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Precision Grouting: Setting the Foundation for Equipment Reliability

A clear understanding of grout material properties is important to ensure that equipment is effectively protected against vibration and misalignment

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IN BRIEF

CRITICAL PROPERTIES

COMPRESSIVE STRENGTH VERSUS FLOWABILITY

TESTING METHODS

Reliability of critical rotating equipment depends first and foremost on maintaining precision alignment. This requires a robust foundation under the equipment that is designed to withstand the amplitude and frequency of vibrations that compound dynamic loads transferred to the base. The importance of grouting, both from a material properties and installation standpoint, is often overlooked during the design of foundations for rotating equipment in the chemical process industries (CPI). While most engineers recognize certain grout properties, such as compressive strength and creep, other important properties, including bond strength, bearing area and flowability, are not as commonly considered during the design process.

FIGURE 1. The aggregate component of a polymer grout acts as a heat sink to absorb the heat created by the exothermic reaction between the epoxy resin and the amine hardener

Supplier datasheets are now including data from ASTM International (West Conshohocken, Pa.; www.astm.org) and other information for cementitious and epoxy grout from organizations like the American Concrete Institute (ACI; Farmington Hills, Mich.; www.concrete.org) and the International Concrete Repair Institute (ICRI; Rosemont, Ill.; www.icri.org). Table 1 lists some relevant industry standards and guidelines related to grouting materials.

Despite the wealth of data available, it can be difficult to narrow down the most important parameters to consider. For instance, what characteristics are truly important for the reliability of critical rotating equipment in terms of damping vibration and maintaining alignment to extend the mean time between failures? This article explores and identifies the important grout properties necessary to reduce production downtime and repair costs associated with excessive vibration of machinery related to grout.

Critical properties

Fundamental property examination of cementitious and epoxy grouts has traditionally focused on strength and the ability of a material to maintain that strength over an extensive period. Maintaining alignment and damping vibration is the best way to ensure longer mean time between failures for

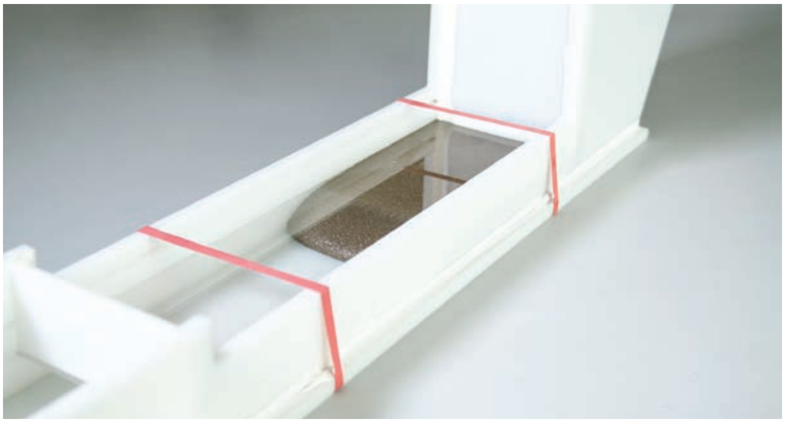

FIGURE 2. The flow box test, as defined in ASTM 1339, is used to examine the flowability of certain grouts

dynamic equipment. No equipment owner wants to deal with plastic deformation, cracking or voids in the grout layer under equipment. These problems lead to added reliability costs, as well as production downtime costs. Strength plays a major role in the resistance to plastic deformation, which in the case of grout, is the subsidence of a material from its original positioning. Compressive strength is a critical property that provides a criterion of quality grout and allows one to understand the general expectation of cure time.

Furthermore, maintaining strength over time while resisting plastic deformation due to stress, also known as creep, has been the best measurement to understand if a grouting material may subside from the underside of equipment due to compressive loading. Both compressive strength and creep measurements have long dominated the space of vendor datasheets with comparable testing from an ASTM standpoint [*1*]. Harder to find on datasheets is information about rheological properties, and specifically, the balance between flowability and compressive strength, especially for polymer grouts. A grout can have five times the compressive strength of concrete, but without being able to place via flowable means, what good is the high-strength grout material for stabilizing aligned equipment? If voids are present under the equipment, then there is, in effect, no strength at those points of absence. Like that of concrete, cementitious grouts flow better with higher water content, but this higher water presence adversely affects compressive strength and creep [*1*]. Likewise, epoxy grouts flow better with a higher resinous content, but also have similar compressive-strength reductions with increased fluid to aggregate components. There is a balance of properties when it comes to strength and placement, and one comes at the sacrifice of the other.

Compressive strength versus flowability

Identifying the need for compressive-strength values depends on the expected live loads (unstable and transient) and dead loads (fixed and static). In the case of precision grout, these live and dead loads are due to the equipment being supported and any forces acting on that equipment. Examine one equipment owner's specifications and it may require 16,000 psi compressive strength

TABLE 1. SELECTED INDUSTRY GUIDELINES AND REFERENCES RELATED TO GROUTING MATERIALS
ASTM C125 Standard Terminology Relating to Concrete and Concrete Aggregates
ASTM C1107 Standard Specification for Packaged Dry, Hydraulic Cement Grout (Nontrunk)
ASTM C940 Standard Test Method for Expansion and Bleeding of Freshly Mixed Grouts for Preplaced Aggregate Concrete in the Laboratory
ASTM C579 Standard Test Methods for Compressive Strength of Chemical Resistant Mortars, Grouts, Monolithic Surfacings, and Polymer Concretes
ASTM C1437 Standard Test Method for Flow of Hydraulic Cement Mortar
ASTM C939 Standard Test Method for Flow of Grout for Preplaced Aggregate Concrete (Flow Cone Method)
ASTM C230 Standard Specification for Flow Table for Use in Tests of Hydraulic Cement
ASTM C1339 Standard Test Method for Flowability and Bearing Area of Chemical Resistant Polymer Machinery Grouts
ASTM C827 Standard Test Method for Change in Height at Early Ages of Cylindrical Specimens of Cementitious Mixtures
ASTM C1090 Standard Test Method for Measuring Changes in Height of Cylindrical Specimens of Hydraulic Cement Grout
ASTM C531 Standard Test Method for Linear Shrinkage & Coefficient of Thermal Expansion of Chemical Resistant Mortars, Grouts, Monolithic Surfacings, and Polymer Concretes
ASTM C580 Standard Test Method for Flexural Strength & Modulus of Elasticity of Chemical Resistant Mortars, Grouts, Monolithic Surfacings, and Polymer Concretes
ASTM C469 Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression
ASTM C1181 Standard Test Methods for Compressive Creep of Chemical Resistant Polymer Machinery Grouts
ASTM C512 Standard Test Method for Creep of Concrete in Compression
ASTM C33 Standard Specification for Concrete Aggregates
ACI Committee 351 Foundations for Equipment and Machinery
ACI 351.1R-12: Report on Grouting between Foundations and Bases for Support of Equipment and Machinery
ACI 351.2R-10: Report on Foundations for Static Equipment
ACI 351.3R-04: Foundations for Dynamic Equipment
ACI 351.4-14: Specification for Installation of Cementitious Grouting between Foundations and Equipment Bases
ACI 351.5-15: Specification for Installation of Epoxy Grouting between Foundations and Equipment Bases
ICRI Committee 320 Materials and Methods
ICRI 310.2 Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, and Polymer Overlays (formerly No. 03732)
ICRI 320.5 Pictorial Atlas of Concrete Repair Material Mixing Equipment
API 686 Recommended Practice for Machinery Installation and Installation Design

FIGURE 3. The protocol for a flow box test involves the consolidation of grout into defined dimensions to measure its flow behavior

in 28 days for the grouting material versus another equipment owner that only requires 6,000 psi in that same period for a similar piece of equipment. There can be subjectivity in the requirements by equipment owners and engineers as to why a certain value has been selected as a standard for specification of design. Typically, a higher compressive strength leads to higher strength factors, like fatigue, which can be examined by cyclical testing.

One method of fatigue testing is known as Det Norske Veritas (DNV-OS-C502), which examines a grout cylinder by cyclically loading the specimen at an established compressive value for a predetermined frequency — for instance, so many number of hertz per second. Repeating the cycle, a specific number of iterations will simulate the lifecycle of a piece of equipment and show deformation or failure expected from a grouting material over time. For an equipment owner, knowing the expected life of a grouting material under the operating conditions of the machinery is much more valuable for planning facility maintenance strategies than just knowing the material's compressive strength.

As for compressive strength, it can be evaluated on grout samples for specific cure temperatures, and in the case of cementitious materials, it can be provided in accordance with different consistencies. Consistencies for cementitious materials are standardized into categories for plastic, flowable and fluid, according to ASTM C1437. In installation, a plastic material will have higher compressive values during the curing step, but will be difficult to place under tight base-plate spaces of less than 1–2 in. in depth. An equipment owner sets the expectation for a material's compressive strength, but an installer may not be able to achieve that requirement with the material specified due to accessibility and the ambient temperature during installation.

Understanding the temperature impact of grouting and the necessary working time requires consideration of the rheological properties of cementitious and epoxy grouts. Grouts that are more flowable or fluid will have longer working times at a given temperature. Why is this important? For starters, a more efficiently poured material lowers labor costs, and more importantly, because the same material will act differently during the installation, depending on ambient temperature. For installers, flowability of a grouting material is paramount. In the case of epoxy or polymer grout, temperature and its effects on a grout's rheology are sticky to say the least, since the material is a viscous composition that resembles that of maple syrup. For epoxy grout, there is no addition of water to get a flowable consistency like that of cementitious materials.

Polymer grouts are comprised of three components: epoxy resin, amine hardener and aggregate (Figure 1). The epoxy resin is typically a blend of monomers and oligomers and the hardener is a liquid with amine functionality [*2*]. As the two parts are mixed mechanically, the amine finds an oxirane ring in the epoxy resin to attack. This thermosetting resin creates a violent reaction during the oxirane ring opening, and the composition begins to very quickly undergo exothermic reaction. The third part, which is an aggregate blend, acts as a heat sink and absorbs much of the heat created by the reaction of the epoxy resin and hardener. This reaction can be further accelerated by higher ambient temperature. High temperatures will, in effect, lower the viscosity of the polymer material and allow for better flowability. If the reaction is accelerated too much, the material can become stressed and brittle, leading to post-cure cracking.

When installing polymer grouts, a good practice is to use expansion joints to break up the pour size. Expansion joints can minimize the impact of stresses created from the linear coefficient of thermal expansion between material interfaces and exothermic temperatures. Partitioning the grout into sections that are less than 20 ft^3 in size using expansion joints will typically result in a grout layer that is free of cracking. Furthermore, consideration of installing a polymer grout during a day with 90°F temperatures will lead to lower working time and a higher peak exotherm, resulting in possible stress-induced cracking. The same material may require double the working time in a 65–70°F environment.

Testing methods

Testing of flowability is available for those involved in the specification and installation of grouts. For cementitious materials, ASTM C939 details a flow cone test that measures the time for an established unit of fluid grout to pass through a funnel's orifice. To be considered fluid, the material in a specified volume must pass through the flow cone in less than 30 seconds. A test to measure flow for polymer grout is the flow box test described in ASTM 1339. The flow box test for epoxy grouts is the best standardized way to examine the flowable nature of polymer grout. The test consists of a box with a hopper on one end that constricts to an annular space of either 1 or 2 in. to simulate the condition of a base plate (Figure 2). The base plate, in the case of a flow box, is a polycarbonate plate that allows for viewing of the annular space. The mixed polymer grout is added to the hopper in an 11-in. depth for a 2-in. annular clearance, or an 8-in. depth for a 1-in. clearance, respectively [*3*]. The grout remains in the hopper during a consolidation period of five minutes. At the five-minute mark, a gate is lifted that separates the hopper from the annular space and the grout can flow (Figure 3).

Simultaneously, a timer is started and the grout proceeds to the back of the box. While the grout is flowing in the annular space, there is a viewing period before it comes into full contact with the polycarbonate plate, as well as a time before it contacts the back of the box. These times of contacting the plate and reaching the back of the box, known as the fill time and flow time, respectively, can be used to compare grout products from model to model and manufacturer to manufacturer. Not all materials are created equally, even if they have the same strengths. Consideration should be made for a grout's ability to be placed at a suitable yield level to ensure efficiency in the field. However, when aggregate is withheld to ensure flowability, all of the physical properties of the grout, besides the rheology, are reduced and the yield per unit is essentially lower. In some applications, the loss of strength in terms of bond and compression by aggregate reduction is acceptable, but this decision should be made by the engineer of record.

Another important takeaway from a flow box test is the capability to examine the bearing surface. When a fluid grout flows under a base plate, we assume contact with the bottom side of the plate if the grout fills the fluid volume of the annular space and proceeds to the back of the form. However, as a polymer grout flows under a plate, drag and friction, as well as entrained air from mixing, form pockets and voids under the base plate (Figure 4). These pockets and voids are problematic.

For example, if the grout only contacts the underside at a rate of 70% effective bearing, then the load being distributed is only as uniform as the bearing surface; therefore, compressive loads are dispersed at higher concentrations for the areas that are in contact with the plate. Having a bond to the bottom of the baseplate is a benefit to epoxy grouts and locks a skid or baseplate into place. This "locking" effect, coupled with the lower modulus of elasticity of epoxy grouts, tends to dampen the magnitude of vibration better than cementitious grouts. Having only 70% effective bearing area due to poration and voids will reduce the bond-strength avail-

FIGURE 4. **Pockets and voids in polymer grouts can cause problems, including uneven load distribution and ineffective vibration damping**

ability. Poration present on the top surface of the epoxy grout layer that comes into contact with the base or skid plate can also be a delamination concern. If a pocket of separation from the base plate occurs in the grout layer, or equipment coating separates from the plate, the grout will not dampen the magnitude of vibration as effectively [*4*].

Any number or depth of voids will adversely affect the available distribution of load. Selection of a grouting material with a high effective bearing area will more likely ensure bonding, and will allow for the manufacturer's reported grout tensile strength to be more in line with the actual field conditions. Careful consideration of a coating system and application thickness should be conducted prior to grouting to avoid bonding issues.

Requiring more compressive strength than is necessary from a grout may come at the cost of other important requirements, including rheology, effective bearing area, and, in turn, the effective bond between the base plate and grout material

A specifier of grouting materials should be aware of the balance of properties that exists between compressive strength and rheology. Requiring more compressive strength than is necessary from a grout may come at the cost of other important requirements, including rheology, effective bearing area, and, in turn, the effective bond between the base plate and grout material. Mechanical reliability should not be sacrificed because a material is lacking the properties to be installed correctly. With rotor-stator and peristaltic pumps replacing traditional techniques of using head boxes to install grouts, mechanical tolerances are requiring lower-viscosity materials. The practice of pumping grouts is allowing for safer and more efficient installations, resulting in lower labor costs. Due to all of these considerations, it is critically important to select a precision grout with placeability in mind. ■

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