CONSERVATION TALK

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This month let's talk about the conservation treatment known as blind pinning—the process of joining fractured stone by inserting one or more internal pins in the stone fragments. The goal is for these rods to re-establish the structural continuity of the stone, allowing broken stones to be suitable for normal display. Its value lies in the ability of the pins to redistribute loads and stresses through an area significantly greater than is achieved with a simple epoxy repair (see my Conservation Talk column in the winter 2010 *AGS Quarterly*).

It is important for me to emphasize that the process is never as simple as implied by a host of do-it-yourself books. Nor is the process without complications; but it can be an effective load transfer mechanism. The large numbers of pinned stones that exhibit sound treatments after years of exterior weathering provide clear testimony.

When talking about blind pinning a good place to begin is ASTM C1242-10. ASTM (American Society for Testing and Materials) is an internationally recognized leader in the development of voluntary consensus standards. C1242-10 is the *Standard Guide for Selection, Design, and Installation of Dimension Stone Attachment Systems*. Although it's intended to guide the installation of exterior stone cladding on buildings, it provides some guidance to conservators doing blind pinning. The document suggests that the embedment should be a minimum of two-thirds of the thickness of the stone. Thus for a 2" tablet, the pins should be set a minimum of 1-3/8". In general the deeper the hole the greater the surface area with which the adhesive has to bond. This depth may assist in premature pull-out. It must nevertheless be balanced against the damage that occurs with deeper holes if there is additional damage to the stone.

ASTM C1242-10 also specifies that pins should not exceed one-quarter of the stone's thickness. So our 2" tablet should not have pins greater than ¼" in diameter. Many conservators, however, use pins that are no greater than a third the thickness, perhaps using a 5/8" pin. One conservator (Marco Federico, in his 2008 University of Pennsylvania thesis, *Performance Evaluation of Mechanical Pinning Repair of Sandstone*), suggests that an optimal treatment may consist of using pins larger in diameter with greater depth (when this can be done safely), but reducing the total number. He suggests that overuse of pins can create stress leading to cracking and weakening of the stone. Such damage might be a greater problem in sandstone than marble.

Another document that conservators are familiar with is ACI 318-02, *Building Code Requirements for Structural Concrete*, published by the American Concrete Institute. While concrete does not perform exactly like stone, their guidance suggests that holes should be at least 6 anchor diameters from the edge. In other words, if you are using a ½" pin, it should be placed at least 3" from the edge. The goal is to prevent edge spalls and premature stone failure.

In spite of the available guidance, it is difficult to drill thin stone, especially if the stone has a great deal of veining or some sort of physical impurity that affects its strength. Stone may also be substantially weakened by sugaring, spalling or other inherent problems.

Shifting from the issue of holes to pins, the conservator has to evaluate the best material with which to pin the stone. An ideal pin is one that is inert (most particularly, non-corrosive) and which also have a similar thermal coefficient as the stone itself. In other words, we don't want a pin (like iron) that will corrode, with the corrosion products volumetrically expanding and causing "iron jacking" or cracking of the stone. We also would like a pin that will expand less than the stone itself at the same temperature.

The table below compares the thermal coefficients of a variety of stones and masonry items to a range of metals and fastenings. For many of these materials the coefficients are variable and the table provides only general information; data sheets for specific materials should be examined for more precise information.

Average Coefficient of Linear Thermal Expansion for Various Materials (in 10-6 in./in./°F)

Brick	3.1	Titanium	5.0
Marble	3.1-7.9	Fiberglass	5.5
Limestone	4.1	Gray cast iron	6.0
Granite	4.4	Wrought iron	6.4
Slate	5.8	Stainless Steel	8.9
Cement	6.0	Brass	10.5
Sandstone	6.1	Aluminum	12.9
Concrete	8.0	Zinc	16.5
Plaster	9.2	Lead	28
		Nylon 6/6	80

Clearly some pins, such as nylon, aluminum and brass, have different coefficients of thermal expansion and this fact should lead us to suspect that their use may be problematic. Stainless steel, which is often used by conservators, while somewhat more closely matching many stones, still tends to expand and contract differently than the stones in which it is used. The best matches for many materials may be titanium (rarely used) and fiberglass.

Another issue of concern is the tensile strength or modulus of elasticity of the pin being used. In the vernacular, these may be thought of as the "stiffness" of a material. The modulus of elasticity of some materials that might be used as pins is shown in the table below. In contrast, the modulus of elasticity for marble is between 7.0 and 2510x6 psi and that of slate is between 11 and 15.010x6 psi.

Average Modulus of Elasticity (E) for Various Materials (in lb-in2 [psi] x 106)

Nylon	1.5
Lead	2.0
Fiberglass	4.0
Carbon Fiber	4.3
Aluminum	10.2
Cast Iron	14.5
Naval Brass	15.0
Titanium	16.5
Stainless Steel	27.6
Carbon Steel	29.0

Thus, nylon can be seen to be a relatively "weak" material, which may explain why it has failed to perform adequately in many stone conservation treatments. Stainless steel, which is often used by conservators, is substantially stronger than the stone matrix and this fact suggests that in the event of some external force, it will be the stone that fails or breaks, not the stainless steel pin. In contrast, the fiberglass, which has a comparable coefficient of thermal expansion to many stones, is also not as strong as many stones and this characteristic may help ensure that if some external load is added, it will be the fiberglass rod that fails, not the stone. The study by Federico previously cited found that the fiberglass pins failed by having their fiberglass stands debond from their adhesive matrix, allowing the pins to pull out.

At the last Association for Preservation Technology meeting, George Wheeler, Carolyn Riccardelli and Christina Muir presented a paper that expands on this topic, "'New' Insights on Pinning Fractured Marble." The researchers found that metal pins cause more stone breakage; plastic pins fail before the stone breaks, but the pins typically fail too quickly; and finally, fiberglass (and carbon fiber) pins tend to break, leaving the stone intact. Not only are there benefits to using fiberglass, but the fiberglass appears to have adequate strength—at least based on this initial study.

Wheeler and his colleagues also found that there seems to be little difference in the force required to pull out smooth as opposed to threaded rods; the average force for the two series of tests was about 2,428 pounds (10.8 kN). We may need to do additional testing to determine if threaded rod is really as important as once thought in epoxy pinning. This study suggests it may not be.

Relatively little conservation literature discusses the size of the holes into which the pins will be placed. ASTM 1242, as well as most conservation literature, suggests holes between 1/8" to 1/16" larger in diameter than the pin. Some epoxies (discussed below) will specify the size of the hole. For example, one data sheet notes that the, "glue line should not exceed 1⁄8-inch."

Once we have determined where, how many and how deep our pinning holes should be and what sort of pin we'll use, there remains the question of what sort of adhesive will be used to attach the pin. Typically a hi-mod, moisture insensitive, thixotropic, two-part epoxy is used. Epoxies generally consist of an epoxy resin and a hardener. When mixed together the two react, crosslinking and transforming the two components into a thermosetting material. Several mentioned frequently in conservation literature are shown in the table below, along with their tensile strength and modulus of elasticity.

Several Epoxies Used in Stone Conservation

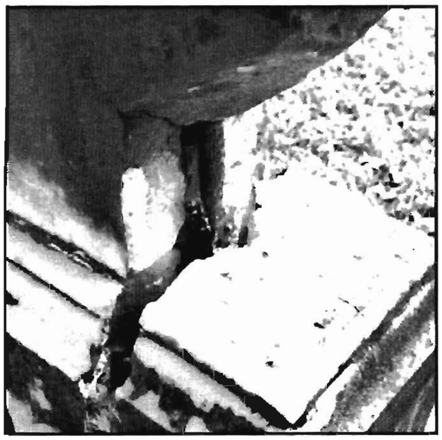
	Tensile strength (psi)	Modulus of elasticity (in lb-in2 [psi] x 106)
Akepox 2000	7250	0.43
Akepox 2010	8700	0.51
Akepox 2030	2900	0.80
Sikadur 31	3300	1.67
Sika Anchorfix 4	4300	0.41

Thus, the strength and stiffness of these few epoxies vary considerably, providing a wealth of choices to the conservator. At least one conservator has added powdered stone to the epoxy in order to reduce its adhesion capability, producing a strength slightly less than the stone in which it was used. It is worth noting that often stronger is not better.

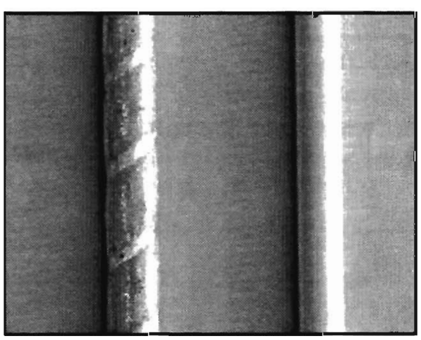
In addition, some conservators also use acrylic-based adhesives, such as Paraloid B-72, either for adhesion of rods or as a barrier coat within drill holes to prevent the epoxy from permeating into the stone matrix. B-72 is UV stable and reversible since it does not crosslink. It can be dissolved in acetone, toluene, ethanol, xylene and methanol. Its thickness can be adjusted by mixing in various fillers, such as calcium carbonate or fumed silica. Its one short-coming for exterior use is that it swells upon exposure to moisture. B-72 is also significantly weaker than most epoxies (in one test the bond strength of epoxy was found to be over 100 times stronger than that of B-72). This strength, however, may do little long-term good if it exceeds the cohesive strength of the stone. It isn't entirely clear if B-72 is sufficiently strong to adequately transfer the load between elements.

There are always problems converting laboratory studies into field practice. Sometimes the real world has more difficult to control variables than the typical lab test. Still, these tests should help explain why conservators are so reticent to answer the generic question, "how do I pin a stone?"

The honest answer is that it depends—on the stone, its condition, what it will face, what the goals of the conservation project are. Hopefully, this brief discussion will help explain some of the issues that the conservator has to consider when making that decision. ♦



This photo shows the damage to a marble die on base resulting from serious iron jacking or expansion of the ferrous corrosion products.



Here are two different types of fiberglass pins. On the left is a rod from Conserv Epoxy. It consists of continuous drawn glass roving saturated with vinyl ester resin that is spiral wrapped. These are available in seven diameters from ¼ to 1 inch. On the right is a rod from Preservation Resources Group (PRG). It consists of fiberglass reinforcements and thermosetting polyester or vinyl ester resin systems and is available in four diameters from ¼ to 1 inch.