the coating layer is not considered as a film but rather as a coating, which essentially becomes the substrate. Due to the porous structure, the water vapor and carbon dioxide permeabilities are very important (de Lame et al, 49)

Additionally, this coating system does not rely on the pH of the concrete to impart a color to the substrate, such as with acid stains (Wilson, 112). This can be a significant advantage for historic structures where the high pH of the concrete has neutralized over time. Mineral silicates can also be a good choice for surfaces which have an existing coating. According to KEIM, "potassium silicate not only provides bonding by silification to mineral surfaces, but builds strong adhesive forces to previously painted, organic paints. This nanoparticle technology penetrates latex paint films to bond deep within the existing paint system and is the ideal repaint system when existing coatings cannot be removed" (KEIM Historic Restoration).

Figure 19: Diagram on the effect of a mineral silicate finish on a masonry wall. Image source: www.keim-usa.com



Chapter 4: Testing Standards

As discussed in Chapter 3, potassium silicate finishes provide a range of benefits that can be important to the conservation of historic concrete structures. In order to determine if mineral silicate paints can offer a viable alternative to acid stains, performance testing was done sample coupons. The following literature review was conducted on the basics of concrete and various test method for determining the performance and durability of architectural coatings, and specifically mineral silicate paints.

4.1. Concrete

It is important to understand the composition and expected performance of the substrate onto which any coating is applied. As mentioned in the previous chapter, concrete is a porous, water absorbing material. If a coating is applied to the surface, it should be water vapor permeable yet repel liquid water. Concrete is one of the few structural materials that can be formed on site. This material is made of four basic components: cement, small aggregates, gravel, and water. This composition has changed little since Antiquity.

The Romans are credited with the first large-scale use of concrete as a structural material. Its formulation was based on the use of lime with pozzolans such as volcanic sand or pulverized brick and tile for hydraulic set.   Modern concrete began in the 18th century with experiments using natural cements, eventually leading to the development of artificial 'Portland Cement'[8] by the English mason Joseph Aspdin in 1824. During this time the material was often referred to as artificial stone. Further advancement such as adding metal reinforcement to increase the tensile strength of concrete made the material a popular structural choice (Allen and Iano, 528). The early twentieth century saw a shift in aesthetic attitudes towards the

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[8] The term "Portland" became associated with the material because of its similarity to natural rocks found in Portland, England.

material, and concrete changed from being a purely structural material to a material celebrated for its raw form and ability to be finished in a multitude of ways. New techniques in manipulating the surface gained in popularity as seen at Jackson Lake Lodge. Throughout the decades of the twentieth century and into the next millennium, advancements in concrete progressed, allowing the material to take on a wider range of characteristics. This was achieved through new means of processing concrete and the use of additives. Modern mixes tend to include additives such as plasticizers, corrosion-inhibitors, and fiberglass fibers to improve the performance of the material.

Since the twentieth century, concrete has been one of the most widespread of building materials. There are various types of cements that can be used in concrete, but Portland cement remains the most widely used. The American Society for Testing and Materials (ASTM) recognizes ten types of Portland cement, and labels them as “Type I” through “Type V”. The type refers to specific properties of the different concrete mixes.[9] There are mixes such as Type I/II that meet the criteria of two cement specifications. This is particularly advantageous, because the Type I/II mix can be used in a wider range of circumstances. The Central Lodge at Jackson Lake utilized Type I/II grey Portland cement in its concrete mix (Underwood, 6-8). Although the mixes vary slightly, all varieties of Portland cement are manufactured through the controlled chemical reaction of calcium, silicon, aluminum, and iron. Raw materials commonly used to manufacture cement are: limestone, shells, and chalk or marl combined with shale, clay, slate, blast furnace slag, silica sand, and iron ore. These materials are crushed, then heated in a kiln to temperatures of 2600-3000°F (1400- 1650°C) (Allen and Iano, 530). The product from this

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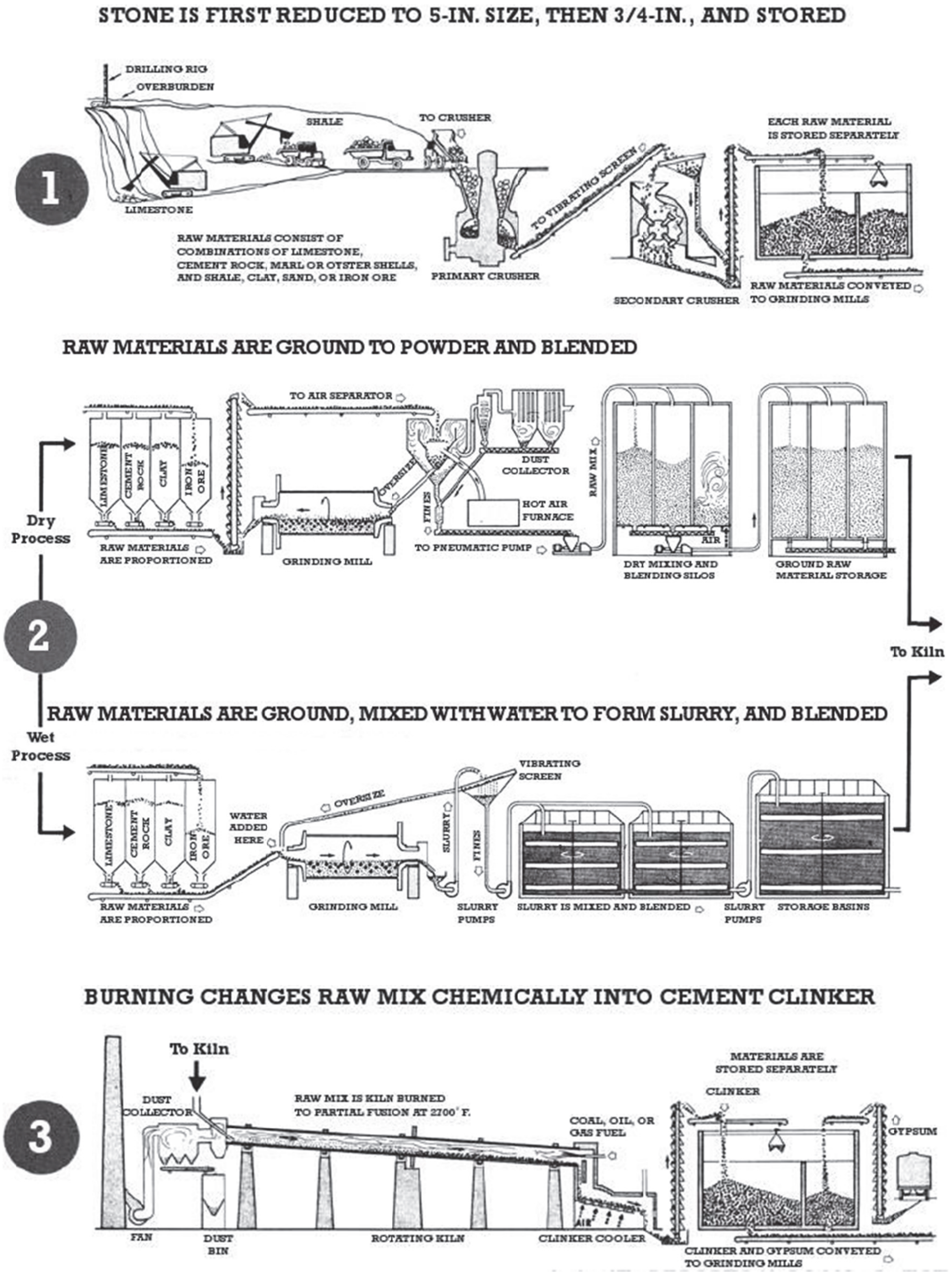
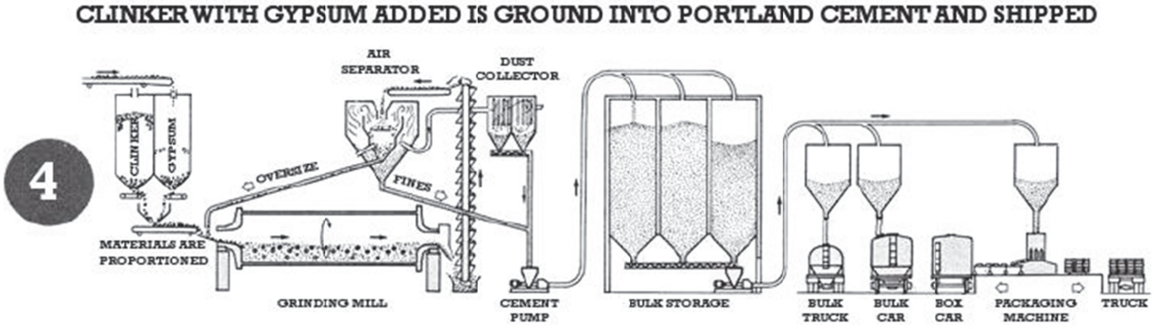
[9] See “Cement Information” in the Appendix for the types of Portland cement typically used in the United States.

process is called a clinker. Once cooled, the clinker is ground into a fine powder and mixed with powdered gypsum and limestone to create ordinary Portland cement (OPC). The cement is the binder component of the concrete that imparts early and eventual high strength of the overall mix; it is the binder that contains the calcium hydroxide and silica that the potassium silicate waterglass reacts with to create the chemical bond between the substrate and coating.

The performance of concrete in the field is determined by numerous factors such as "air content, fineness, expansion, strength, heat of hydration, setting time, [and in regards to the] concrete ingredients, their quantity [in relation to each other], as well as the environment, and the handling and placing procedures used" (Cement Types). Mixing concrete in the proper ratios is extremely important to the performance of the material. Typically, aggregates and gravel comprise three-fourths of the concrete's volume, and are largely responsible for the strength of the material (Allen and Iano 534). Water is another important component for concrete's strength. For instance, too much water will cause the material to lose structural strength because of the creation of excess air voids. Too little water will cause the material to become brittle and friable. Having the appropriate amount of voids within the concrete in itself is an important component to the performance of the material. These air voids act as reservoirs for water, which helps to relieve pressure caused by freezing water. Having the voids helps to create a cushion for this pressure, thus reducing the chance that cracks and spalls will occur. The voids also contribute to the permeability of the concrete and its carbonation.

Figure 20: Steps in the manufacturing of Portland cement. Image Credit: Portland Cement Association, from Design and Control of Concrete Mixtures, 12th edition. (found in Allen and Iano)





4.2. Accelerated Weathering

Evaluating the effects of weathering on architectural coatings can be performed naturally in the field over an extended period of time (e.g. years), or over a shorter amount of time (e.g. months) through accelerated weathering. Accelerated weathering is a testing procedure meant to simulate years of exposure to the elements. In this approach specimens are placed into a weathering device that exposes them to increased levels and frequencies of light and water (spray and vapor) for a specified amount to time. The primary purpose of this is to evaluate a material's relative durability if placed outdoors. In addition to determining durability, such tests can be used to create a performance standard. The machines used in this type of procedure are typically characterized by the light source they use; there are six options: fluorescent UV lamps, carbon arc, xenon arc, metal halide, mercury lamp, and an indoor actinic source. Of these light sources the first three are the most commonly used in laboratory settings (Wypych, 141). Since the author had access to a QUV weatherometer for this testing program, the following information will focus on this type of device.

QUV weatherometers use fluorescent lamps to simulate UV radiation. The first of these lamps created for accelerated weathering purposes was the FS-40 introduced in the 1970s. The next generation was the UVB-313 lamps in 1984 and the UVA-340 lamps in 1987. UVB-313 lamps emit a slightly higher amount of UV radiation than standard daylight. The UVA-340 lamps were developed to better simulate the spectral distribution of sunlight. These lamps were successful at accurately simulating the UV portion, but like their predecessors, did not emit infrared and visible light (Wypych, 145). Since different paints/coatings can be affected differently by the different wavelengths of light, it is important to keep in mind that the samples placed in QUV weatherometers are tested for UV durability. It is also important to note that even though the UVB lamps emit higher UV levels than standard daylight, the lamps have successfully been used to simulate weathering on a variety of materials. For instance "studies on automotive paint showed that fluorescent exposures using UVB lamps have good correlation with Florida weathering, which was also confirmed with paints, plastics, and textiles" (Sahutski, 35). It is important to recognize that the duration of accelerated weathering does not translate into an actual or specific product lifespan (Wypych, 211).

Another important component in accelerated weathering is moisture exposure. The QUV weatherometer has the option of incorporating water spray and condensation exposure for varying durations. Incorporating water into the test simulates rain and humidity exposure. Cool water is sprayed from a series of nozzles inside the test chamber onto the exposed face of samples. Condensation is produced by heating the water at the bottom of the test chamber. It should be noted that QUV weatherometers are equipped with a temperature gauge to measure the temperature of the water in the reservoir, but not humidity.

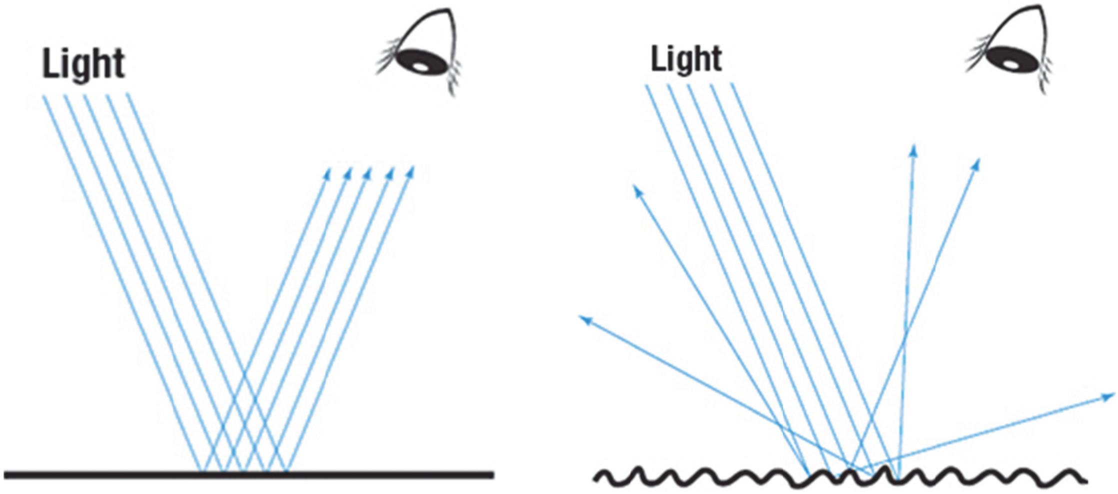
4.3. Quantitative Measurements of Color-Spectrophotometry

There are a range of methods for evaluating color, from visual comparison (e.g. comparing samples to color chips) or through a more quantitative analysis using instrumentation. Quantitative analysis of color tends to be more precise and this information can be used to create and visualize color. Spectrophotometry is the “quantitative measurement of the reflection or transmission properties of a material as a function of wavelength”, and can be used to provide an accurate analysis of color (Spectrophotometry). The device (a spectrophotometer) consists of two components: a spectrometer and a photometer. The spectrometer measures the wavelength of a particular color, and a photometer is used to measure light intensity.

These devices can collect color information in a wide range of standardized color models such as: the Commission Internationale de l'Eclairage (CIE) L*a*b* and L*C*h models, Munsell, CMC, Hunter Lab, and XYZ color space, to name a few. These readings can be collected, and the samples remeasured at a future time to determine if the color has changed. The selection of the color model depends on the intended use of the data. For instance to determine (quantitatively) how much a sample has changed, models such as CIE L*a*b* and L*C*h would be appropriate. Conversely, if the user wanted to obtain the color of the sample and use that information for matching purposes for a wide range of applications, Munsell may be more straightforward. While being cognizant of the appropriate method to choose, it is also important to understand that surface conditions —such as texture and gloss— can affect readings.

Color is perceived when the light hits an object and reflects back into the eye. Light reflects off of objects in two ways: specular reflection and diffusion reflection. Specular reflection occurs when the light reflects at an equal but opposite angle. This typically happens on very glossy and smooth surfaces, and can make the color appear more vivid and saturated. Diffusion reflection occurs on matte, textured or irregular surfaces, where the light hits the object and is reflected in different directions. This tends to make the color appear duller, less saturated, and less glossy. It is important to take into account the surface of the sample so one can determine what reflection mode would be best to take measurements with.

Figure 21: Diagrams illustrating SCI (left) and SCE (left) light reflection. Image Credit: www.sensing.konicaminolta.us



Spectrophotometers can record the color information in terms of light reflection in two modes: specular component included (SCI) or specular component excluded (SCE). SCI is a measurement of the true color of the sample. This mode does not take into account the specular or diffusion reflection. For instance if two objects had different textures —one smooth and glossy and the other textured and matte— the SCI reading would be the same. SCI is typically used "when formulating recipes to match colors and meet color quality standards more effectively". SCE is used to measure the appearance of the object's color. This mode takes into account the texture of the object, and is typically used for quality control evaluations to ensure the appearance of products remains consistent and meets standards (Konica Minolta Sensing).

4.4. Vapor Transmission

Evaluating the vapor permeability or 'breathability' of a material is an important consideration in assessing the performance and compatibility of coatings applied to a porous substrate. A common procedure to evaluate this physical property is through a moisture vapor permeability rate test (MVPR), also known as water vapor transmission rate test (WVTR). Water vapor, like other gases, is constantly moving from areas of high pressure to low pressure to achieve equilibrium. Often, in order to achieve this equilibrium the vapor must pass through a material. Vapor permeability is defined as the ability of a material to allow water vapor to pass through it. Permeation occurs in three steps. First the water vapor or permeator is absorbed into the material. Then it diffuses within the material. Lastly, the permeator is desorbed from the material, to the area of low pressure. The permeability of a material is evaluated in perms. There are four categories of vapor permeability:

- Vapor Impermeable: 0.1 perm or less
- Vapor Semi-impermeable: greater than 0 .1 perm but less than or equal to 1.0 perm
- Vapor Semi-permeable: greater than 1.0 perms but less than or equal to 10 perms
- Vapor permeable: greater than 10 perms

Concrete is classified as vapor semi-permeable, with a permeability of around 3.0-4.0 perms. It is important that any coatings that are added onto the concrete surface have a perm value above 3.0 to ensure that the material can adequately breathe.

4.5. Water Repellency

Water repellency is defined as a material or surface that liquid water is not able to easily penetrate. If the material is not naturally water repellant, a hydrophobic coating is typically applied to provide this characteristic. Water has a relatively high surface tension (approximately 72.8 Dynes/centimeter). Whether or not a surface is hydrophobic or water repellent has to do with the surface's microstructure or chemistry and its ability to resist the covalent bonds of the water molecules. A common test for determining if a surface is hydrophobic is to measure the contact angle between a drop of water and the surface. If the angle is greater than 90˚ then the surface is considered to be hydrophobic; less than 90˚ it is labeled as hydrophilic. Measuring the contact angle is only one means of revaluating whether or not a coating is water repellant. Although it may seem counter intuitive, measuring the water absorption of a material treated with a coating can help determine how repellant the coating is.

Two common means of evaluating the water absorption of material is through a Reunion Internationale des Laboratoires D'essais et de Recherches sur les Materiaux et les Constructions (RILEM) tube test and a water immersion test. Originally used by the water repellent manufacturing industry in the 1980s, the RILEM tube test was created to assess the water absorption properties of a variety of materials. This test "measures the quantity of water absorbed by a particular substrate over a given time through an uptake tube", attached to the material with waterproof putty (Saldanha and Eichburg). It should be noted that "although widely used, there is currently no industry standard on how to perform a RILEM test" (Ibid). Despite not having a US standard, there are instructions on how to properly conduct this test. The instructions can be found in the 1980 RILEM developed report Test *No. II.4 Water Absorption Under Low Pressure (Pipe Method)*. In order for this test to be successful it is imperative that a watertight seal is created between the material and the test tube. If not, water can leak out creating false results. Also surfaces that are heavily textured and/or suffering from an extreme level of sugaring/disaggregation may be difficult to achieve a tight seal. This test can be performed in the field and in a laboratory setting. RILEM tube tests are considered to be non-destructive, and can yield useful results when repeated on the same surface before and after a water repellant coating is applied. Although the test is non-destructive, the putty can leave residue that may stain the surface of the material.

The other procedure, an immersion test, involves submerging a material in water to determine the amount of water absorbed into the material over a period of time. Prior to submerging, the material is weighed. This weight is compared to the saturated mass obtained at the conclusion of the test. This can produce a more precise quantitative measurement of the material's ability to absorb water compared to the RILEM tube test. Absorption tests are typically performed in a laboratory setting under known conditions.

Chapter 5: Methodology

In order to test out the performance of the mineral silicate stains, various shaped concrete coupons were created. Rectangular coupons approximately three by four inches[10] were made to test color durability and pH changes through accelerated weathering. Cylindrical coupons approximately two inches in height and two inches in diameter were created to test water immersion rates. Cylindrical disks — ¾ of an inch in height and two inches in diameter— were created to test water vapor transmission.

The rectangular coupons were created using wood molds designed to impart the Shadowood texture onto the surface of the concrete. These molds were constructed with a combination of plywood and solid wood. The sides were made of ¾ of an inch birch plywood and the bottom sections were made of either solid Cypress or Douglas fir. The bottom pieces were sandblasted to recreate the characteristic Shadowood texture, found on the Central Lodge. To ensure that the corner butt joints remain tight as the concrete cured, duct tape was used to secure the sides and bottom of the molds. To create the cylindrical coupons, molds made from standard 2” PVC pipe were used. Before the concrete mixture was placed into the PVC or wood molds, the interior surfaces were brushed with mineral oil.[11]

5.1. Mixing Concrete

The first step in evaluating whether mineral silicates can be a variable alternative coating system was to create concrete samples. Specifications from Underwood called for a concrete mix of a ½ part of Portland cement, 3 parts aggregate (comprised of 1 part fine aggregate and 2 parts coarse aggregate) and a ½ part of water (Underwood, 6-8). In order to fit

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[10] The size of the rectangular molds were influenced by the size of the QUV weatherometer brackets

[11] In the original 1953 specifications for Jackson Lake Lodge, mineral oil was cited as the release agent on the formwork (Underwood, 6-3).

into the QUV Weatherometer, the coupons had to be ½ of an inch or less in depth. Using coarse aggregate as instructed in the specifications would have created facsimiles that were too thick to fit into the weatherometer brackets. Also using course aggregates in a relatively thin samples could have interfered with the Shadowood surface texture. Because of this the coarse aggregate was exchanged for finer aggregate. Previous use of the Shadowood molds noted difficulty with the texture transferring to the concrete using the specified mix. To help ensure that the Shadowood texture would transfer, the ratio of water was increased 25%. The modified concrete mix used in this testing program was: ½ part Type I/II gray Portland cement; 3 parts concrete sand,[12] and approximately $^5/_8$ parts deionized water. The ratios were measured out by volume for the mix. The procedure for mixing the concrete followed ASTM C192/C192M-Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory.

The first step in creating the concrete mix involved sieving the dry cement with a 425-µm (No. 40) sieve. Prior to using the concrete sand, a representative sample was extracted for gravimetric analysis. The purpose of this analysis was to ensure that the sand was well graded (a good mixture of various sized aggregates). The graph below illustrates the results of this analysis.

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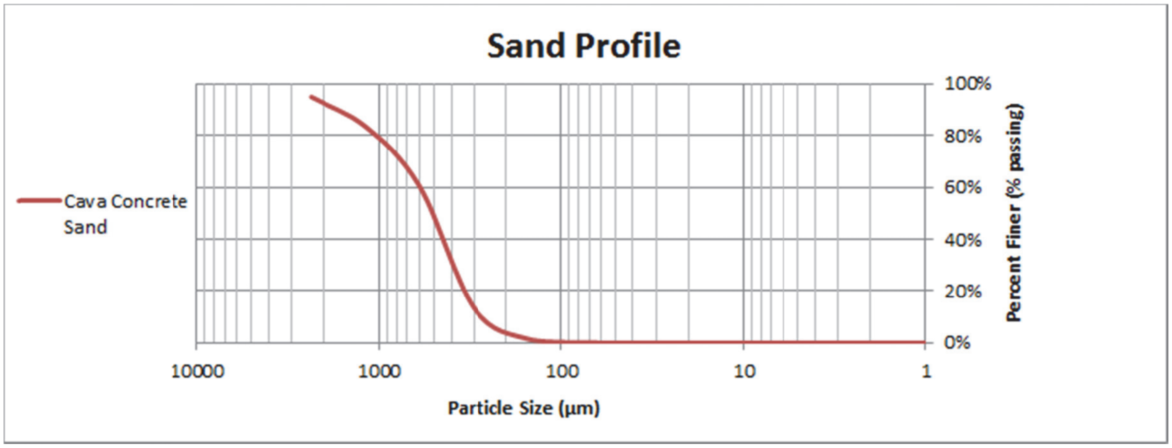
[12] Concrete sand is usually composed of gneiss, trap rock, limestone or granite. The aggregates have grain sizes typically ranging from 4.75 mm to a #200 sieve. (Concrete Sand - NJ, NY, NYC, PA.)

Figure 22: Cava Concrete Sand Particle Size Profile. Credit: Author



A HOBART mixer was used to combine the dry ingredients and water. Prior to starting the mixer, premeasured sand and concrete were added to a five quart metal bowl, with a small amount of water to help keep dust down as the mixer was started. As the mixer was running at the lowest speed (Speed 1) the remaining water was added. This was mixed for three minutes followed by a three minute rest period, during which the sides of the bowl were scraped down. For the remaining time, the bowl was covered to prevent the mixture from drying out. After the rest period, the mixture was mixed for another two minutes. Then, the wet concrete was placed onto a counter covered with a plastic sheet, and hand mixed using a trowel until it appeared uniform in color and consistency.

Figure 23: Author Adding Sand to Mixer. Image Credit: Nicole Declet

5.2. Placing concrete into molds and curing period

After the final mix, the wet concrete was spooned into oiled molds in lifts. Each lift was tampered down with a rectangular wooden tamper. For the Shadowood coupons, once the first lift was in place the molds were shaken back and forth and forcibly tapped on the counter to ensure that air bubbles were not trapped between the bottom of the mold and the concrete. A second lift of concrete was then applied, tamped, and the molds were again shaken back and forth and tapped on the counter. The cylindrical molds followed a similar process, but were not shaken and forcibly tapped against the counter because the base was not secured to the PVC tube.

After placing the concrete in their respective molds, the mixture was left to cure uncovered for three days in an enclosed room with an average temperature of 68˚F (20˚C) and a relative humidity of 20-25% . After the third day the samples were removed from their molds, and placed on a tray[13] to cure for 28 days in the same room. The temperature and humidity of the room was not controlled during the curing period.

Figure 24: Author Spooning Concrete into Shadowood Mold. Image Credit: Author

5.3. Staining

At the conclusion of the curing period, the facsimiles were washed and scrubbed with warm water and a small nylon brush to remove any residual mineral oil or laitance- a friable layer made from cement and fine aggregates that rises to the surface during drying and curing. After the coupons had been scrubbed, they were be left to dry for at least 24 hours prior to applying the first coating— which was either the water repellant (Silan-100) or the KEIM Concretal®-Lasur mineral silicate stain.

5.4. Determining Colors

There was an extensive process to determining the appropriate colors and dilutions of the mineral silicate stains, in order to match samples created by Gilmore. KEIM Mineral Coatings

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[13] The tray on which the concrete coupons cure on was lined with a 2-ply tissue paper sheet with a polyethylene backing.

of America Incorporated products were chosen for this testing program because of their extensive color inventory and reputation as a leader in potassium silicate coatings. KEIM carries approximately 200 standard stock colors and also performs custom color matching. This portion of the testing program began with matching the three Kemiko acid stain colors stated in Gilmore's thesis —Malay Tan, Cola, and Black— with mineral silicate equivalents. KEIM is able to create custom stains based on established color models such as CMYK, RGB, and the Munsell color system. The latter was chosen to match the Kemiko stains.

The Kemiko acid stains samples created by Gilmore were visually matched to matte Munsell color standards.[14] Three Munsell colors were chosen (see Table 1) that appeared to be a close match to the acid stains. These Munsell numbers were sent to KEIM to create custom stain matches.

Table 1: Munsell Color Match Information

Kemiko Color Name	Munsell Color Match	Code of KEIM's custom match	Corresponding color name given for testing program
Malay Tan	10 YR 7/8	CL-15234	Yellow
Cola	7.5 YR 4/3	CL-16267	Red
Black	7.5 YR 3/1	CL-16276	Black

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[14] It should be noted that the acid stains were applied onto grey Portland cement coupons, and did not represent the color of the stain but its appearance on a grey substrate. These samples were the only ones available of the acid stain colors used in Gilmore's thesis at the time.

Figure 25: Gilmore Acid Stain Samples used for Munsell Match. Image Credit: Author

After applying the custom stain colors to the concrete coupons it was determined that the Cola match was too yellow and needed more of a red hue. Instead of visually rematching the acid stain to Munsell color chips, sample tiles (of the Cola and other stains) created by Kemiko were sent to KEIM in the hopes of achieving a closer match. Unfortunately due to the complexity of the stains, the company's production team had difficulty creating custom matches for the Malay Tan and Cola (the Black was matched). Since the test application of the Munsell matched Malay Tan mineral silicate stain was a good match, it was deemed acceptable for the test program. As for the Cola, the author browsed through stock colors found in the *KEIM Exclusiv [sic]* palette book, and through visual assessment color #9007 was chosen (see Figure 25). Table 2 summarizes the final color selection used for further testing.

Figure 26: Visual Match of Cola Acid Stain Samples (on right) with KEIM Exclusiv #9007 Swatch. Image Credit: Author

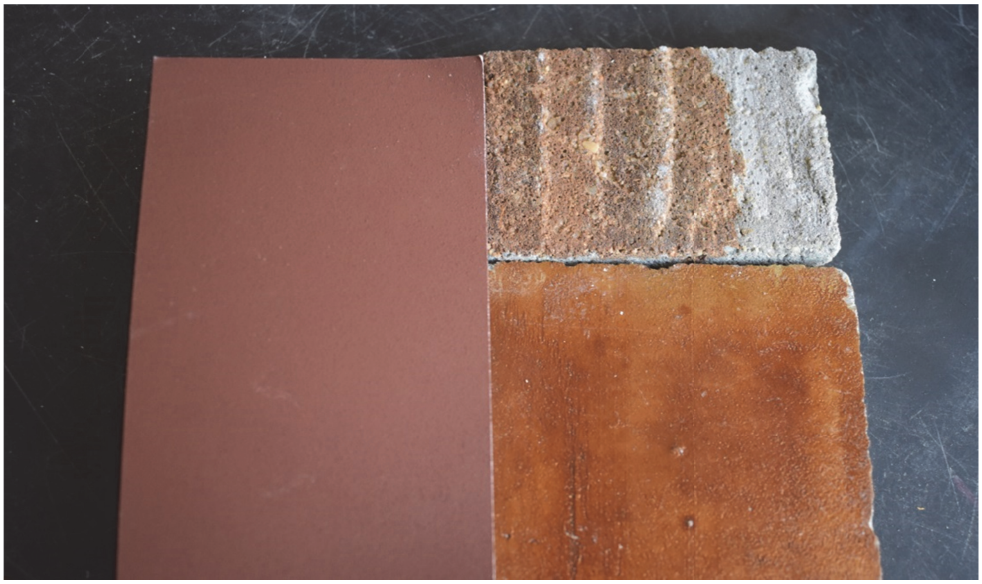


Table 2: Finalized Colors for Testing

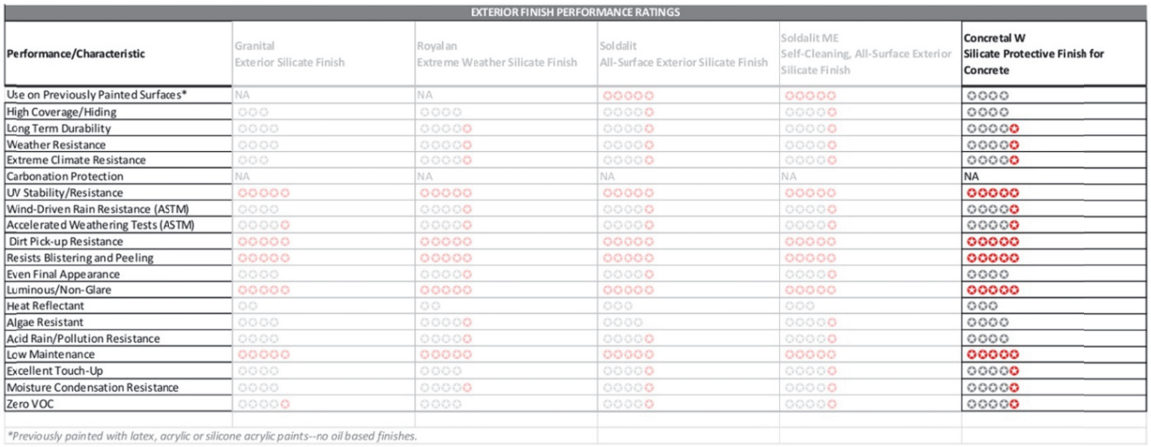
Kemiko Color Name	KEIM Match Equivalent	Means of Determining Match	Name Given for this Testing Program
Malay Tan	CL-15234 (custom match)	Munsell color chart	Yellow
Cola	#9007 (stock)	KEIM Exclusiv Palette book	Red
Black	CL-16276 (custom match)	Munsell color chart	Black

5.5. Application Technique

Once the colors were finalized, the proper dilutions of the KEIM product needed to be determined in order to create a low-pigmented transparent stain. It was assumed that overlaying different colors of stain would create the variegated appearance necessary to restore the original redwood finish of the Central Lodge (similar to the process used with the acid stains). The first step in confirming this assumption was to determine the pigment concentration of for stain. Since concrete would be the substrate for this testing program KEIM's Concretal®-

Lasur mineral coating was chosen. The critical performance characteristics needed for this testing program (transparency of the finish, resistance to blistering/peeling, UV protection, and liquid water protection) were checked against the list of performance ratings and the technical data sheet provided by the manufacture for the Concretal® line. The manufacturer's literature also highlighted many other benefits of this product some of which are being able to be used over previously painted surfaces (non-oil based), algae, dirt, and acid rain resistant, plus zero VOC.[15] To create the stains for this testing program the following procedure was performed.

Figure 27: KEIM Exterior Finishes Performance Rating. Image Credit: www.keim-usa.com/



EXTERIOR FINISH PERFORMANCE RATINGS

Performance/Characteristic	Granital Exterior Silicate Finish	Royalan Extreme Weather Silicate Finish	Soldalit All-Surface Exterior Silicate Finish	Soldalit ME Self-Cleaning, All-Surface Exterior Silicate Finish	**Concretal W Silicate Protective Finish for Concrete**
Use on Previously Painted Surfaces*	NA	NA	●●●●●	●●●●●	○○○○
High Coverage/Hiding	○○○	○○○○	○○○○●	○○○○●	○○○○
Long Term Durability	○○○○	○○○○●	○○○○●	○○○○●	○○○○●
Weather Resistance	○○○○	○○○○●	○○○○●	○○○○●	○○○○●
Extreme Climate Resistance	○○○	○○○○●	○○○○●	○○○○●	○○○○●
Carbonation Protection	NA	NA	NA	NA	NA
UV Stability/Resistance	●●●●●	●●●●●	●●●●●	●●●●●	●●●●●
Wind-Driven Rain Resistance (ASTM)	○○○○	○○○○●	○○○○●	○○○○●	○○○○●
Accelerated Weathering Tests (ASTM)	○○○○●	○○○○●	○○○○●	○○○○●	○○○○●
Dirt Pick-up Resistance	●●●●●	●●●●●	●●●●●	●●●●●	●●●●●
Resists Blistering and Peeling	●●●●●	●●●●●	●●●●●	●●●●●	●●●●●
Even Final Appearance	○○○○	○○○○●	○○○○●	○○○○●	○○○○
Luminous/Non-Glare	●●●●●	●●●●●	●●●●●	●●●●●	●●●●●
Heat Reflectant	○○	○○	○○○	○○○	○○○
Algae Resistant	○○○○	○○○○●	○○○○	○○○○●	○○○○
Acid Rain/Pollution Resistance	○○○○	○○○○●	○○○○●	○○○○●	○○○○
Low Maintenance	●●●●●	●●●●●	●●●●●	●●●●●	●●●●●
Excellent Touch-Up	○○○○	○○○○	○○○○●	○○○○●	○○○○●
Moisture Condensation Resistance	○○○○	○○○○●	○○○○●	○○○○●	○○○○●
Zero VOC	○○○○●	○○○○	○○○○●	○○○○●	○○○○●

**Previously painted with latex, acrylic or silicone acrylic paints--no oil based finishes.*

Following the manufacturer's instructions and the advice of Tom Tipps, National Sales Manager for KEIM, stains were creating using ratios of two products: KEIM Concretal®-Lasur and KEIM Concretal®-Dilution (also referred to as Fixativ). Concretal®-Lasur is a sol-silicate pigmented mineral stain for concrete. The Material Safety Data Sheet lists the primary composition of the product to include Sodium Aluminum Silicate, inorganic pigments, quartz, mica, and diethylene glycol. As supplied by the manufacturer, the viscous Concretal®-Lasur itself creates an opaque stain. In order to create transparency, Fixativ is required. The Fixativ

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[15] These performance characteristics were not tested during this testing program

dilution is comprised of a liquid solution of potassium waterglass, silica sol[16], and additives (KEIM Concretal-Fixativ MSDS, 1). Based on the manufacturer's recommendations, the application sequence for the stains progressed from lightest to darkest- yellow, red, then black. The following paragraph outlines the procedure for creating and applying the stains.

After mixing the appropriate ratio of Lasur to Fixativ in a plastic beaker[17] using a syringe with millimeter increments, the dilution was hand stirred for approximately 15 seconds or until it achieved an even consistency. After stirring the solution, the yellow stain was applied to the surface of the concrete facsimile using a 1 ½ inch wide natural bristle brush. The stain was allowed to remain on the surface for one minute then a six inch paint roller was used to remove the excess liquid. The sample was then left to air dry at room temperature for at least 24 hours before the second coat of stain was applied. When applied the red stain remained on the surface for 1 ½ minutes, then the excess was removed with the paint roller. After waiting another 24 hours the application of the third coating (black stain) followed the same procedure.

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[16] The silica sol component is added to the waterglass solution to improve adhesion of the coating to the substrate. This is particularly adventitious for existing structures, where changes to the substrate may have occurred due to extended exposure to the elements. KEIM advertises paints with sol silica as the "third generation of mineral silicate stains"(Sol-Silicate Paint)

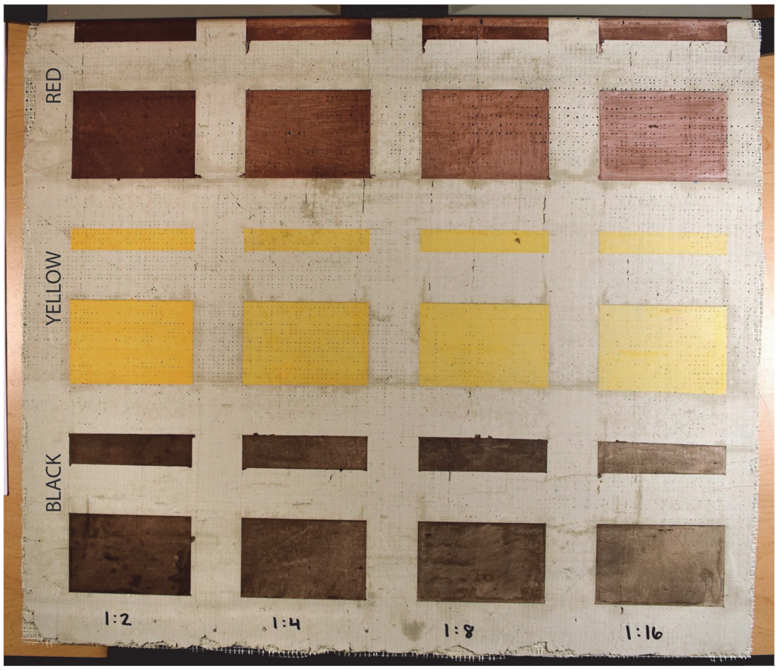
[17] Plastic beakers were utilized opposed to glass to prevent staining of the glassware.

Figure 28: Supplies Used to Stain Samples. Image Credit: Author

5.6. Mock-Ups and Final Sample Preparation

Prior to applying the stains to the concrete coupons, a mock-up board was used to visually assess how different dilutions of the three colors would appear. USG Durock® Cement board was used for this initial assessment in order to preserve the limited number of concrete coupons for final mock ups. Different dilutions of the 3 stains were applied onto a ¼ inch cement board that measured approximately 21x18 inches. Using blue painter's masking tape a grid of 24 cells was created. The dilution ratios applied to the board are as follows (paint: dilution medium) — 1:2. 1:4, 1:8, and 1:16. Through visual assessment it was determined that the 1:8 and 1:16 ratios would be most appropriate for this testing program.

Figure 29: Mock Up Board Showing Various Dilution (Lasur: Fixativ). Image Credit: Author



After finalizing the 1:8 and 1:16 dilutions, mock-ups of the three stains overlaid on top of each other were created to determine if a variegated finish could be created. Due to the limited number of concrete samples, the first mock-ups were performed on 6x6 inch cement boards. In addition to creating samples with all three colors, it was decided to make samples using only the yellow and red stains.[18] After a visual comparison of the cement board mock-ups to Gilmore's control acid stain sample, several mock-ups were chosen for final assessment on concrete samples. Using five Shadowood coupons, ten color schemes were applied (two per coupon). After comparing the final mock-ups to Gilmore's control sample, color formulation 1:8 yellow and 1:16 red was selected as the staining option for this testing program. It was determined that adding the black stain, even at a low dilution (1:16) made the samples too dark, so a coating of black was eliminated from the final sequence. The remaining concrete coupons

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[18] See Mock-up List in Appendix for a summary the color combinations and dilutions used for the mock-ups

(the Shadowood panels, disks, and cylinders) were stained using color scheme 1:8 yellow and 1:16 red.

Even though the research states that potassium silicate coatings have good water repellency capabilities, the author decided to also evaluate the effect of including a water repellant to the testing program. KEIM manufactures a solvent-free, silane-based water repellent (Silan-100) that can be used either as a priming coat or as a standalone finish. This product was applied to a portion of the samples in each test. The application of the Silan-100 followed manufacturer's instructions.

5.7. Performance Evaluation Testing

In order to determine the viability of using potassium silicate stains to recoat the exterior of the Central Lodge the following attributes were tested: color durability, pH, water vapor permeability, and water repellency. To determine these properties, the following tests were conducted: accelerated weathering, vapor transmission rate testing, and water absorption testing. Also, an evaluation of the hydrophobicity of a treated and untreated surface was assessed by measuring the contact angle between a drop of water and the sample's surface. Table 3 summarizes the tests that were performed and supporting information.

Table 3: Testing Schedule

Test Method	Criteria Being Tested	Reference	Sample Dimensions	Sample Shape	Number of Groups	Samples per Variable	Total Samples per Test
Accelerated Weathering	-color -pH	ASTM D2244, E1164	3x4	rectangle	2	6	12
Vapor Transmission Rate	-water vapor permeability	ASTM E96	2x2	cylinder	4	3	12
Water Absorption	-liquid water repellency	ASTM D6489	2x.75	disk	4	3	12
Water Absorption	-liquid water repellency	RILEM tube test	3x4	rectangle	4	1	4
Contact Angle	-hydrophobic nature of surface	ASTM D7334, Woodward , 1999; Lamour, 2010;	2x.75	disk	4	1	4

5.8. Performance Evaluation Test 1: Accelerated Weathering

Accelerated weathering was used to test the color and pH performance of the KEIM potassium mineral silicate stain. The finish of the concrete can have a significant effect on how color is perceived. Due to this, the textured Shadowood panels were used for this portion of the testing program. In total 12 samples were created for this assessment. Prior to applying the coatings, roman numerals were inscribed on the back of the coupons using a Dremel® rotary tool with an aluminum oxide sanding disc. Six coupons were primed with three coats of Silan-100 (samples A1-A6) and the remaining six were not (samples A13-A17 and B1-B2). All 12 samples were coated using the selected KEIM Concretal® Lasur-Fixativ color formulation and sequence specified in the previous section. It was recommended that the samples with Silan-100 be allowed to dry for 28 days, but due to time restrictions the cure time had to be reduced. The samples were left to dry in an enclosed room at approximately 20°C for 16 days prior to being weathered. Of the cohort, two samples —one containing the Silan-100 primer and one without— were selected as controls and not placed in the weatherometer.

A QUV Weatherometer (model: QUV/SE/SO) was utilized to perform the accelerated testing. The machine contained eight UVB-313 fluorescent lamps. UVB lamps produce a more intense UV exposure than UVA lamps, resulting in faster deterioration because of its smaller wavelength. Due to this and the limited amount of time available for this test, a UVB light source was chosen. Since the color durability results of this testing would be compared to conclusions made by Gilmore on accelerated weathering of acid stain finishes, it was important to replicate her testing procedure.

Table 4 summarizes the three types of cycles typically used with UVB accelerated weathering. Of these cycles, Gilmore chose Standard 1 because it would produce the most damaging intensity of UV light. Within a 24-hour period, six cycles would occur -- three UV and three condensation cycles. This testing program also included a five minute spray cycle at the beginning of the four-hour condensation cycle. This was meant to create thermal shock by rapidly cooling the concrete samples after they had been in a 63°C environment for approximately four hours (Gilmore, 51-52).

Table 4: Typical Cycle Selection for Accelerated Weathering Using UVB Lamps

Standard	Irradiance $Wm^{-2}nm^{-1}$	Wavelength nm	Cycle Time (hours)		Temperature During Cycle	
			UV	Condensation	UV	Condensation
1	0.63	310	4	4	63±3°C	50±3°C
2	0.55	310	8	4	70±3°C	50±3°C
3	0.44	310	20	4	80±3°C	50±3°C

A few days prior to beginning the test, the interior of the machine and the mounting devices were cleaned with a 5% solution of acetic acid to reduce the possibility of contamination. Also, the temperature gauge and irradiance panel for the weatherometer were calibrated to ensure that measurements by the machine would be accurate. A few hours before inserting the samples into the machine, the weatherometer was tested to ensure that the UV, spray and condensation cycles, in addition to the heater, were performing as expected.

After the machine was cleared for use, the Shadowood samples were mounted into aluminum brackets— one sample per bracket in order to reduce contamination between the samples. The brackets measured approximately 3 ¼ x 12 inches with two rectangular openings of 2 ¾ x 3 ¾ inches to expose the face of the samples to the weathering effects of the machine. Even though the concrete coupons were designed to fit into these brackets, it was necessary to secure them in place with additional materials. Similar to Gilmore's procedure, the samples were secured using thin strips of ethylene-vinyl acetate. A strip of the acetate was placed on the left side of the bracket, and then the sample was pushed into place. If a tight fit wasn't achieved with the strip of acetate, a second piece was inserted into the right side of the sample. The use of the acetate, opposed to using a more rigid material, was meant to provide cushion and reduce chipping of the edges when the sample was pushed into place (Gilmore, 53).

After the samples had been secured into the brackets, the assembly was placed into the weatherometer. The machine was set for conditions corresponding to Standard 1 and programmed to begin half-way into a UV cycle. This was done to ensure that the samples would be dry when they were checked every 120 hours. During the rest period the samples were measured for changes in color and pH. After the measurements were recorded, the samples were reinserted into brackets and placed into the weatherometer. At the beginning of every 120-hour period, the samples were rotated to prevent the same samples from being exposed to localized high velocity spray.

Figure 30: Samples inside of weatherometer. Image Credit: Author

5.8.1. Color and pH testing

Every 120 hours (and prior to beginning the accelerated weathering test) the color and pH levels of the samples were measured. To determine color stability a Konica Minolta CM-2600d Spectrophotometer was used. A spectrophotometer was chosen over other color analytical procedures in order to obtain quantitative data. Color evaluation followed ASTM

E1164-12: Standard Practice for Obtaining Spectrometric Data for Object-Color Evaluation. To ensure that the same locations were tested, a template constructed of white cardstock paper was used.

The device was connected to the computer and measurement parameters were defined through the supporting software, *SpectraMagic NX*. Parameters for the device were as follows:

- Angle of observation set at 10°
- Daylight illuminant set at D65
- Taking three measurements of each target
- Averaging multiple targets to create an overall average
- Collecting both SCI and SCE measurements

Prior to collecting data, the spectrophotometer was calibrated according to the manufacturer's instructions. Due to the variegated appearance of the finish, multiple points were sampled to determine an overall color. For each sample five measurements were taken—one in the center and one near each of the four corners. And for every location, three measurements were taken. These measurements were taken in the CIELAB color space system. This system defines color using three values, L*, a*, and b*. Similar to the value scale on the Munsell chart, the L* value represents the lightness of the color and ranges from 0 (pure black) to 100 (pure white). a* represents the amount of green and red in the sample. Negative values represent greens and positive reds. The final value, b*, represents the amount of blue to yellow in the reading. Negative values represent blues and positive yellows (Gilmore, 46). In total fifteen measurements were taken per sample and the data were averaged by the computer to create a single reading. The final color values at hour 845 were compared to the initial values in order to determine if there was a significant change in color. To determine this change the following equation was used.

$$\Delta E = \sqrt{(\Delta L *)^2 + (\Delta a *)^2 + (\Delta b *)^2}$$

E=color-difference

L*= change in the lightness value

a*= change in the blue to yellow value

b*=change in the red to green value

After completing the color measurements, pH readings of the samples were taken. pH is a logarithmic measurement of the hydrogen ion concentration of a material. The pH scale runs from 1 to 14. The lower end of the scale, pHs of 1-6, are referred to as acidic. The higher end of the scale, 8-14, are alkaline (also referred to as basic). A pH of 7 and is considered to be neutral. The surface pH of the samples was obtained using an Oakton PCS Testr 35. Following the manufacturer's instructions the tester was calibrated using a buffer series with the following pH levels: 4.01, 7.00, and 10.01. Once the device was calibrated, a dime-size amount of deionized water (pH of 7) was placed on the center of each sample. After waiting approximately two minutes, the pH of the liquid was taken. At the conclusion of each reading the sensor was rinsed with deionized water, before proceeding to the next sample. Once the pH recordings were complete, the samples were placed back into the brackets for continued accelerated weathering.

Figure 31: Author taking color measurements with the spectrophotometer. Image Credit: Author

Figure 32: Author taking pH Readings of Accelerated Weathering Cohort. Image Credit: Author

5.9. Performance Evaluation Test 2: Water Vapor Transmission Rate Test

To evaluate the degree of water vapor permeability imparted by the mineral silicate stain and water repellant treatment, a water vapor rate transmission (WVRT) test was performed. This test was used to determine a quantitative measurement of the coating's permeability. Water vapor permeability is defined as "the time rate of water vapor transmission through a unit area of flat material of unit thickness induced by a unit vapor pressure difference between two specific surfaces, under specified temperature and humidity conditions" (Standard Test Methods for Water Vapor Transmission of Materials). The testing procedure followed ASTM E96/E96M-15 Standard Test Methods for Water Vapor Transmission of Materials.

Three types of coatings were tested for vapor permeability: 1-only potassium silicate stain, 2- only the Silan-100 water repellant, and 3-the potassium silicate with the water repellant. These coatings were applied to the 2x2 cylindrical concrete coupons. The application of the finishes followed the procedure outlined in Section 5.5 *Application Techniques*, and applied to the top face of the facsimile coupons. The coupons were labeled 1-12 with a permanent marker for identification. The testing cohort is as follows:

- Samples 1-3: Silan-100 water repellant and Lasur-Fixativ stain
- Samples 4-6: Silan-100 water repellant only
- Samples 7-9: Lasur-Fixativ stain only
- Samples 10-12: no coating (control group)

The samples were oven dried at 60°C for 24 hours, to remove excess moisture. After achieving room temperature, electrical tape was wrapped around the circumference of the samples. This was required to slightly increase the diameter of the samples in order to create a tight fit when inserted (face down) into the rim of a 100 mL polypropylene tri-cornered beaker.

Prior to inserting the samples, the beakers were filled with 50 mL of deionized water so that the water line was approximately ¾ of an inch from the face of the sample. Once the samples were in place, melted paraffin wax was used to seal the assembly. The cohort was then weighed to the nearest .01 gram, recorded, and placed into a desiccator with a bed of Drierite® anhydrous calcium sulfate mesh size 8 desiccant. Approximately 300 mL of silica gel desiccant was added to the calcium sulfate as a color indicator, to signify when the material was saturated with moisture.

Measuring for this test program followed Section 12- Procedure for Water Method - ASTM 96/E96M. Since measurements tend to vary drastically during the beginning of testing, there was a higher frequency of measurements during the first 24 hours. During this time period the samples were weighed after 5 minutes, 15 minutes, 30 minutes, 1 hour, 1 ½ hours, and 2 hours, then once every 24 hours. This information was recorded in a table and at the conclusion of ten days the WVT was calculated using the following formulas:

$$WVT = \frac{G}{tA}$$

G=weight change (grams)

t=time (hours)

G/t= slope of the straight line between a minimum of six points (grains/h)

A= test area (square centimeters)

$$\text{Permeance}=\frac{WVT}{\Delta p}=\frac{WVT}{S(R_1-R_2)}$$

Δp = vapor pressure difference, mm Hg (1.333 × 102 Pa),

S = saturation vapor pressure at test temperature, mm Hg (1.333 × 102 Pa),

R_1 = relative humidity at the source expressed as a fraction (the test chamber for desiccant method; in the dish for water method), and

R_2 = relative humidity at the vapor sink expressed as a fraction

Figure 33: WVTR Test in Progress. Image Credit: Author

5.10. Performance Evaluation Test 3: Water Absorption and Repellency Tests

In order to confirm the manufacturer's claims of water repellency, absorption tests were performed using the concrete cylinders. To ensure that the cylinders were close in height (approximately 5 centimeters or 2 inches) and had two flat surfaces, the samples were measured and cut using a wet saw. The testing procedure followed ASTM D8489-99: Standard Test Method for Determining the Water Absorption of Hardened Concrete Treated with a Water Repellent Coating. The coatings were allowed to cure for two weeks, before proceeding to the testing program. The cohort for this testing program was similar to the WVT test, with the exception that all the surfaces of the cylinders were coated:

- Samples 1-3: Silan-100 water repellant and Lasur-Fixativ stain
- Samples 4-6: Silan-100 water repellant only
- Samples 7-9: Lasur-Fixativ stain only
- Samples 10-12: no coating (control group)

The samples were oven dried at 75°C for 30 hours to remove excess moisture, then left to cool to room temperature (1 hour). Following the ASTM standard, the cut face of the cylinder was sealed using a two-part epoxy compound. Two coats of epoxy were applied using a small natural bristle brush. The epoxy was left to dry for 24 hours at room temperature.

Prior to beginning the absorption test the samples were weighed to the nearest .01 gram and recorded. The samples were when placed into square containers (with the epoxy face upwards) with a layer of glass rods on the bottom. The glass rods allowed water to circulate under the specimens. Once in place, deionized water at 18°C was slowly added to the container until the level was approximately ¼ inches from the top of the samples. Care was taken not to pour the water directly onto the samples.

The cylinders were allowed to soak for a total of 48 hours. Their weights were recorded twice during the test — at the 24 and 48 hour mark. Along with the weights, the percent of water absorbed was also determined using the equation below. The higher the percent absorbed the more permeable the coating.

$$Percent\ Absorbed = \frac{100\ (W_2 - W_1)}{W_1}$$

W_2= Final weight

W_1= Initial weight (grams)

Percent Absorbed= amount of water absorbed into the sample (in the form of a of percentage of the total mass)

After seeing the results of the immersion test, it was determined that a RILEM tube test should also be conducted. Graduated RILEM tubes with increments ranging from 0 to 5 milliliters were used, and attached to rectangular Shadowood samples with plumber's putty. Like the other tests, the three coating options were tested (Silan-100 water repellant and Lasur-

Fixativ stain, Lasur-Fixativ stain only, and Silan-100 water repellant only) along with an untreated sample (the control). Deionized water was poured into the tube until it reached the 0 mark, and then a timer was started. The water level was recorded every 5 minutes for 75 minutes.

In addition to the absorption tests, the contact angle of a drop of water on the samples was measured. Since a goniometer was not available, an alternative method using the procedure outlined in Courtney Magill's 2014 thesis was used.[19] This method involved taking a close-up photograph of a drop of water on a sample's surface, and using open source software to measure the contact angle.

Four representative cylindrical samples (one from each testing group), were used to measure the hydrophilicity of the different coatings.[20] Using a plastic transfer pipette, a drop of deionized water was placed on the face of the sample. A Nikon D3400 DSLR camera with an AF-P NIKKOR 18-55mm 1:3.5-5.6G lens was used to take the photographs. The camera was positioned so that the center of the lens was level with the face of the sample. The distance between the sample and the lens was approximately four inches.[21] In order to gain an accurate reading of the contact angle, the photographs were taken within ten seconds of the droplet coming into contact with the surface. This procedure was conducted in an enclosed room with a temperature of 69˚F (20˚C) and a relative humidity of 25%. The photographs of the droplets were analyzed using the Contact Angle plugin in the open source software ImageJ. To determine the contact angle, points were placed along the outer edge of the droplet to create the curve of

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[19] Magill's procedure was based in part on ASTM D7334 – 08: Standard Practice for Surface Wettability of Coatings, Substrates and Pigments by Advancing Contact Angle Measurements and papers by Roger Woodward and Guillaume Lamour et al.

[20] The cylindrical samples were chosen because a flat surface was required to produce an accurate measurement and the other concrete shapes had the Shadowood texture.

[21] This was the minimum distance that the camera could focus on the sample.

best fit. Then by using the "Manual Point Procedure" option, the software calculated the contact angle between the sample and the drop of water.

Figure 34: Absorption (immersion) test setup. Image Credit: Author

Chapter 6: Observations and Results

6.1. Permeability Testing

Table 5 presents the average temperature, relative humidity, saturated vapor pressure (S), and the humidity difference between the inside the plastic beaker with the deionized water (R1) and the interior of the test chamber (R2).

Table 5: Average Conditions in Desiccator (Testing Chamber)

	Temperature	Relative Humidity in desiccator	Saturated Vapor Pressure (S)	R1-R2 (24%-0%)
Average Condition	19°C (66.2°F)	24%[22]	17.22 mmHg	.24

Measurements for the WVTR test were taken over the span of ten days, producing a total 17 measurements. It was observed during the first 24 hours that the weights of the samples either remained the same or went down as expected. At the conclusion of the test, the WVT was calculated. As instructed in ASTM E9696, the difference between six data points that showed a steady decline were used for the calculations. This corresponded to points between and including the hours of 48 and 164.5. Prior to calculating the WVT, the average surface area of the 12 samples was determined to be approximately 20.258 square centimeters. This was converted to square meters (0.0020258) to be used in the WVT equation. The results of the WVT were used in the permeance equation stated in Chapter 5. The following are the averaged results of the 12 samples grouped into their four categories.

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[22] The relative humidity was approximately 24% after the first 30 hours

Table 6: Averaged Test Results, Percent Change, and Standard Deviation[23]

Sample	Avg. WVT (metric)	Avg. Permeance (metric/SI)	% Change (from control)
Silan-100 + Mineral Silicate (D1-D3)	2.914	.705/1.07	6.07%
Silan-100 (D4-D6)	2.986	.723/1.10	3.74%
Mineral Silicate (D7-D9)	3.059	.740/1.12	1.40%
Control (D10-D12)	3.102	.751/1.14	---
STANDARD DEVIATION (Of Samples D1-D12)	.1610	.0123/.0591	--

As previously stated, it was very important that any coatings applied to the concrete did not significantly reduce the vapor permeability, or act as a vapor retarder. ACI 302.1R-05, *the Guide for Concrete Floor and Slab Construction*, states that "a vapor *retarder* should have a permeance below 0.3 US perms (SI unit) (Comparing Vapor Barrier Permeance). The results from the WVTR test showed that all the samples had permeances that fall into the semi-permeable category, which is well above the threshold for a vapor retarder. This confirmed that the coatings were vapor permeable.

As expected the samples treated with the Silan-100 water repellant had a lower permeance than the untreated concrete (the controls D10-D12). The samples with the water repellant plus the mineral silicate stain (D1-D3) had the largest percent change compared to the control samples—6.07%; followed by the water repellant only samples (D4-D6) with a percent change of 3.74%; and lastly the samples treated with only the mineral silicate stain (D7-D9) at 1.40%.

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[23] See section: Water Vapor Transmission Rate Data in the Appendix for table showing all the values for samples A1-A12

6.2. Repellency

As expected, at the conclusion of the immersion test the results showed that the control group samples C10-C12 had the greatest average percent change compared to the initial mass (1.35%). Of the coatings cohort, samples C3-C5 (the Silan-100 only samples) had the second highest average percent change (1.30%); followed by samples C1-C3, the Silan-100 plus mineral silicate stain (1.28%). The group that repelled the most water contained samples C7-C9, treated with only the mineral silicate stain. This result was surprising. Even though potassium silicate coatings have hydrophobic properties, it was hypothesized that the samples that contained the water repellant, the Silan-100, would offer the most protection. To confirm that these results were indeed correct, the test was repeated using the same samples after they were oven dried from approximately 48 hours at 75°C.

After oven drying the concrete cylinders, it was noted that a number of the samples had chipped edges. Following Note 3 under section 8.10 in ASTM D6489, these chipped portions were coated with a two-part epoxy, and the new weight recorded. The second trial followed the same procedure as the first test; and the results from this trial were different. From greatest to lowest average percent change the results were: 1.99% (mineral silicate stain group); 1.76% (the control group); 1.66% (the Silan-100 group), and 1.41% (the Silan-100 plus mineral silicate stain group). In this test, the results were more in line with what was hypothesized-- the samples treated with the water repellent absorbed the least amount of water. But it was not expected that the samples treated only with the mineral silicate stain, would absorb more water than the control; especially since in the first trial this group had the highest level of repellency. A reason behind this discrepancy may be due to the large surface area of the mineral silicate group that needed to be covered with the epoxy. Perhaps water was still able to enter the samples around the edges of the patches, and enter the samples. Under these epoxy patches, there wasn't a protective coating layer or the fine compact layer of cement that forms during the initial curing of the concrete. This may have allowed the water to move more easily into the samples, making them more absorbent. Since the results of the immersion test did not draw a clear conclusion, a RILEM test was also performed.

The RILEM test used the rectangular shaped Shadowood samples, opposed to the cylinders used in the immersion test. The test was conducted for an hour, and the results were more in line with what was expected. The samples containing the water repellant (sample A11 and sample S) had the highest repellency with no change after an hour. The sample treated with only the mineral silicate stain (sample B2) had the seconded highest repellency, and the control sample (sample C) had the lowest repellency. This test was repeated, with the control and the mineral silicate stain sample and the results were the same.[24] This confirmed that adding the Silan-100 as a primer coating did offer greater water repellency protection. The samples with the Silan-100, were rechecked after 48 hours and the water level for both samples had gone down .5 a millimeter.

To further understand how the various coating treatments affected the surface hydrophobicity, the contact angle of four samples chosen at random were measured (one from each treatment group). Using the open source software ImageJ along with the plugin Contact Angle the contact angle of four cylinder-shaped samples was evaluated. Table 7 summarizes these results.

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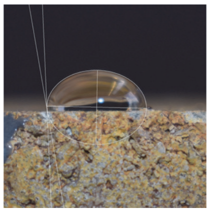
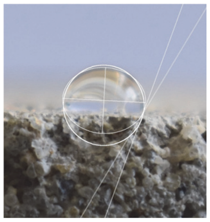
[24] The samples treated with the water repellent from the first trial were allowed to continue during second trial. It was observed that there was no change in the water level after three hours for these samples.

Table 7: Contact Angle Measurement from Cylindrical Samples C11, C8, C5, and C3. Images Credit: Author

	Control (C11)	Mineral Silicate Stain (C8)	Silan-100 (C5)	Silan-100+Mineral Silicate Stain (C3)
Contact angle	88.11	98.56	115.15	97.90
				

The results showed that the treated samples did improve the hydrophobicity of the concrete surface. The software found that the Silan-100 sample was the most hydrophobic, followed by the Mineral Silicate Stain sample, then the Silan-100 and Mineral Silicate Stain sample, and finally the control sample that was untreated.

6.3. Color Durability

All 12 samples used for the color durability testing contained coatings of mineral silicate stain as outlined in the Chapter 5: Methodology. Ten samples (A1-A5, A13-A16, and B1) were weathered in the QUV Weatherometer for approximately 35 days (845 hours). The two control samples (A11 and B2) were stored in an enclosed room on a partially enclosed tray rack. The temperature of the room remained around 21°C (70°F) and the relative humidity was approximately 24%.

As previously stated, due to the limited time available for this testing program, the coatings on the samples were cured for 16 days, opposed to the preferred 28 days specified by Tom Tipps of KEIM. Since the water-repellant primer (which is comprised of a 100% alkylalkoxysilane solution) was not able to fully cure, the samples treated with this coating (A1-

A6 and A11) appeared slightly darker and more yellow than they should have been when the initial spectrophotometer readings were taken. These samples should have appeared similar to the samples not treated with the water repellant. The averaged L*a*b* readings for samples treated with the Silan-100, and the second group treated with only the mineral silicate stain can be seen in Table 8.

*Table 8: Average L*a*b* measurements of first reading (Hour 0)*

	Accelerated Weathering Samples			Controls (single samples so not averaged) (A11-with Silan-100 and B2-without Silan-100)		
	L*	a*	b*	L*	a*	b*
With Silan-100 (A1-A5, A11)	26.512	8.204	29.238	24.18	7.85	27.74
Without Silan-100 (A13-A16, B1-B2)	34.936	8.458	22.218	35.97	8.44	24.39

The measurements from the spectrophotometer showed that there was a significant difference between the cohorts. There was a 31% change for L* between the group treated with the water repellant and the one without. The a* value was less significant at 3%; and b* had a change of 24%.[25]

When samples A1-A5 were checked after 120 hours in the weatherometer, it was noted that the samples appeared less dark (compared to the initial observation at the beginning of the test), and more similar in tone to the samples without the water repellant. This was also confirmed after the color measurements of both groups were taken. The similarity between the groups can be seen by comparing the values in Tables 8 and 9, and on lines "avg L* (with Silan-100)" and "avg L* (without Silan-100)" at hour 120 in Figure 33. The biggest change for samples

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[25] The L* value represents the lightness of a color from 0 representing black and 100 representing white. The a* value represents the amount of green and red in the sample. The b* value represents the amount of blue and yellow in the sample.

A1-A5 was the L* value. At hour 120, the average L* value of the samples had risen approximately 49% from the initial measurement. There was also a change in the b* value of this group. Between hour 0 and 120, *b went down representing a 21% decrease in the yellow spectrum. The green-red spectrum, represented by the a* value, had little change with a 4% change towards the red side.

*Table 9: Average L*a*b* measurements for the Two Weathered Cohorts at Hour 120*

	Accelerated Weathering Samples at Hour 120		
	L*	a*	b*
With Silan-100 (A1-A5, A11)	39.618	7.744	23.24
Without Silan-100 (A13-A16, B1-B2)	36.766	8.518	20.892

As seen in Figure 34, the greatest change in the L*a*b* values occurred during the first 120 hours for the samples treated with the Silan-100. After this point there was steady increase in the L* levels (representing the color becoming lighter or more white); the a* levels decreasing (representing the color becoming less yellow but not passing into the negative values representing an increase blue presence); and the b* levels went down slightly, but for the most part remained the same.

After 845 hours, the results showed that the accelerated weathering had the biggest impact on the L* and b* levels, which affected the ΔE values. Due to the extreme change in the white-black spectrum (L*) the weathered samples treated with the Silan-100 experienced the greatest ΔE with a value of 24.97. This drastic change was due to white chalky deposits that had formed on the exposed face of the samples. These deposits were first noticed on samples A1-A5 when they were measured at the 360 hour mark. For samples A13-A16 and B1 the deposits were not apparent until the next check at 480 hours. The deposits steadily became more apparent as the weathering continued.

*Table 10: Changes in L*a*b* values between Hour 845 and Hour 0*

	ΔL*	Δa*	Δb*	ΔE
With Silan-100 (A1-A5)	21.00	-1.704	-13.358	24.97
With Silan-100 Control (A11)	11.02	-0.33	-4.89	12.06
Without Silan-100 (A13-A16, B1)	10.314	-1.606	-10.09	14.54
Without Silan-100 Control (B2)	-0.01	0.03	-0.99	0.99

The samples were observed under a stereoscope, and it was confirmed that the white substance was deposition and not an integral color change of the stain. It was also observed that areas along the perimeter of each sample that was protected by the bracket during the weathering process did not develop deposits. The deposits were believed to be insoluble salts, so a basic solubility test was conducted using distilled water and a cotton swab. After attempting to clean an area on sample A4, it was determined that the deposits were not water soluble. Next a 15% solution of hydrochloric acid (HCl) was used to clean an area, and the deposits were removed (see Figure 32). Spectrophotometric readings were also taken of cleaning test areas.[26] The reading for the area cleaned with deionized water showed no noticeable change compared to uncleaned areas. As expected the reading of the middle HCl area (L*= 37.65, a*= 6.67, and b*=24.7) was significantly different than an uncleaned area. This

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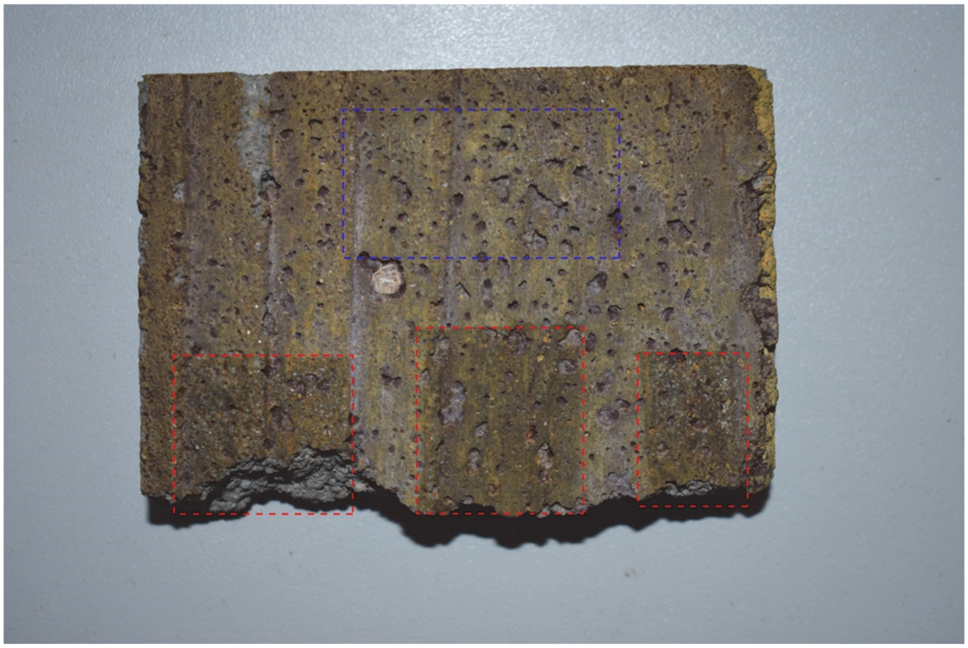
[26] The spectrophotometric readings were taken approximately two hours after the cleaning test was conducted. Also one spot was measured opposed to the five spots that were averaged as stated in the Methodology chapter (see Section: 5.8.1).

reading was compared to Sample A4's Hour 120 reading.[27] The results showed that cleaning the sample restored the surface color to approximately the same levels as Hour 120 (see Table 11).

*Table 11: Changes in L*a*b* values between unclean and areas cleaned with HCl*

	Change between uncleaned spot and HCl cleaned area	Change between HCl cleaned area and Hour 120 reading
ΔL	8.3	1.76
Δa	1.05	0.63
Δb	7.13	0.34
ΔE	10.99	1.90

Figure 35: Sample used for efflorescence cleaning test (Sample A4). Area outline in blue was cleaned with distilled water and showed no change. Areas outline in red were cleaned using a 15% solution of hydrochloric acid. Image Credit: Author



In an attempt to determine the elemental and chemical composition of the efflorescence, SEM-EDS (scanning electron microscope-energy-dispersive X-ray spectroscopy) was performed. Dr. Jamie Ford, a scientist at the University of Pennsylvania Krishna P. Singh Center for Nanotechnology performed the analysis using a FEI Quanta 600 Environmental

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[27] Hour 120 was chosen because it is believed to have the closest L*a*b* reading to what the sample would have appeared as if the coating was allow to cure for the full 28 days.

Scanning Electron Microscope. Scrapings of the whitish efflorescence was placed onto an aluminum pin with carbon tape, and then inserted into the machine. The results showed notable quantities of the following elements: Carbon, Oxygen, Magnesium, Aluminum, Silicon, and Calcium. It should be noted that potassium was not found in the scrapings. It is likely the salts formed on the surface are either calcium/magnesium carbonates or bicarbonates from the concrete substrate calcium/magnesium silicates from the coating, although the former is more likely.

Along with monitoring the durability of the color, the pH levels of the samples were also recorded. The pH readings showed that overall the alkalinity of both the weathered and control samples decreased over testing period, but remained above neutral (pH of 7). The average pH at the beginning of the test was about 9.69 (with a standard deviation of .24) and at the end (845 hours) the average pH was approximately 8.05 (with a standard deviation of .23). Graph 36 illustrates the fluctuations and overall decrease of the pH levels.

*Figure 36: Graph showing the change in average L*a*b* values for weathered samples throughout the testing period. Image Credit: Author*

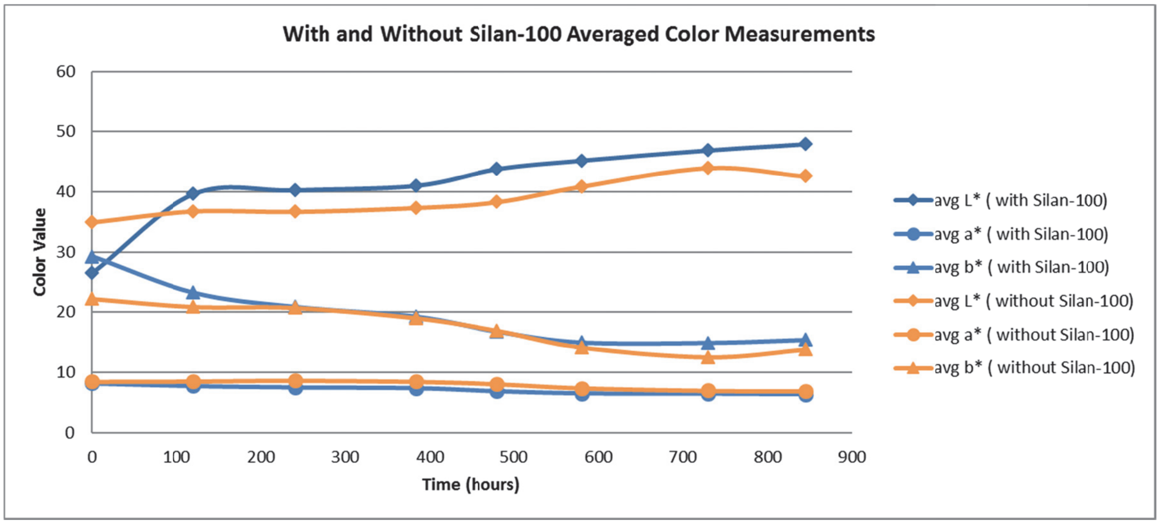


*Figure 37: Graph showing the change in average L*a*b* values for the samples treated with only the Silan-100. Image Credit: Author*

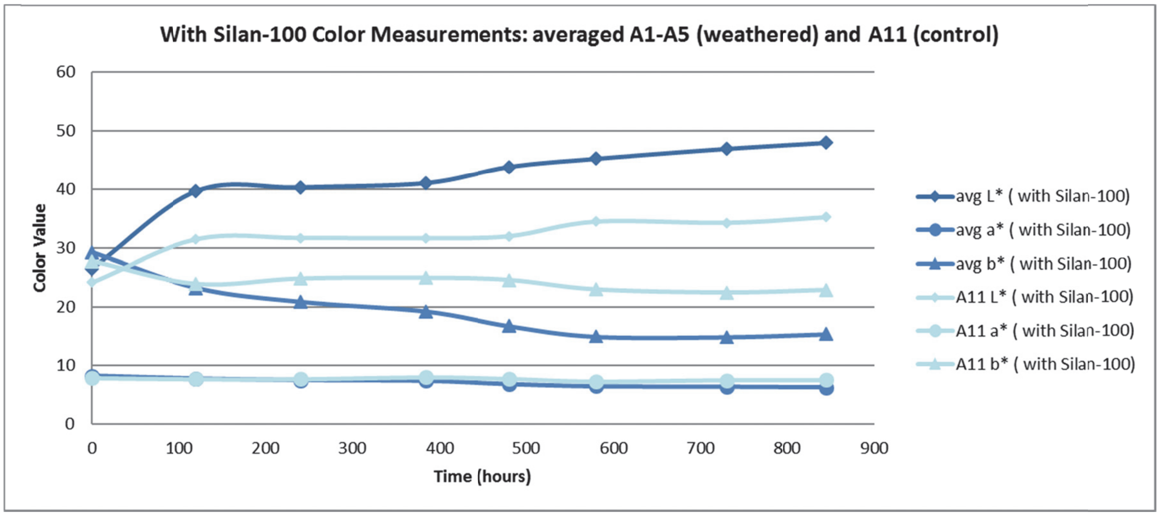


*Figure 38: Graph showing the change in average L*a*b* values for the samples treated without the Silan-100. Image Credit: Author*

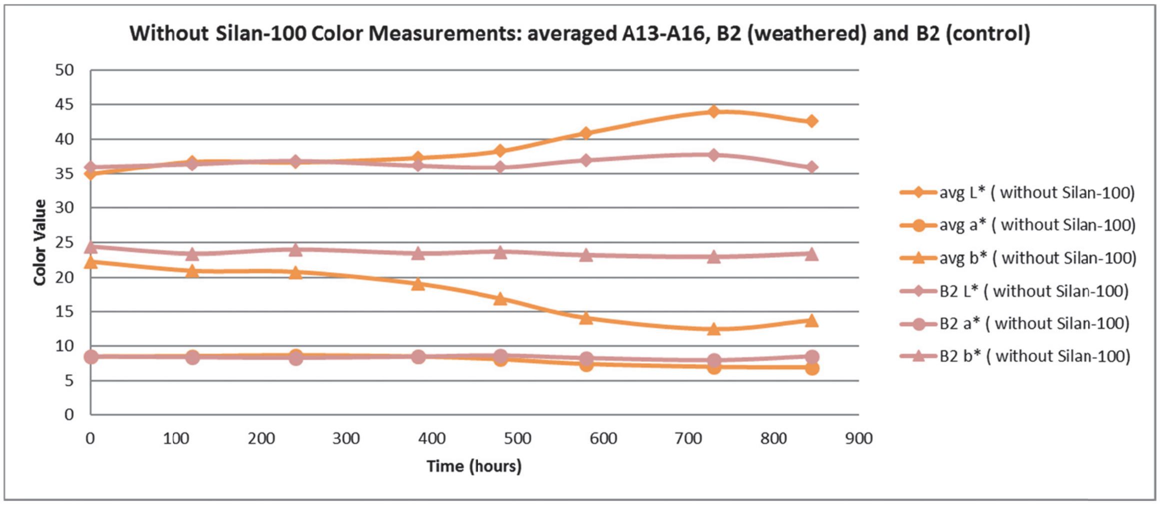
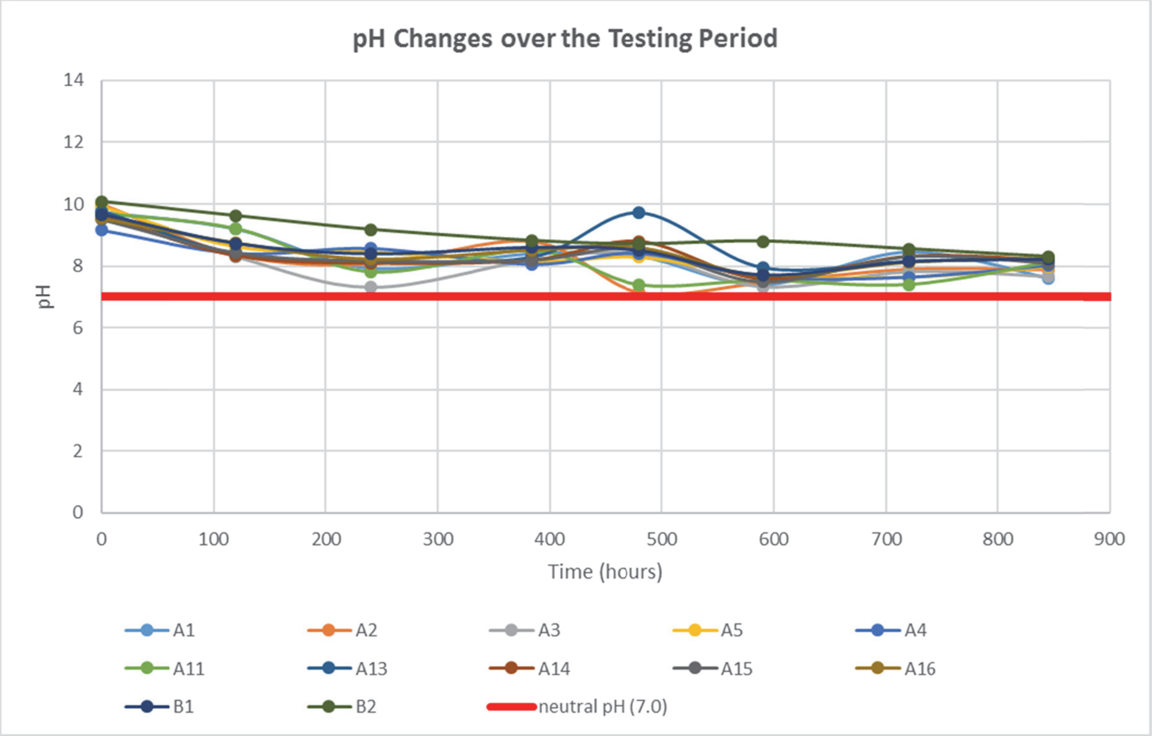


Figure 39: pH changes over the testing period. Image Credit: Author



Chapter 7: Conclusion and Recommendations

In conclusion, the vapor permeability and water repellency tests proved that mineral silicate stains can provide functional benefits when applied to a concrete substrate. The vapor permeability test performed as predicted, with a relatively small change in the permeability rates compared to the untreated control samples. Adding a coating to any substrate will cause some level of reduced permeability, but it is important that the rate isn't reduced to the point where the substrate is negatively impacted. The sample coated with the Silan-100 water repellant and two coats of the mineral silicate stain had the greatest percent change compared to the control samples, 6.07%.

The results from the repellency tests were less straightforward. The first test conducted was an immersion test, meant to determine how much water entered the sample after being submerged for 48 hours. The results of this test were not as expected, so the test was repeated. A possible reason for the unclear results could have been due to imperfections of the cylindrical-shaped concrete coupons. When the concrete forms were created, it was difficult to create a distinct 90° angle (where the face of the cylinder meets the curved side). Instead of a squared condition, the edge of many of the samples were somewhat feathered (see Figure 37). Perhaps this defect created a compromised condition that allowed water to penetrate the sample more easily at these locations, even if the sample was treated with a water repellent. Even though the results of the absorption test were somewhat inconclusive, the results from the RILEM test corroborated findings from the literature review. It showed that having a mineral silicate coating improved water repellency compared to an untreated surface. Furthermore, incorporating a water repellent before adding mineral silicate coating vastly improved the repellency of the surface.

Figure 40: Image of cylindrical sample showing the feathered edge condition. Image Credit: Author

Due to the formation of insoluble salts an accurate assessment of color durability over time could not be determined; and these results could not be compared with the Gilmore's 2016 results for acid stains. Time was a significant limitation in this testing program. A possible reason why the efflorescence formed on all the weathered samples could be because the coatings had not cured for the recommended 28 days prior to beginning the accelerated weathering. It is believed that the efflorescence is from the concrete which released calcium and silicate ions during the wet cycles of the accelerated weathering test. The research found pertaining to efflorescence on mineral silicate coated materials cited freshly cured concrete opposed to historic or existing substrates. Common types of efflorescence found in these cases were varieties of carbonates, sulfates (such as Arcanite), and nitrates. Despite the presence of efflorescence, the literature review provided many examples of buildings treated with mineral silicate coatings that demonstrated the color durability of this coating. A recommendation for further study would be to redo this portion of the assessment using the same coatings but waiting the full 28 days before beginning the accelerated weathering.

If time had allowed for further analysis, Fourier transform infrared spectroscopy (FTIR) would have been used to analysis the white deposits on the samples. FTIR is used to identify the composition and chemical properties of various materials. This type of analysis is useful for identifying specific types of efflorescence, because instead of a list of elements (as in the case of SEM-EDS) the composition of compounds is given. This process could have been used to determine what kind of efflorescence was on the samples.

As for the ability to replicate the red-brown hue of the acid stains, mineral silicate stains can achieve a variegated finish by overlaying different colors. It was noted that the mineral silicate stains appearance less saturated in color (or matte) than Gilmore’s acid stain samples, but still created a variegated finish. It should be noted that if mineral silicate stains are chosen to recoat the Central Lodge, mock ups should be performed on the building to confirm that the stains will produce the same overall color and variegated finish in the field.

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Appendix

ASTM Standards used during assessment

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ASTM D2244-16 Standard Practice for Calculation of Color Tolerances and Color Differences from Instrumentally Measured Color Coordinates, ASTM International, West Conshohocken, PA, 2016.

ASTM E1164-12 Standard Practice for Obtaining Spectrometric Data for Object-Color Evaluation, ASTM International, West Conshohocken, PA, 2016.

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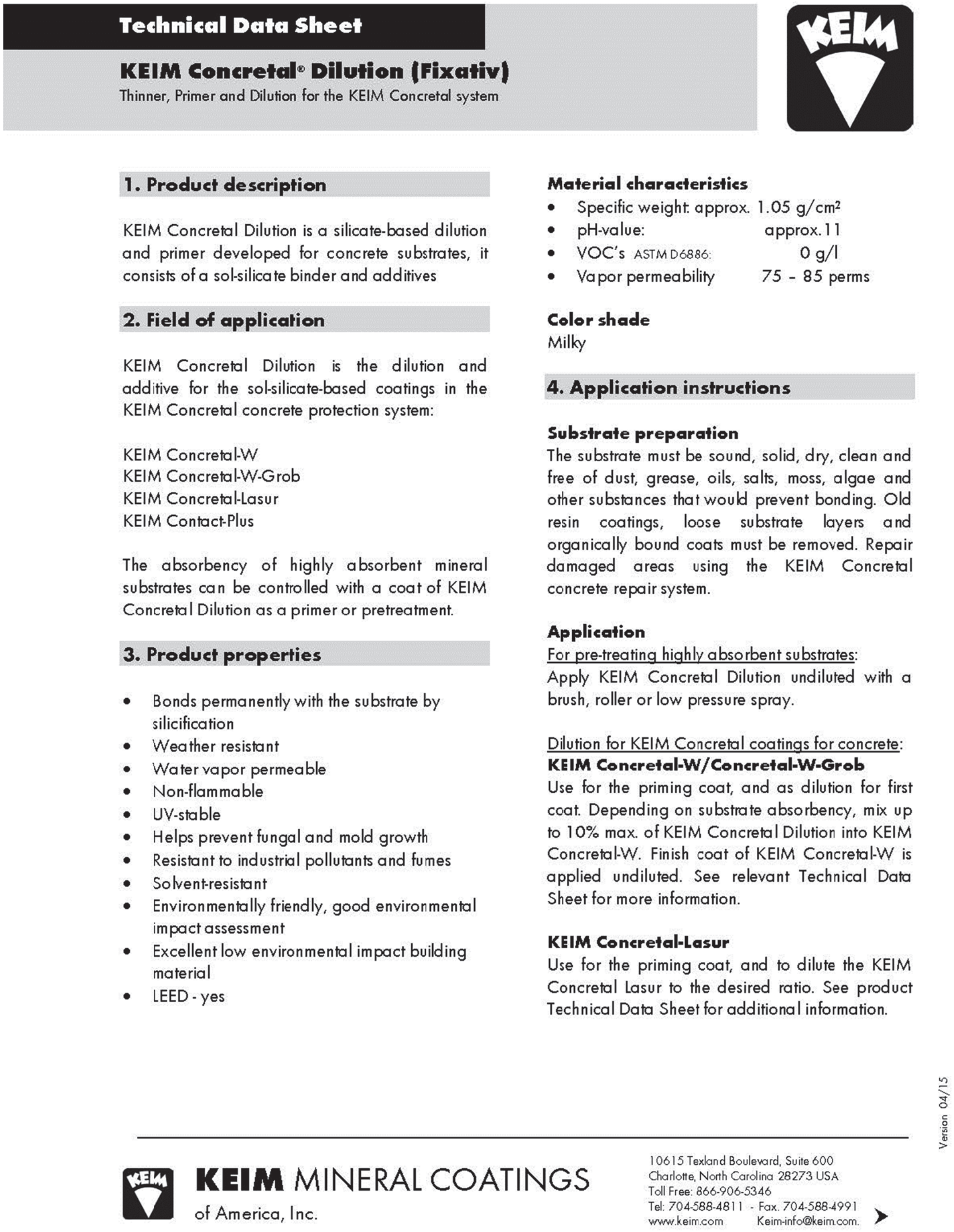

Technical Data Sheet

KEIM Concretal® Dilution (Fixativ)

Thinner, Primer and Dilution for the KEIM Concretal system

1. Product description

KEIM Concretal Dilution is a silicate-based dilution and primer developed for concrete substrates, it consists of a sol-silicate binder and additives

2. Field of application

KEIM Concretal Dilution is the dilution and additive for the sol-silicate-based coatings in the KEIM Concretal concrete protection system:

KEIM Concretal-W
KEIM Concretal-W-Grob
KEIM Concretal-Lasur
KEIM Contact-Plus

The absorbency of highly absorbent mineral substrates can be controlled with a coat of KEIM Concretal Dilution as a primer or pretreatment.

3. Product properties

- Bonds permanently with the substrate by silicification
- Weather resistant
- Water vapor permeable
- Non-flammable
- UV-stable
- Helps prevent fungal and mold growth
- Resistant to industrial pollutants and fumes
- Solvent-resistant
- Environmentally friendly, good environmental impact assessment
- Excellent low environmental impact building material
- LEED - yes

Material characteristics

- Specific weight: approx. 1.05 g/cm²
- pH-value: approx. 11
- VOC's ASTM D6886: 0 g/l
- Vapor permeability 75 - 85 perms

Color shade

Milky

4. Application instructions

Substrate preparation

The substrate must be sound, solid, dry, clean and free of dust, grease, oils, salts, moss, algae and other substances that would prevent bonding. Old resin coatings, loose substrate layers and organically bound coats must be removed. Repair damaged areas using the KEIM Concretal concrete repair system.

Application

For pre-treating highly absorbent substrates:
Apply KEIM Concretal Dilution undiluted with a brush, roller or low pressure spray.

Dilution for KEIM Concretal coatings for concrete:
KEIM Concretal-W/Concretal-W-Grob
Use for the priming coat, and as dilution for first coat. Depending on substrate absorbency, mix up to 10% max. of KEIM Concretal Dilution into KEIM Concretal-W. Finish coat of KEIM Concretal-W is applied undiluted. See relevant Technical Data Sheet for more information.

KEIM Concretal-Lasur
Use for the priming coat, and to dilute the KEIM Concretal Lasur to the desired ratio. See product Technical Data Sheet for additional information.

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KEIM MINERAL COATINGS
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Application conditions
Air and substrate temperature: >41°F up to max. 86°F (5°C –30°C) up to max. 80% relative humidity.
Apply only to dry surfaces and in dry weather. Do not apply under direct sun or on sun-heated substrates or in strong wind. Surfaces must be protected after application from rain, wind and direct sun until they are completely cured.

Drying time
A drying time of at least 12 hours must be allowed between pre-treatment/priming and between coats.

Consumption
600-800 sq.ft./1.3 gallon (5 l) container when applied as a pretreatment and primer.

For KEIM Concretal-W/Concretal-W-Grob at 10% 12 - 13 oz / gallon of the respective coating. Used in the first coat only.

For KEIM Concretal-Lasur consumption depends on the dilution ratio. For example a 1:1 ratio would be 1 gallon of KEIM Concretal-Lasur and 1 gallon of KEIM Concretal-Dilution.

The stated consumption value is for guidance and depend on the absorbency and texture of the substrate desired translucency effect, application method and substrate conditions. Exact consumption values can only be determined by a trial application on site using the tools, methods and techniques that will be used for the final application.

Cleaning of tools
Clean with water immediately after use.

5. Packaging

1.3 gallon (5 l) and 5.3 gallon (20 l) containers.

6. Storage

Storage life is approx. 12 months in a sealed container under cool, frost-free conditions. Protect from heat and direct sunlight.

7. Hazardous substances ordinance class

n/a

8. Transport hazard class

n/a

9. Disposal

EC Waste Code no. 06 02 99
Any residues must be emptied out of containers before recycling.

10. Safety instructions

KEIM Concretal-Fixativ is alkaline. Provide appropriate protection for surfaces which are not to be coated (e.g. glass, natural stone, ceramics etc.). Any splashes on surrounding surfaces or traffic areas must be rinsed off immediately with plenty of water. Protect the eyes and skin from splashes. Keep out of reach of children.

The stated values and properties are the result of extensive development work and practical experience. Our recommendations for application, whether given verbally or in writing, are intended to provide assistance in the selection of our products and do not establish a contractual relationship. In particular, they do not release those purchasing and applying our products from the duty of establishing for themselves, with due care, the suitability of our products for the intended application. Standard building industry practices must be complied with. We retain the right to make modifications to improve the products or their application. This edition supersedes all earlier editions.

Version 04/15

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Technical Data Sheet

KEIM Concretal®-Lasur

Pigmented mineral stain for concrete

1. Product description

Sol-silicate-based, thin-layer coating for providing a low pigment finish when diluted with KEIM Concretal-Dilution (Fixativ) or KEIM Concretal-Base, as well as for opaque thin-layer protective coatings. Complies with DIN EN 1504-2/2.2 when using together with KEIM Silan-100.

2. Field of application

KEIM Concretal-Lasur provides a low-pigment finish on fair-faced interior and exterior concrete surfaces, e.g. to retain the fair-faced appearance. It is commonly used for changing the color completely or simply concealing stains, wide color variations or blending repairs with a concrete color shade. KEIM Concretal-Lasur is also used for providing decorative color wash finishes. KEIM Concretal-Lasur can be diluted as required with KEIM Concretal-Dilution (Fixativ) or KEIM Concretal-Base.

KEIM Concretal-Lasur can also be applied as an opaque thin-layer coatings retaining surface texture and providing protective water and weather resistant finish.

Water-proofing may be further enhanced by providing the substrate with a water-repellent pre-treatment using KEIM Silangrund or KEIM Silan-100. The application of KEIM Concretal-Lasur together with KEIM Silan-100 complies with water protection requirements as per DIN EN 1504-2/2.2

KEIM Concretal-Lasur is not as weather resistant on horizontal and slightly inclined surfaces.

Color shade

Shades from KEIM Palette Exclusiv or a custom match to your color selection within our natural mineral range.

3. Product properties

KEIM Concretal-Lasur protects the concrete from the action of weather and also prevents the penetration of aggressive atmospheric pollutants. Surface textures on the concrete, such as shuttering board textures, are fully retained. The surface is mineral matt. At various dilutions with KEIM Concretal-Dilution (Fixativ) or KEIM Concretal-Base, different low-pigment finishes may be achieved or optical problems, such as stains or color differences can be corrected.

- Lightfast, will not fade
- Weather resistant
- Resistant to environmental influences
- Mineral matt finish that lasts
- LEED - yes

Technical data

Density:	1.20 g/cm³
VOC's (white and tinted) ASTM D6886:	< 1g/l
Vapor diffusion resistance:	s_d (H_2O) = <0.01 m
Lightfastness of color pigment:	A1
	(Fb-Code acc. to BFS technical bulletin No. 26)
Non-flammable	
Vapor Permeability	75 - 85 perms

4. Application instructions

Substrate preparation

The substrate must be sound, solid, dry, clean and free of dust, grease, oils, salts, moss, algae and other substances that would prevent bonding. Old resin coatings, loose substrate layers and organically bound coats must be removed. Repair damaged areas using the KEIM Concretal concrete repair system.

For new concrete structures; Concrete should be at least 28 days old and any formwork oil for Concrete, mold lubricating oil, shuttering oil, mold release oil, concrete form oil residues and curing

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compounds should be removed with KEIM Concrete Cleaner (Betonschnellreiniger) or by other methods.

Clean, strong concrete without a sinter layer requires no pre-treatment.

Before KEIM Concretal-Lasur is applied, highly absorbent substrates or surfaces exposed to severe weather may be treated with a water-repellent substrate treatment using KEIM Silangrund or KEIM Silan-100 (tested to ZTV-ING) to enhance waterproofing. A subsequent base coat of KEIM Concretal-Lasur may be applied after approx. 4 hours for KEIM Silangrund and after 4 to 12 hours for KEIM Silan-100.

Soft, porous concrete surfaces or existing mineral coats may be stabilized by pre-treatment with KEIM Concretal-Dilution (Fixativ).

Low-pigment coating

In exterior applications, the requirement for weathering resistance requires applying two coats of low pigment coating. For the base and top coat, KEIM Concretal-Lasur may be diluted in any ratio with KEIM Concretal-Dilution (Fixativ) or KEIM Concretal-Base depending on the desired translucency of the finish. It is recommended to coat trial areas in order to determine the dilution ratio. Keep diluted KEIM Concretal-Lasur well stirred before and during work. Neither water nor any other materials may be added. It is important to work swiftly wet-in-wet and to maintain a wet edge to a corner or architectural feature.

Note

The system components Concretal-Lasur, Concretal-Base and Concretal-Dilution (Fixativ) can be mixed together in any desired ratio. KEIM Concretal-Base provides an attractive uniform transparency together with ideal application consistency and layer thickness. KEIM Concretal-Dilution (Fixativ) allows most translucent low-pigment finishes with brilliant colors and thin layer thickness.

Opaque coating

A base coat plus top coat are necessary in order to obtain an opaque protective coating which retains texture of the surface. this type of application requires 2 coats minimum with the first coat being diluted 10 - 25% with KEIM Concretal-Dilution (Fixativ) and the second coat applied undiluted by brush, roller or spraying, keeping a wet edge. It is important to work swiftly wet-in-wet and to maintain a wet edge to a corner or architectural feature.

Application conditions

Air and substrate temperature: >41°F up to max. 86°F (5°C –30°C) up to max. 80% relative humidity.

Apply only to dry surfaces and in dry weather. Do not apply under direct sun or on sun-heated substrates or in strong wind. Surfaces must be protected after application from rain, wind and direct sun until they are completely cured.

Drying times

At least 12 - 24 hours between coats.

If a pretreatment of one of the following water repellencies was applied allow drying before base coat is applied. Approx. 4 hours after KEIM Silangrund or 4 - 12 hours after KEIM Silan-100.

Consumption

<u>For an opaque finish</u>:
375-625 sq.ft./gallon undiluted

<u>For a low-pigment finish</u>:
Stated values are for diluted ready to use material
375-625 sq.ft./gallon

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The quantity of KEIM Concretal-Lasur and KEIM Concretal-Base or KEIM Concretal-Dilution (Fixativ) depends on the mixing ratio. A trial application using the tools and techniques for the final application may be required.
The consumption values given are for guidance and depend on the desired translucency effect, application method and substrate condition. Exact values may only be determined by a trial application on site.

Cleaning of tools
Clean with water immediately after use.

5. Packaging

KEIM Concretal-Lasur
1 gallon
2 gallon
and
4 gallon (packaged in a 5 gal pail)

KEIM Concretal-Dilution (Fixativ)
1.3 gallon (5 l) and 5.3 gallon (20 l) containers

KEIM Concretal-Base
1 gallon and 4 gallon (packaged in a 5 gal pail)

6. Storage

KEIM Concretal-Lasur, KEIM Concretal-Dilution (Fixativ) and KEIM Concretal-Base have a shelf life of 12 months in a closed container and under cool, frost-free conditions.

7. Hazardous substances ordinance class

n/a

8. Transport hazard class

n/a

9. Disposal

EC Waste Code No. 08 01 12
Any residues must be emptied out of containers before recycling.

10. Safety instructions

Provide appropriate protection for surfaces which are not to be coated (e.g. glass, natural stone, ceramics etc.). Any splashes on surrounding surfaces or traffic areas must be rinsed off immediately with plenty of water. Protect the eyes and skin from splashes. Keep out of reach of children.

Product Code: M-SK 01

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Cement Information

Types of Portland Cement from ASTM Standard C150/C150M: Standard Specification for Portland Cement

Name	Description
Type I	For use when the special properties specified for any other type are not required
Type IA	Air-entraining cement for the same uses as Type I, where air-entrainment is desired
Type II	For general use, more especially when moderate sulfate resistance is desired
Type IIA	Air-entraining cement for the same uses as Type II, where air-entrainment is desired
Type II (MH)	For general use, more especially when moderate heat of hydration and moderate sulfate resistance are desired
Type II (MH)A	Air-entraining cement for the same uses as Type II(MH), where air-entrainment is desired.
Type III	For use when high early strength is desired.
Type IIIA	Air-entraining cement for the same use as Type III, where air-entrainment is desired
Type IV	For use when a low heat of hydration is desired.
Type V	For use when high sulfate resistance is desired

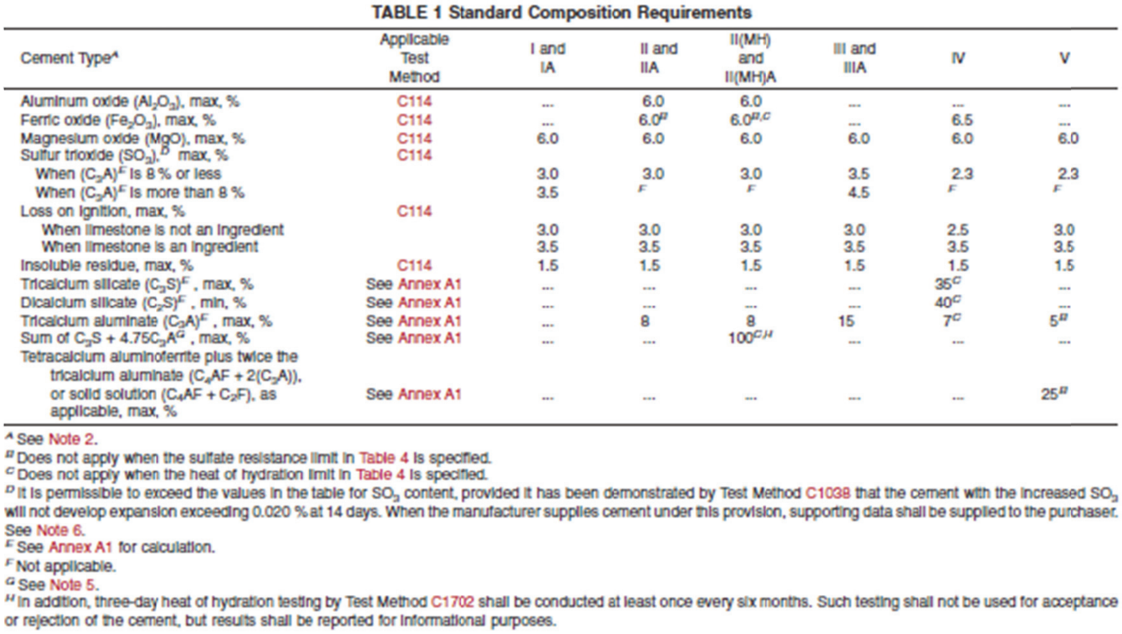


TABLE 1 Standard Composition Requirements

Cement Type[A]	Applicable Test Method	I and IA	II and IIA	II(MH) and II(MH)A	III and IIIA	IV	V
Aluminum oxide (Al_2O_3), max, %	C114	...	6.0	6.0	...	...	...
Ferric oxide (Fe_2O_3), max, %	C114	...	6.0[B]	6.0[B,C]	...	6.5	...
Magnesium oxide (MgO), max, %	C114	6.0	6.0	6.0	6.0	6.0	6.0
Sulfur trioxide (SO_3),[D] max, %	C114						
When (C_3A)[E] is 8 % or less		3.0	3.0	3.0	3.5	2.3	2.3
When (C_3A)[E] is more than 8 %		3.5	[F]	[F]	4.5	[F]	[F]
Loss on ignition, max, %	C114						
When limestone is not an ingredient		3.0	3.0	3.0	3.0	2.5	3.0
When limestone is an ingredient		3.5	3.5	3.5	3.5	3.5	3.5
Insoluble residue, max, %	C114	1.5	1.5	1.5	1.5	1.5	1.5
Tricalcium silicate (C_3S)[E], max, %	See Annex A1	...	...	...	...	35[C]	...
Dicalcium silicate (C_2S)[E], min, %	See Annex A1	...	...	...	...	40[C]	...
Tricalcium aluminate (C_3A)[E], max, %	See Annex A1	...	8	8	15	7[C]	5[B]
Sum of $C_3S + 4.75C_3A$[G], max, %	See Annex A1	...	...	100[C,H]	...	...	...
Tetracalcium aluminoferrite plus twice the tricalcium aluminate $(C_4AF + 2(C_3A))$, or solid solution $(C_4AF + C_2F)$, as applicable, max, %	See Annex A1	...	...	...	...	...	25[B]

[A] See Note 2.

[B] Does not apply when the sulfate resistance limit in Table 4 is specified.

[C] Does not apply when the heat of hydration limit in Table 4 is specified.

[D] It is permissible to exceed the values in the table for SO_3 content, provided it has been demonstrated by Test Method C1038 that the cement with the increased SO_3 will not develop expansion exceeding 0.020 % at 14 days. When the manufacturer supplies cement under this provision, supporting data shall be supplied to the purchaser. See Note 6.

[E] See Annex A1 for calculation.

[F] Not applicable.

[G] See Note 5.

[H] In addition, three-day heat of hydration testing by Test Method C1702 shall be conducted at least once every six months. Such testing shall not be used for acceptance or rejection of the cement, but results shall be reported for informational purposes.

Source: ASTM Standard C150/C150M

Common raw materials used in present day Portland cement production

Calcium	Silicon	Aluminum	Iron
Limestone	Clay	Clay	Clay
Marl	Marl	Shale	Iron ore
Calcite	Sand	Fly ash	Mill scale
Aragonite	Shale	Aluminum ore refuse	Shale
Shale	Fly ash		Blast furnace dust
Sea Shells	Rice hull ash		
Cement kiln dust	Slag		

Source: http://iti.northwestern.edu/cement/monograph/Monograph3_3.html

S.H. Kosmatka, B. Kerkhoff, and W.C. Panarese, Design and Control of Concrete Mixtures, Portland Cement Association, Skokie, IL, Table 2.1

Kemiko Jackson Lake Lodge Advertisement (1950s)

Faulty concrete color or finish Kemiko Stain with Col-r-tone Finish will produce uniformity and profound beauty on faded pigmented concrete or on surfaces that are dusting, stained, unevenly textured, patched or worn.

Brief Specification Greater satisfaction and economy will result if KEMIKO is specified in the General Specifications under Concrete Finishes. Because "acid Staining" is an ambiguous term, often applied to such materials as vegetable dyes, oil stains, etc., misunderstanding and disappointment will be avoided by specifying as follows:

> "*All concrete areas to be colored as described in these specifications or as indicated on the plans are to be treated by the* KEMIKO PROCESS."

Complete detailed information, custom color guide, and specifications will be gladly supplied upon request.

KEMIKO

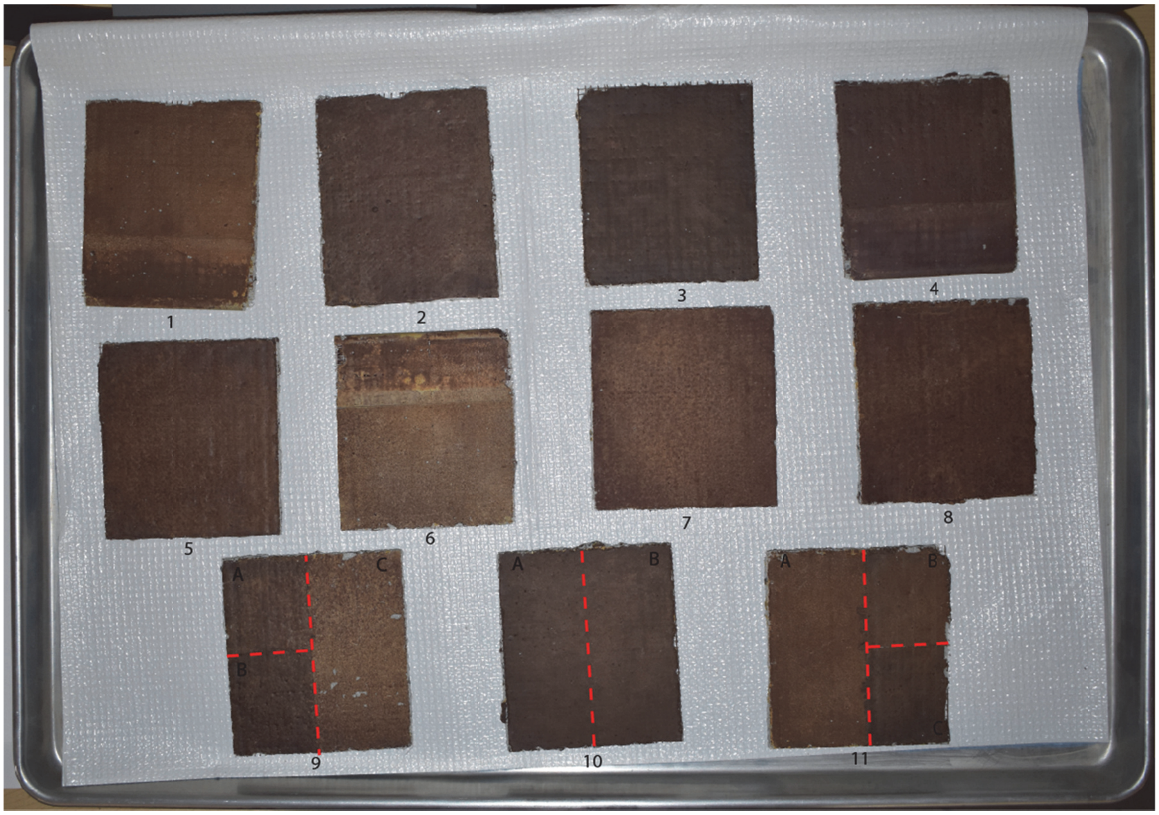
KEMIKO BEAUTY AND PROTECTION
CHOSEN FOR FAMOUS

Jackson Lake Lodge

The snow-crested Grand Teton mountains are inspiring, colorful surroundings for Wyoming's famous, $6,000,000 Jackson Lake Lodge. To harmonize with the natural beauty of the setting exterior lodge walls of concrete were cast against Shado-Wood, then stained with Kemiko's rich Malay Tan, highlighted with Colorado Brown and Black. Through sub-zero winters and summer sun, the stain provides permanent, maintenance-free color. A John D. Rockefeller, Jr. interest, the lodge is operated on a non-profit basis for tourists by Jackson Hole Preserve, Inc. Close-up illustrates natural beauty of concrete wall.

Source: http://www.kemikostainforconcrete.com/history.html

Mock-Up List

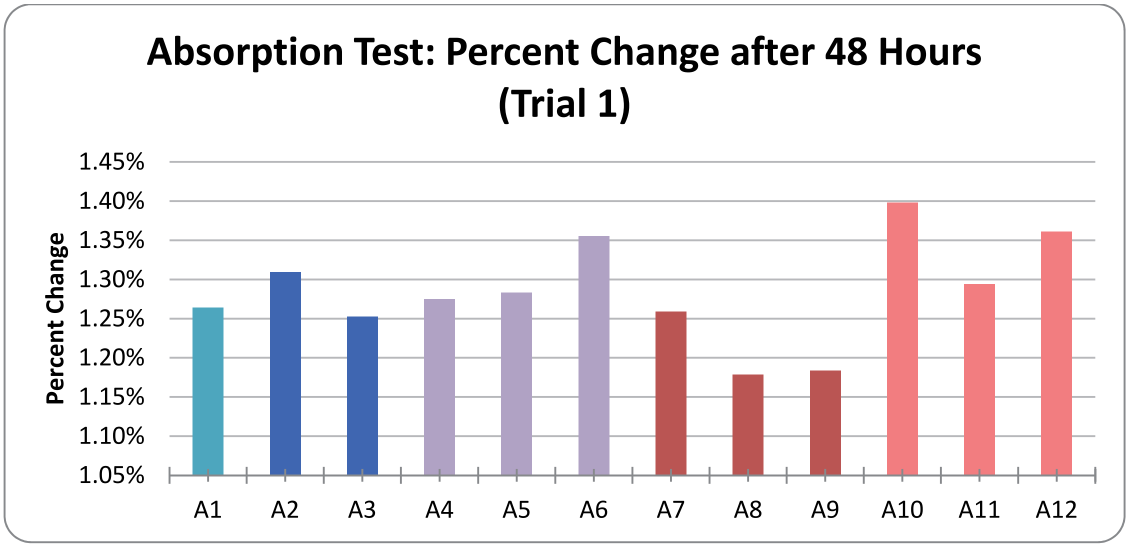


Number/Label	Application Time	Stain used with dilution information
1	30 sec	YELLOW-1:8 OLD RED+RED1:8
2	1 min	YELLOW- 1:8 RED-1:8 (2 coats) BLACK-1:8
3	2 min	YELLOW- 1:8 RED-1:8 (2 coats) BLACK-1:8 (2 coats)
4	30 sec	YELLOW- 1:8 RED-1:8 (2 coats) BLACK-1:16
5	1 min	YELLOW- 1:8 RED-1:8 (2 coats) BLACK-1:16

6	2 min	YELLOW- 1:8 RED-1:8
7	1 min	YELLOW- 1:8 RED-1:8
8	2 min	YELLOW- 1:8 RED-1:8 (2 coats)
9A	2 min	YELLOW- 1:8 RED-1:8 BLACK-1:16
9B	2 min	YELLOW- 1:8 RED-1:8 BLACK-1:16 (2 coats)
9C	2 min	YELLOW- 1:8 RED-1:8
10A	1 min	YELLOW-1:8 OLD RED+RED1:8 (2 coats) BLACK-1:8
10B	1 min and 2 min	YELLOW-1:8 (1 min) OLD RED+RED1:8 (2 coats at 1 min) BLACK-1:8 (2 mins)
11A	1 min	YELLOW-1:8 OLD RED+RED1:8
11B	1 min	YELLOW-1:8 OLD RED+RED1:8 BLACK-1:16
11C	1 min	YELLOW-1:8 OLD RED+RED1:8 BLACK-1:16 (2coats)

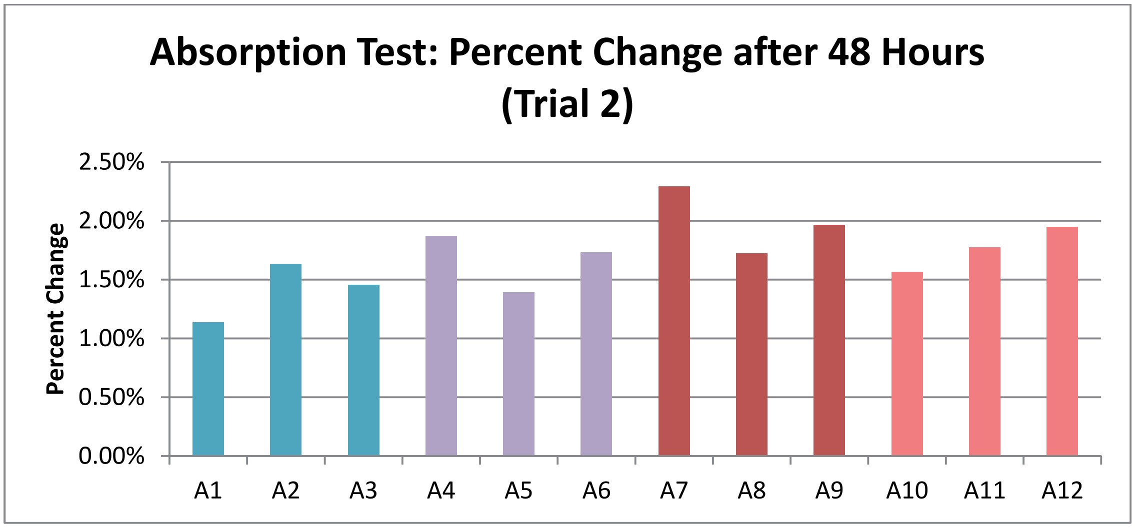
Absorption Test Results

Trial 1 Immersion Test



Sample	W_0	W_1	W_1-W_0	% change (W_1-W_0)	AVG % change	W_2	W_2-W_0	% Change (W_2-W_0)	AVG % change
A1	200.95	202.67	1.72	0.86%	0.88%	203.49	2.54	1.26%	1.28%
A2	200.91	202.84	1.93	0.96%		203.54	2.63	1.31%	
A3	200.43	202.07	1.64	0.82%		202.94	2.51	1.25%	
A4	203.96	205.57	1.61	0.79%	0.85%	206.56	2.6	1.27%	1.30%
A5	209.6	211.31	1.71	0.82%		212.29	2.69	1.28%	
A6	202.89	204.78	1.89	0.93%		205.64	2.75	1.36%	
A7	201.76	203.65	1.89	0.94%	0.86%	204.3	2.54	1.26%	1.21%
A8	201.96	203.56	1.6	0.79%		204.34	2.38	1.18%	
A9	191.74	193.39	1.65	0.86%		194.01	2.27	1.18%	
A10	190.25	191.72	1.47	0.77%	0.92%	192.91	2.66	1.40%	1.35%
A11	201.71	203.48	1.77	0.88%		204.32	2.61	1.29%	
A12	200.54	202.76	2.22	1.11%		203.27	2.73	1.36%	

Trial 2 Immersion Test



Sample	W_0	W_1	W_1-W_0	% change (W_1-W_0)	AVG % change	W_2	W_2-W_0	% Change (W_2-W_0)	AVG % change
A1	200.74	202.45	1.71	0.85%	1.10%	203.02	2.28	1.14%	1.41%
A2	200.32	202.95	2.63	1.31%		203.59	3.27	1.63%	
A3	199.43	201.67	2.24	1.12%		202.33	2.9	1.45%	
A4	205.89	209.01	3.12	1.52%	1.28%	209.74	3.85	1.87%	1.66%
A5	208.5	210.62	2.12	1.02%		211.4	2.9	1.39%	
A6	201.73	204.34	2.61	1.29%		205.22	3.49	1.73%	
A7	201.53	204.34	2.81	1.39%	1.42%	206.15	4.62	2.29%	1.99%
A8	201.75	204.44	2.69	1.33%		205.22	3.47	1.72%	
A9	191.38	194.3	2.92	1.53%		195.14	3.76	1.96%	
A10	189.82	192.2	2.38	1.25%	1.26%	192.79	2.97	1.56%	1.76%
A11	201.38	203.54	2.16	1.07%		204.95	3.57	1.77%	
A12	199.99	202.91	2.92	1.46%	1.10%	203.88	3.89	1.95%	

RILEM Test Results

Trial 1				
Time lapse (minutes)	Sample (measurement in mL)			
	Mineral Silicate and Silan-100 (sample B2)	Mineral Silicate (sample A11)	Silan-100 only	Control (untreated)
0	0	0	0	0
5	0	0	0	0.125
10	0.25	0	0	0.5
15	0.5	0	0	0.75
20	0.75	0	0	1
25	1.125	0	0	1.25
30	1.5	0	0	1.75
35	2	0	0	2
40	2.5	0	0	2.375
45	2.75	0	0	2.75
50	3	0	0	3
55	3.5	0	0	3.5
60	3.75	0	0	4

Trial 2				
Time lapse (minutes)	Sample (measurement in mL)			
	Mineral Silicate and Silan-100 (sample B2)	Mineral Silicate (sample A11)	Silan-100 only	Control (untreated)
0	0	0	0	0
5	0	0	0	0.25
10	0.5	0	0	.5
15	1	0	0	1
20	1.25	0	0	1.5
25	1.375	0	0	1.75
30	1.5	0	0	2.125
35	1.625	0	0	2.25
40	1.75	0	0	2.25
45	2	0	0	2.5
50	2	0	0	2.875
55	2.25	0	0	3
60	2.25	0	0	3.125

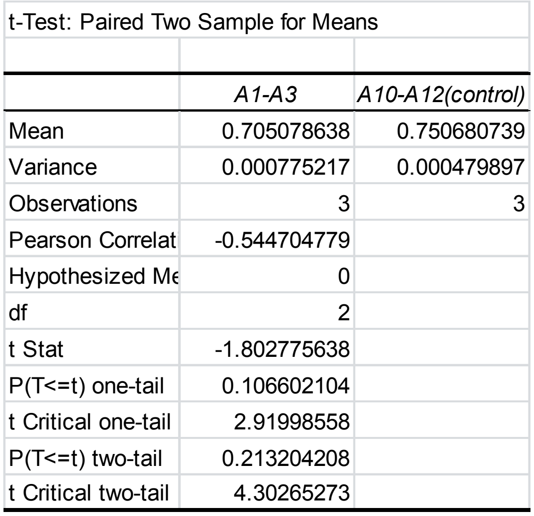
Water Vapor Transmission Rate Data

Weights (in grams) of sample assemblies A1-A12

Time (hrs)	Samples											
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
	SILAN-100 + MINERAL SILICATE			SILAN-100			MINERAL SILICATE			CONTROL		
0	158.70	161.47	158.82	158.69	162.06	157.62	161.11	159.93	162.80	160.85	158.95	158.09
0.083	158.69	161.48	158.82	158.70	162.06	157.62	161.11	159.53	162.79	160.86	158.96	158.08
0.5	158.70	161.48	158.82	158.70	162.05	157.63	161.10	159.53	162.80	160.86	158.96	158.09
1	158.71	161.48	158.82	158.69	162.04	157.63	161.11	159.53	162.81	160.85	158.96	158.08
1.5	158.71	161.47	158.82	158.69	162.04	157.63	161.12	159.53	162.81	160.86	158.97	158.08
2	158.69	161.47	158.82	158.69	162.04	157.63	161.12	159.53	162.80	160.85	158.96	158.08
22	158.62	161.41	158.64	158.65	161.97	157.55	161.05	159.47	162.77	160.77	158.89	158.01
51	158.40	161.21	158.57	158.43	161.76	157.34	160.84	159.24	162.57	160.53	158.66	157.79
70	158.28	161.10	158.43	158.31	161.63	157.21	160.71	159.10	162.44	160.40	158.52	157.67
94	158.15	160.96	158.30	158.19	161.48	157.07	160.57	158.92	162.30	160.27	158.37	157.52
118	158.00	160.83	158.16	158.04	161.33	156.92	160.42	158.79	162.18	160.10	158.23	157.38
139	157.88	160.72	158.04	157.92	161.19	156.79	160.29	158.65	162.06	159.97	158.11	157.26
164.5	157.71	160.57	157.89	157.78	161.05	156.64	160.15	158.47	161.92	159.81	157.93	157.10
191.5	157.39	160.25	157.57	157.46	160.72	156.29	159.81	158.12	161.61	159.47	157.60	156.79
214	157.22	160.10	157.42	157.31	160.56	156.14	159.66	157.93	161.45	159.30	157.42	156.61
238	157.04	159.95	157.24	157.16	160.39	155.98	159.47	157.72	161.27	159.08	157.23	156.44

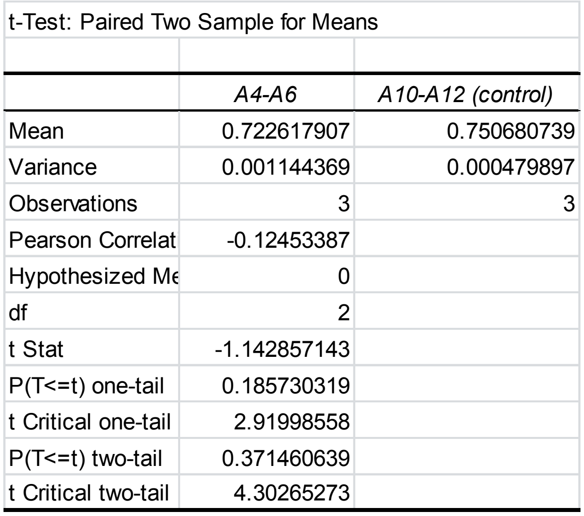
🟨 =data used for WVT and permeance calculation

Data Analysis									
Sample		g/t	WVT	AVG WVT	% Change (WVT to Control)	Permeance (metric/SI)	AVG perm	% change	p-value
A1	SILAN-100 + MINERAL SILICATE	6.08E-03	3.00	2.91	0.06	0.73/1.10	0.71/ 1.07	0.06	1.00
A2		5.64E-03	2.78			0.67/1.02			
A3		5.99E-03	2.96			0.72/1.09			
A4	SILAN-100	5.73E-03	2.83	2.99	0.04	0.68/1.04	0.72/ 1.10	0.04	1.00
A5		6.26E-03	3.09			0.75/1.13			
A6		6.17E-03	3.04			0.74/1.12			
A7	MINERAL SILICATE	6.08E-03	3.00	3.06	0.01	0.73/1.10	0.74/ 1.12	0.01	0.99
A8		6.78E-03	3.35			0.81/1.23			
A9		5.73E-03	2.83			0.68/1.04			
A10	CONTROL	6.34E-03	3.13	3.10	0.00	0.76/1.15	0.75/ 1.14	0.00	
A11		6.43E-03	3.17			0.77/1.17			
A12		6.08E-03	3.00			0.73/1.10			
STANDARD DEVIATION			0.16			0.01/0.06			
Area= 0.0020 m^2			R1-R2=.24		S= saturation vapor pressure at 19˚C=17.22				



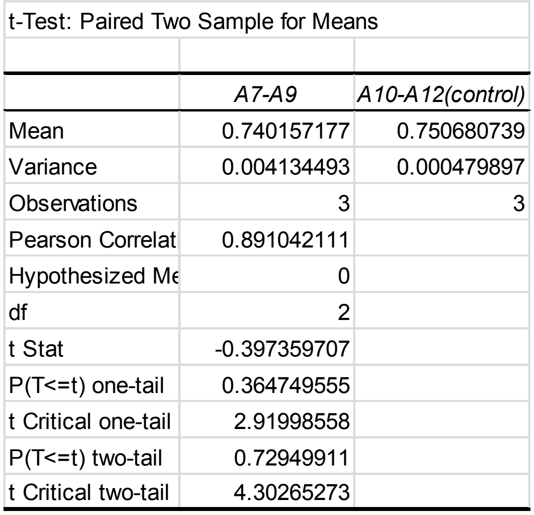
t-Test: Paired Two Sample for Means

	A1-A3	A10-A12(control)
Mean	0.705078638	0.750680739
Variance	0.000775217	0.000479897
Observations	3	3
Pearson Correlat	-0.544704779	
Hypothesized Me	0	
df	2	
t Stat	-1.802775638	
P(T<=t) one-tail	0.106602104	
t Critical one-tail	2.91998558	
P(T<=t) two-tail	0.213204208	
t Critical two-tail	4.30265273	



t-Test: Paired Two Sample for Means

	A4-A6	A10-A12 (control)
Mean	0.722617907	0.750680739
Variance	0.001144369	0.000479897
Observations	3	3
Pearson Correlat	-0.12453387	
Hypothesized Me	0	
df	2	
t Stat	-1.142857143	
P(T<=t) one-tail	0.185730319	
t Critical one-tail	2.91998558	
P(T<=t) two-tail	0.371460639	
t Critical two-tail	4.30265273	

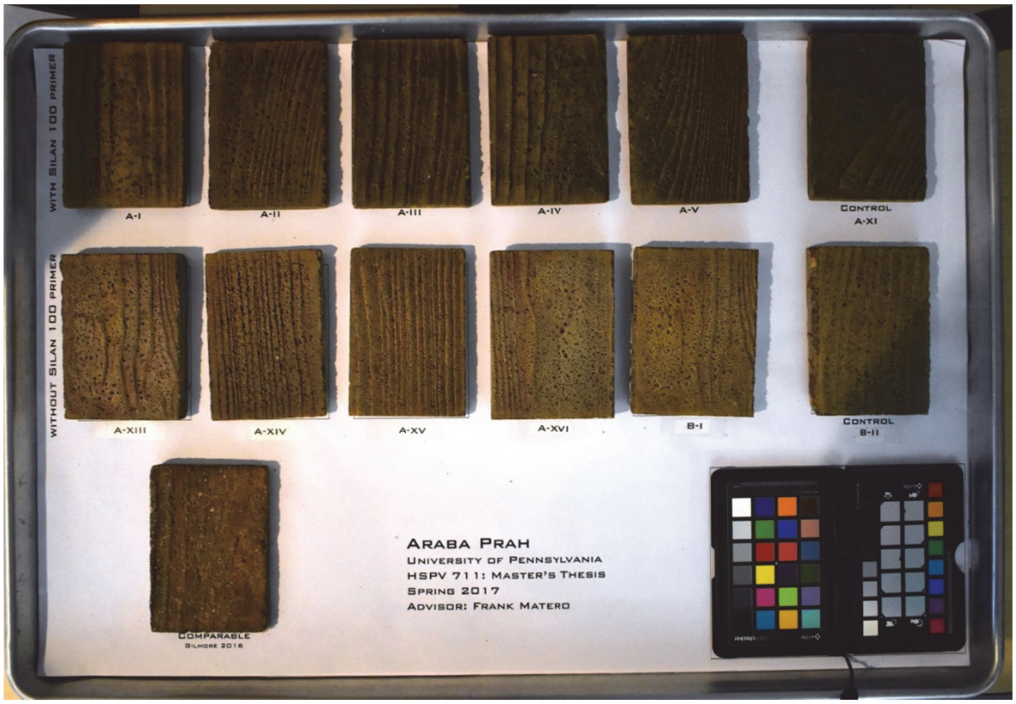


t-Test: Paired Two Sample for Means

	A7-A9	A10-A12(control)
Mean	0.740157177	0.750680739
Variance	0.004134493	0.000479897
Observations	3	3
Pearson Correlat	0.891042111	
Hypothesized Me	0	
df	2	
t Stat	-0.397359707	
P(T<=t) one-tail	0.364749555	
t Critical one-tail	2.91998558	
P(T<=t) two-tail	0.72949911	
t Critical two-tail	4.30265273	

Accelerated Weathering Color Durability Photos and Spectrophotometric Readings

Hour 0



Samples with Silan-100					Samples without Silan-100				
Sample	Group Traits	L*(D65)	a*(D65)	b*(D65)	Sample	Group Traits	L*(D65)	a*(D65)	b*(D65)
A1	SCI	29.27	8.43	29.2	A13	SCI	36.66	8.28	20.5
A1	SCE	29.7	8.28	28.5	A13	SCE	36.94	8.22	20.25
A2	SCI	28.71	7.52	27.43	A14	SCI	30.34	9.23	23.77
A2	SCE	29.11	7.4	26.82	A14	SCE	30.82	9.08	23.14
A3	SCI	21.68	9.04	30.07	A15	SCI	33.28	8.5	24.18
A3	SCE	22.4	8.68	29.8	A15	SCE	33.71	8.39	23.64
A4	SCI	26.5	7.54	28.68	A16	SCI	34.63	8.08	19.64
A4	SCE	27.01	7.34	28.01	A16	SCE	35.01	8	19.32
A5	SCI	23.8	9.64	33.28	B1	SCI	37.86	8.67	25.13
A5	SCE	24.34	9.32	33.06	B1	SCE	38.2	8.6	24.74
A11	SCI	23.69	8.08	28.41	B2	SCI	35.57	8.53	24.89
A11	SCE	24.18	7.85	27.74	B2	SCE	35.97	8.44	24.39

Hour 120

Samples with Silan-100					Samples without Silan-100				
Sample	Group Traits	L*(D65)	a*(D65)	b*(D65)	Sample	Group Traits	L*(D65)	a*(D65)	b*(D65)
A1	SCI	41.49	7.43	20.17	A13	SCI	38.2	8.41	19.15
A1	SCE	41.81	7.38	19.92	A13	SCE	38.52	8.35	18.89
A2	SCI	38.53	7.89	25.53	A14	SCI	33.14	8.84	20.96
A2	SCE	38.9	7.83	25.08	A14	SCE	33.59	8.73	20.47
A3	SCI	37.9	8.21	22.63	A15	SCI	35.13	8.45	23.26
A3	SCE	38.34	8.14	22.21	A15	SCE	35.54	8.36	22.78
A4	SCI	39.01	7.35	25.48	A16	SCI	35.6	8.26	18.75
A4	SCE	39.41	7.3	25.04	A16	SCE	36	8.17	18.44
A5	SCI	39.32	8.13	24.34	B1	SCI	39.84	9.04	24.26
A5	SCE	39.63	8.07	23.95	B1	SCE	40.18	8.98	23.88
A11	SCI	31.06	7.79	24.45	B2	SCI	35.99	8.45	23.87
A11	SCE	31.51	7.67	23.86	B2	SCE	36.39	8.36	23.38

Hour 240

Samples with Silan-100					Samples without Silan-100				
Sample	Group Traits	L*(D65)	a*(D65)	b*(D65)	Sample	Group Traits	L*(D65)	a*(D65)	b*(D65)
A1	SCI	40.6	7.53	19.79	A13	SCI	38	8.55	19.65
A1	SCE	40.94	7.46	19.55	A13	SCE	38.34	8.46	19.36
A2	SCI	39.1	7.72	22.89	A14	SCI	33.07	9.18	21.03
A2	SCE	39.45	7.66	22.54	A14	SCE	33.54	9.04	20.52
A3	SCI	41.09	7.19	18.84	A15	SCI	35.33	8.43	22.59
A3	SCE	41.45	7.14	18.62	A15	SCE	35.74	8.32	22.14
A4	SCI	38.46	7.55	21.96	A16	SCI	36.14	8.15	17.87
A4	SCE	38.81	7.48	21.62	A16	SCE	36.54	8.07	17.58
A5	SCI	40.28	7.86	22.41	B1	SCI	38.94	9.4	24.53
A5	SCE	40.64	7.79	22.09	B1	SCE	39.28	9.31	24.11
A11	SCI	31.27	7.8	25.41	B2	SCI	36.4	8.38	24.49
A11	SCE	31.71	7.67	24.81	B2	SCE	36.85	8.28	23.96

Hour 384

Samples with Silan-100					Samples without Silan-100				
Sample	Group Traits	L*(D65)	a*(D65)	b*(D65)	Sample	Group Traits	L*(D65)	a*(D65)	b*(D65)
A1	SCI	37.61	8.56	18.8	A13	SCI	37.61	8.56	18.8
A1	SCE	37.97	8.48	18.49	A13	SCE	37.97	8.48	18.49
A2	SCI	33.25	8.91	19.11	A14	SCI	33.25	8.91	19.11
A2	SCE	33.74	8.78	18.66	A14	SCE	33.74	8.78	18.66
A3	SCI	36.6	8.36	20.92	A15	SCI	36.6	8.36	20.92
A3	SCE	37.04	8.27	20.55	A15	SCE	37.04	8.27	20.55
A4	SCI	37.13	7.91	15.99	A16	SCI	37.13	7.91	15.99
A4	SCE	37.5	7.84	15.77	A16	SCE	37.5	7.84	15.77
A5	SCI	40.12	8.99	22.03	B1	SCI	40.12	8.99	22.03
A5	SCE	40.45	8.92	21.71	B1	SCE	40.45	8.92	21.71
A11	SCI	35.81	8.52	23.88	B2	SCI	35.81	8.52	23.88
A11	SCE	36.18	8.44	23.42	B2	SCE	36.18	8.44	23.42

Hour 480

Samples with Silan-100					Samples without Silan-100				
Sample	Group Traits	L*(D65)	a*(D65)	b*(D65)	Sample	Group Traits	L*(D65)	a*(D65)	b*(D65)
A1	SCI	44.56	6.67	15.5	A13	SCI	39.15	8.18	17.76
A1	SCE	44.82	6.63	15.4	A13	SCE	39.53	8.11	17.52
A2	SCI	42.46	7.05	18.11	A14	SCI	34.54	8.63	17.29
A2	SCE	42.76	7.01	17.94	A14	SCE	35	8.51	16.96
A3	SCI	43.87	6.49	14.99	A15	SCI	37.22	7.57	17.09
A3	SCE	44.18	6.45	14.89	A15	SCE	37.6	7.5	16.83
A4	SCI	43.73	6.55	17.19	A16	SCI	37.49	7.69	14.58
A4	SCE	44.08	6.51	17.04	A16	SCE	37.85	7.62	14.4
A5	SCI	42.71	7.58	18.84	B1	SCI	41.17	8.65	19.23
A5	SCE	42.99	7.53	18.64	B1	SCE	41.52	8.58	18.97
A11	SCI	31.56	7.83	25.17	B2	SCI	35.48	8.71	24.21
A11	SCE	32.01	7.71	24.56	B2	SCE	35.93	8.59	23.65

Hour 589.5 *The QUV Weatherometer malfunctioned 589.5 hours into the test. This point was midway through the condensation cycle. Samples were left to air dry for 2 hours prior to taking photo. The test was resumed approximately 48 hours later.

Samples with Silan-100					Samples without Silan-100				
Sample	Group Traits	L*(D65)	a*(D65)	b*(D65)	Sample	Group Traits	L*(D65)	a*(D65)	b*(D65)
A1	SCI	45.69	6.56	14.81	A13	SCI	41.4	7.61	14.98
A1	SCE	45.92	6.53	14.75	A13	SCE	41.69	7.56	14.86
A2	SCI	44.41	6.45	15.35	A14	SCI	37.32	7.85	13.99
A2	SCE	44.61	6.43	15.29	A14	SCE	37.67	7.77	13.87
A3	SCI	45	6.42	13.9	A15	SCI	41.64	6.52	12.7
A3	SCE	45.26	6.4	13.85	A15	SCE	41.92	6.48	12.65
A4	SCI	45.29	5.86	14.57	A16	SCI	39.32	7.39	13.14
A4	SCE	45.57	5.85	14.51	A16	SCE	39.62	7.33	13.05
A5	SCI	44.3	7.11	16.64	B1	SCI	43.32	7.82	16.47
A5	SCE	44.53	7.08	16.53	B1	SCE	43.59	7.77	16.36
A11	SCI	34.13	7.35	23.35	B2	SCI	36.55	8.33	23.59
A11	SCE	34.48	7.28	22.95	B2	SCE	36.94	8.25	23.19

Hour 730

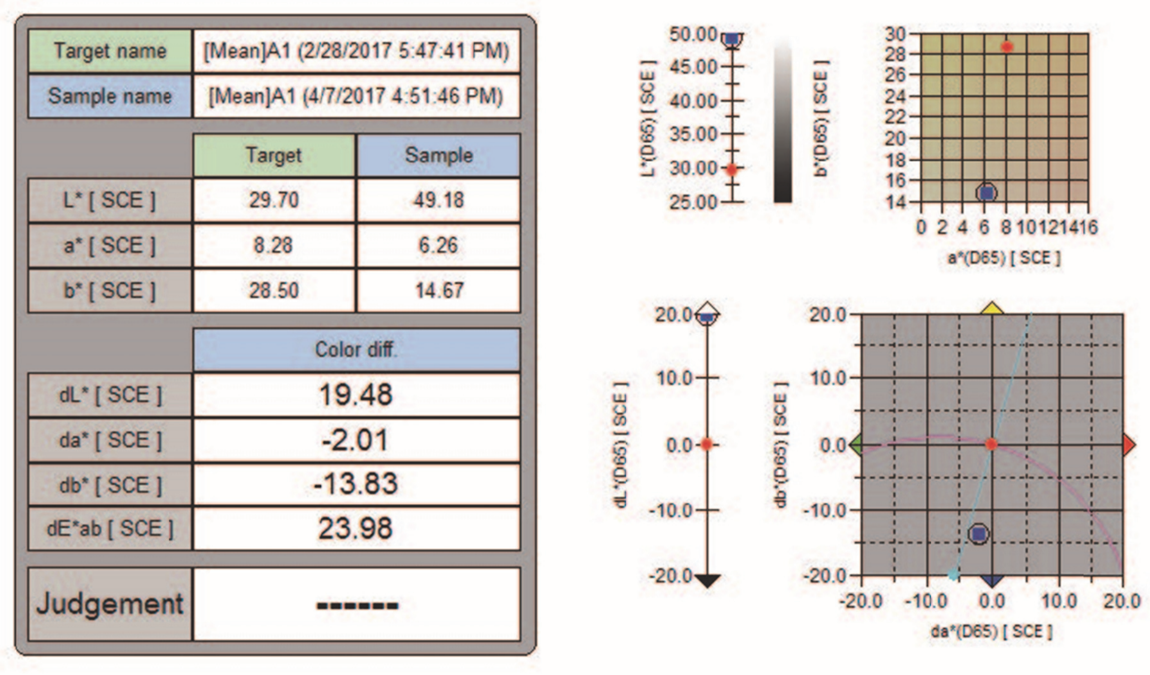
Samples with Silan-100					Samples without Silan-100				
Sample	Group Traits	L*(D65)	a*(D65)	b*(D65)	Sample	Group Traits	L*(D65)	a*(D65)	b*(D65)
A1	SCI	47.17	6.45	14.62	A13	SCI	43.68	7.16	13.07
A1	SCE	47.37	6.44	14.58	A13	SCE	38.87	7.4	12.75
A2	SCI	47.13	6.44	16.06	A14	SCI	39.17	7.34	12.65
A2	SCE	47.36	6.42	16	A14	SCE	45.6	6	10.9
A3	SCI	47.45	6.16	14.36	A15	SCI	45.85	5.97	10.89
A3	SCE	47.73	6.14	14.32	A15	SCE	42.36	6.91	12.13
A4	SCI	45.78	5.76	12.86	A16	SCI	42.65	6.86	12.07
A4	SCE	46.01	5.74	12.84	A16	SCE	48.29	7.47	14.08
A5	SCI	45.67	7.24	16.96	B1	SCI	48.5	7.44	14.03
A5	SCE	45.91	7.21	16.87	B1	SCE	37.29	8.04	23.35
A11	SCI	33.92	7.59	22.84	B2	SCI	37.71	7.96	22.94
A11	SCE	34.27	7.51	22.43	B2	SCE	43.68	7.16	13.07

Hour 845

Samples with Silan-100					Samples without Silan-100				
Sample	Group Traits	L*(D65)	a*(D65)	b*(D65)	Sample	Group Traits	L*(D65)	a*(D65)	b*(D65)
A1	SCI	48.95	6.28	14.71	A13	SCI	45.95	6.96	12.04
A1	SCE	49.18	6.26	14.67	A13	SCE	46.17	6.93	12.01
A2	SCI	47.1	6.63	16.21	A14	SCI	40.31	7.31	12.06
A2	SCE	47.3	6.61	16.14	A14	SCE	40.61	7.25	12.01
A3	SCI	46.99	6.62	15.95	A15	SCI	46.26	6.05	10.89
A3	SCE	47.23	6.6	15.87	A15	SCE	46.51	6.02	10.89
A4	SCI	47.65	5.75	14.94	A16	SCI	44.18	6.68	11.25
A4	SCE	47.9	5.73	14.91	A16	SCE	44.42	6.64	11.22
A5	SCI	45.69	7.33	17.91	B1	SCI	48.33	7.45	14.56
A5	SCE	45.95	7.3	17.81	B1	SCE	48.54	7.42	14.51
A11	SCI	34.83	7.59	23.25	B2	SCI	35.55	8.58	23.86
A11	SCE	35.2	7.52	22.85	B2	SCE	35.96	8.47	23.4

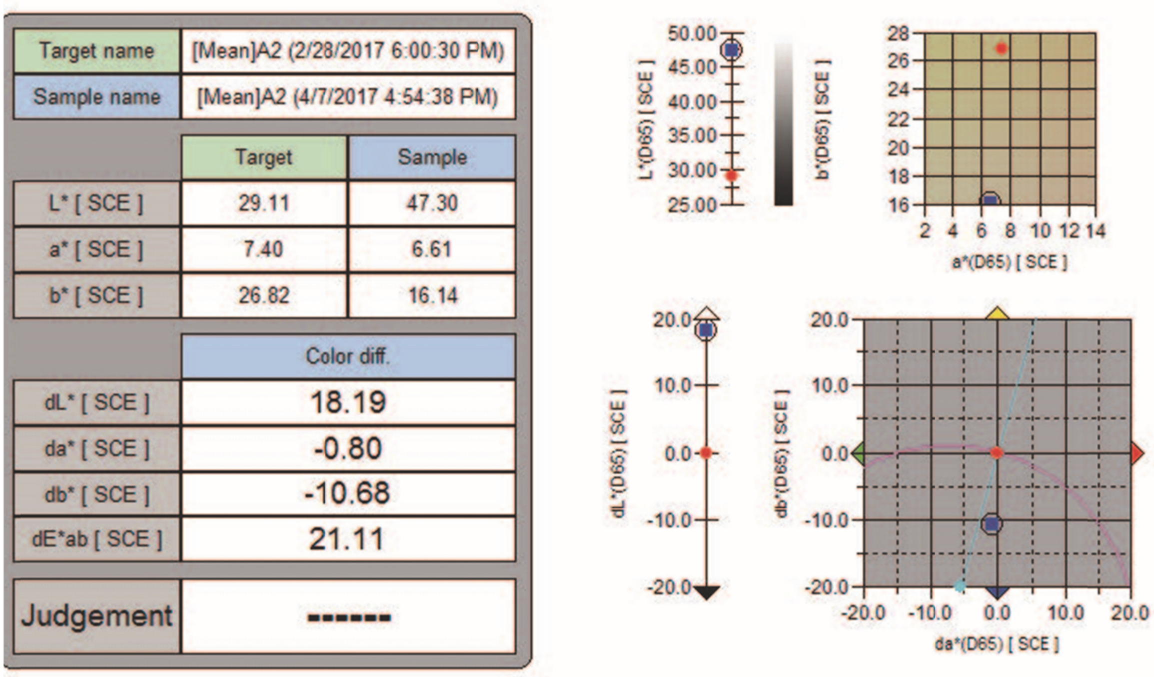
Before and After Spectrophotometric Measurements (Hour 845 and Hour 0)

Sample A1



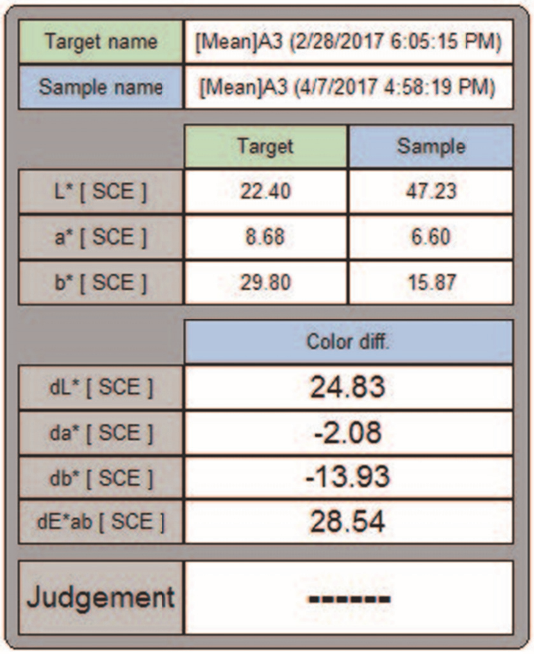
Target name	[Mean]A1 (2/28/2017 5:47:41 PM)	
Sample name	[Mean]A1 (4/7/2017 4:51:46 PM)	
	Target	Sample
L* [SCE]	29.70	49.18
a* [SCE]	8.28	6.26
b* [SCE]	28.50	14.67
	Color diff.	
dL* [SCE]	19.48	
da* [SCE]	-2.01	
db* [SCE]	-13.83	
dE*ab [SCE]	23.98	
Judgement	------	

Sample A2

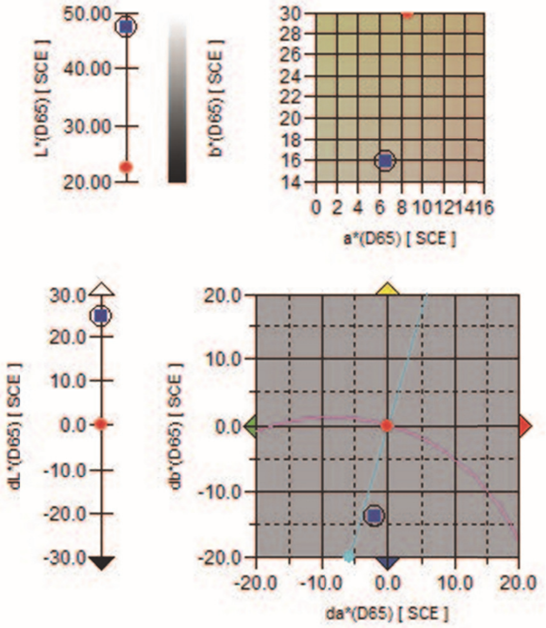


Target name	[Mean]A2 (2/28/2017 6:00:30 PM)	
Sample name	[Mean]A2 (4/7/2017 4:54:38 PM)	
	Target	Sample
L* [SCE]	29.11	47.30
a* [SCE]	7.40	6.61
b* [SCE]	26.82	16.14
	Color diff.	
dL* [SCE]	18.19	
da* [SCE]	-0.80	
db* [SCE]	-10.68	
dE*ab [SCE]	21.11	
Judgement	------	

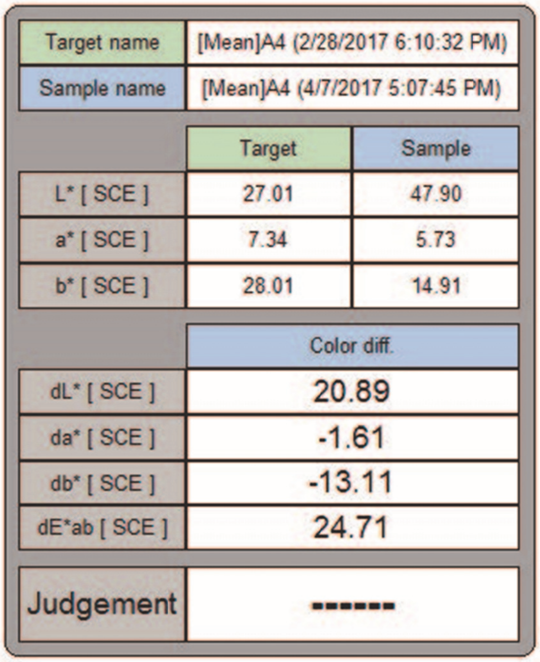
Sample A3



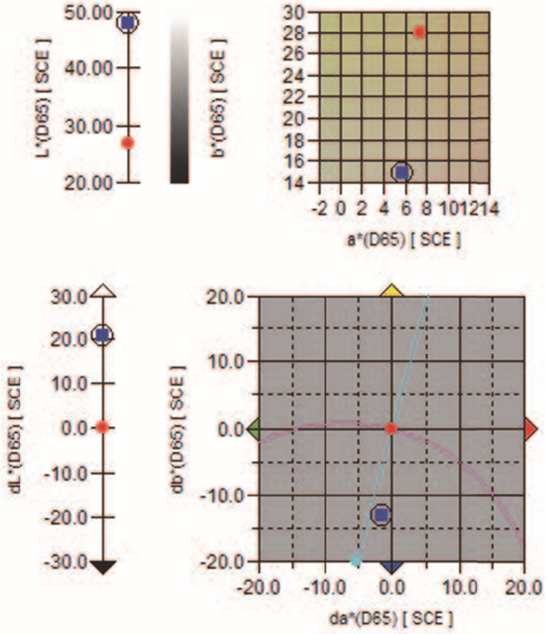
Target name	[Mean]A3 (2/28/2017 6:05:15 PM)	
Sample name	[Mean]A3 (4/7/2017 4:58:19 PM)	
	Target	Sample
L* [SCE]	22.40	47.23
a* [SCE]	8.68	6.60
b* [SCE]	29.80	15.87
	Color diff.	
dL* [SCE]	24.83	
da* [SCE]	-2.08	
db* [SCE]	-13.93	
dE*ab [SCE]	28.54	
Judgement	------	



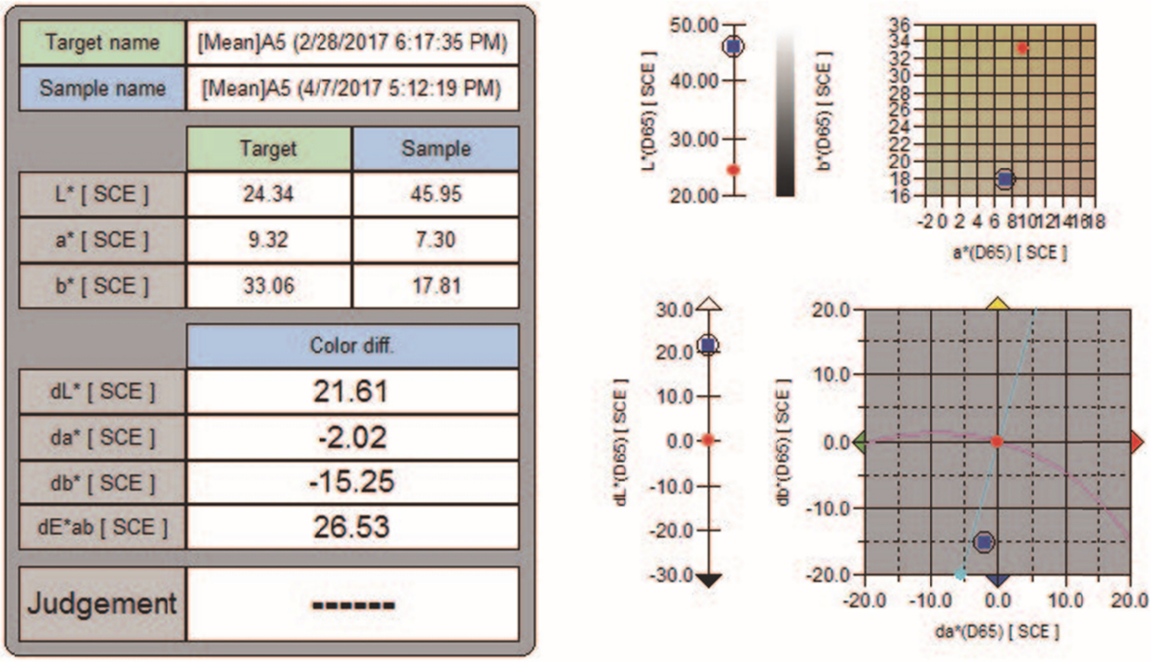
Sample A4



Target name	[Mean]A4 (2/28/2017 6:10:32 PM)	
Sample name	[Mean]A4 (4/7/2017 5:07:45 PM)	
	Target	Sample
L* [SCE]	27.01	47.90
a* [SCE]	7.34	5.73
b* [SCE]	28.01	14.91
	Color diff.	
dL* [SCE]	20.89	
da* [SCE]	-1.61	
db* [SCE]	-13.11	
dE*ab [SCE]	24.71	
Judgement	------	



Sample A5

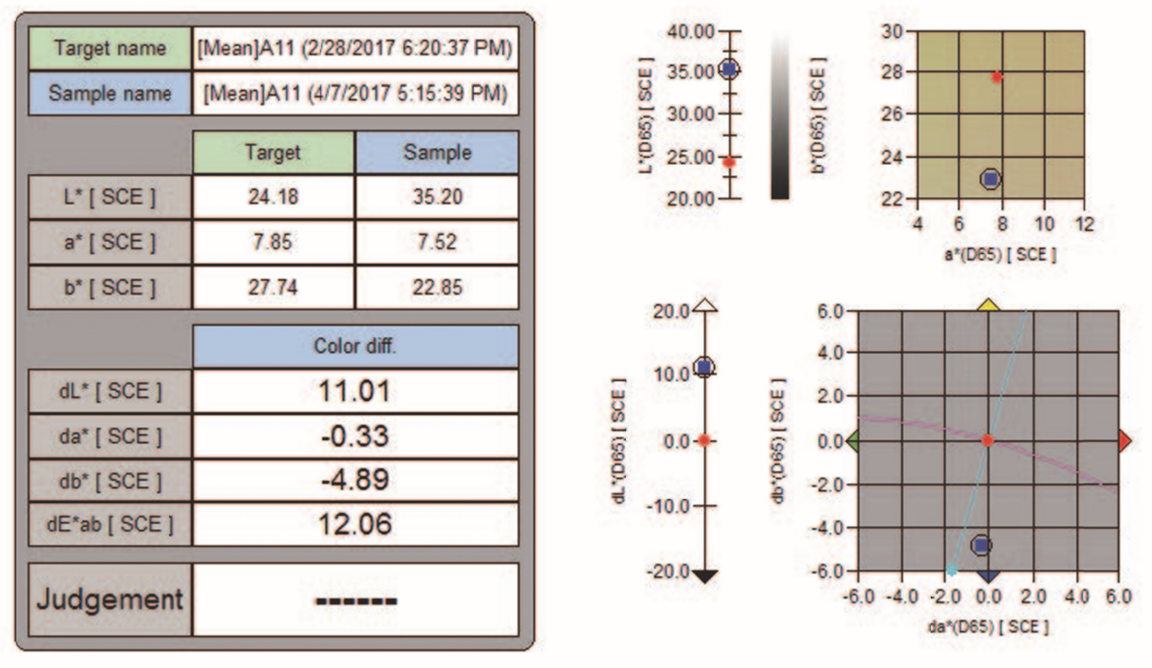


Target name	[Mean]A5 (2/28/2017 6:17:35 PM)
Sample name	[Mean]A5 (4/7/2017 5:12:19 PM)

	Target	Sample
L* [SCE]	24.34	45.95
a* [SCE]	9.32	7.30
b* [SCE]	33.06	17.81

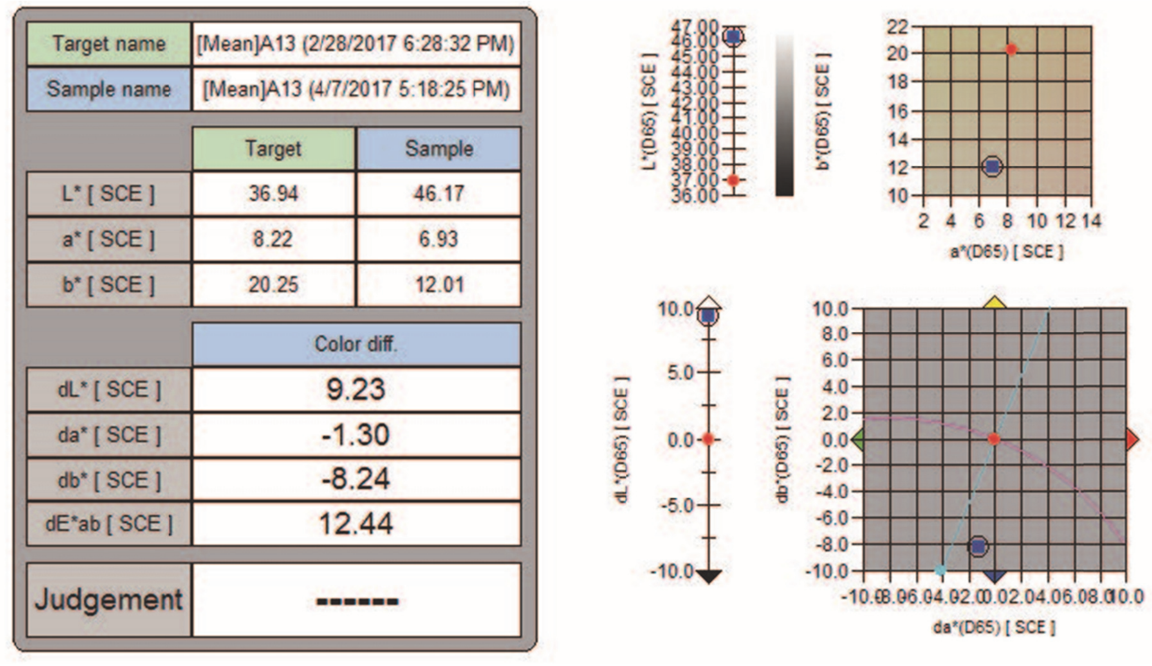
	Color diff.
dL* [SCE]	21.61
da* [SCE]	-2.02
db* [SCE]	-15.25
dE*ab [SCE]	26.53
Judgement	------

Sample A11



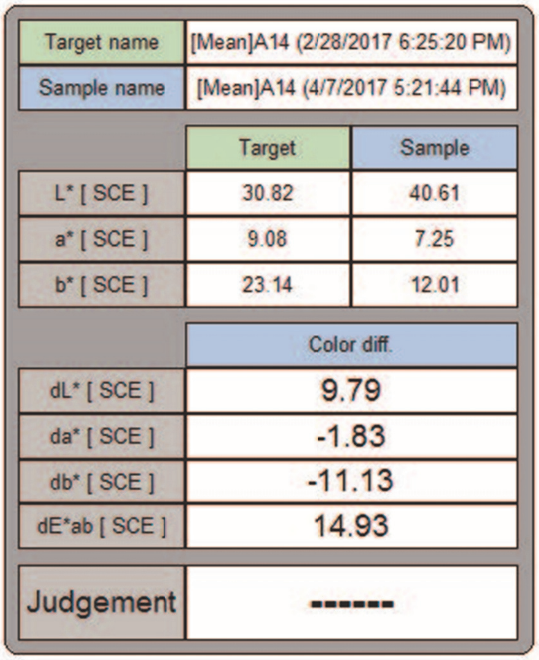
Target name	[Mean]A11 (2/28/2017 6:20:37 PM)	
Sample name	[Mean]A11 (4/7/2017 5:15:39 PM)	
	Target	Sample
L* [SCE]	24.18	35.20
a* [SCE]	7.85	7.52
b* [SCE]	27.74	22.85
	Color diff.	
dL* [SCE]	11.01	
da* [SCE]	-0.33	
db* [SCE]	-4.89	
dE*ab [SCE]	12.06	
Judgement	------	

Sample A13

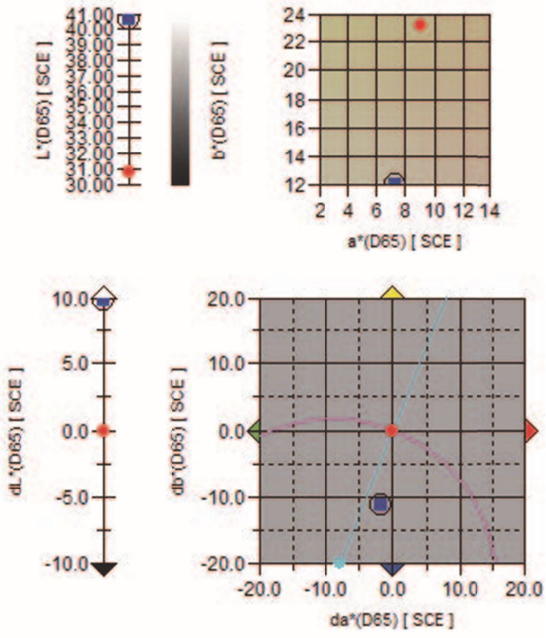


Target name	[Mean]A13 (2/28/2017 6:28:32 PM)	
Sample name	[Mean]A13 (4/7/2017 5:18:25 PM)	
	Target	Sample
L* [SCE]	36.94	46.17
a* [SCE]	8.22	6.93
b* [SCE]	20.25	12.01
	Color diff.	
dL* [SCE]	9.23	
da* [SCE]	-1.30	
db* [SCE]	-8.24	
dE*ab [SCE]	12.44	
Judgement	------	

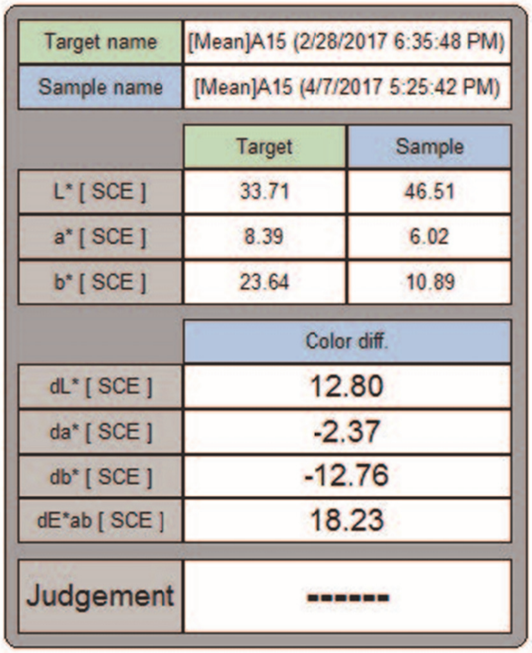
Sample A14



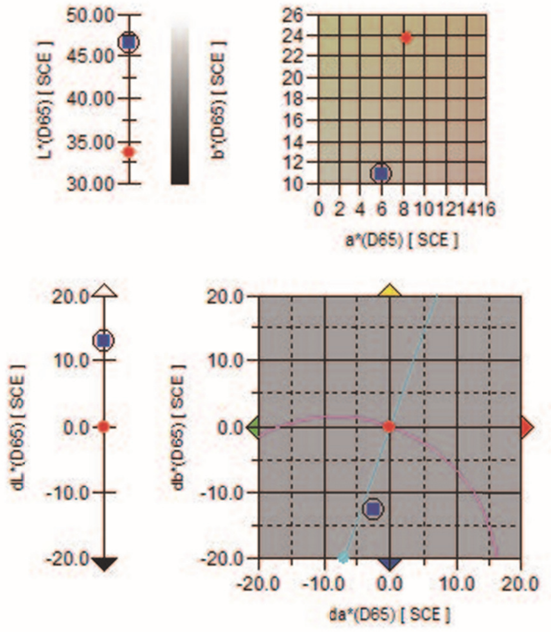
Target name	[Mean]A14 (2/28/2017 6:25:20 PM)	
Sample name	[Mean]A14 (4/7/2017 5:21:44 PM)	
	Target	Sample
L* [SCE]	30.82	40.61
a* [SCE]	9.08	7.25
b* [SCE]	23.14	12.01
	Color diff.	
dL* [SCE]	9.79	
da* [SCE]	-1.83	
db* [SCE]	-11.13	
dE*ab [SCE]	14.93	
Judgement	-------	



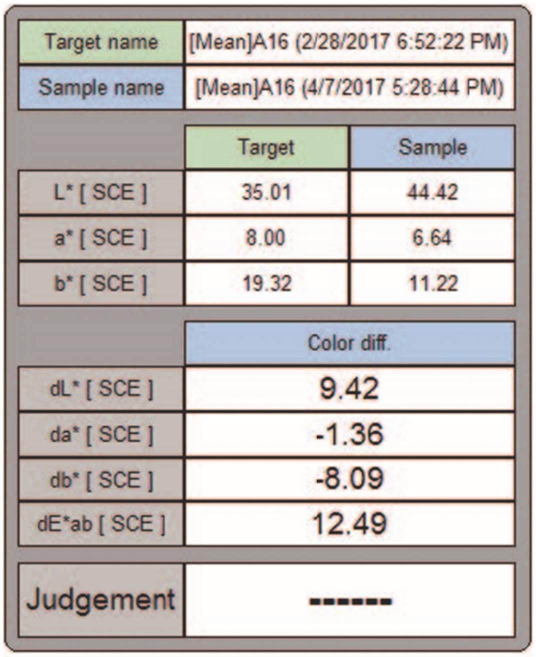
Sample A15



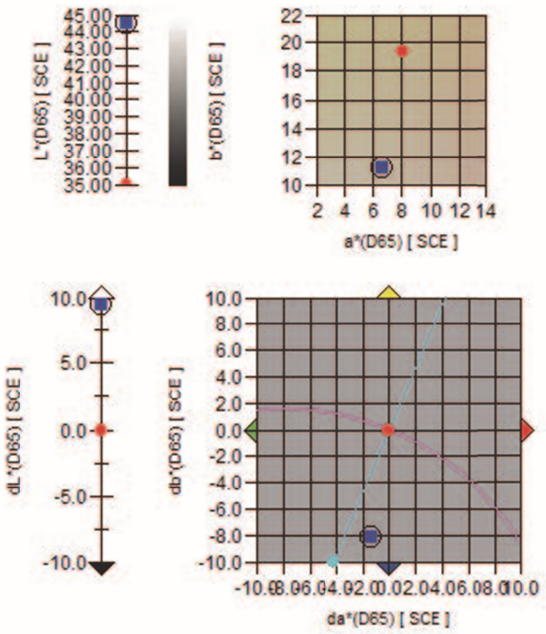
Target name	[Mean]A15 (2/28/2017 6:35:48 PM)	
Sample name	[Mean]A15 (4/7/2017 5:25:42 PM)	
	Target	Sample
L* [SCE]	33.71	46.51
a* [SCE]	8.39	6.02
b* [SCE]	23.64	10.89
	Color diff.	
dL* [SCE]	12.80	
da* [SCE]	-2.37	
db* [SCE]	-12.76	
dE*ab [SCE]	18.23	
Judgement	-------	



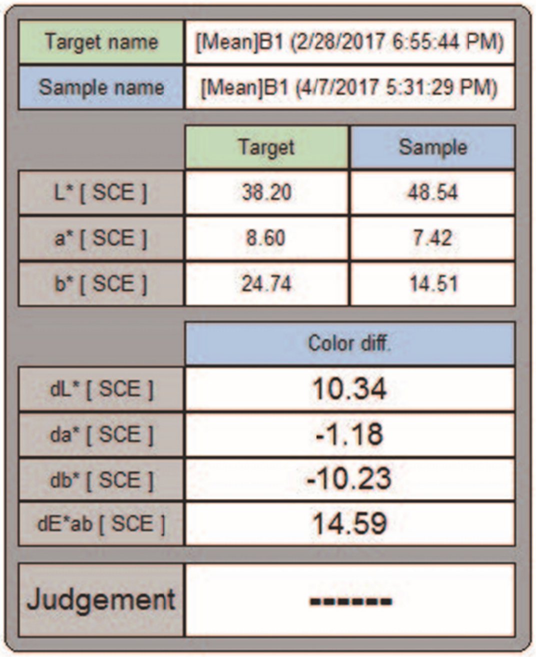
Sample A16



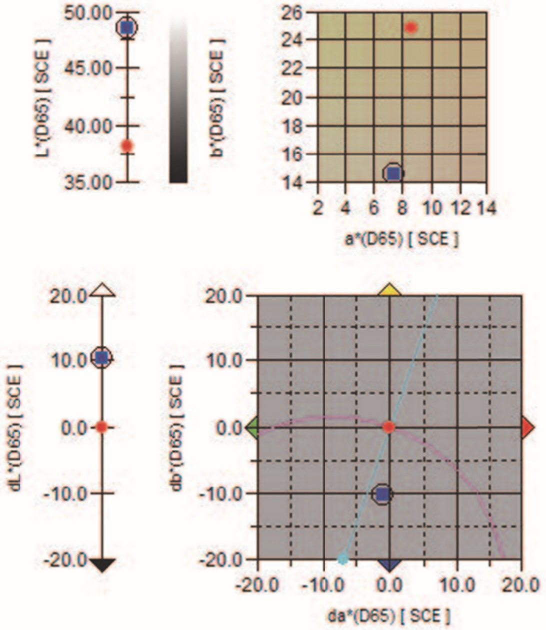
Target name	[Mean]A16 (2/28/2017 6:52:22 PM)	
Sample name	[Mean]A16 (4/7/2017 5:28:44 PM)	
	Target	Sample
L* [SCE]	35.01	44.42
a* [SCE]	8.00	6.64
b* [SCE]	19.32	11.22
	Color diff.	
dL* [SCE]	9.42	
da* [SCE]	-1.36	
db* [SCE]	-8.09	
dE*ab [SCE]	12.49	
Judgement	------	



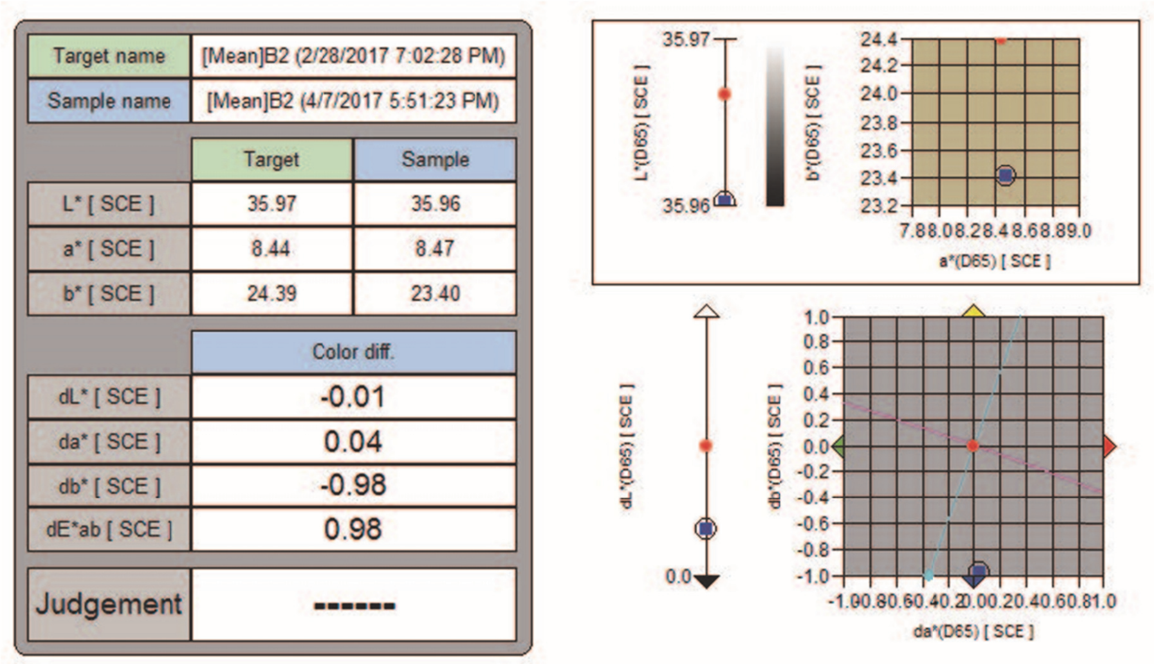
Sample B1



Target name	[Mean]B1 (2/28/2017 6:55:44 PM)	
Sample name	[Mean]B1 (4/7/2017 5:31:29 PM)	
	Target	Sample
L* [SCE]	38.20	48.54
a* [SCE]	8.60	7.42
b* [SCE]	24.74	14.51
	Color diff.	
dL* [SCE]	10.34	
da* [SCE]	-1.18	
db* [SCE]	-10.23	
dE*ab [SCE]	14.59	
Judgement	------	

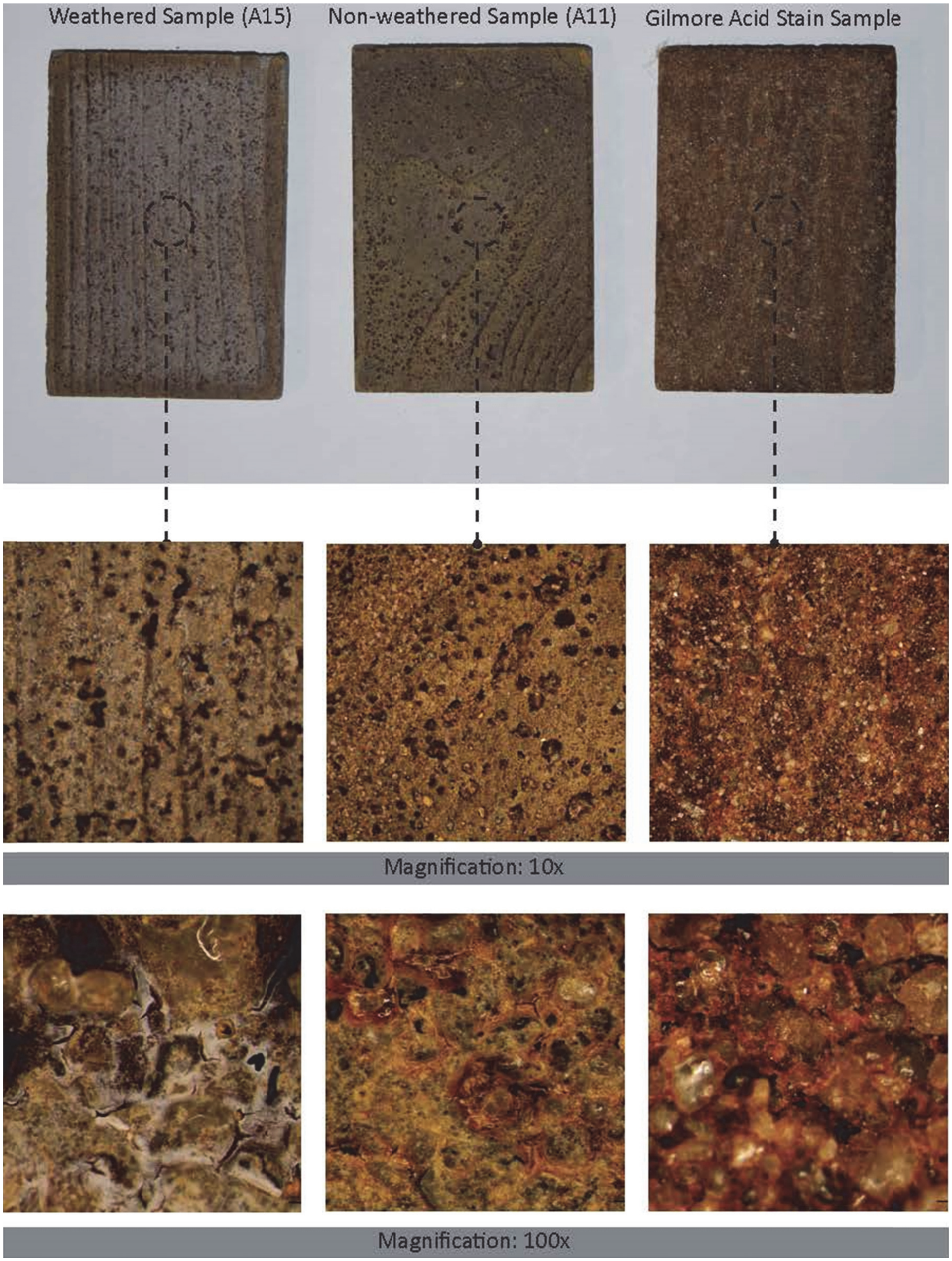


Sample B2



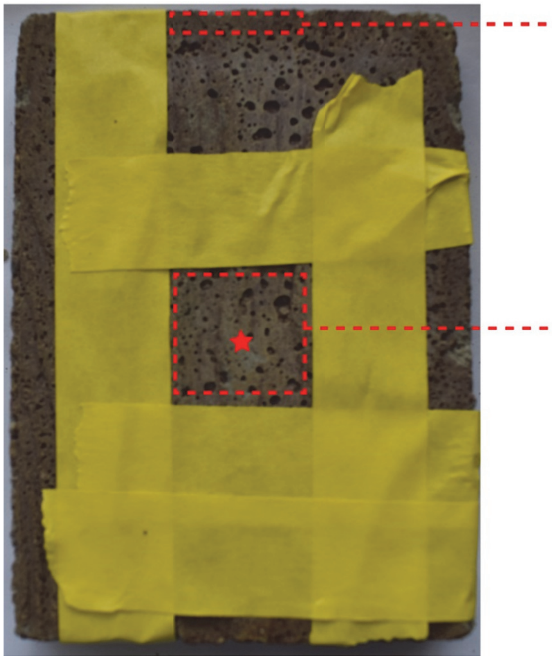
Target name	[Mean]B2 (2/28/2017 7:02:28 PM)	
Sample name	[Mean]B2 (4/7/2017 5:51:23 PM)	
	Target	Sample
L* [SCE]	35.97	35.96
a* [SCE]	8.44	8.47
b* [SCE]	24.39	23.40
	Color diff.	
dL* [SCE]	-0.01	
da* [SCE]	0.04	
db* [SCE]	-0.98	
dE*ab [SCE]	0.98	
Judgement	------	

Comparison between weathered sample, non-weathered, and acid stain samples



SEM-EDS Results

Sample used for SEM-EDS Analysis (A11-treated with only Mineral Silicates)

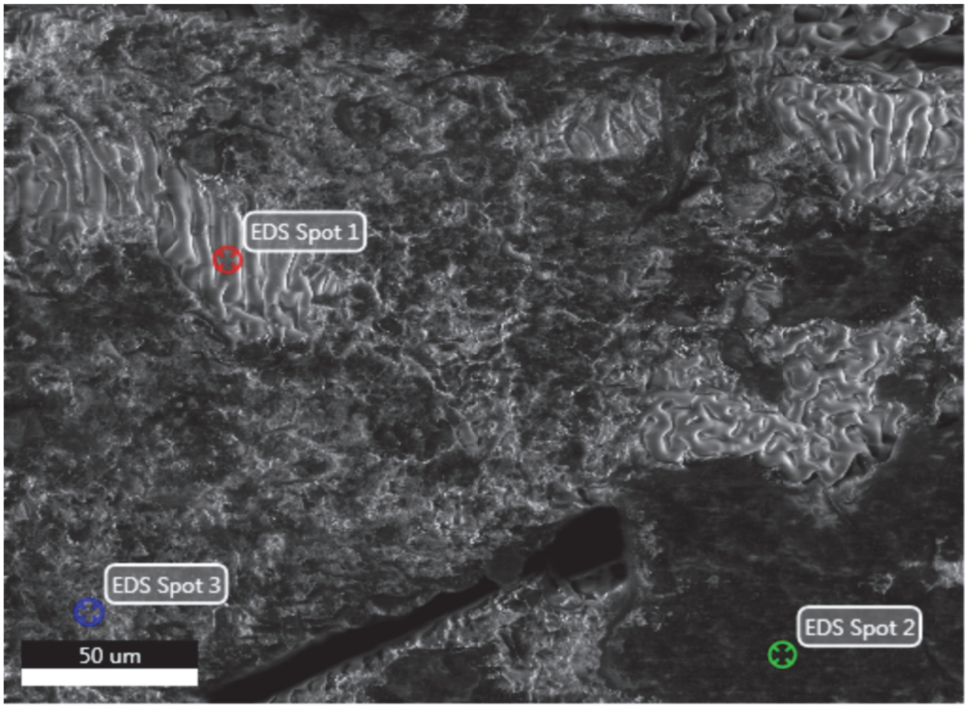


"A": area covered by bracket and free of efflorescence

"B": area with efflorescence

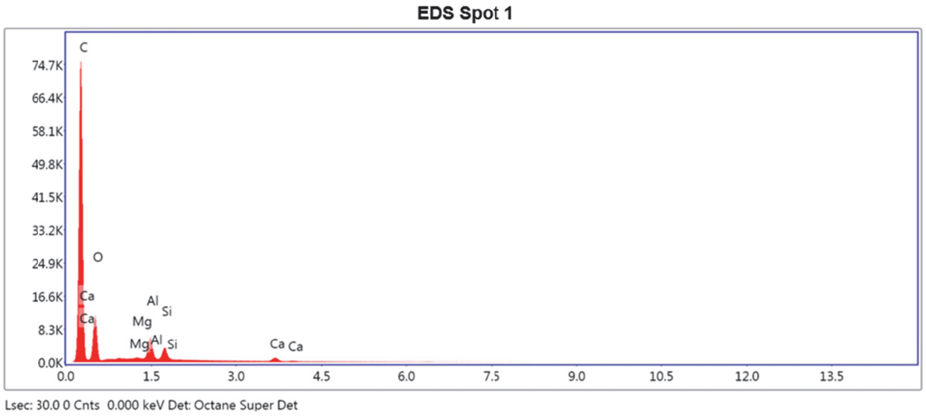
★ : area scraped for analysis

Scape Analysis



EDS Spot 1

kV: 10 Mag: 1002 Takeoff: 34.9 Live Time(s): 30 Amp Time(µs): 1.92 Resolution:(eV)134.4

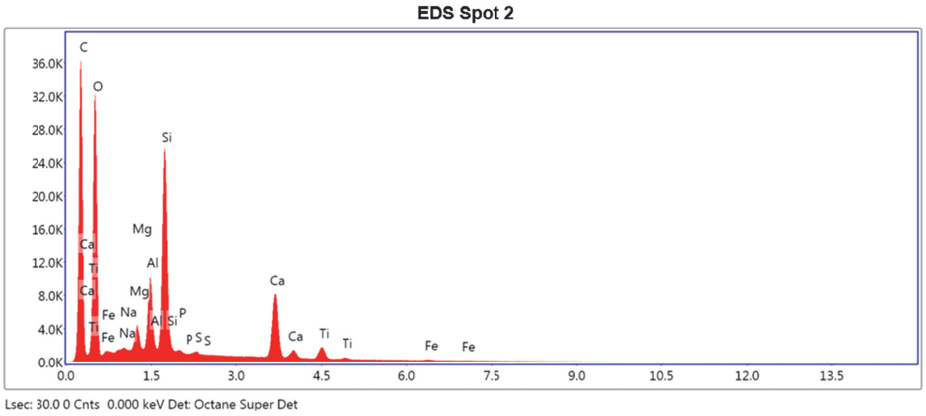


eZAF Smart Quant Results

Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	R	A	F
C K	77.35	83.94	18373.94	4.36	0.5996.5995	1.0207	0.9923	0.7593	1.0000
O K	16.34	13.31	2958.68	9.03	0.0500.0501	0.9628	1.0095	0.3183	1.0000
MgK	0.19	0.10	125.96	8.89	0.0016.0015	0.8724	1.0344	0.8708	1.0055
AlK	2.73	1.32	1730.83	3.35	0.0216.0215	0.8369	1.0391	0.9343	1.0062
SiK	1.61	0.75	962.56	3.49	0.0136.0133	0.8522	1.0433	0.9603	1.0071
CaK	1.78	0.58	336.87	5.68	0.0140.0147	0.7875	1.0565	1.0106	1.0422

EDS Spot 2

kV: 10 Mag: 1002 Takeoff: 34.9 Live Time(s): 30 Amp Time(µs): 1.92 Resolution:(eV)134.4

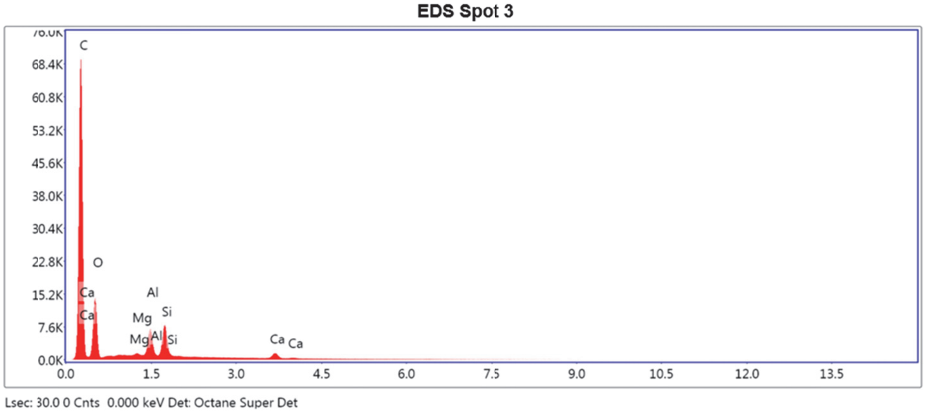


eZAF Smart Quant Results

Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	R	A	F
C K	38.61	53.22	7768.68	7.33	0.1984	1.0836	0.9661	0.4741	1.0000
O K	30.69	31.76	8199.71	8.57	0.1086	1.0242	0.9860	0.3454	1.0000
FeL	0.40	0.12	57.70	12.92	0.0017	0.7629	1.1319	0.5622	0.9979
NaK	0.18	0.13	106.25	15.27	0.0012	0.9177	1.0089	0.6938	1.0039
MgK	0.93	0.63	772.29	5.44	0.0071	0.9299	1.0152	0.8138	1.0069
AlK	3.06	1.88	2522.10	3.80	0.0245	0.8924	1.0210	0.8883	1.0104
SiK	9.59	5.65	7536.80	3.10	0.0814	0.9090	1.0262	0.9265	1.0077
P K	0.13	0.07	74.41	15.79	0.0011	0.8704	1.0309	0.9273	1.0127
S K	0.14	0.07	77.28	14.78	0.0012	0.8847	1.0351	0.9563	1.0199
CaK	12.55	5.18	3162.66	3.47	0.1084	0.8414	1.0455	1.0007	1.0253
TiK	3.72	1.29	599.92	5.41	0.0288	0.7554	1.0451	0.9953	1.0300

EDS Spot 3

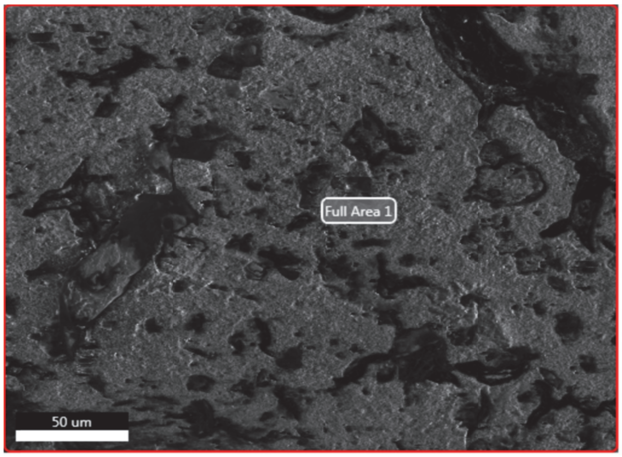
kV: 10 Mag: 1002 Takeoff: 34.9 Live Time(s): 30 Amp Time(µs): 1.92 Resolution:(eV)134.4



eZAF Smart Quant Results

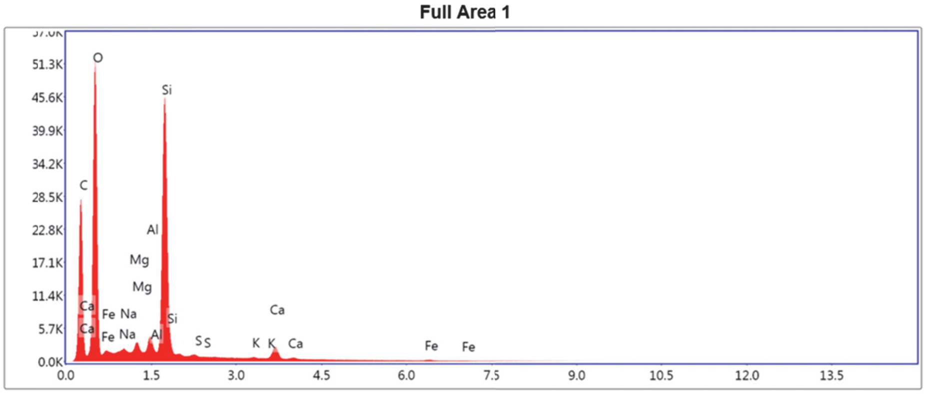
Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	R	A	F
C K	72.72	80.86	16789.21	5.13	0.5100 0.5100	1.0270	0.9897	0.6830	1.0000
O K	17.95	14.98	3590.80	8.93	0.0566 0.0566	0.9690	1.0072	0.3253	1.0000
MgK	0.26	0.14	181.70	6.76	0.0020 0.0020	0.8781	1.0325	0.8670	1.0063
AlK	2.91	1.44	1991.36	3.37	0.0230 0.0230	0.8424	1.0373	0.9311	1.0077
SiK	3.67	1.75	2361.46	3.00	0.0304 0.0304	0.8578	1.0416	0.9573	1.0065
CaK	2.49	0.83	506.03	4.92	0.0206 0.0206	0.7928	1.0554	1.0090	1.0358

Analysis A: Area without efflorescence



Full Area 1

kV: 10 Mag: 1002 Takeoff: 33.6 Live Time(s): 30 Amp Time(µs): 1.92 Resolution:(eV)134.4

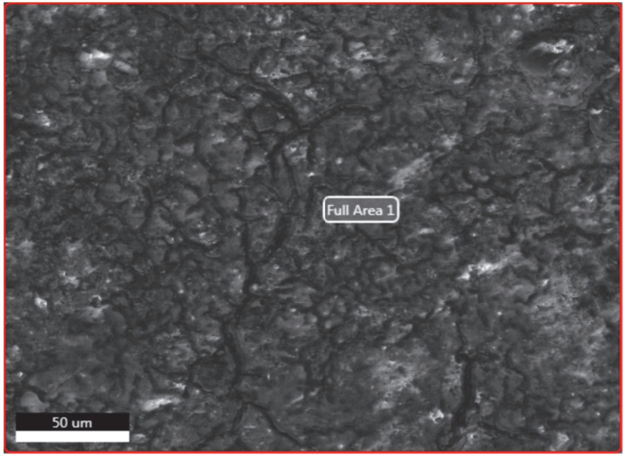


Lsec: 30.0 0 Cnts 0.000 keV Det: Octane Super Det

eZAF Smart Quant Results

Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	R	A	F
C K	38.00	49.78	6615.25	8.20	0.1587 0.1587	1.0657	0.9750	0.3918	1.0000
O K	38.18	37.55	13179.26	7.72	0.1639 0.1639	1.0065	0.9940	0.4264	1.0000
FeL	0.73	0.21	112.00	8.58	0.0032 0.0032	0.7495	1.1406	0.5803	0.9979
NaK	0.44	0.30	273.57	8.28	0.0028 0.0028	0.9013	1.0159	0.7049	1.0047
MgK	0.69	0.45	609.53	5.45	0.0052 0.0052	0.9131	1.0219	0.8222	1.0086
AlK	1.19	0.69	1036.59	4.18	0.0095 0.0095	0.8761	1.0273	0.8966	1.0150
SiK	16.86	9.45	14004.64	2.88	0.1420 0.1421	0.8923	1.0322	0.9403	1.0045
S K	0.35	0.17	197.77	5.91	0.0029 0.0029	0.8682	1.0404	0.9448	1.0105
K K	0.32	0.13	109.04	15.90	0.0026 0.0026	0.8136	1.0484	0.9926	1.0338
CaK	3.25	1.27	852.00	4.32	0.0274 0.0274	0.8252	1.0494	0.9979	1.0249

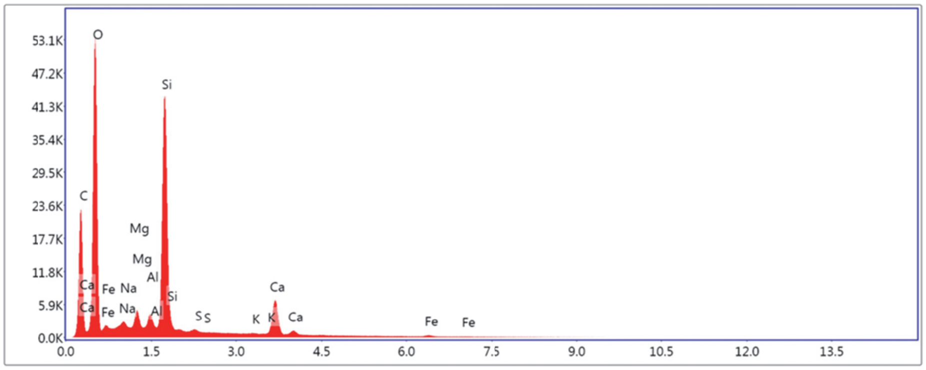
Analysis B: Area with efflorescence



Full Area 1

kV: 10 Mag: 1002 Takeoff: 34.3 Live Time(s): 30 Amp Time(μs): 1.92 Resolution:(eV)134.4

Full Area 1



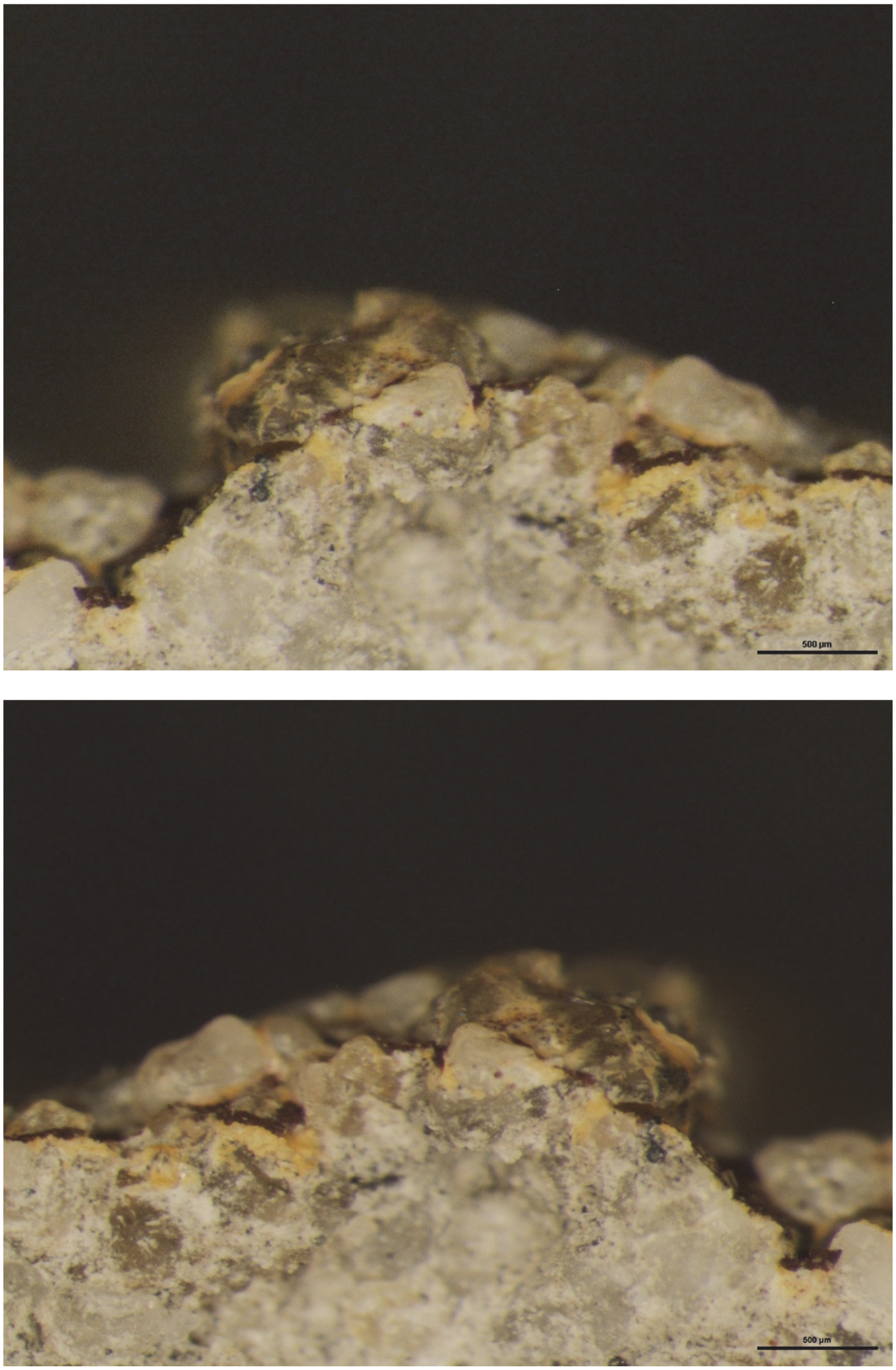
Lsec: 30.0 0 Cnts 0.000 keV Det: Octane Super Det

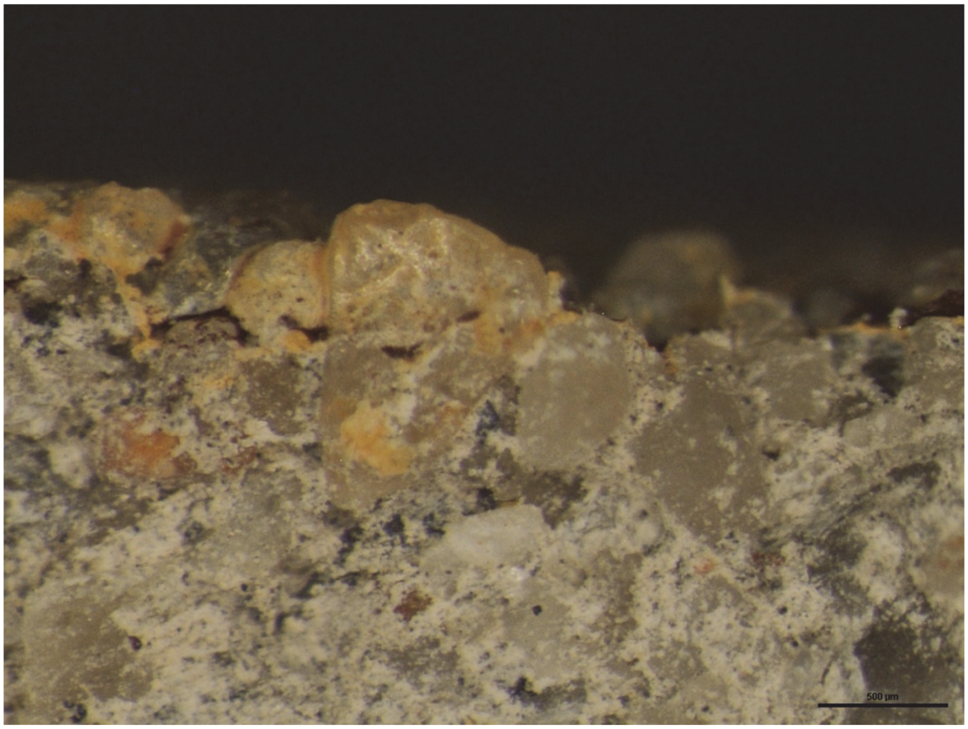
eZAF Smart Quant Results

Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	R	A	F
C K	28.97	40.73	4950.35	8.29	0.1216.1215	1.0833	0.9672	0.3872	1.0000
O K	40.51	42.76	13596.11	7.79	0.1738.1738	1.0237	0.9870	0.4192	1.0000
FeL	0.87	0.26	127.86	9.64	0.0030.0037	0.7625	1.1329	0.5593	0.9979
NaK	0.71	0.52	429.50	7.00	0.0046.0045	0.9171	1.0098	0.6887	1.0044
MgK	1.16	0.80	987.03	4.92	0.0088.0088	0.9293	1.0160	0.8073	1.0079
AlK	1.10	0.69	928.59	4.56	0.0088.0088	0.8917	1.0218	0.8826	1.0138
SiK	16.35	9.83	13267.29	2.99	0.1390.1390	0.9083	1.0270	0.9305	1.0058
S K	0.46	0.24	259.96	6.07	0.0039.0039	0.8839	1.0358	0.9417	1.0145
K K	0.28	0.12	98.16	17.51	0.0026.0025	0.8286	1.0446	0.9909	1.0532
CaK	9.60	4.04	2465.35	3.54	0.0819.0819	0.8404	1.0460	0.9966	1.0189

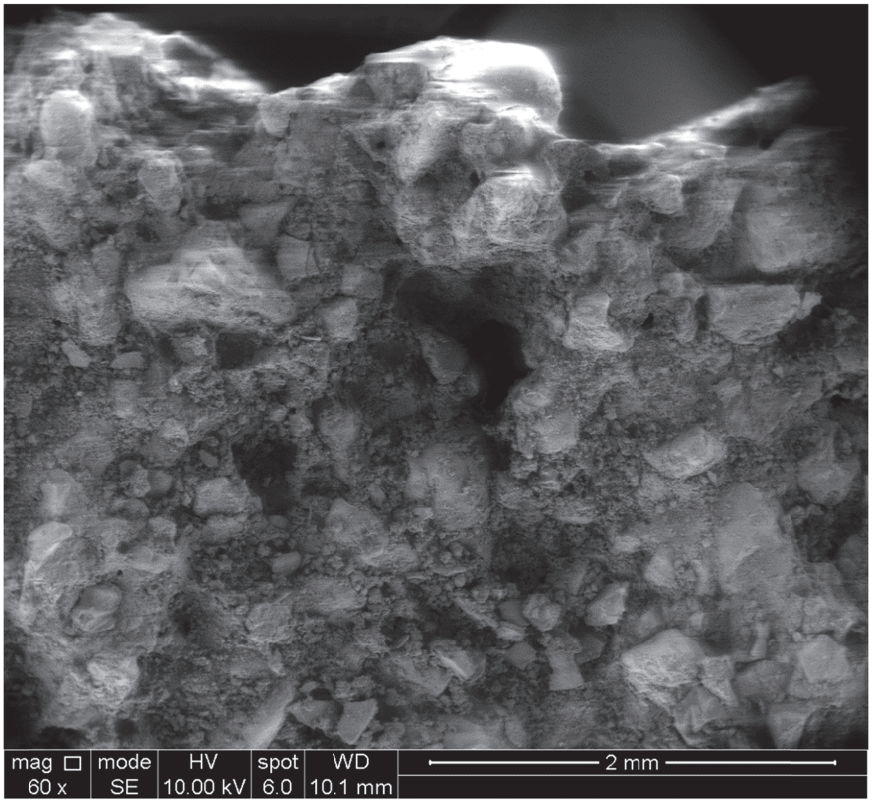
Cross Section Microphotographs

Sample treated with Mineral Silicate Stain and Silan-100 (microphotographs were taken from a LEICA MZ16 Stereoscope at 100X magnification)





SEM Microphotograph Cross sample treated with Mineral Silicate Stains and Silan-100



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