MACHINERY GROUTS

A DISCUSSION OF GROUT PROPERTIES REQUIRED

FOR THE INSTALLATION OF ROTATING MACHINERY,

AND SUGGESTIONS FOR GROUT EVALUATION.

G D Goldsbro,
Alphatec Engineering Group

1. DEFINITIONS

"GROUT" is defined by the Concise Oxford Dictionary as "a thin fluid mortar for filling interstices". "MORTAR" is then defined as "a mixture of lime or cement, sand and water (originally made in a mortar) for joining stones or bricks", and "INTERSTICE" is further defined as "an intervening space, chink or crevice". This compound definition of grout is the one that seems to be most commonly understood in general civil engineering practice, although it is obviously about 50 years out of date. Since a "joining" function is considered for the mortar material, the property of adhesion is implicitly required. This property is apparent to any substantial degree only in the resin based mortars or grouts, which are the products which we are interested in.

Firstly, let us examine the uses to which grout is put, and then focus specifically on the design parameters for Machinery Grouts.

2. GROUT APPLICATIONS

A great deal of grout is manufactured around the world. We estimate the volume produced in Japan alone as between 30,000 and 40,000 cubic metres. That does not include all the grout or mortar which is simply mixed at a jobsite for a specific purpose, from the cement and sand available. In the relatively mature market of the US, approximately 4,000 to 5,000 cubic metres of epoxy grout is sold each year, and the inorganic market is probably 10 to 20 times larger.

Grout is used in one form or another to:

- fill the space between the facade and the rock wall of a tunnel and to seal any fissures in the rock;

- fill the space between the walls of a well and the ground or rock through which the original hole has been drilled;

- fill the space between the top of the piers and the steel base plates for bridge spans;

- fill the annular space between the prestressing rods or wires and the concrete slab of a bridge deck;

- fill the legs of an offshore platform, after it has been set in place and spudded;

- fill the annular space between gas distribution piping and the sleeve which carries the pipe under the road;

- fill the spaces between one brick and another, or between a concrete wall and the tiles stuck onto it (although we would usually probably call such a product a "mortar", it is definitely performing a grout function);

- fill the space between structural steel columns and the pier footings on which they are set;
- fill the shrink cracks in very large concrete structures such as dams;

- fill the space between the concrete foundations and process vessels, tanks and exchangers in industrial plants.

- And, finally, grout is used to fill the space between the concrete foundation and the equipment base or mounting flange of ROTATING MACHINERY.

3. WHY USE MACHINERY GROUTS AT ALL?

Primarily, because it is not feasible to set the machine floating in space, and pour the concrete up underneath it until it is properly embedded. Secondly, the concrete would shrink in any case, and would thus tend to pull the equipment out of alignment. Thirdly, the properties of concrete are simply not suitable for use in direct contact with a rotating machine. The required grout properties are spelled out in the next paragraph. The concrete foundation is, therefore, poured first to within 50 to 100 millimetres of where the machine base should finally be, and allowed to cure for 28 days or so. This gets rid of some of the dimensional changes that can be expected in the initial set and curing stages, and provides a relatively stable platform to work from. The equipment is set at its correct elevation, on some type of temporary support, and a non-shrinking, load-bearing grout is pushed or poured into place in the interstice.

4. GENERAL GROUT PROPERTIES

To properly fulfill its function, a grout must have several important properties. Some of these are:

4.1 The ability to change from a plastic state to a solid state; without any change in dimension.

4.2 The ability to contact intimately the surface it will support.

4.3 The ability to form a bond with the contacted surface.

4.4 The ability to withstand considerable compressive loading in a dynamic form.

4.5 The ability to withstand cyclic changes in the loaded condition.

4.6 The ability to withstand vibration.

4.7 The ability to maintain its dimensions to very close tolerances, over a very long period of time.

4.8 The ability to withstand weathering over a very long period of time.

4.9 The ability to withstand changes in temperature of a cyclic nature, or of a sudden, extreme nature.

4.10 The ability to withstand chemical degradation from the immediate or general environment.

4.11 The ability to transmit vibrations into the foundation mass where they will be damped out.

5. TRADITIONAL GROUTING

Cement-based grouts, due to the inherent nature of the materials used, are unable to fulfill all the requirements stated above, for the following reasons:

5.1 It is a fact of life that cement shrinks on cure. Regardless of what the *old hands* would like to have us believe, there is no such thing as a non-shrinking cement mix. The Concrete Manual states the problem this way – "the absolute volume of the products of hydration is less than the sum of the absolute volumes of the original cement and water. Thus, as hydration proceeds, the hardened cement paste cannot occupy the same amount of space as the original fresh paste". Note that this is true not only for a pure cement and water mix, even assuming that the amount of water used was the theoretical amount needed for hydration, but also to mixes of cement, sand and water, or cement, sand, gravel aggregates and water. The only option open to a manufacturer of a cement grout is, therefore, to include something in the mix which will expand enough to offset the hydration shrinkage. However, the timing of the supposedly offsetting expansion is difficult to predict, and the net result is usually a product which goes through a series of dimensional changes consecutively, rather than concurrently as designed. Excess water is another prime cause of cement shrinkage, since it will eventually migrate through the cured material, and is the reason that cement grout manufacturers make a point of including notes on the maximum permissible water to be used in any set of conditions. These rules are widely observed only in the breach thereof.

5.2 The requirement to intimately contact the surfaces implies a high degree of "wetting ability". This is obviously incompatible with the above-mentioned requirement for minimal water in the case of cement grouts. Pre-wetting of the concrete surface is usually carried out. This is also a very uncontrolled procedure, resulting in either too much or too little moisture on the surface when the grout is poured. Wetting of the steel surface is not generally called for due to the obvious corrosion-promoting possibilities, and the contact with this surface is thus less than optimum.

5.3 Forming a bond with the surface once contact has taken place requires attractive forces due to molecular polarity. While metal surfaces generally exhibit high polarity, concrete is relatively non-polar, as is cement-based grout itself. Resins, particularly epoxies and other polyethers, are highly polar, and thus exhibit good adhesion to both polar and non-polar substrates.

5.4 While many cement-based grouts exhibit very high compressive strengths, their internal cohesion, and thus tensile strength is very low. Also, their resistance to vibration is poor, and the weak cohesive bonds, together with the internal stresses generated during cure, mean that they tend to break down under cyclic loading fairly rapidly. This tendency is exacerbated by the presence, and penetration into the grout, of lubricating oils, water, and other liquids which find their way into the minor cracks, and through a combination of physical forces (hydraulic action) and chemical attack, the remaining cohesive strength of the grout is rapidly destroyed.

5.5 While in theory the grout should never be subject to tensile forces, it is noticed in practice that oil, for example, will penetrate under the flange of a reciprocating machine, and remain there as a dis-bonding film. There is no way for the oil to get there in the first place unless there is some vertical movement opening a gap. This vertical movement, or rather, differential movement between the machine and the grout, does occur, mainly due to the elasticity of the anchor bolts. Assuming the grout is bonded to the underside of the machine, it will obviously be subjected to some degree of tensile stress, even if only momentarily. Cement grouts will break down rapidly under these conditions.

5.6 Cement, being basically a mixture of chemical compounds, rather than a single, homogenous compound, has a lot of weak chemical, or electrical, bonds between its component molecules. This is why cement, and concrete in general, is recognized as having very little tensile strength. Since concrete is generally broken up, when required, by applying a vibrating force on a relatively small area (a jack-hammer acting on a moil point chisel illustrates the point quite well), it should be apparent that its resistance to vibration is not high.

5.7 Cement products do not, in general, have exceptional dimensional stability. The phenomenon of creep has been observed in concrete 20 years after it was originally placed. Most cement grouts exhibit low initial deflection on loading, but are subject to long-term creep, and, much more serious, to surface breakdown resulting in a fretting action between the equipment flange and the grout.

5.8 While most critical machinery is installed in some type of shelter, there are still large amounts of plant machinery installed in the open. The grout is thus exposed to all the stresses and strains connected with diurnal temperature variations, particularly due to radiant heat, and also to UV rays, rain, hail and snow and so on. The cyclic temperature changes can be the most devastating, and, although epoxy grouts have a larger coefficient of thermal expansion, this is more than compensated for by their high tensile strength, and cohesive and adhesive bonds.

5.9 While natural temperature changes are relatively slow and mild, temperature changes in a process plant due to a temporary upset condition can be lightning fast and over enormous ranges - an accidental discharge of liquid nitrogen or natural gas can cause an instantaneous temperature differential of more than 100 degrees Celsius, and will crack cement-based compounds immediately.

5.10 Many industrial processes involve the use of chemicals which will attack concrete. Due to the porous nature of cement-based materials, the corroding agent has more surface area to work on at any one time, than is the case with resin-based grouts. The resins themselves are generally very chemical resistant, and provide a barrier and protection for the inorganic aggregates in the grout, and for the underlying concrete.

5.11 The ability to transmit vibrations is very closely allied to the abilities of the material to contact the surface, and having made contact, to maintain a bond with that surface. Cement-based grouts basically do not have either characteristic, and are therefore bad transmitters of vibration. Resin grouts, on the other hand, exhibit these qualities in high degree, and are thus excellent transmitters of vibrations into the foundation, where they are damped out by its mass.

6. CHOOSING A GROUT SUPPLIER

There is still no perfect grouting material, but the type which comes closest at the present time to meeting most of the requirements stated above is a grout based on epoxy resins, polyamide or polyamine hardeners, and inorganic fillers or aggregates – more simply known as EPOXY GROUT. Where chemical resistance of a higher order is required, different resins, such as novolac epoxies, or vinylester epoxies, can be substituted to obtain that resistance without sacrificing the other qualities which make a grout work.

There are now a great number of so-called epoxy grouts on the market around the world. Some of these are simply base resins and hardeners as sold by the original resin manufacturer, with little or no thought given to mixing ratios, package sizes, or physical properties. Often, the viscosity, compressive, tensile, or adhesive strengths of the resin system itself are not published, let alone the completed grout product, since the customer is frequently encouraged to procure any old sand aggregate, and in essence, blend his own grout.

Most large plant owners are now aware of the fact that the physical properties of epoxy grouts vary so much that it is worth paying the extra price for a material that has been properly designed, manufactured under quality control standards, and that will be installed under the supervision of an experienced site supervisor. Since most plant owners and operators also tend to be conservative when it comes to approving new materials, those products which can show the best documented case histories often have the advantage.

Epoxy Grout was virtually invented by Bob Rowan in Houston in 1957, to meet the requirements of the Union Carbide plant maintenance personnel. The initial product was based on an existing flooring product consisting of epoxy resins filled with a graded sand, and performed pretty well – certainly better than the cement grouts employed previously. The machine grouted, an Ingersoll-Rand gas engine compressor in Union Carbide's Texas City plant was believed to be still in operation in the 1980s. Since those days, epoxy grouts have been studied in some depth, as has the service environment. The service requirements are best known by the end user, the equipment manufacturer and the installer or consultant, and good relations with all these groups is a prime qualification for an epoxy grout manufacturer. Product modifications should be considered and carried out when needed, to keep the product characteristics in line with the various requirements of these different parties.

7. EPOXY GROUT PROPERTIES

To properly perform its stated function as a long-term grout material, certain properties of the proprietary epoxy grout are vital, and should help separate the professional from the amateur product, and from the "off-the-cuff" resin and sand mix.

7.1 The grout must place well. To achieve this, it is necessary for the manufacturer to supply a properly graded aggregate as part of the grout package. Flow properties, plate contact properties, shrinkage rates, exotherm temperatures, and all basic physical properties change so drastically with a change in aggregate type that site-available sands or aggregates simply cannot be used to obtain the established properties. When different placement properties are required, such as high flow for very small clearances, or dry-pack consistency where formwork cannot be used, the aggregate itself may be substituted, or volumes used may be adjusted to suit the conditions. These changes, however, must always be made within parameters established by the manufacturer; the physical properties at different aggregate loadings having been properly documented,

7.2 The grout must cure with negligible shrinkage. Although it is virtua1ly impossible to obtain a workable mix without any shrinkage at all, the formulation used must aim in this direction, and the tests used to determine shrinkage should be designed to approximate the conditions seen in the field.

7.3 The grout should show the maximum area of contact with the equipment being grouted, regardless of the ambient temperature at which it is placed. In other words, air inclusion must be kept to a minimum.

7.4 The grout should show a minimum amount of plastic deformation on loading, particularly at the elevated temperatures at which most rotating machinery operates. This necessitates a relatively high modulus of elasticity throughout the operational temperature range, but not so high that cracking becomes a problem (see below).

7.5 The grout should show a minimum rate of long-term creep, again, particularly at the elevated temperatures at which rotating machinery operates.

7.6 The grout materials should be so balanced that the hardened grout does not crack after the exothermic reaction, or during operational temperature changes.

7.7 The grout should be designed with an optimum aggregate loading, designed so that the resin completely fills the voids between the aggregate particles. This loading should be used for all critical installations, but may be changed to suit field conditions as stated earlier.

7.8 The aggregate loading should also be designed to absorb the heat generated by the exothermic reaction of the resin and hardener at different pour masses.

Finally, and only after the above conditions have been met, the grout materials should be chosen for economy. Since the value of the equipment supported by the grout is usually several hundred times the value of the grout itself, it makes little sense to cut corners on such critical materials.