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 C827 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.

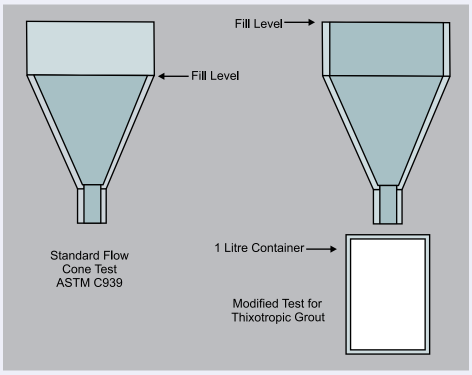

Figure 1 - Standard and Modified ASTM C939 Flow Cone Test

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).

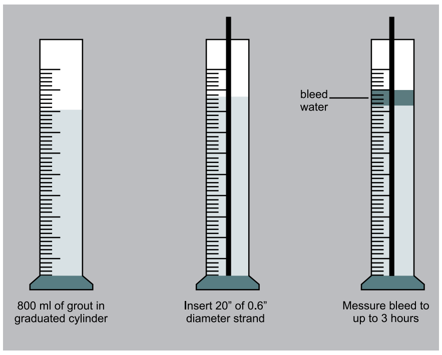

Figure 2- Wick Induced Bleed Test

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

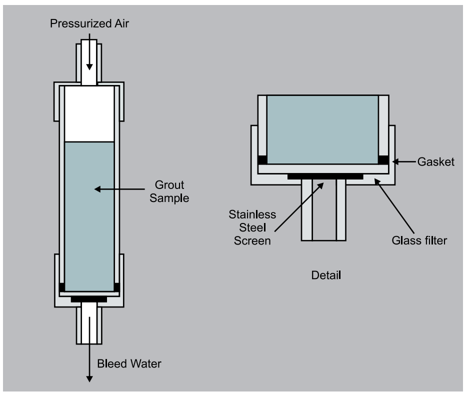

Figure 3 - Bleed Under Pressure Test (Gelman Filtration Funnel)

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").