Highlights of Some Selected Repair Grouts with Special Emphasis on PU Grouts

(Extracted partly from www.avantigrout.com/files/literature by David Magill with Richard Berry; "Guide for the Selection of Materials for the Repair of Concrete", ACI Committee 546; http://concretemonthly.com/monthly/art.php? 3104, Polyurethane Chemical Grouting"by Scott Kelly,March 2008 of Concrete Monthly)

The following types of grouts are generally used in concrete repair:

- Cementitious Grout
- Polymer-cement Grout
- Epoxy Grout
- Polyurethane Grout

Cementitious grout

A grout is a mixture of cementitious material and water, with or without aggregate, that is proportioned to produce a pourable consistency without segregation of constituents (ACI 116R).

Cement-based grouts are available in a wide range of consistencies; therefore, the methods of application are diverse. These materials are perhaps the most economical of the choices available for repair. They do not require unusual skill or special equipment to apply, and are reasonably safe to handle. These materials tend to have similar properties to the parent concrete, and have the ability to undergo autogeneous healing due to subsequent hydration of cementitious materials at fracture surfaces. Cement-based grouts are not suitable for structural repairs of active cracks.

Cementitious grout may be used to repair cracks that are 6 mm and greater in width. Generally, some form of routing and surface preparation, such as removal of loose debris and prewetting to achieve a Saturated-Surface-Dry (SSD) condition, are required to obtain the minimum required width and suitable substrate appropriate for the use of these materials.

One of the most common uses of cement-based grouts in crack repair is to simply provide a fill for the crack before the application of a coating. While grouts are generally mixed to a pourable consistency, as stated previously, the consistency may be adjusted for application by hand troweling or dry packing into vertical and overhead cracks.

There are no standards developed strictly for grouts used for crack repair. ASTM C 1107 (Specification for Packaged Dry,Hydraulic-Cement Grout of Nonshrinkable) is intended for materials used under applied loads such as base plates for a structure or machine.

Polymer-cement grout

Polymer-cement grout is a mixture consisting primarily of cement, fine aggregate, water, and a polymer such as acrylic, styrene-acrylic, styrene-butadiene, or a water-borne epoxy. The consistency of this material may vary from a stiff material suitable for hand-packing large cracks on overhead and vertical surfaces to a pourable consistency suitable for gravity feeding cracks in horizontal slabs. These materials are available in a wide range of consistencies suitable for many applications. No special tools and equipment are necessary, and the required applicator skill levels are low to moderate. These materials are generally more economical than polymer grouts, and the performance, with respect to bond strength, tensile strength, and flexural strength, are improved compared with cement-based materials that do not contain any polymers.

The potentially high shrinkage of polymer-cement grouts may make it difficult to obtain a watertight repair. Additionally, these materials are chemically resistant.

Polymer-cement grout is generally used to repair cracks that are 6 mm and greater in width. The surface should be prepared to ensure a clean, open-pore substrate.

The substrate should be in a saturated-surface-dry (SSD) condition, with no standing water at the time of application. Mixing may be done using a drill and paddle or a mixer. The material should be scrubbed into the substrate to fill all pores and voids, and then packed into the crack and finished flush with the concrete surface. The polymer component should conform to the requirements of ASTM C 1438 (Specification for Latex and Powder Polymer modified for Hydraulic Cement Concrete and Mortar), Type II. No standards exist for mixtures of the polymer component with grout; however, recommended tests for these materials are found in ASTM C 1439 as well as ASTM C157/ C157M(Length Change), C 293(Flexural Strength of Concrete), C 469(Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression), C 496/C 496M(Splitting Tensile Strength of Cylindrical Concrete Specimens), and C 531(Linear Shrinkage and Coeffficient of Thermal Expansion of Chemical-Resistant).

Epoxy grout

Epoxy grout,also known as Polymer grout, is a mixture where the polymer, such as an epoxy resin, serves as the binder, and where sand, usually an oven-dried silica with a grading from 0.8 to 0.4 mm (No. 20 to + 40 mesh) is the filler and a curing agent some times called hardener.

The curing agent selection plays the major role in determining many of the properties of the final cured epoxy. These properties include pot life, cure or drying time, penetration and wet-ability. Curing agents come in many different chemical flavors, all based on amines or amides.

The consistency of this material may vary from a stiff material suitable for hand-packing large cracks on overhead and vertical surfaces to a pourable consistency suitable for gravity feeding cracks in horizontal slabs.

Epoxy grouts bond extremely well to concrete and have low shrinkage, resulting in a liquid-tight repair in dormant cracks.

Epoxy resins are also injected for repair of hair line cracks and fissures due to their unique property of super low viscosity.Injection can be made of low pressure or high pressure system depending on the nature of cracks.It is advisable to use two-component pumps with a static mix head to prevent premature reaction.

Epoxy injection for repair of crack

Travels and exists through the port

Generally epoxy resins will have either good chemical resistance or good heat resistance, but not both. Another characteristic of this type of product in its cured state is the lack of flexibility, and the system might be prone to failure if movement occurs due to seismic activity, and or expansion/contraction. Epoxies are almost totally UV resistant. The two-component epoxy resins have better expansive properties than some hydrophobic type products.

No standards currently exist for polymer and epoxy grouts intended for use as crack repair. ASTM C 882 (Bond Strength of Epoxy-Resin system used with concrete By Slant Shear), D 638 (Tensile Properties of Plastics), and D 695 (Compressive Properties of Rigid Plastics) are among the recommended tests to consider when evaluating these materials.

Polyurethane grout

Polyurethane grouts are usually used to repair cracks that are both wet and active, or that are leaking a significant amount of water. These grouts are semi flexible; thus, they may tolerate some change in crack width. The reaction time to form the foam may be controlled from a few seconds up to several minutes using different catalyst additives.

For example, where a crack is leaking heavily, the polyurethane chemical grout reaction may be highly accelerated to stop the leak. These grouts penetrate effectively, and the technique of chemical grouting is a well-proven method of repairing cracks.

Polyurethane grouts generally are not suitable for structural repairs. Additionally, a highly skilled work crew is required along with special injection equipment. Finally, these materials typically are not stable when exposed to UV light. This is usually not a major concern because the material is injected into a narrow crack where exposure to UV light is minimal.

Pneumatic injection equipment

Hand operated injection gun

Polyurethane grouts may be used to treat cracks that are 0.12 mm and greater in width. These materials are injected at high pressures. In contrast to epoxy resins that are suitable for dormant, dry or damp cracks, polyurethane grouts are suitable for injection of vertical, overhead, and horizontal cracks that are active or leaking. These characteristics make them particularly suited for vertical, overhead, and horizontal applications, and it is their ability to stop active leaks that makes them particularly well suited for tanks for the storage of liquids, dams, tunnels, sewers, and other water-containment structures.

No standards currently exist for polyurethane chemical grouts. ASTM D 1623 (Tensile and Tensile Adhesion

Properties of Rigid Cellular Plastics) may be used to determine the tensile strength and elongation properties of the grout at all urethane-to-water ratios.

Although there are other forms of chemical grouts, polyurethanes are by far the most common choice of material for repair of cracks by chemical grouting, and are classified into hydrophobic and hydrophilic types. Polyurethane chemical grouts consist of a polyurethane resin that reacts with water to form an expansive, closed-cell foam (hydrophobic types) or gel (hydrophilic types). Hydrophobic types are generally recommended for applications subject to intermittent wetting and drying; hydrophilic types should be continuously wet (USACE EM 1110-1-3500).

Hydrophilic grout systems

Description

Hydrophilic - Latin (hydro) = Water and (philic) = affinity. Hydrophilic expansive grouts react upon contact with water, absorb water while curing, and cure to a flexible foam or gel. The reaction time is typically 30-45 seconds for foams and 12- 15 seconds for gels. They are generally used to seal leaks in joints or cracks and to repair leaking water-stops. Hydrophilic expansive foam grouts chase and absorb the water in the crack and in all of the fractures that branch off from the main crack. A key characteristic of any liquid is its viscosity (cps) compared to water. Water has a cps of 1, where hydrophilic expansive grouts could range from 300-2500 cps. The lower the cps (the lower the viscosity) of any hydrophilic expansive grout the better suited for tighter cracks (for better penetration) and for applications that might require greater travel. The higher the cps (the higher the viscosity) of any hydrophilic expansive grout the better suited for high flow/high volume applications so as not to become diluted. The grout prepolymer is usually mixed with water at ratios of 6:1, 8:1, and up to 12:1 to obtain a gel ranging from firm to weak.

Applications

Hydrophilic expansive foam grouts have an initial cure and final cure. The initial cure is the time it takes for the polyurethane grout to foam up, and the final cure is the time it takes for the grout to fully expand. This final cure time, which may take up to 12 hours, is critical to the success of the grouting process. Hydrophilic foams have been successfully used in above grade as well as below-grade applications, but hydrophilic gels should be used below grade as they will shrink in a dry environment.

Hydrophilic expansive PU foam

PU injection

Hydrophilic expansive foam grouts are typically single component products requiring small delivery systems for the injection process. These types of grouts are used in below grade structures, basements, and other areas that are often wet, such as subways and interior portions of a concrete dam. Pumping systems for hydrophilic foam grouts tend to be high pressure and low volume, while the gels utilize high volume and lower pressure systems.

Most polyurethane grouts are considered to be “non toxic” although safe handling procedures should be closely followed with these and all other chemicals.Some hydrophilic foam grouts are certified to be used with potable drinking water systems.

The expansion rate of hydrophilic foam grouts can be up to 5 to 8 times its original volume, and hydrophilic gels typically do not gain volume upon curing rather they shrink after cure in the absence of water.

Limitations

Hydrophilic expansive foam grouts stick to concrete and stretch in a moving crack and are generally used in crack sealing or filling voids in joints or void areas in sewers and other underground structures. Hydrophilic gel grouts will not stick to concrete and are not recommended for moving cracks. They are used for sealing sewer joints and manholes, and other underground applications. Due to their relatively short gel times and high viscosities compared to the acrylics, they are usually not used in sealing lateral sewers with remote lateral packers.

Hydrophobic grout systems

Description

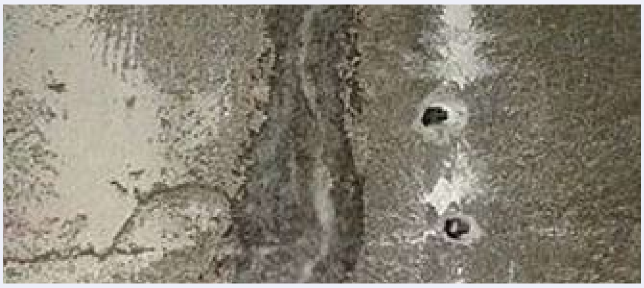
Hydrophobic - Latin (hydro) = water and (phobic) = fear. Hydrophobic resins are water activated systems that require roughly 4% water to start the chemical reaction upto a maximum dosage of 10% by volume.The reaction time is 10 to 12 seconds.They have expansive qualities, ranging from 6 times up to 29 times expansion in volume and are generally referred to as "foams", sometimes as rigid foams. Due to the low water content they are considered non-shrink, as the foam matrix has so little water that even in extremely arid conditions they will maintain their cured form. One of the other characteristics is that they are controllable. Unlike hydrophilic, they have an additive that is referred to as an accelerator as it allows the applicator to control their cure time from 1 to up to 10 min. The accelerator is not to be confused as a catalyst as it does not start the reaction, but allows it to be controlled. Before the reaction can begin, the accelerated resin must still come into contact with water to start the reaction.

Two-component systems can have high expansive properties with many of them capable of curing to a foam density of 96 kg/m^3. Unlike the hydrophobic or hydrophilic systems, they do not require water as a catalyst as the reaction is started when resin comes into contact with hardener in a static mixing tube. They are generally much faster reacting systems and can reach up to 25 times expansion in as little as 7 to 10 seconds. With the high expansion rates and extremely fast reaction times, they can have the potential to move structures and require extreme care when using.

Applications

Typical applications include sealing cracks/joints, creating a water impenetrable barrier between the backside of a structure and the soil matrix from the negative side. Hydrophobic foams can also be used to fill voids or abandoned underground pipes, vaults, tanks, etc. A major advantage to sealing active leaking cracks/joints is that material is water activated as opposed to most materials that require the water intrusion to be eliminated before the repairs can be done. The cured resin is designed to accept movement, allowing the materials to be successful in applications subject to movement due to seismic activity, contraction/expansion or movement designed into the structure where a rigid material like epoxy is prone to failure.

Hydrophobic foam injected in a basement pool



PU injection in a canal

Many below-grade structures start out with a membrane installed on the positive side as waterproofing. While these systems have proven to be effective, they, like many others, have a lifespan anywhere from 15 to 30 years. Once the systems lifespan is exceeded the owners are faced with the costly replacement that includes excavating to expose the failed system, removing and replacing. With the polyurethane systems a series of holes are drilled through the structure from the negative side and the resin is injected to create a monolithic barrier between the backside of the substrate and the soil. This application provides a long-term repair at a considerable savings.

Limitations

As with all materials, Polyurethanes also have limitations. Hydrophobic polymers usually have better chemical resistance. To insure proper cross-linking during the reaction, water should be tested to insure a pH level of 10 or less. A pH close to neutral (7) produces the most ideally cured polymers. A pH below 7 slows down the reactivity and too far below 7.0 will "kill" the reaction. Higher pH will increase reactivity up to a pH 8-9, but after that will begin to degrade the quality (the water holding ability) of the cured polymer as the pH increases. Recall that pH 7 is neutral and as the pH falls exponentially toward 1, it becomes a stronger acid. As the pH climbs above 7, the same is true for increasing alkalinity up to the maximum of 14. While a water temperature of 10^{o}C or higher is preferred, the materials have been successfully used with water temperatures near freezing. Below 10^{o}C the material will steadily decrease its cure rate as well as its physical characteristics, and once the water begins to crystallize, the resin cannot absorb it and the reaction will not occur.

Hydrostatic pressure has similar effects on the resins. Starting at one atmosphere, the material reaction time as well as the expansion and swelling begins to lessen, and after 10 atmospheres they will still react, but at an extremely slower rate and without any expansion or swelling. The water/diisocyanate reaction creates carbon dioxide and hydrostatic pressure controls the amount of CO_2 that can dissolve into the water column. High pressure and colder water temperature will produce the least amount of foaming in the cured polymer while lower pressure and warmer water increase the foam yield. Grouts that reacted on a "desktop" at room temperature without any containment form the maximum amount of CO_2 hence the larger amount of cured foam. High concentrations of hydrocarbons will not allow proper cross-linking of the molecules and the material will not react. Hydrophobic foams tend to be rigid and some will not stretch, meaning they are not the best product for a moving crack. All urethanes are adversely affected by UV rays and high temperatures, say in excess of 93^{O}C.

Knowing the basic differences in hydrophobic and hydrophilic chemical grouts is a crucial step in making the correct choice of repair material.

What to Do and What to Avoid

If a leak repair project involves a non-structural defect in a concrete or masonry structure, a hydrophilic chemical grout should be used to seal the leak unless job conditions dictate otherwise.

Gels should be used only in below grade structures where either moisture from the interior (like in a manhole) or from ground water is present to keep the cured gel hydrated. Gels will shrink if water becomes absent, but provide a low-cost alternative to foams.

Foams are appropriate for above grade or below grade installation. They are typically 85 percent air filled after cure and have excellent elongation, compression and rebound for use in expansion joints,cracks, or any other non-structural defect in concrete structures.

The aggressive expansion of hydrophobic chemical grouts should be utilized if repairing a gushing leak that is impractical to repair with milder expanding hydrophilic resins. In below grade structures, this is a good way to fill voids that may be present outside the structure. Once the leak is reduced to a manageable level, hydrophilic resin should be injected into the defect to back up the hydrophobic material.

Hydrophilic gel should be injected into gushing leaks neat or with a 1:1 water-to-resin mix ratio to shut down gushing leaks. This is a case where as much material as possible can be pushed in as fast as it can be. If a high volume pump is available, less material will be used to stop the leak because it reduces the dilution of the resin in the mass of water source.

Installing gels should be avoided in expansion joints or cracks that are subject to movement. Gels form a solid material with little or no cellular structure to disperse tension under compression. This tension can split the gel and damage the seal.

Installing hydrophobic chemical grouts should be avoided for repairing minor leaks in cracks or joints. The repair will be temporary.

When repairing tight cracks and minor leaks one should not be in a hurry. These can be the most difficult to repair long term.

Testing of Polyurethane Grouts for Leak Control in Concrete Facilities

Polyurethane is used in civil engineering applications such as coatings, adhesives, concrete repair materials and joint sealants. Polyurethane is also increasingly used in hazardous and non-hazardous waste treatment and containment technology. When done correctly, polyurethane grouting can ensure a permanent repair/rehabilitation, but incorrect grouting can cause many problems. Also grout has to set within the cracked space under confined condition and various pH environments. Hence grout tests should consider some of these factors. The construction/repair market for polyurethane is expect to grow even further in the coming years. Lack of standard testing procedures for foam, gel and rigid polyurethanes in civil engineering applications makes it difficult for the design engineer to select this material.

Conclusion

As our infrastructure ages, chemical grouting will continue to maintain its value as one of the easiest,most cost-effective and longest-lasting repair solutions available. If the right polyurethane chemical grout is chosen for your repair project and the correct installation techniques are used, the repair will actually outlast the structure.

*For crack repair with PU and epoxy injection refer our "Rebuild" Volume 4 (October-December 2007), page 7-10.