CHAPTER 2 – REVIEW OF POLYURETHANE AND EPOXY GROUTS

The study was focused on the use of polyurethane resin (PUR) injection techniques for stabilizing rock slopes, unique rock features, historic retaining walls and other features/structures where minimizing visual and aesthetic impacts is required. Typically these features have been stabilized using rock bolting, ground anchors and other invasive methods that can diminish the historic nature and/or visual quality. To evaluate PUR products it is necessary to also review and compare the other related polymer products such as single-stage polyurethane mixes and epoxy resins.

There are tens of thousands of different combinations and component mixes of polyurethane (PU), polyurethane resin, and epoxy resin. Due to the multitude of component mixing options, it is sometimes difficult to distinguish PU from PUR products when evaluating different vendor products. To further add uncertainty, vendors commonly interchange the terms PU and PUR. General characteristics broadly define separate types of polymers, including density, strength, number of mixing stages, and reactivity with water. In order to fully compare PU, PUR and EP products it is necessary to understand how the products interact with water and what types of component mixing are typically done to prepare the product for injection. For PUR applications, this document provides special contract requirements in Appendix A, specifying both physical property and installation requirements.

WATER INTERACTIONS - HYDROPHILIC vs. HYDROPHOBIC

When evaluating an epoxy or polyurethane product it is important to determine the effects of the presence or absence of water for the application. These products are typically categorized as either having hydrophilic or hydrophobic water interaction properties.

Hydrophilic products will foam in the presence of water. The product incorporates water into the chemical structure and will shrink and swell indefinitely depending on the groundwater conditions present. Hydrophilic products can expand from approximately 25% to 3,000%, and/or elongate approximately 10% to 500% depending on the type of product and availability of water. Upon drying, hydrophilic products can also shrink in excess of 10%. The shear strength of the foamed product is significantly less than denser hydrophobic products. Since the interaction of groundwater dramatically affects the strength and effectiveness of the product, the hydrophilic polyurethane grouts are typically used for sealing and creating barriers to groundwater flow. The hydrophilic products also perform better if they do not dry out. If they dry out completely, they typically shrink and crack allowing water to transmit past the seal.

Hydrophobic products are less likely to react with water; however, these products may still have expansion and elongation properties similar to hydrophilic products. In general, the hydrophobic products are less affected by the interaction with water than the hydrophilic products (i.e. less foam), which results in a final product with greater shear strength and higher density. Hydrophobic products are also considered less likely to shrink in the absence of water.

Epoxy grouts are the only products reviewed in this study that are truly hydrophobic, neither shrinking nor swelling in the presence of water.

Depending on the application, interaction of the product with water and subsequent foaming is often necessary to insure that the grout is permeating the fracture or void. The foaming products generally permeate well into moist or water filled fractures and/or discontinuities without drastically increasing pumping pressures. Epoxy products generally have to displace the water, and will not as effectively permeate water-bearing structures. The required pumping pressures are also increased in hydrophobic products since the head pressure of the water has to be overcome to inject the product into the fractures or voids.

SINGLE-STAGE INJECTION SYSTEMS

Polyurethane (PU) products generally only require a single-stage mix component with an accelerator added to set the reaction time. Set-times can vary widely, ranging from 15 seconds to several hours. Single-stage PU products, using foams or gels, are commonly used for crack repair, void filling, consolidation of weak substrata, and groundwater contaminant flow barriers. The single-component system, generally pumped at low pressures, greatly simplifies the injection process and equipment requirements. Injected PU densities range from 0.5 kN/m^3 to 7 kN/m^3 (3 lb/ft^3 to 50 lb/ft^3). PU applications are less technically demanding than the two-component systems, but may foam extensively in the presence of water. When the product foams, the shear strength of the material dramatically decreases.

TWO-STAGE INJECTION SYSTEMS

Polyurethane resins (PUR) and epoxy resins (EP) most commonly fall within the category of a two-stage mix component system. As with PU products, reaction set-times can also be varied from seconds to hours depending on the application and temperature. In general, the two-stage mix systems are associated with products that have greater compressive and tensile strengths than single-stage mix systems.

In underground mining applications, caving or failing ground sections require high product strengths early in the application. Fractured, incompetent rock strata are injected under pressure with two components at a 1:1 ratio forming an elastomer commonly known as “glue”. This process provides supplementary support of weak areas and structures. Densities for this type of product generally range from 3 kN/m^3 to 11 kN/m^3 (20 lb/ft^3 to 70 lb/ft^3), with high compressive, flexural, shear and torsional properties that can exceed 70 MPa (10,000 psi). Initial set times are on the order of a few minutes, with final resin cure within 1-2 days.

TOXICITY AND ENVIRONMENTAL ISSUES WITH POLYMER PRODUCTS

PU, PUR and EP products are considered inert and chemically stable in a cured form. However, depending on the formulation, PUR products that have isocyanate-based grouts have the potential to be moderately toxic in an uncured form. The solvents used to dilute and control the viscosity of the urethane prepolymers may also have the potential to contribute pollutants to groundwater sources. There may be additional safety issues related to combustion products if the grout is exposed to flame. Some grout mixtures are highly flammable before and after setting; however, injected products are generally well protected within natural rock or man-made structures.

The PUR used in this study consists of two components: polymeric isocyanate (component A) and polyol resin (component B). Polymeric isocyanate is an irritant to skin, eyes and mucous membranes and my cause an allergic reaction if inhaled. Conversely, polyol resin may produce a slight skin irritation, but is generally considered a low toxicity hazard. To avoid contact with the individual components, they should both be contained within separate 208-l (55-gal) drums that are clearly labeled and connected to a closed pumping system. In an outdoor setting and closed pumping system, the two PUR components did not appear to pose any significant health concerns during the demonstration projects. Final curing of the mixed components, which can occur in just a few minutes, results in an inert, non-toxic final product.

Two main environmental factors that may affect the performance of PUR products include ultraviolet light (UV) degradation and microbial attack. For the purposes of this report, it is assumed that all or a great majority of the product would be injected within a structure or groundmass and, therefore, would not be affected by sunlight. In addition to UV susceptibility, the literature review indicated potential fungi-related biodegradability issues with polyester-based PUR products. No polyester-based products were evaluated in this study.

Excessive PUR foaming may also be an issue in certain applications. As previously noted, PUR products commonly foam when encountering water. In some cases, foamed PUR may noticeably extrude from the treated area; however, cleanup can easily be managed at the time of application.

TEMPERATURE CONSTRAINTS

PUR products have typically been used in underground settings subject to constant air and rock temperatures. Wide variations in application temperature will greatly influence injection processes and overall product performance. In general, PUR products should be injected at an ambient air/structure temperature between 13^{o} and 32^{o} C (55^{o} and 90^{o} F) as shown in Figure 2. If the product is installed above or below this temperature range, the resin viscosity, shown in centipoise (cps), and set times will be greatly affected: failing to penetrate narrow fractures if too cold, or “flash setting” in the mixing nozzle/delivery rod assembly during injection if too hot.

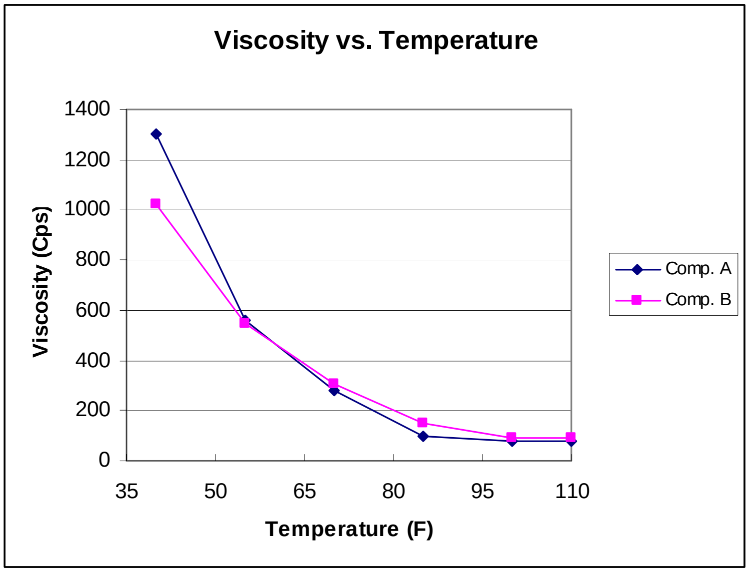

Figure 2. Graph. Representative Viscosity vs. Temperature relationship for isocyanate and polyol resin components for a typical PUR product (Source: Micon).

COMPARISON OF PU, PUR, AND EPOXY

Polymer injection products in this report have been divided into three classes: polyurethane (PU), polyurethane resin (PUR), and epoxy (EP). Based on a review of the available literature and a limited industry survey, PUR is predominately used for "gluing" and consolidating weak roof strata in underground coal mine applications. The single-stage PU products are used mostly for water-stop applications, where high shear strength is not required. The PU products generally foam in the presence of water and, as a result, lose strength and density; however, in many cases the product strength is still much greater than the surrounding material. The EP products are used primarily for structural foundations that are dry, and where only small product quantities are required. EP products are commonly injected with low-pressure pumps that have surface ports attached to a dry surface. Table 1 provides relative comparisons between PU, PUR and EP.

Table 1. Relative comparison of PU, PUR and EP.

Property	Polyurethane (PU)	Polyurethane Resin (PUR)	Epoxy (EP)
Component Mixing	One-Stage	Two-Stage	Two-Stage
Injection Type	Foam/Gels/Grout	Grout	Grout
Injection Pressures	Low to High (100 to 3,000 psi)	Low to High (10 to 3,000 psi)	Low to Medium (30 to 800 psi)
Density	Low to Medium (3 to 50 pcf)	Medium to High (20 to 70 pcf)	Low to High (5 to 60 pcf)
Compressive/Tensile Strength	Low (10 to 500 psi)	Low to High (15 to 20,000 psi)	Medium to High (5,000 to 20,000 psi)
Viscosity	Low to Medium	Low to High	Very Low to High
Water Interactions	Hydrophilic	Hydrophilic/Hydrophobic	Hydrophobic
Expansion/Elongation	Varies (10% to 3,000%)	Varies (10% to 3,000%)	Minimal
Shrinkage	Varies (1% to 10%)	Varies (0% to 3%)	Minimal
Relative Product Cost	Low	Mid to High	High

It should be noted that Table 1 provides a relative comparison of products; there are always exceptions, and products can be manufactured with different component mixes to address a broad range of applications. The intent for this section is to provide a brief background and comparison of the products that are used in stabilization of ground or structures.