Rotating equipment and heavy machinery cannot simply be installed on a concrete foundation since irregularities in both the machine base and concrete surface will create load-bearing issues and alignment difficulties. Additionally, a concrete foundation is not tough enough to withstand the compressive and dynamic loading needed to support the heavy machinery. For this reason, machinery bases are aligned and leveled by shims or jack bolts above the mechanically prepared concrete foundation and the resulting space between the machine base. This space is filled with a machinery grout for load and energy transfer from the equipment into the foundation.

The grout must be fluid enough to be poured or pumped under the baseplate to completely fill this space and must also maintain its volume throughout the service life of the equipment to ensure intimate contact between these surfaces for maximum load-bearing capability. Additionally, the grout must exhibit the necessary mechanical properties such as high ultimate compressive strengths over a variety of application and service temperatures.

One of the challenges of quality machinery grouting is proper material selection for lasting security, stability and alignment of the critical equipment it supports. All grout manufacturers publish physical properties of their products, determined either from tests performed in-house or by an independent testing laboratory. But these properties are not uniformly reported, as many of these tests are modified and different.
test methods are used depending on the grout composition (i.e., epoxy or cement). There is no clear justification for using different test methods to measure the same performance properties between grouts when determining suitability of use. The test methods specified to determine the critical performance properties of any grout should be dictated by the function and not by the grout chemistry.

This article compares the key performance properties of two types of grout using identical testing methods so that a comparison of performance properties can be made on an apples-to-apples basis to aid in selection of the best grout for a particular application. Results are presented for an epoxy grout and an ultra-high strength hydraulic grout (known as hybrid performance grout in this article). Interviews conducted with design professionals and contractors provided identification of the following critical performance factors for machinery grouts:

- Compressive Strength
- Creep Resistance
- Modulus of Elasticity
- Fatigue Resistance
- Impact Resistance
- Coefficient of Thermal Expansion
- Flowability and Bearing Area

Compressive strength ranked as the most important property in material selection, but flowability and bearing area are just as critical. If the grout can’t be placed properly under the base plate to support the machinery, does it really matter what the compressive strength of the grout is? Therefore, the combination of factors of compressive strength, flowability and bearing area together, are critical for overall long-term performance. In addition, for the grout to be durable, it must be able to withstand the fatigue from repeated loading, resist impact and have a compatible coefficient of thermal expansion to the surrounding materials.

**Compressive Strength**

Compressive strength is a measure of the maximum load the grout can withstand and is a significant predictor for many of the other critical performance parameters. Most machinery grouts will exhibit compressive strengths of 5,000 to 18,000 psi (34.5 to 124 MPa) to bear the weight of the particular equipment they support.

There are many ways to test for a material’s compressive strength.
Different test methods and protocols yield different results, so it is important to specify a standard method to make a fair comparison between different grouts. These differences are due to geometries of the test specimens, such as aspect ratio (ratio of the test specimen’s length to the area loaded), and to the rate of loading.

The ASTM test method for determining compressive strength in this study is ASTM C579, “Standard Test Methods for Compressive Strength of Chemical Resistant Mortars, Grouts, Monolithic Surfacing and Polymer Concretes.” There are three different methods for determining compressive strength in ASTM C579. Method B for 2-inch (50-mm) cubes should be used, as this method is for the size of the aggregate commonly used in these grouts. The testing equipment should be properly set for the travel rate of 0.2 inches per minute (5 mm per minute). Using travel rates higher than this can result in artificially high compressive strength values and create a risk of misalignment and loss of torque in anchor bolts. Creep is a time-dependent measure of the dimensional change of the grout under constant load. It is permanent, long-term deformation that a grout experiences over time. Excessive creep can cause equipment misalignment and loss of torque in anchor bolts. Creep is measured in microstrains where 1 microstrain equals 1 millionth of a unit length of deflection occurring in 1 unit length of material (i.e., 1 microstrain equals 1 millionth of an inch, per inch). Creep can ultimately cause enough deflection in a grouted baseplate to adversely affect machinery alignment resulting in premature wear or failure of bearings and other rotating parts.

There are several methods to determine the creep behavior of materials such as bricks, lumber, and concrete. Compressive creep for grouts should be tested per ASTM C1181, “Standard Test Methods for Compressive Creep of Chemical-Resistant Polymer Machinery Grouts.” When specifying creep properties, it is necessary to include the temperature and loading requirements as these properties are not part of the test method and changing them can affect the reported results. This way, materials can be selected based on an equivalent comparison (Table 1).

The hybrid performance grout exhibits extremely low creep compared to an epoxy grout due to its high strength and modulus over a wide range of temperature extremes. As operating temperatures increase, so does creep. The same forces that result in lower compressive strength also accelerate permanent deformation of the grout under applied loads. High creep resistance at equipment operating temperatures is essential to maintaining critical equipment alignment and long-term service life.

**Table 1: Creep resistance tested using ASTM C1181**

<table>
<thead>
<tr>
<th>Epoxy Grout</th>
<th>Hybrid Performance Grout</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0035 in/in</td>
<td>0.0023 in/in</td>
</tr>
<tr>
<td>(3,500 microstrains)</td>
<td>(2,300 microstrains)</td>
</tr>
<tr>
<td>ASTM C1181</td>
<td></td>
</tr>
<tr>
<td>600 psi, 140 F (4.1 Mpa, 60 C)</td>
<td></td>
</tr>
</tbody>
</table>

Modulus of Elasticity (MOE)

Different types of testing methods are used to determine the modulus of a material. Selection of the right method depends on what type of stress is acting on the material. Shear stress should use modulus of rigidity; volumetric stress should be reported as bulk modulus, and direct stress as modulus of elasticity. The modulus of elasticity measures the ability of the grout to resist deflection under load and is the measure of the “stiffness” of a grout. A higher modulus material produces less deflection under a given load.
For a given load (stress), the higher the modulus the lower the deflection (strain). Modulus = Stress/Strain

<table>
<thead>
<tr>
<th>Material</th>
<th>Modulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>29 Million</td>
</tr>
<tr>
<td>Concrete</td>
<td>3 to 5 Million</td>
</tr>
<tr>
<td>Hybrid Performance Grout</td>
<td>5 Million</td>
</tr>
<tr>
<td>Epoxy Grout</td>
<td>1 to 2.5 Million</td>
</tr>
</tbody>
</table>

Fatigue Resistance

During their lifetime, grouts are exposed to millions of dynamic load cycles that need to be transferred or absorbed by the grout. Fatigue resistance determines the ability of the grout to resist cyclical loading under simulated conditions of service for rotating or reciprocating equipment. Fatigue occurs when a material is subjected to repeat loading and unloading. If the loads are above a certain threshold, microscopic cracks will begin to form. Eventually these cracks will grow to a critical size leading to fracture and reliability issues.

The only standardized test to measure fatigue performance of grouting materials is the Det Norske Veritas:

MOE is tested per ASTM C580, "Standard Test Method for Flexural Strength and Modulus of Elasticity of Chemical-Resistant Mortars, Grouts, Monolithic Surfacings, and Polymer Concretes." This test determines the ability of the grout to resist deflection under load. Too low of a modulus can result in excess deflection.

As an industrial machine warms up to its operating temperature, its alignment can be altered as the grout modulus decreases with higher temperatures for epoxy grouts. To some extent, a reduced modulus helps grout absorb and dissipate forces from operating conditions; however a significant reduction of modulus will adversely affect the equipment as dynamic forces occur. Therefore grouts should be specified that retain modulus at the highest expected operating temperatures.

**Fig. 3:** Modulus of elasticity can be measured using ASTM C580, "Standard Test Method for Flexural Strength and Modulus of Elasticity of Chemical-Resistant Mortars, Grouts, Monolithic Surfacings, and Polymer Concretes." This test determines the ability of the grout to resist deflection under load. Too low of a modulus can result in excess deflection.

MOE is tested per ASTM C580, "Standard Test Method for Flexural Strength and Modulus of Elasticity of Chemical-Resistant Mortars, Grouts, Monolithic Surfacings, and Polymer Concretes." Typical modulus values for steel, concrete, epoxy grout and the hybrid performance grout are compared in Figure 3. The hybrid performance grout values are very close to the modulus of concrete. Epoxy grouts have a modulus of elasticity lower than concrete and will exhibit more deflection than the hybrid performance grout under the same loading conditions.

As an industrial machine warms up to its operating temperature, its alignment can be altered as the grout modulus decreases with higher temperatures for epoxy grouts. To some extent, a reduced modulus helps grout absorb and dissipate forces from operating conditions; however a significant reduction of modulus will adversely affect the equipment as dynamic forces occur. Therefore grouts should be specified that retain modulus at the highest expected operating temperatures.

Fatigue Resistance

During their lifetime, grouts are exposed to millions of dynamic load cycles that need to be transferred or absorbed by the grout. Fatigue resistance determines the ability of the grout to resist cyclical loading under simulated conditions of service for rotating or reciprocating equipment. Fatigue occurs when a material is subjected to repeat loading and unloading. If the loads are above a certain threshold, microscopic cracks will begin to form. Eventually these cracks will grow to a critical size leading to fracture and reliability issues.

The only standardized test to measure fatigue performance of grouting materials is the Det Norske Veritas:

MOE is tested per ASTM C580, "Standard Test Method for Flexural Strength and Modulus of Elasticity of Chemical-Resistant Mortars, Grouts, Monolithic Surfacings, and Polymer Concretes." This test determines the ability of the grout to resist deflection under load. Too low of a modulus can result in excess deflection.

As an industrial machine warms up to its operating temperature, its alignment can be altered as the grout modulus decreases with higher temperatures for epoxy grouts. To some extent, a reduced modulus helps grout absorb and dissipate forces from operating conditions; however a significant reduction of modulus will adversely affect the equipment as dynamic forces occur. Therefore grouts should be specified that retain modulus at the highest expected operating temperatures.

**Fig. 4:** This figure shows modulus of elasticity affected by temperature. Epoxy grout was cured for 24 hours at room temperature and post cured 16 hours at 140 F. Hybrid performance grout was cured for 28 days at 73 F. Both grouts were then conditioned for 24 hours at test temperature.

**Fig. 5:** This figure displays the results of the impact resistance test performed as per ASTM C535 with the hybrid performance grout after 2,000 cycles (top) and the steel impact balls used in the test.
DNV-OS-C502, “Offshore Concrete Structures (DNV)” used in offshore wind turbine structures. The DNV method uses specimens cyclically loaded at 5 Hz for 2,000,000 cycles.

The epoxy and hybrid performance grout were cyclically loaded at 40 percent of their ultimate compressive strength with no damage.

Impact Resistance
The impact resistance of grouts can be measured with the equipment of ASTM C131, “Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine” or ASTM C535 for coarse aggregate. When evaluating the impact resistance of grouts, 2-inch (50-mm) cube specimens are prepared, weighed and placed into a rotating steel drum containing 2-inch diameter steel ball bearings, and rotated at a speed of 32 rpm. A shelf within the rotating drum creates a crushing impact effect while the tumbling of the cubes with the ball bearings creates abrasion. After every 500 revolutions the cubes are removed, weighed, and the drum is cleaned. This process is repeated for a total of 2,000 revolutions.

The epoxy grout lost 25 percent mass while the hybrid performance grout lost 43 percent mass. The results indicate that the epoxy grout has higher impact resistance and toughness than hybrid performance grout (Fig. 5, p. 31).

Coefficient of Thermal Expansion
The coefficient of linear thermal expansion (CTE) measures a length change of a material as the temperature changes. Temperature changes in a grout occur diurnally, seasonally and from ambient-to-equipment operating temperatures. The CTE value represents the amount each material will expand or contract when a one-degree increase or decrease in temperature occurs. The CTE is expressed in units comparing the length change per degree of temperature change (i.e., inches per inch per degree F) of the material. The closer the CTE between two materials, the more compatible they become over a wide range of temperature changes. This is because they will tend to grow and shrink at the same rate as the temperature changes. Materials in contact with each other with significantly different CTE will tend to “jam” over extended temperature changes.

<table>
<thead>
<tr>
<th>Material</th>
<th>CTE (in/in/F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>6.5x10^-6</td>
</tr>
<tr>
<td>Steel</td>
<td>6.5x10^-6</td>
</tr>
<tr>
<td>Hybrid Performance Grout</td>
<td>5.7x10^-6</td>
</tr>
<tr>
<td>Epoxy Grout</td>
<td>19x10^-6</td>
</tr>
</tbody>
</table>

Fig. 6: Coefficient of linear thermal expansion was tested using ASTM C 531 and recorded results of a temperature change from 73 F to 210 F.

Fig. 7: Flowability and bearing area were tested using a head box (left) as per ASTM C1339.
CTEs experience stresses at the interface, which can lead to cracking or loss of bond. The hybrid performance grout is much more dimensionally compatible with steel and concrete over a wide range of temperatures compared to the epoxy grout (Fig. 6, p. 32).

**Flowability and Bearing Area**

The objective of foundation grouting is to achieve ease of placement and flowability in order to properly reach all areas to be grouted while the grout remains in contact with the baseplate.

By obtaining maximum contact underneath a baseplate, the grouted equipment is stable and any imposed loads are evenly distributed to the foundation. This lengthens the life of the equipment, the grout and the foundation. Bearing area and flowability are determined by ASTM C1339, “Standard Test Method for Flowability and Bearing Area of Chemical-Resistant Polymer Machinery Grouts.” In this test, the grout is poured through a head box, a type of funnel that creates hydraulic head to assist gravity flow into the defined grout cavity.

The measured flow time is the length of time that the grout takes to flow the length of the box and the fill time is how long the grout takes to completely fill the area under the simulated baseplate. Once hardened, the baseplate is removed and the grout surface is abraded to open air bubbles and voids formed under the baseplate. The amount of effective bearing area is determined by visual comparison to a standard to estimate what percentage of the grout would actually be supporting the baseplate (known as effective bearing area, or EBA). The hybrid performance grout’s flow characteristics and EBA are superior to an epoxy grout (Fig. 7, p. 32).

**Summary**

One of the challenges of grouting is the material selection based on critical performance properties. Many of the tests used to generate performance properties are commonly modified making the values not uniformly reported. This creates difficulty when design professionals must make informed decisions regarding grout selection. Comparing key performance properties generated with the same testing protocols, one can readily see where both the hybrid performance grout and epoxy grouts perform well.

Epoxy grouts offer excellent strength development, durability and impact resistance but can have performance gaps in creep resistance.
Safespan is a leader in access solutions and provides safe & secure methods for accessing virtually any structure.

**SIMPLE INSTALLATION**

The components are all designed with fast installation in mind and our research and development team is always working on system improvements to save contractors time.

The dimensions and weight of the Safespan panels have been designed and manufactured specifically for platform use, are easy to handle, and support more weight than any other panel.

Our fastening devices are easily installed from above and provide a seal.

**DEBRIS SHIELD**

The strength of the work platform makes Safespan the system of choice for deck demolition and rehabilitation. It is built to handle the heavy abuse of falling debris and protects roadways and waterways below as nothing can fall through.

**A STABLE WORK PLATFORM**

Our platforms provide a cost effective solution utilizing a safe solid floor. The stability of the system allows for work to be performed faster along with increased safety and comfort for workers.

**CONTAINMENT**

For projects with containment needs the system easily converts to a completely enclosed environment with the addition of tarps. Safespan is the best system for projects with Class A containment requirements. It protects the environment and dramatically simplifies waste disposal.

**RELIABLE**

Superior engineering has made our approval rate second to none.

All components are backed by exhaustive load test data to ensure safety and load handling.

Click our Reader e-Card at paintsquare.com/ric
and elevated temperature service. A hybrid performance grout can bridge this performance gap in many situations; as well as offer simplicity of packaging, mixing and cleanup.

From a chemistry standpoint, hybrid performance grouts are based on hydraulically active minerals and additives that provide for ultra-high strength development with desirable placement characteristics and performance in severe service environments required for today’s grouting of industrial equipment.

Fred Goodwin, fellow scientist, product development BASF Construction Chemicals, is a chemist with over 30 years of experience in the construction chemicals industry, including cement manufacture, research, development and technical support of grouts, adhesives, coatings, shotcrete, stucco, flooring and concrete repair materials. He has been with BASF and its predecessors for 25 years and is an active member of ICRI, ACI, ASTM, NACE, SDC and SSPC. Goodwin is a fellow of ACI and ICRI, an Honorary Member of ASTM C1 + C9, current chair of the ICRI Technical Activities Committee (TAC), ACI 515 Protective Systems, ASTM C09.41 Cement Based Grouts, SSPC 8.3 Commercial Floor Coatings and a member of ACI TAC. Goodwin is also a guest lecturer for the Grouting Fundamentals short course (Colorado School of Mines) and was awarded the JPCL Editors Award in 2006, 2010, and 2012 as well as the ACI 2011 Delmar Bloem Distinguished Service Award. He is a NACE Corrosion Technologist, holds four U.S. patents and was named a Top Thinker in JPCL’s Annual Bonus issue of 2012. Goodwin also frequently speaks at national conventions.

Frank Apicella is the research and development manager for inorganic chemistry at BASF Construction Chemicals. He has over 25 years of experience in the development of hydraulic and polymer-based protection and repair products for the construction industry including adhesives, coatings, concrete repair mortars, floors, composite systems, and machinery grouts. He is an active member of the ACI, SSPC, NACE and ICRI.