OUTSIDE THE CANON: A REVIEW OF UNIQUE APPROACHES TO STONE CONSERVATION

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Abstract

For the best of reasons, conservators tend to rely on tried and true means and methods when treating stone at the expense of innovation. Failures with previous inventive materials and applications have made us cautious about trying new approaches. As a result, most practitioners rely on a relatively narrow range of proven treatments.

The authors will present examples of new and not-so-new treatments they have performed using materials, means and methods that are outside of the generally accepted canon of cleaning, biocidal treatments, structural repairs, surface treatments, and material replications for outdoor stone monuments and sculptures. Some treatments have been developed recently while others have been in service for decades yet remain obscure. These include the use of bacteriostatic detergents and polymeric gel cleaners for biocidal treatments, alternative lasers and ultrasonics for cleaning, re-purposed traditional scagliola and mosaic techniques, grouted anchors, and several structural reinforcing and strongback designs.

The authors will describe their techniques, review advantages and disadvantages, provide guidelines on how and where they may be applicable, and assess their long-term effectiveness if known. As these treatments are relatively obscure, relevant publications are limited but available references are sited.

Keywords: bacteriostatic detergent, laser cleaning, gel cleaning, consolidation, structural stabilization, unconventional

1. Introduction

Many conservators in practice are reluctant to part with commonly accepted methods of addressing stone deterioration. This caution may stem from past treatment errors or concerns experienced by the conservator or his colleagues in either the lab or the field. This is a reasonable approach as it promotes reproducible, expected results, and reduces the risks of failure and liability. However, such caution can also constrain the potential for growth, innovation and advancement of the field and is ultimately self-limiting. Not only does this prevent the introduction of entirely new and novel technologies, but it also limits access to existing—and indeed, sometimes antique or traditional—methodologies which have proven historical track records but have not become widely accepted or understood. Regional preferences can also heavily influence treatment selection, as several commonly applied European treatments—such as vacuum consolidation, cleaning poultices and, to a somewhat lesser degree, laser cleaning—remain under-utilized in North America. Over the past decade, the authors have sought creative solutions to stone deterioration in sometimes unconventional places, including borrowing and refining technologies from other industries as well as looking back at traditional craft techniques for inspiration. The authors will present a selection of the materials and procedures that they have worked with the hopes of introducing them to a wider conservation audience.

2. Cleaning

2.1 Bacteriostatic Detergent

Uniquest CB-4 is a bacteriostatic detergent that penetrates microbiologically influenced biofilms. Although initially developed for the purification of water wells, consultations with the manufacturer suggested that this cleaner could be effective in removing tenacious biological soiling in and on stone surfaces as well. The action of the detergent leads to three major impacts: (1) the breaking apart and dispersion of the biofilms; (2) the destruction of the microbial cells particularly when the concentrations applied exceed 0.5%; and (3) dispersing attached materials formed by the infestation and growth of microorganisms associated with the biofilms. In general these impacts on the entrenched biofilms on surfaces require sufficient retention times to allow each of the three events listed above to be completed in the appropriate sequence. In water wells and pipelines the retention times vary but the ideal should be 12 to 24 hours for each stage. This allows enough time for the CB-4 to effectively disperse the infesting biofilm and associated concretious chemical accumulates; effectively reduce the active cells by at least three orders of magnitude; and then disperse attached materials from within underpinning surfaces (e.g. eroded pores into the marble).

The material was tested in sequence with other common detergents and quaternary biocides. Cleaning was effected first with a surfactant (Triton X-100, 3% solution) then a quaternary biocide (D/2 Biological Solution, 50% solution) followed by applications of CB-4 (5% solution, paper poultice, wrapped in plastic sheeting for a 24-hour dwell time). It is believed that the detergent removes surface soiling and exposes the biofilm. D/2 penetrates and disrupts the biofilm and biomass. The CB-4 acts as a penetrating biocide which attacks the structures formed on and beneath stone surfaces. These structures then collapse and can be easily removed by light scrubbing/ rinsing. This combined technique was used successfully to significantly reduce red-orange microbiological staining on the white marble sculpture *Slide Mantra* (Isamu Noguchi; Miami, FL), previously thought to be an intractable problem (Konkol et al. 2009). The authors have also used this method selectively on the New York Public Library Lions and elsewhere.

Figure 1, 2. Disfiguring biological staining before (left) and after (right) treatment with CB-4 bacteriostatic detergent.

2.2 Gel Cleaner

Both the dwell time and maintenance of physical contact with the substrate without drying are critical for the effectiveness of CB-4, which was designed to be used in water wells. A paper poultice contained in plastic sheeting was only partially effective at achieving this goal, particularly on vertical surfaces where it tended to lose adhesion and pull away. It relied solely on the penetrating capacity of the CB-4 to reach the microbiota, which proved generally effective on the smooth surface of the *Slide Mantra*. However, the highly porous Adair marble National Law Enforcement Officer's Memorial (Washington, DC) exhibited similar soiling conditions with a much more challenging surface. Further, the paper poultice method did not inherently remove the killed biota afterwards, thus leaving nutrient-laden beds, which encourage re-infestation and return of bio-soiling. Both the effective killing through prolonged contact of the biocide with the biota, and the removal of the killed infestations within the pits, were problematic and necessary to the treatment goals (Rabinowitz et al. 2011). This was achieved by modifying the process through the use of Prestór Gel (CBI Polymers, Honolulu, Hawaii, USA) as the transmission agent for CB-4 as a replacement for the paper poultice.

The product, based on a material developed to decontaminate nuclear sites, is a polymeric gel that has the capacity to wick into microscopic pores. Unlike other commercially available gel-cleaners, which are typically latex rubber-based and polymerize into an elastic film, Prestor is water-based and water-soluble, and offers much greater mechanical cleaning ability through its tenacious cling to and pull from the surface. It readily clings to vertical and overhead surfaces, although its relatively low viscosity necessitates careful site protection and application methods. As it dries, it shrinks approximately 20% and forms a tough, pliable skin that encapsulates anything contained within it. After approximately 24 hours, depending on environmental site conditions, the gel can be peeled away and disposed. This period corresponds to the necessary dwell time for the CB-4, meaning that it can be used to both ensure the CB-4 has sufficient contact time to effectively act upon the bio-colonies as well as remove them afterward, potentially reducing re-soiling rates. One year after treatment the stone of the Memorial remains unsoiled, confirming this effect. Please note that the tenacious pull of the gel is not appropriate for friable substrates and should only be used on sound, dense stones.

Figure 3. Prestor gel being pulled from the surface of the National Law Enforcement Officers Memorial, Washington, DC.

2.2 Ultrasonic Cleaning

Ultrasonic cleaning utilizes high frequency sound waves passed through a water medium aided by a cleaning agent to effectively remove soiling, commonly used on jewelry, industrial equipment and sensitive electronics. The authors have also experimented with expanding this technology for use in the cleaning of masonry materials, including limestone and terra cotta. Ultrasonic cleaning is necessarily limited by the size of a vessel that can contain the object to be cleaned; it also requires a significant investment in equipment (transducers). Despite these potential hurdles, the authors saw an opportunity for ultrasonic cleaning of terra cotta and limestone elements from the Four Seasons Fountain in Ames, Iowa. At this site, the decorative fountain elements had been marred by an accumulation of iron stains and calcium carbonate deposits due to hard water and deterioration of the internal plumbing system.

Figure 4, 5. Panel encrusted with calcium and magnesium deposits before treatment (above) and after successful ultrasonic cleaning (below).

Typically, stains and deposits of this nature might be broken down through the use of strong oxidizing acids, or mechanical means such as abrasive blasting. These methods, while effective, can also render permanent damage to the underlying surfaces. Ultrasonic cleaning was explored as a way to effectively reducing this soiling without introducing damage to the substrate. Through a sequence of testing using different ultrasonic frequencies, water temperatures, and cleaning agents, parameters for treatment were established. It was determined that frequencies in the range of 38-42 KHZ afforded effective but not overly aggressive cleaning, aided by Branson OR, a proprietary, citric acid-based cleaning solution. Water temperature was maintained at 150*F and a pH of 4-4.2. Each element was situated in the custom-built ultrasonic tank and cleaned for successive 1-hour intervals, which typically totaled 6-8 hours of treatment overall. After cleaning, the element was transferred to a rinsing bath of deionized water. The net findings were that the ultrasonic cleaning was highly successful at effectively cleaning terra cotta surfaces without damaging the substrate, however, this cleaning method was not initially successful at reducing the same deposits on the softer, more delicate limestone (Sembrat 1998). Additional research will be needed to evaluate appropriate ultrasonic frequencies, duration of cleaning cycles, and cleaning agents to effectively clean limestone and other historic materials. It is possible that some modification of the system may allow for more localized treatments, increasing its effectiveness.

2.1 Er/YAG Laser cleaning

Laser cleaning still remains underutilized in the US compared to its general acceptance in Europe. It is not clear if this is due to the burden of the relative high cost of the equipment, the lack of client demand for its use, concerns about the limits of the effectiveness of the tool based on past experience, or a combination of factors. The tool generally used in the cleaning of stone uses the Nd:YAG laser 1064 and 532 nm wavelength. Its advantages, as well as limitations, are well known and it has been successfully applied in the treatment of lighter toned stones for decades. The cleaning action relies on the different absorption of the laser energy by darker materials than lighter substrates (Martin and Cooper 1998). Ideally suited to removing black inorganic crusts from white stones, its effectiveness on dark substrates and organic soiling is limited. Use of the erbium (Er:YAG) laser at 3 nm in the treatment of stone was based on the theory by Adele de Cruz that laser energy at this wave length is absorbed by the –OH molecule, meaning that ablation can occur on materials that can be saturated with water or alcohol, regardless of the colour of the soiling or substrate. The tool has been shown to be effective on removing overpaint, varnishes, wax, and bio-colonies on stone substrates. Our tests showed it to be effective at removing wax from Rosso di Verona marble without detrimental effects. It has also been successfully tested on removal of lichen and overpaint on polychrome sculptures in testing. We are not aware of any wholesale use of the technology in treatment despite these successful tests.

3. Consolidation

3.1 Nano-Particle Lime Consolidants

Throughout much of the 20th century, the primary consolidants commercially available in the United States and Europe for the treatment of granular stone disintegration had been organic polymers. However, research into nano-lime consolidants represents a new wave of development with potential for further success and innovation. The fundamental premise behind this technology is not new, namely that the consolidant (calcium hydroxide) should be compatible with its host material (a calcareous stone, mortar, or lime plaster). Applied lime washes (calcium hydroxide dispersed in water) have certainly been used in the past, with varying success (Hansen et al. 2004). Calcium hydroxide $Ca(OH)_2$, when exposed to carbon dioxide (CO_2) will be converted to calcium carbonate ($CaCO_3$, or calcite), much in the same way a mortar cures through traditional carbonation. However, nano-lime particle solutions offer several theoretical advantages over traditional limewashes. The nano-particles are borne in different alcohols and are extraordinarily fine; for these reasons, it is hypothesized that the nano-sols can achieve a greater depth of penetration than traditional limewaters (Hirst Conservation 2012). Further, the fact that the solvent is alcohol, rather than water, should also limit premature carbonation of the particles, and theoretically allow for a greater deposition of material prior to carbonation (Doehne and Price 2010). Not surprisingly, depth of penetration and the time necessary for carbonation will necessarily vary based on the host material, pore size distribution, and other environmental factors which may not yet be fully understood (D'Armada and Hirst 2012). Further, the fact that the only commercially available nano-lime consolidant (CaLoSiL) is not distributed in the United States further complicates the spread of this technology for the time being.

The authors have, to date, performed one field test using a nano-lime consolidant, on an outdoor sculpture of Vicenza Stone, a whitish to pale-yellow Italian limestone. CaLoSiL E-50 was diluted 1 part solution to 2 parts ethanol and gently mixed. The solution was applied to the selected stone using a natural bristle brush, which allowed reasonable control of the material and recapture of excess run-off, if needed. A portion of the stone was pre-wet with ethanol to see if and how this affected absorption; because more rapid absorption and less excess run-off was observed without pre-wetting, this became the treatment standard. Ultimately, two cycles of treatment were applied to the same area, 48 hours apart. Due to the sensitivity of the material it was not possible to remove a stone sample for compressive strength or modulus of rupture calculations beforehand. Little evidence has been published thus far about the long-term performance of nano-lime; the authors will continue to intermittently monitor and make qualitative observations about the condition of the stone moving forward.

Figure 6 (above). Core drilling a sculpture to facilitate installation of a grouted anchor.

Figure 7 (below): A grouted anchor system prior to installation.

4. Structural Reinforcement

4.1 Grouted Anchors

Grouted anchor systems, in a variety of proprietary iterations, have been used over for more than 20 years to effectively stabilize historic masonry structures by "stitching" together unstable walls, particularly those with internal voids or poorly bonded courses. Due to concerns about the use of synthetic adhesives for bedding anchors, the authors have also successfully extended this technology to the internal stabilization of compromised stone sculptures. The goal is to replace the epoxy binder with grouts whose thermal expansion and moisture transmission characteristics are closer to those of stone. For installations other than vertical cores that are accessible from the top, this process requires bedding the stainless steel anchor within a polyester fabric sleeve, then inflating it by injecting a cementitious grout under low pressure. The sleeve expands with grout to fill the hole as the fabric is inflated. Some grout leaches through the fabric, which allows the paste to adhere to the core walls while containing the aggregates within the sock. With the sleeve's flexibility, it is able to mold into the voids and spaces within the sculptures, allowing it to be used to pin and reassemble fragments while minimizing or excluding the use of epoxy. The sock also allows for installation in conditions that would not otherwise be feasible, such as horizontal or upward cores, where grout would simply run out of the holes if not contained (Cintec 2012). The system has been used to pin stones on the Barnard Statuary Groups at the Pennsylvania State Capitol (Harrisburg, PA); the Tripoli Monument at the US Naval Academy (Annapolis, MD); cast stone reliefs by artist Constantine Nivola at Yale University (New Haven, CT); and on several travertine, coral stone, and Vicenza stone sculptures and fountains at Vizcaya Museum & Gardens (Miami, FL).

The flow capacity of the grout and its ability to remain viscous and not separate during installation are essential characteristics. Presstec grout used as part of the Cintec system is the only grout the authors have found with these characteristics. Where there have been concerns about possible differential compressive strength or when used to repair narrow stone units, such as in the repair of the pedestal supporting a basin within a marble fountain at Kykuit in Tarrytown, NY, narrow closed-cell foam backer rods have been inserted into the holes parallel with the anchors to act as bond breakers and to allow for and absorb some expansion, minimizing stress on the surrounding stone.

4.2 Strongbacks

Installation of internal anchors may not be feasible on sculptures that are very narrow or where they are still attached to their bases and removal would not be warranted.

However, sculptures on building cornices and those installed with limited views of their rear sides can be supported with exterior strongbacks. Usually these require attaching anchors to the backs of the sculptures set as high up as possible to reinforce top-heavy figures while remaining visually unobtrusive. The authors have observed several sculptures in locations subject to high winds where these mounting sites have become sites of damage due to concentration of forces at these points, which occurs if

Figure 8. (left) Example of a strongback mounted to the sculpture of *Pomona*, an example of a sound sculpture secured to a new concrete footing.
Figure 9. (right) Example of a low-impact strongback in which nylon-coated stainless steel cables were used to secure a sculpture on a roof parapet.

the sculptures are not fully bedded and soundly pinned. The authors have developed variations on the basic strongback design to address this issue.

A strongback for a sound sculpture with an adequate footing and mounting consists of a solid stainless steel bar, approximately the height of the figure, mounted vertically behind the sculpture, generally following the profile of the base and sculpture, which is set into a reinforced concrete footing. The bar is connected to the figure with several strategically placed reinforcement points, located at or above the mid-section and middle-upper back. Neoprene pads may be set between flanges on the bar and the stone sculpture to provide cushioning. Ensuring the rigidity of the post allows for use of a rigid mounting bolted to the sculpture. For example, the sculpture of *Pomona* located at Vizcaya Museum & Gardens features a strongback that was welded to an internal grouted anchor which continued through the base of the sculpture and was embedded in a newly poured concrete footer upon which the entire sculpture assembly was positioned. Due to the frequency with which the authors have had to implement this kind of support in the Miami, FL area, they have worked with a structural engineer to develop a design which has been engineered to withstand the Florida Building Code requirements for high velocity hurricane winds. The system presumes that the sculpture is itself well-supported.

An alternate design has been used in situations where it is not possible to confirm that a sculpture is soundly mounted. To avoid excess loading at bolt points when some movement may be encountered from high winds, a similar bar is used but it is only attached to the sculpture with surrounding cables. Coated aircraft grade stainless steel cable is looped around the figure at several locations and connected to flanges on the vertical bar. On a roof top, this bar is also braced with diagonal supports, all bolted to the roof deck and waterproofed. The cables are kept snug against the figure but not overly tightened. The cable shield consists of semi-transparent nylon, which can be painted if needed to blend with the sculpture. This design is intended to support the sculpture against catastrophic loss in a severe wind event while allowing for some rocking or movement. It has proved effective on parapet figures, where some evidence of rubbing of the cables against the stone five years after installation demonstrates that movement has occurred. Ideally, the work should be hoisted and securely pinned as well as provided with a strongback if needed but, in situations where this is not feasible, this method may be used. In conditions where previous strongback installations have already failed, leaving weakened and cracked stones that cannot safely be pinned unobtrusively, it may be the best available method to prevent disastrous loss and limit threats to

Figure 10. Example of a sample stone mosaic repair held in front of the host stone for comparison.

persons and property. It can also be used for short term stabilization for life/safety concerns pending more thorough restoration. A disadvantage of this strongback is its higher visual intrusiveness than one solely mounted to the back, which is a greater concern for sculptures at ground level than those atop buildings. However, a well-thought out design, discreet placement of the reinforcing cables, and coating the bar and cables with a sympathetic color of paint, can minimize the visual impact while still lending adequate support to the figure.

5. Fills and Loss Remediation

5.1 Scagliola and Mosaic Patches

Exotic marbles, such as Cipollino (Greece/Mediterranean), Rosso Antico (Italy), Rosso di Verona (Italy) or other brecciated varieties can be difficult to repair due to both the intense colouring and vivid figuring of the marbles. When dimensional losses and voids develop on such stones, typical patching techniques common in the conservation trade which utilize repair mortars are not effectual due to the highly complex and variegated colouration of the host stones. For this reason, conservators have had to borrow and modify traditional craft methodologies into a suitable repair strategy.

Cipollino and Rosso Antico stones, which have multi-colored veins running parallel or complexly knitted together, may be patched using scagliola techniques. Adapted from interior plastering methods, this repair was used to great effect on pieces within the collection of Vizcaya Museum and Gardens (Miami, FL), at the Biltmore Estate (Asheville, NC), and at the University of Virginia (Charlottesville, VA). A palette of restoration mortars (Jahn M120), tinted as needed with mineral pigments, was mixed in separate small batches to match the varying colors of the marble. For linear veined stones, the appropriate mortar colors were shaped into flat briquettes and stacked with others in thicknesses to match the colors and veining of the host stone. The stacked briquette was sliced perpendicular to the sections and laid to align with the stone veins. More complex figures can be replicated by laying in base colors, cutting back figured areas, and then filling those voids with other colors. All fills are placed proud and allowed to set before the repairs are dressed back to match the historic profile.

Major losses on brecciated marble columns at Vizcaya Museum & Gardens were rebuilt either by creating a terrazzo-like patch or creating a mosaic matrix. On the mosaic patches, a variety of stones comparable to the range exhibited in the existing column were selected and broken or cut to create tesserae that matched the shapes in the original stone. Once the void was properly cleared and prepared for repair, a colour-matched acrylic-modified grout was laid into the void to serve as a bedding mortar and the stone tesserae were set in it slightly proud of the profile to approximate the colour, veining, and texture of the natural stone. Joints were grouted with the same mortar used in the bedding. Once the grout was set, the entire patch area was honed down using a wet-polisher equipped with a 50-grit diamond bit pad. Care was taken to ensure the patch repair was shaped to match the round profile of the column. Final dressing of the patch was done using sequentially finer pads up to 2000-grit. Care was taken to ensure adjacent surfaces of the column were not abraded during this process. Any minor losses of tesserae or voids in the grout were filled with additional material and screeded flush.

For stones that exhibited a more truly “broken” appearance, the process was modified to one that resembled terrazzo. A stone similar to the embedded fragments was identified and broken into pieces sized to match the original stone. These were cast into prepared voids within a paste of a latex modified color-matched mortar. To ensure that the stone fragment distribution matched that of the marble, it was necessary to cast the repair at least ½" proud of the finished surface, as spacing between the fragments tended to decrease towards the core of the patch. This too was then carefully honed back like the other repairs.

6. Conclusion

The techniques and materials summarized above represent a cross-section of atypical treatments to suit a wide variety of stone conservation challenges. Both antique and cutting-edge, they remain outside the typical range of treatments selected by stone conservators. However, the authors have found these somewhat unconventional treatments to find applications in the field: sometimes modest, sometimes significant. Undoubtedly, each technique will continue to benefit greatly from the dispersion of information amongst our peers and with that, expanded testing, a broader shared knowledge base, and refinement of the materials and methods.

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