Materials Considerations for Cave Installations

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What materials are safe and cost effective for long-term use in the harsh environments of caves? Characteristics of common construction materials are described in this chapter. Emphasis is placed on materials that are considered corrosion resistant, tough, and readily available. Other exotic materials, though their characteristics may be beneficial to the protection of underground habitats, tend to be expensive, less available, and sometimes require special fabrication procedures.

Before planning and designing cave construction projects, evaluate the material options and fabrication requirements. Several reference manuals are especially useful when considering options.

- Machinery's Handbook (Industrial Press)
- Manual of Steel Construction (American Institute of Steel Construction, Inc.)
- Electrode Pocket Guide (Airco)
- Ryerson Steels Stock List and Data Book and Ryerson Special Metals Data Book (Joseph T. Ryerson and Son, Inc.)

Most materials reference books are updated regularly and contain useful information for any construction project. For example, Machinery's Handbook contains sections on types and properties of materials, welding specifications, and finishes. The strength of materials section in Machinery's Handbook provides simplified mathematical formulas to use in calculating material strengths.

Stainless Steels

Chromium–nickel austenitic steels are commonly known as stainless steels. Both names refer to the same family of steel materials. The corrosion resistance and toughness of stainless steels make them highly suitable for cave installations. The longevity of stainless is ten-fold that of mild steels. Even though stainless is more costly than other materials, it is increasingly used to replace wood and steel structures in caves.

Stainless steel life expectancy and corrosion resistance far exceed the characteristics of most other materials. Any of the chromium–nickel austenitic steels offer good characteristics for cave installations, however there are important fabrication requirements for these stainless steel materials.

There are a number of weldable chromium–nickel austenitic steels on the market. If the project is fabricated in a controlled, clean welding shop, any of the weldable austenitic stainless steels will work well. Find complete listings of the characteristics of austenitic steels in Machinery's Handbook. For austenitic stainless steels, welding requirements call for shielded gas metal arc welding processes to minimize the potential for carbide precipita-
Manganal®

A high-manganese, austenitic, work-hardening steel that is currently used in some cave gates is available under the trade name Manganal. Typically, the chemical composition is manganese (12.00–14.00%) and carbon (1.00–1.25%). Manganal bars, plates, and castings are used for high-impact industrial applications. Cost of these high-manganese materials tends to run two to three times that of mild steel (Stulz–Sickles Steel 2002).

Manganal is used in extreme wear conditions and is hardened by impact, hammering, and abrasion. This surface characteristic is known as work hardening. As this alloy work hardens, strength and resistance increase (Amodt and Mesch 2004). In other steels (for example, carburized or casehardened), the depth of hardness is fixed. When Manganal is subjected to wear, the surface toughens and the material remains ductile underneath.

Characteristics include high strength, ductility, toughness, and substantial longevity. Corrosion resistance (resistance to rust and attack by acids) is about the same as ordinary steels. Manganal is extremely tough when work hardened and may tolerate harsh environments. Functional mine rails made from this material are over 100 years old (Louis Arnodt, personal communication). Cave gates constructed of Manganal can deter vandals using hacksaws. However, power tools or cutting torches can breach the closures. Manganal is used for wear resistance in jail bars, bulldozers, scrapers, stone chutes, and military equipment.

Continuous high temperature can embrittle the high-manganese, austenitic steels. In electric arc welding processes, no local area should remain at visible red heat for more than two or three minutes. If there is build up with multiple layers from weld passes, the welder should either skip weld, or weld intermittently to reduce localized heat.

Manganal is a good choice for field fabrication if the high cost is justified. Preferred applications tend to be in remote sites where minimal acidic conditions exist and where vandals cannot easily use power tools. Manganal is durable and has excellent longevity characteristics.

Structural Steels

Because mild steels (structural cold-rolled steels) corrode quickly, these materials should be carefully evaluated before installing within cave environments. However, structural steels often provide cost-effective solutions for cave gates. When constructing cave gates, stainless steel life expectancy and corrosion resistance far exceed the characteristics of other steel materials. However, since repetitious vandalism is a key issue at some
cave sites, and since replacing stainless is expensive, cost may dictate the use of structural steel for gate construction. If the environment is too harsh for mild steels to survive, the site conditions may dictate that stainless be selected for its increased life expectancy.

The most common grade of structural steel (sometimes called mild steel) is ASTM A-36. The high-strength structural steels ASTM A-529 and A-440 have high carbon content for strength but they are no more durable than mild steels. Corrosion-resistant, high-strength steels have one advantage over the mild varieties in that they are more difficult to vandalize.

Mild steels are easy to fabricate, readily available, and cost less than most other options. Mild steel is available in a variety of structural shapes that are easily welded and fabricated in the field. For gate construction at cave entrances, the life expectancy is 50 to 100 years. However, within caves, the life expectancy of structural steels may be tremendously reduced by the environmental conditions, and habitat may be compromised by rapid degradation of the material.

Aluminum

Aluminum can deteriorate rapidly and the degradation may introduce toxins into cave habitats. For example, an aluminum ladder left in a cave located in the arid southwestern U.S. literally deteriorated to a pile of scrap in less than 20 years (Werker 2003). Aluminum carabiners left in caves for varying time intervals rapidly show signs of pitting and corrosive deterioration (Storage 1994). Aluminum will probably work for gates placed in dry, nonalkaline environments. However, aluminum is easy to vandalize because, generally, it is not as strong as steel.

When aluminum structures are exposed to the atmosphere, a thin, invisible oxide skin forms immediately and protects the surface from additional oxidation. This self-protecting characteristic gives aluminum its high resistance to corrosion unless it is exposed to some substance or condition that destroys the oxide coating. Alkalis are among the few substances that will attack the oxide skin—thus, the alkaline conditions of most limestone caves will cause aluminum to corrode.

When aluminum is placed in direct contact with other metals, the presence of an electrolyte (moist conditions or high humidity) will cause galvanic corrosion of the aluminum at the contact points. Dissimilar metals in direct contact with each other within a moist environment will definitely induce corrosion.

If dissimilar metals are already in place, nylon or neoprene washers can be used to separate or isolate the materials from each other and delay the corrosion. (A moisture film may eventually form across barriers and corrosion will continue.)

Depending on the site conditions, protective coatings may increase the life expectancy of aluminum. Chromate coating can be brushed on in the field, but anodizing must be done at a coating lab. However, once any kind of coating is breached by a scratch or nick, the integrity of the surface is compromised and the electrochemical process begins to produce pitting and deterioration as the metal corrodes (Spate and others 1998).

Because aluminum is especially susceptible to both vandalism and corrosion, it is usually a less desirable material for cave applications.

Concrete

Concrete works well in most environments. It is resistant to chemical and corrosive attack and has extremely good longevity characteristics. Structures
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Figure 1. These aluminum carabiners were left on a traverse in Virgin Cave, New Mexico. After only six months in the cave, pitting and corrosion was abundant. Material strength was greatly reduced, and some of the biner gates no longer closed. Stainless steel carabiners are recommended for long-term use in cave environments. (See page 6 of color section.)

built with 3,000 psi (20,680 kilopascal) concrete reinforced with rebar will deter vandals and will hold up for many decades in most circumstances. The chemical composition of concrete resembles the natural composition of some cave passages and it introduces few toxins to cave systems. Cement, which is basically burned limestone, is also known as Portland cement. Sand, gravel, and water are added to cement products to make concrete.

An Australian paper by Spate and others (1998) recommends applying a protective membrane between natural floors, rock, or flowstone before pouring concrete. Also, fine sand is recommended for covering microgours and sharp surfaces and can be vacuumed away if the concrete is removed in the future.

If concrete is chosen for cave projects, use high tensile strength cement with low-content calcium hydroxide, which will last longer in most cave environments. The calcium hydroxide in cement products is very soluble and it will quickly dissolve and redeposit to form new “soda straws” or “flowstone” below concrete structures (Horrocks and Roth 2006, page 369 in this volume). (For additional information on cement choices, see the speleothem repair section (page 476).

Culvert and Pipe

Culverts and pipes installed as cave access structures can be made from a variety of materials. Several material types are addressed below. Be aware that culverts or pipes may not be the best option for protecting bat colonies and habitats for other animals. Small diameter flyways and absence of natural barriers can set the stage for easy predation. Culverts and pipes can change the natural airflow of a cave, alter air temperatures and relative humidity, and impede or increase the presence of biota. However, where cave entrances have been enlarged for human access, a culvert may provide the best protection.

Galvanized Steel

For decades, galvanized steel culvert has been used in roadway construction where it seems to function well. However, in caves, galvanized culvert may deteriorate rapidly. For example, a galvanized culvert installed in Lechuguilla Cave in 1986 showed visible signs of degradation by 1994, and had severely deteriorated by the time it was replaced in 2000 (Werker
As the zinc coating of galvanized steel degrades, it may generate toxins that are harmful to flora, fauna, and perhaps to speleothems (Jameson and Alexander 1996; Spate and others 1998). Welding galvanized material results in noxious fumes that can be hazardous to human health and cave-dwelling animals. The breakdown, outgassing, and deterioration of galvanized steel culvert result in byproducts that may be especially toxic to bats and other cave-dwelling biota.

**Plastics**

Little is known about the degradation processes of plastics that are used in cave environments. Polyvinyl chloride (PVC) used in water lines and air conduits tends to become brittle over time. PVC also outgasses potentially harmful substances. Until studies further define the longevity and degradation characteristics of PVC and various plastics placed in subterranean environments, other construction materials are preferred for cave use.

**Recycled Materials Developed for Environmental Use**

Advances in fabrication technologies have provided recycled construction products that are intended to be environmentally friendly. These materials are generally designed for aboveground applications. Time will tell how well these products endure subterranean environments. Timpanogos Caves National Monument, Oregon Caves National Monument, and various other sites are using products made from recycled materials for in-cave installa-
All products will break down over time, but archival products are formulated to do less harm than those on the general market.

Archival Epoxies and Adhesives

All glues break down over time. Many epoxies and adhesives are known to be composed of detrimental materials and display degradation characteristics that will destroy or harm biota.

Any new product should be checked by research chemists and biologists who understand the cave environments where use is proposed. What are the components of the agent and how will the degradation and outgassing characteristics of those compounds affect cave-dwelling biota, ecosystems, chemistry, water quality, or the minerals of a cave system? Arrange for a chemist or a materials engineer to evaluate long-term degradation and potential chemical interactions. Get the federally regulated Material Safety Data Sheets (MSDS) and understand recommended safety precautions. Wise product choices for cave environments are based on thorough research. Updated information is often available on the Web. (See MSDS, page 70.)

Epoxies, bonding agents, and quick glues found in neighborhood hardware and variety stores are certainly easier to obtain than the archival-quality adhesives, but the mass market products can introduce toxins and nasty agents into caves. All products will break down over time, but archival products are formulated to do less harm than those on the general market.

To augment safe travel in caves, stainless steel bolts are sometimes installed. For outdoor applications, adhesives have been used in the installation of climbing bolts. However, an archivial-grade epoxy may be the best choice for installing bolts in cave systems because most consumer epoxies have not been studied in underground environments.

When adhesives are necessary, use archival products, museum-grade epoxies, or pure forms of cyanoacrylate adhesives. All products will degrade over time, but some compounds are formulated to be more archival than others. The following recommended adhesives, used in subterranean applications over the past several decades, appear to be relatively safe for long-term use in cave environments.

**Epon 828® With Versamid® or Epi-cure® 3234 (TETA)**

- Epon 828 epoxy has been successful in underground environments for decades.
- Epon 828 epoxy resin combined with Versamid 40 curing agent works for dry surfaces, even in humid cave environments.
- For wet applications, Versamid 28 hardener cures 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 pounds per square inch—6,000 psi (41,370 kilopascal).
- Curing time can take 24–72 hours and sometimes longer. Shrinkage is minimal. The bond is resistant to a broad range of chemicals.
- Mixing ratio is typically 1:1—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.
- Epon 828 and the Versamid hardeners were lab tested for long-term underground use at the US Department of Energy Nevada Test Site and have proved successful in cave applications for several decades.
- These products are available from the Shell® Chemical Company and through local chemical or plastic product suppliers. However, the Versamid curing agents are increasingly difficult to locate and fabrica-
tors in the plastics industry are recommending a replacement Shell product, Epi-cure 3234, which is a highly concentrated curing agent with bonding properties and archival characteristics similar to Versamid.

- Epi-cure 3234 (TETA) is now the recommended curing 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, helicitites, thin draperies, and other delicate speleothems or small applications in caves. Hot Stuff adhesives are industrial-strength products containing a very pure form of cyanoacrylate that remains clear when it cures. Oil is not added to lengthen shelf life (as it is in many other instant glues).

- Hot Stuff Super T is often used in paleontological applications and model-building and works well for small repairs in caves.
- Hot Stuff Special T is a more viscous product, formulated to fill in gaps and is extremely useful for cave applications.
- In most caves, Hot Stuff cures in 30–90 seconds, but bonding can be accelerated with NCF-Mild Accelerator. 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 Hot Stuff NCF-Mild 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 catalogs, and through a few sources on the Web.

**Finishes and Paints**

Finishes applied to the surfaces of materials are intended to enhance longevity but may introduce contaminants to cave environments. All paints and finishes deteriorate over time. Flaking onto the habitat floor is obviously detrimental, but there are more subtle degradation characteristics. Outgassing and chemical deterioration of finishing products may introduce potentially toxic materials to cave systems. Increased corrosion may be generated if a paint layer is compromised—severe corrosion may result when an electrolyte, perhaps a simple film of moisture on a scratched finish, reacts with the large metal anode area under the paint (Spate and others 1998). Research is needed to investigate the potential benefits and harms of various finishes applied to installations within caves and near cave entrances.

**Common Sense**

Function and cost are important components of materials selection for cave environments. Characteristics of materials and finishes are vital factors in any design and planning process. Assessment of site environmental conditions and evaluation of longevity criteria are essential to project planning. For each material historically used in caves—stainless steels, Manganal, mild structural steels, concrete, aluminum, galvanized steel, plastic products, epoxies, adhesives, paints, and other finishes—there are beneficial as well as disadvantageous characteristics. Specific knowledge about species that use the cave, habitat requirements, chemical compositions within the cave, and general common sense must dictate design and material selection.
The arduous tasks of investigating the multitude of material choices, evaluating their varying characteristics, analyzing the costs, considering the potential for vandalism, and understanding the inherent longevity of the materials may appear overwhelming. First, evaluate the site, the habitat, and the purposes for any structure or installation. Simplify the goals, state the site objectives, and then allow common sense to dictate material choices and construction techniques. When planning projects to protect caves, the priority is to be realistic about the habitat, the site requirements, and the budget. Keep it simple and remember that opting for no construction is sometimes the best decision.

Cited References


