Section A—Introducing Speleothem Repair

Speleothem Repair Materials
Jim C. Werker and Val Hildreth-Werker

The materials recommended in this book are relatively safe for long-term use in caves. Based on current best practices in caves, coupled with lab analysis and several decades of practical observation in subterranean environments, the materials listed in this section are generally considered safe for speleothem repair. Keep in mind that the term *cave-safe* is used to describe the best of contemporary understanding.

State-of-the-art techniques and materials for speleothem repair will change as knowledge advances. It is important to exchange information with others who repair speleothems and to make every effort to stay current.

Cave-Safe Epoxies and Adhesives

Cavers prefer to be out exploring caves, not repairing someone’s speleothem accident or an act of vandalism. Cavers tend to hunt for new, sure-fire, quicker repair materials and techniques—but faster is not necessarily better.

Throughout this volume, only tested archival-grade epoxies and adhesives are recommended for use in cave environments. The epoxies, bonding agents, and quick glues found in neighborhood dime stores and variety outlets are certainly easier to obtain than the archival adhesives. However, mass-market products may create a lot more harm than good.

Most hardware store epoxies and quick-glues will break down rapidly and may add unwanted toxins and nutrient sources that will harm or destroy cave biota and habitat. Before choosing epoxies, hardeners, cyanoacrylate adhesives, solvents, or metal fixtures, research and understand the characteristics of the materials. (See cave-safe materials, page 172.) Don’t trust the mighty marketing claims of wonder products.

All glues break down over time, but archival products are formulated to do less harm than those on the general market. In the future, technological advances will introduce better products that are safer for cave environments. Always carefully research and test products before using them for cave applications.

Any new product should be checked by research chemists and biologists who understand the specific cave environments where product use is proposed. Find out the physical characteristics and short-term effects of proposed products.

What are the components of the agent and how will the degradation and outgassing characteristics of the compounds affect cave-dwelling biota, ecosystems, chemistry, water quality, or the minerals of a cave system? Arrange for a cave-savvy chemist or a materials engineer to evaluate how the long-term degradation characteristics may interact with the naturally occurring chemicals and minerals of the cave.

Get the manufacturer’s data sheets and the federally regulated Material Safety Data Sheet (MSDS). Understand the recommended safety precautions.
Wise product and material choices for cave environments are based on thorough research. Call on speleological consultants for input about any material that is considered for long-term underground use. Use educated common sense and constantly gather information about current best practices.

Sometimes referred to as archival epoxies and pure cyanoacrylate adhesives, the adhesive agents listed in this chapter have been used in subterranean applications over the past several decades and appear to be relatively safe for long-term installations in cave environments.

**Epon® 828 With Versamid® or Epi-cure® 3234 (TETA)**
- Epon 828 epoxy has been successful in underground environments and speleothem repair for decades.
- Epon 828 epoxy resin combined with Versamid 40 curing agent will bond dry surfaces, even in humid cave environments.
- For wet applications or speleothems with active dripping, Versamid 25 hardener will cure more efficiently. Epon 828 with Versamid 25 curing agent will bond underwater.
- The Epon family of archival adhesives will develop strong bonds with shear strengths up to 6,000 psi (41,370 kilopascal).
- Curing time can take 24–72 hours and sometimes longer in moist cave environments. Shrinkage is minimal. The bond is resistant to a broad range of chemicals.
- Mixing ratio is typically 1:1. Use one part Epon to one part Versamid (50:50 mix). However, for a more rapid drying time, use just a little more hardener for a 40:60 mix. Faster cure rates result in weaker bonds. Accelerating the drying time reduces the shear strength of the joint. A slower curing time typically increases the durability of the bond.
- Epon 828 and the Versamid hardeners were lab tested for long-term underground use at the U.S. Department of Energy Nevada Test Site and have proved successful for speleothem repair during several decades of use and observation.
- The combined epoxy and curing agent mixes to a creamy-white color and viscous consistency—when dry, it is colorless or a slightly shiny, translucent yellow.
- These products are available from the Shell® Chemical Company and through regional chemical or plastic product suppliers. However, the Versamid curing agents are increasingly difficult to locate and fabricators in the plastics industry are recommending a Shell replacement product, Epi-cure 3234 (TETA). Epi-cure 3234 is a highly concentrated curing agent with bonding properties and archival characteristics similar to Versamid.
- Epi-cure 3234 (TETA) is currently the recommended hardening agent for Epon 828 and is typically mixed in a 12:1 ratio, twelve parts Epon to one part TETA.

**Hot Stuff® Super T and Special T**
Fast-drying cyanoacrylate adhesives are useful for repairing soda straws, helictites, thin draperies, and other delicate speleothems or small applications in caves. Hot Stuff adhesives are industrial-strength products containing a very pure form of...
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**Figure 2** (Versamid) and **Figure 3** (TETA). Epon 828 epoxy mixed with Epi-cure 3234 (TETA) curing agent in a 12:1 ratio is a relatively safe adhesive for cave applications. The Epon and Epi-cure products are manufactured by the Shell Chemical Company and are available through regional chemical or plastic product suppliers. Versamid hardeners are also used with Epon 828. For speleothem repair, always have mixing cups, mixing sticks, and disposable gloves on hand. To ease handling the products in a cave, premeasure both the epoxy and the hardener into small containers.

**Figures 4a and 4b.** Hot Stuff Super T or Special T with NCF Mild Accelerator are relatively safe quick-setting adhesive products for cave applications. All Hot Stuff adhesives are industrial strength and contain a very pure form of cyanoacrylate that remains clear when it cures. Pieces are held in place with wire for curing (detail right).

- Hot Stuff Super T is often used in paleontological applications and model-building activities and works well for small repairs in caves.
- Hot Stuff Special T is a more viscous product that is formulated to fill in gaps and is extremely useful for cave applications.
- Both Hot Stuff cyanoacrylate adhesive products are clear and colorless when wet or dry.
- In most caves, Hot Stuff cures in 30–90 seconds but bonding can be accelerated with NCF Mild Accelerator (also a Hot Stuff product). Shear strength is weakened by accelerated curing times, but cyanoacrylate does not bond quickly in large quantities. One spritz from a spray pump bottle of NCF will cause chain reaction bonding.
- Hot Stuff Super T, Special T, and NCF Mild Accelerator can be purchased in model-building stores, quality woodworking shops, museum supply catalogues, and through sources on the Web.

Cyanoacrylate that remains clear when it cures. Oil is not added to lengthen shelf life (as it is in many other instant glues).

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### Stainless Steel Rods, Pins, and Wires

Chromium–nickel austenitic steels, commonly known as stainless steels, are more suitable than other products for speleothem repair. Stainless steel is tough and highly resistant to corrosion. Longevity is ten-fold that of mild steels. Stainless steels that are not austenitic will degrade more rapidly in most cave environments. Metals that work best underground include high austenitic stainless steels, particularly types 304L, 316L, and 321.

#### Stainless All-Thread

Stainless steel all-thread is the choice material for pin-stabilization of broken speleothems. The ridges of all-thread grab and adhere better than pins made from regular round-stock stainless. Most stainless all-thread is type 304. All-thread is stocked in assorted diameters and cut to the required lengths.

- Installed as a stabilization rod for rehanging stalactites, all-thread will provide greater shear strength. If repairing naturally leaning stalagmites, the resulting shear load is better resisted with all-thread stabilization rods. Support pins made from regular round-stock stainless are usually successful for repairing stalagmites that have minimal shear load.

- Consider the expansion characteristics of any material before using it to pin broken speleothems. Over time, corrosion will cause expansion, even when stabilization devices are epoxied inside of speleothems. Structural steel (also called mild or cold-rolled steel), plastic, fiberglass, wood, and nylon rods tend to expand and break apart the repaired cave formations when epoxied into the centers. Stainless is more corrosion resistant than most other materials. The corrosion-resistant characteristics of high-austenitic stainless steels minimize the potential for breakage from material expansion.

- What about using other metals for pinning broken cave formations? Aluminum is not a good choice. (See characteristics of aluminum, page 169.) Some of the other alloyed stainless steels are very strong but their interaction with cave environments has not been studied.

- Titanium is expensive and is sometimes alloyed with lead or other materials, but again, the interaction with cave environments is not known. There are other exotic metals and materials that might work, but they are expensive and no experience of use in caves is documented.

- On the other hand, use of high-austenitic stainless steels in harsh environments has been documented for decades. Stainless materials are highly resistant, durable, and readily available.

#### Stainless Steel Wire

Stainless wire makes sense from a theoretical materials standpoint and is a good choice for some speleothem repair jobs. In practice, stainless steel wire is difficult to bend and conform to the shapes of cave formations. However, if the wire is installed as a permanent material in a repaired speleothem, it may be worth the time and aggravation to use stainless wire.

- Nevertheless, common sense should play a major role in selecting materials for speleothem repair applications. For example, copper wire bends easily, and while it should not be left on the outside of speleothems for long-term applications, it is extremely useful for temporarily holding epoxied seams together on repaired stalactites. Of course, copper wire should be removed as soon as the epoxy sets up, usually within a few days of application.

- Stainless is the best all-around metal choice for long-term applications in caves.

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What Size Support Pins?

Select pin diameter and length to fit the characteristics of the project. Determine the size of the pin according to the size and shape of the formation repair.

If you lack experience in bolt sizing, ask for help to decide the pin dimensions. Length depends on the application. We’ve used pins ranging in length from 2 inches up to 12 inches (about 5 to 30 centimeters). The smallest pin we’ve used is $\frac{1}{16}$-inch diameter (1.6-millimeter). The largest is $\frac{5}{8}$-inch diameter (1.5-centimeter).

If a speleothem is not likely to be vandalized again, use a short pin. The only real benefit a short pin provides is to prevent sliding from shear load while the epoxy cures. A longer pin provides additional strength.

When you have questions, seek consultation from cavers in construction trades, civil engineers, or those experienced in speleothem repair.

Repairs with Cement Products

Some cement products work well for some types of repairs in cave environments. Concrete is resistant to chemical and corrosive attack, has extremely good longevity characteristics, and introduces few toxins to most cave systems because the chemical composition resembles the natural composition of some rocks and cave passages. (See concrete, pages 169–170.)

If concrete products are chosen for speleothem repair projects, use high tensile strength cement with low-content calcium hydroxide. The calcium hydroxide in cement is very soluble—it will quickly dissolve, redeposit, and introduce new, unwanted “soda straws” or “flowstone” below or near cement-based structures or repairs. The concrete deposits grow at an accelerated pace compared to normal calcium carbonate speleothems. However, the concrete speleothem problem is reduced by using high tensile strength cement products that contain minimal amounts of calcium hydroxide. (See artificial fill removal, page 369; also see rimstone dam repair, page 476.)

Summary

Choose speleothem repair materials that are considered safe for cave environments. Archival-grade adhesives, stainless steel, and cement products with low-content calcium hydroxide are some of the best options. Contact trained interdisciplinary speleologists for review when other products or materials promise cave-safe qualities.
Choose Cave-Safe Speleothem Repair Materials
Jim C. Werker

Cave-Safe Archival Epoxy
- Epon® Resin 828 with Versamid® Curing Agent or approved equivalent.
  - Versamid® 40 for dry surfaces, even in humid conditions.
  - Versamid® 25 for wet, dripping, or underwater applications.
- Tetra® is currently replacing the Versamid products.
- Minimal harmful outgassing.
- Does not support growth of fungi.
- NOT just any ole' hardware store epoxy.

Pure Form of Fast-Acting Cyanoacrylate Adhesive
- Hot Stuff® Super T or Special T.
- Hot Stuff® NCF-Mild Accelerator (non-CFC).

Austenitic Stainless Steel Pins and Wires
- Stainless steel all-thread for stabilization rods and pins.
- Stainless steel wire.
- Other materials will expand and break speleothems. For example, steel pins will rust, expand, and discolor.

Cement
- Quik-crete® or quick-set cement.
- Form and sculpt by hand to match rimstone dams.

Use Cave-Safe Natural Materials for Coloring
- Grind cave rocks and mix with approved epoxy.
- Test soil or dust from the cave floor for color mix with epoxy.
- Try natural chalks to match unusual colors. Charcoals may work for matching dark colors.
- Avoid oil-based materials.

Test All Materials In Situ—Avoid Surprises
- Some products will grow fungi or introduce harmful nutrient sources for cave organisms.
- Test first. Some agents will become unstable in underground applications.