



ReBuild

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Dr. Fixit Institute of Structural Protection & Rehabilitation

A Not-for-Profit Knowledge Centre

Grouts and Grouting

Grouting materials are some of the most complex systems that an engineer encounters as it is necessary to control not only the fluid properties but also the set properties and to place the material into a void which may be of complex shape or into ground which may be heterogeneous. The void is generally out of sight so that the operator has to rely on his experience to design and execute the grouting system and to assess what actually happens at the time of execution. The use of the grouting materials requires an understanding of the following aspects:

- The nature of the void / void system to be grouted.
- The intrinsic properties of the grout to be used including its health and safety requirements.
- The on-site preparation and QC procedures.
- The fluid properties of the grout including its behaviour during and after injection.
- The properties of the hardened grout.
- The test methods for the hardened grout.
- The durability of grout.

Although there is some guidance available from the suppliers, the physical and chemical properties of this class of material are still poorly understood and the experience of the grouting experts turn out to be the most valuable at site.

There are different classes of grouts, as we all know. By and large, they fall into three broad categories: cement-based structural grouts, geotechnical grouts containing cement & replacement materials and special chemical grouts. An essential feature of all grout systems is that they must be sufficiently fluid to be injected into the void to be grouted and must set to a solid after injection.

This ultimate requirement depends on a host of properties, the more important ones being the following:

- Rheology
- Penetrability
- Bleeding
- Filtration
- Bleed and filtration in combination
- Escape of water
- Injectable time
- Set time

There are certain test procedures evolved through experience to study the above properties.

In addition, properties like volume change, drying shrinkage and durability often become crucial in actual operations.

The setting of grouts may be based on many different chemical reactions involving different binders such as Portland and non-Portland cements, sodium silicate, sodium aluminate, polyacrylamides, polyacrylates, polyurethanes and a wide range of resins and, hence, the costs involved also vary. Ultimately, the balance of cost and performance becomes a prime consideration.

Volume change is a critical parameter especially in chemical grouts. It is not possible to consider all the volume change mechanisms that may occur in chemical grouts. However, one process, called syneresis, merits attention. Syneresis is a general term for processes, other than gravity driven separation of solids, occurring within the grout mass which cause a reduction in the solid volume. The processes may be physical or chemical or a combination of both and may lead to shrinkage of the external volume of the grout or the opening of fissures within the grout. Depending on the chemical system, syneresis may be complete in a few days or it may continue for many years. Clearly syneresis can substantially damage the strength and permeability of a grouted soil. Hence, its understanding, methods for laboratory assessment and application of laboratory generated values to field conditions constitute an area of in depth appreciation.

In reality there are few data on the long-term behaviour of grouts, which also need to be generated by the scientific and engineering community.

Finally, grout specifications must be appropriate to the grout material. A specification drafted for a chemical grout may be wholly inappropriate to a cement grout.

All in all, grouts and grouting still continue to be a field of many unknowns and of many arbitrary practices. Considering all these aspects, we decided to devote this issue of Rebuild to this subject, bringing some useful inputs to our readers.

I hope you will find it of some value and significance.

Properties of Cementitious Repair Grouts and their Testing Methods

(Extracted from "Cementitious Grouts and Grouting" published by Portland Cement Association, USA, 1990, & "Post-Tensioning Tendon Installation and Grouting Manual", Bridge Technology, U.S. Department of Transportation-Federal Highway Administration)

The required properties of grout, such as strength and consistency and the proportions of grout ingredients depend on the grouting application. The proportions of ingredients and choice of ingredients must be determined in the laboratory to obtain certain properties such as expansion, strength and fluidity. The important properties, their significance and methods of testing are summarised below.

Consistency

Consistency refers to the ability of grout to flow. The consistency of fresh grout varies with application. Grout can range in consistency from a near-water or very-thin-paint consistency to an almost thick, stiff mortar or thixotropic consistency, depending on the application and desired workability.

Consistency is especially important with respect to bond strength. Fluid grouts have better bond than stiff dry grouts. Grouts for self-leveling applications or filling voids without vibration must be very fluid.

Consistency can be measured with various techniques such as the flow cone or flow table. The flow cone, ASTM C 939 and Corps of Engineers CRD-C611, measures consistency by monitoring the time for a specific amount of grout to run out of the cone (Figure 1). This time period is called the efflux time. The flow cone is used for thin fluid grout with an efflux time of 35 seconds or less. Fluid grouts are considered to have an efflux time of 5 to 30 seconds - they form a near-level surface without vibration or rodding. Water has an efflux time of 8 seconds. There are some commercial pre-bagged, thixotropic grouts that meet all other requirements yet show very low viscosity (high fluidity) after agitation, resulting in the 5 second lower limit.

The flow table, ASTM C 230, is used for thick grouts. The test measures the spread of grout after the table is dropped a specified number of times within a certain time period. The flow-table test for grout per ASTM C 827 uses 5 drops in 3 seconds with the ASTM C 230 flow table. Using the ASTM C 827 (Change in Height at Early Ages) consistency test (flow table) grout consistency can be defined as follows (i) a stiff plastic grout has a flow of less than 100%. (ii) Plastic grout has a flow between 100% and 125% (iii) a flowable grout has a flow between 125% and 145%. Plastic grout levels off only after vibration or rodding while a flowable grout levels off with light vibration or rodding.

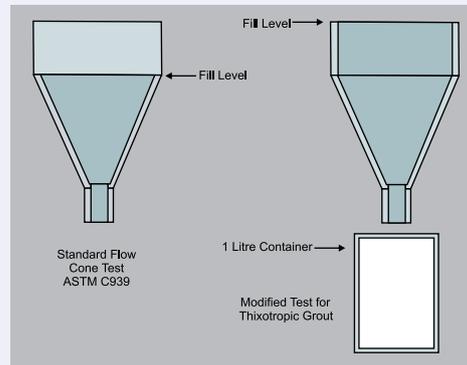


Figure 1 - Standard and Modified ASTM C939 Flow Cone Test

Workability and Working Time

Workability is the ease with which a grout can be placed, handled and consolidated without segregation or excessive bleeding. Without good workability, a grout can be difficult to handle and result in a poor quality product. The amount of time a grout remains workable is called the working time or pot life, which varies with grout types and needs. The working time of a grout should be known before it is used on a project. Proprietary grout manufacturers should provide working times for their products. Working time should be of a sufficient period to allow for transport, handling, and placing of grout at a comfortable pace. Retempering—adding water and remixing the grout to regain desired consistency or workability—should be avoided to maintain the strength, durability and other properties of the grout. Grout that becomes unworkable should be discarded and replaced with new grout. Working time can be tested by running consistency tests over time.

Bleeding, Settlement and Water Retention

Bleeding may be described as the development of a layer of water at the top of freshly placed grout caused by sedimentation (settlement) of solid particles (cement and any aggregate) and the simultaneous upward migration of water. Excessive bleeding can result in a surface with a high water-cement ratio causing poor durability and reduced strength; even a water pocket or void can develop. After evaporation of bleed water, the hardened surface will be lower than the freshly placed surface. This reduction in volume or vertical dimension from time of placement to initial set is often called settlement shrinkage.

The bleeding rate and bleeding capacity (total settlement per unit of original paste or mortar height) increases with initial water content, grout height, and pressure. The water-retention property - ability of grout to keep water in the grout and cement particles in suspension—significantly affects bleeding. High water-retentivity grouts such as thixotropic grouts, allow little or no bleeding. Use of water-retention or gelling agents, certain general chemical admixtures, air entrainment, silica fume and other mineral admixtures, clays and finer cements can also reduce bleeding. Grouts used to fill voids, provide support, or provide water-tightness by

intimate contact should have low-bleeding properties to avoid development of water pockets between the grout surface and the item grouted.

Bleeding can be tested according to ASTM C232 (Bleeding of Concrete), C 243 (Bleeding of Cement Pastes and Mortar) and C 940 (Expansion and Bleeding of Freshly Mixed Grouts). Water retentivity can be tested accordingly to ASTM C 941 (Water Retentivity of Grout Mixtures).

The "Wick Induced Bleed Test" involves completely immersing a 0.5M length of strand in a cylinder of carefully prepared grout and following a modified version of ASTM C940 to record the bleed water above the grout. A bleed of 0.0% after 3 hours at normal room temperature is acceptable (Figure 2).

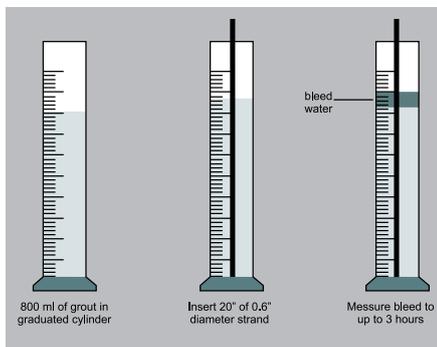


Figure 2- Wick Induced Bleed Test

The "Schupack Pressure Bleed Test" uses a Gelman Filter to retain grout particles and records the bleed water expelled under air pressure applied up to 0.34MPa (Figure 3). Table 1 shows permissible maximum bleed water percentages at specific pressure values that should indicate the grout will have little or no bleed for the given vertical rise.

Vertical Rise	Pressure MPa	Max% Bleed
0 to 0.6M	0.14	4
0.6M to 1.8M	0.21	2
1.8 to 30.5M	0.34	0

Table 1 Permissible Bleed Under Pressure

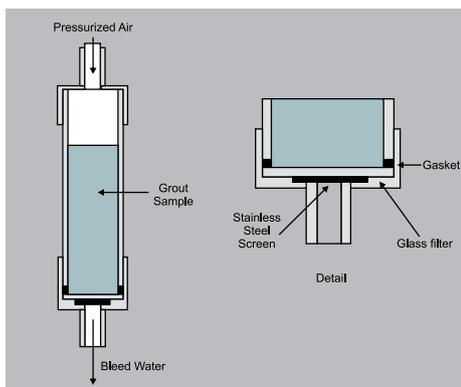


Figure 3 - Bleed Under Pressure Test (Gelman Filtration Funnel)

Setting and Hardening

The setting, hardening, strength development and other properties of grout are due to a chemical reaction called hydration that occurs between cement and water in the cement paste. Each hydrating cement particle forms a type of fiber like growth on its surface that gradually spreads until it links up with the growth from other cement particles or adheres to adjacent substances such as aggregate. The formation of this growth structure (primarily calcium silicate hydrate) is responsible for the paste's binding or cementing action. Without water, hydration stops, thereby terminating any further strength gain. Therefore it is important to retain moisture in the grout until the desired strength has been achieved. Generally, this is not a problem for many grouting applications as grout is often placed in locations where the water in the grout cannot readily escape. After sufficient hydration, the paste along with any encapsulated aggregate, forms a hardened grout of stone like appearance and properties. Once hydration is deemed sufficient to accomplish the desired properties, curing can be terminated; any remaining water in the grout will evaporate from the microscopic pores and capillaries within the paste. The time of set can be tested according to applicable ASTM standards C 191 (Setting Time of Hydraulic Cement by Vicat Needle), C 266 (Setting Time of Hydraulic Cement by Gillmore Needles), C 403 (Setting Time of Concrete Mixtures by Penetration Resistance), C 807 (Setting Time of Hydraulic Cement Mortar by Modified Vicat Needle) or C 953 (Setting Time of Grouts for Preplaced-Aggregate Concrete).

The setting time should be more than 3 but less than 12 hours.

Strength

The compressive, flexural and tensile strength required of a grout depends upon the grouting application, whereas the strength actually achieved by the grout is a direct result of the amount of cementitious materials and water in the grout as well as degree of hydration. The strength of grout is directly related to the water-cement ratio. As the water-cement ratio is reduced, the strength increases. Also as long as sufficient moisture (relative humidity greater than 80 % in the grout), unhydrated cement, and void space are present in the grout, the strength will increase.

An excess of water causes not only low strength but also excess bleeding, increased shrinkage, and reduced durability. The time of set is reduced and strength development increased with reduced water-cement ratios and higher temperatures. Bond strength is more dependent on consistency than the amount of water in grout; a wetter grout bonds better than a very dry grout.

Cylinders or cubes can be used to test the compressive strength of grout : however, 50 mm cubes are most common. Top-restrained cubes must be used for non shrink (expansive) grouts or grouts used in preplaced aggregate concrete. ASTM

C 942 (Compressive Strength of Grouts). The test method for strength of masonry grout is the grout prism test ASTM C1019 (Sampling and Testing of Grout), which uses masonry units for the mold.

The strength should be 21MPa at seven days and 35MPa at 28 days.

Volume Changes

The volume of hardened grout can vary significantly from the original volume of the fresh unhardened grout. The shrinkage of unhardened grout by settlement or bleeding was discussed earlier. A cement and water paste first undergoes a very slight transient expansion that occurs at the end of the cement system's dormant (nominally non reactive) stage. This is followed by a small amount of contraction that occurs before, during, and after hardening in isolated grout as normal cement hydrates and consumes water. This volume change has been referred to as chemical shrinkage, autogenous shrinkage, or absorption of water during hardening. Chemical shrinkage also refers to the reduction of cement and water (reactants in the grout) as opposed to the increase of hydrated cement (products in the grout). If water outside the paste is not available (for example, sealed samples) cement hydration will cause internal drying (self-desiccation) and slight shrinkage. This shrinkage can be offset by special admixtures added to grout, use of proprietary non-shrink grout, or by continuous future submersion in water, causing expansion.

Hardened grout changes volume slightly with changes in temperature, moisture content, and load. Chemical effects such as carbonation cause shrinkage and sulfate attack and alkali-aggregate reactivity cause expansion. Hardened grout expands slightly as temperature rises and contracts as temperature falls, although it can expand slightly as any free water present in the grout freezes. Temperature changes are caused by environmental conditions or by temperature rise due to cement hydration.

Volume change should be tested in accordance with ASTM C1090 "Standard Test Method for Measuring Changes in Height of Cylindrical Specimen from Hydraulic Cement Grout".

A value of 0.0% to less than 0.1% at 24 hours and no more than +0.2% at 28 days is acceptable.

Temperature Rise

Temperature rise can be a problem where thermal cracking of mass grouting is of concern. The amount of heat generated in a cementitious grout depends upon the fineness, amount and type of cementitious material, the placing temperature, available heat loss and volume or thickness of grout. When thermal cracking is a concern, the grout should be kept as cool as possible, and a low cement content and low-heat-of-hydration cement should be used.

Low-heat-of hydration pozzolans are also very helpful for mass grouting or pours where temperature rise must be kept to a minimum.

Durability

Durability refers to the ability of hardened grout to withstand deterioration in its service environment. Grout that is to be exposed to sulphate soils or waters should use sulphate-resistant cements as recommended and use a high cement content. If alkali-aggregate reactivity is a potential problem, low-alkali cement should be used and pozzolans that reduce alkali-silica reactivity should be considered. Air entrainment should be used for freeze-thaw environments. Freeze-thaw resistance can be tested by ASTM C 666 (Resistance of Concrete to Rapid Freezing and Thawing). Resistance to deicers can be tested by ASTM C 672 (Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals).

Grout should be stable after hardening. Some grouts contain materials that may allow the grout to expand significantly after hardening. These should be avoided in certain environments as excessive expansion may occur, resulting in cracking and disintegration of the grout.

Permeability

The permeability of hardened grout is reduced as the amount of hydrated cementitious material increases, moist curing continues, and the water-cement ratio decreases. Grout permeability should be tested in accordance with ASTM C1202 "Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration"

A value less than 2500 Coulombs after 6 hours is generally acceptable when subjected to a potential of 30 volts.

Corrosion

An Accelerated Corrosion Test (ACT) may be used to quantify the expected level of corrosion for a specific grout. The test is based on research made under FHWA-RD-91-092 which indicates that a mean time to corrosion of 1,000 hours when tested at 0.2V is suitable. This test is not yet standardized. However, it is particularly useful in determining combinations of admixtures that may adversely affect the corrosion protection performance of a grout.

Wet Density

A wet density value for grout can be established in the laboratory using ASTM C185 "Standard Test Method for Air Content of Hydraulic Cement Mortar". Once established, it can be monitored in the field using an American Petroleum Institute Mud Balance (API Recommended Practice 13B-1: "Standard Procedures for Field Testing Water-Based Drilling Fluids").

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 Coefficient 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/m³. 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°C or higher is preferred, the materials have been successfully used with water temperatures near freezing. Below 10°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 CO₂ 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 CO₂ 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°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 expected 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.

Experience of using PU Grout

(Excerpt from the article "Injecting Long Life" by Scott Kelly, Cleaner, July 2008, pp 86-87)

Chemical grouting provides simple and cost-effective repair for manhole leaks-by using right material and the right installation method.

There are many ways to repair leaks in concrete structures like sanitary and storm pipes, man-holes and basins. One of the oldest yet least understood methods uses polyurethane chemical grouts that react with water to bond with the concrete to form watertight, permanent seals, or to become rigid, filling voids and stabilizing soil.

According to the National Association of Sewer Service Companies (NASSCO), chemical grout was developed in 1955. Since then, it has been used in sewers, manholes, tanks, vaults, tunnels, and many other applications worldwide.

Recent studies and more than 40 years of experience indicate that grouting - known as the nation's first trenchless technology - is still a highly cost-effective, long-term defence against infiltration of groundwater into structurally sound sewer systems.

Grouting can be especially effective for sealing leaks in manholes, which by some estimates account for up to 40 percent of infiltration to waste water collection systems.

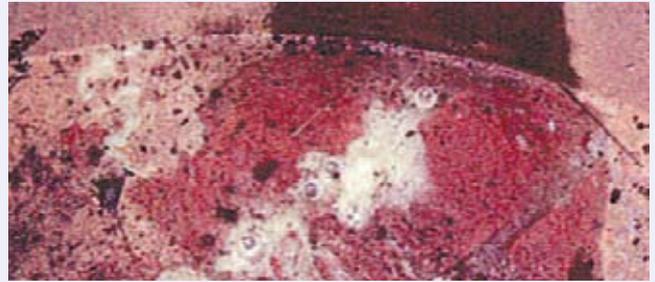
Reducing infiltration

The nation's infrastructure is aging while its population continues to grow. As a result, municipalities and contractors are under pressure to find effective repair options to reduce infiltration, which increases treatment plant loads, adds treatment cost, and increases the risk of sanitary sewer overflows (SSOs).

Groundwater leaks also carry sand, silt, and other debris into the system, increasing wear and tear on equipment. Voids often form around leaking structures that can lead to instability and settling. A properly chosen grout can stop leaks in seconds, forming a long-lasting seal and providing immediate cost-savings.



A crack at the base of a manhole allows water to infiltrate.



A hydrophilic chemical grout was used to repair the crack and stop all leaks.

(Photos courtesy Prime Resins Inc.)

Some manholes require structural rehabilitation, usually involving a sprayed, hand-applied or cured-in-place (CIP) lining. Contractors and municipal crews must realize that groundwater infiltration needs to be stopped before such linings are installed.

Too often, leaks in manholes are treated by applying a quick-set hydraulic cement over the active infiltration. This stops the leak temporarily and allows time for the lining to be installed. But water remains within the primary structure and can weaken the bond and eventually cause a lining failure.

Installation basics

Polyurethane chemical grouts are usually injected under pressure as a liquid resin into or near the leak. Once the resin contacts water, a chemical reaction occurs. Depending on the material formulation, the grout/water combination forms an expansive closed-cell foam or a gel. The foam can be flexible and resilient (hydrophilic) or rigid, meaning the cell structure of the foam crushes when compressed (hydrophobic).

In most manhole leaks, the water flow can be used to pull the grout into the structure. To accomplish this, a hole is drilled near the leak, and the chemical grout is injected through the wall into the water source. As the resin reacts with the groundwater, it is pulled back into the structure and seals the leak from the outside in, creating a seal through the entire wall.



An injection specialist uses chemical grout to repair a leaking joint

Where the leak is not strong enough to pull the grout into the structure, the grout can be injected directly into the defect. The expansion of the foam helps drive the grout through the structure to seal the gap. Hydrophilic polyurethane resins that produce gels are typically installed by running water along with the resin through a manifold that briefly mixes the two before they are injected. These gels are non-expansive but can be produced at water-to-resin ratios as high as 15 parts water to one part resin.

Knowing the material

Both hydrophilic and hydrophobic chemical grouts seal leaks in all types of concrete structures initially. The issue is how to create a permanent seal. The longevity of the repair depends on choosing the right material. No single product will repair all leaks in concrete. Many products will temporarily fix a leak, but if applied correctly, most polyurethane grouting repairs are essentially permanent.

To break down the decision process, it helps to examine the basic properties of both hydrophobic and hydrophilic grouts. The properties of each type can be used to reduce installation cost and improve the quality and life of the repair.

What to do

This basic knowledge of the two types of polyurethane grout helps in choosing the right product and the right method for a given repair.

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



Water enters the manhole due to a pipe penetration.



Hydrophilic chemical grout is injected around the area.

Gels should be used only in below-grade structures where either moisture from the interior (like in a manhole) or from groundwater 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.

The aggressive expansion of hydrophobic chemical grouts is helpful in 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 gels can also be used to stop gushing leaks when injected near or with a 1:1 water-to-resin mix. In this case, it is necessary to push in as much material as possible, as fast as possible. If a high-volume pump is available, less material will be used to stop the leak, because the high flow of resin reduces the dilution.

It is wise to use activated oakum (dry oakum soaked in hydrophilic resin) to reduce the flow in gushing leaks. If the leak can be slowed, a hydrophilic resin may be used to complete the repair.

What to avoid

Users should avoid installing gels 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.

It is also important to avoid installing hydrophobic chemical grouts for repairing minor leaks in cracks or joints. The repair will be temporary. Don't hurry when repairing tight cracks and minor leaks. These can be the most difficult to repair for the long term.

As infrastructure ages, chemical grouting will 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 a repair project, and the correct installation techniques are used, the repair will actually outlast the structure.



Lecture Session



Demonstration

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Tailore Made Training Programme dated 13th Dec 2008 at Evalueserve, Gurgaon on the theme "Construction Chemicals - An Emerging Trend"

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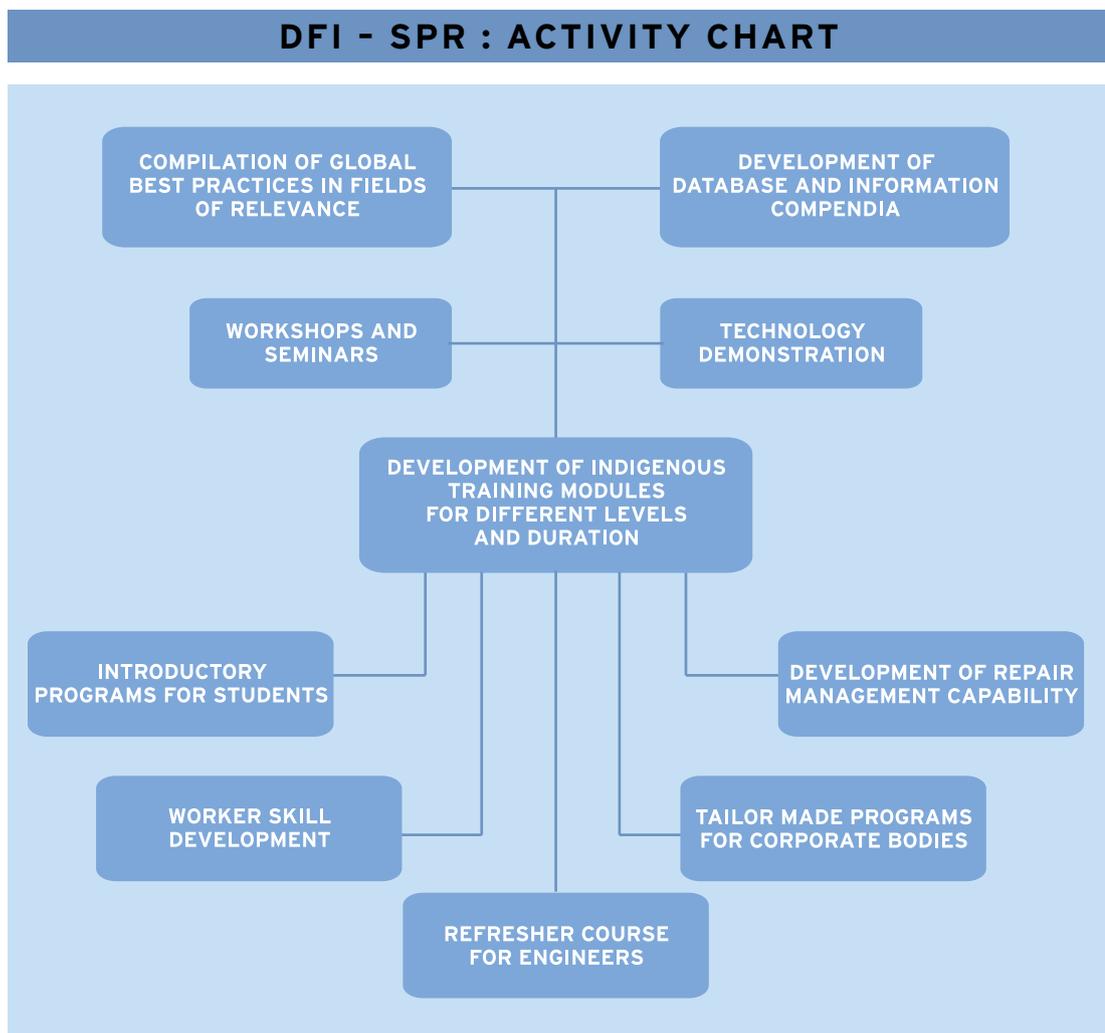
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VISION

To become a premier national knowledge and skill development center in waterproofing and other areas of renewal engineering through international networking in order to proliferate the global best practices in the country.

MISSION

To act as a platform for enhancing the service life of built environment through global sharing of knowledge and practices in the field of waterproofing, structural protection, repairs and rehabilitation.



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