Evaluation of Lime-Based Hydraulic Injection Grouts for the Conservation of Architectural Surfaces

A Manual of Laboratory and Field Test Methods

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4. Field Testing Procedures

4.1. Injectability with Syringe

Aim

The aim of this field test is to compare the ability of a grout to fill a prewetted or dry capillary network of different granular materials under pressure. Injectability is a critical property for injection grouts, which must be suitable for injection through a syringe or tubing to fill internal cracks and voids.

Description

Grout is poured into a vertically held syringe that is partially filled with granular material, and pressure is applied on the grout using the syringe plunger. This field test can also be used for testing nonhydraulic injection grouts.

Equipment and Materials

- crushed travertine or crushed brick (particle size, 2–4 mm); alternatively, debris removed from the location where the injection grouting will be conducted can be used
- 100 mL distilled water
- two 60 mL syringes
- 20 mL syringe
- ruler in millimeters

Procedure

1. Pour 20 mL granular material into an empty 60 mL syringe with the plunger removed (fig. 4.1.1).
2. Hold the syringe in a vertical position and tap the side of it 10 times with a finger while slowly rotating the syringe.
3. Inject 20 mL grout from the 20 mL syringe into a 60 mL syringe (fig. 4.1.2).
4. Insert the plunger into the syringe and apply gentle pressure to the plunger (fig. 4.1.3).
5. Repeat steps 1–3 using the second 60 mL syringe.
6. If damp medium is used, pour 100 mL of distilled water into the syringe partially filled with granular material and let the excess water drain for 5 minutes.

Figure 4.1.1 Pouring 20 mL crushed brick into a 60 mL syringe.

Results

1. Classify the injectability of the grout as: easy (E)—if grout flows out of the syringe tip when pressure is applied (fig. 4.1.4); feasible (F)—if grout reaches the tip of the syringe but does not flow through when pressure is applied; or difficult (D_L)—if grout stops before reaching the tip of the syringe when pressure

Figure 4.1.2 Injecting 20 mL grout into a 60 mL syringe.

Figure 4.1.3 Inserting the plunger into the syringe.

Figure 4.1.4 Applying pressure to the plunger either until grout comes out the tip or until grout stops moving through the granular material.

is applied. Using the millimeter ruler, record the distance reached by the grout (L) in millimeters.

2. Repeat the test for the same material type until two experimental runs providing the same classification are obtained. For the grouts classified as difficult, the average level reached by the grout is calculated from the distances reached by two independent runs. The average distance reached in the syringe of the two runs should not differ more than 25% from the individual results; otherwise, the test should be repeated.
3. Record results on a data collection sheet; see figure 4.1.5 for an example.

INJECTABILITY WITH SYRINGE

Grout name	
Grout proportions	
Operator	
Date	

EASY (E): If grout flows out of the syringe tip when pressure is applied

FEASIBLE (F): If grout reaches the tip of the syringe but does not flow through when pressure is applied

DIFFICULT (D_L): If grout halts before reaching the tip of the syringe when pressure is applied; record the distance reached (L) in mm

	Travertine-wet		Travertine-dry		Brick-wet		Brick-dry	
	1	2	1	2	1	2	1	2
Classification								

Figure 4.1.5 Data collection sheet for the injectability with syringe test method.

4.2. Flow with Syringe

Aim

The aim of this field test is to compare the ability of a grout to pass through a prewetted or dry capillary network of different granular materials under gravitational force.

Description

Grout is poured into a vertically held syringe (without a plunger) that is partially filled with granular material, and the penetration of grout into the granular material in the syringe is observed. This field test can also be used for testing nonhydraulic injection grouts.

Equipment and Materials

- crushed travertine or crushed brick (particle size, 2–4 mm); alternatively, debris removed from the location where the injection grouting will be conducted can be used
- 100 mL distilled water
- two 60 mL syringes
- 20 mL syringe
- clear rigid plastic tube or graduated cylinder with approximately 45 mm diameter and longer than 15 cm
- ruler in millimeters
- wristwatch

Procedure

1. Pour 20 mL granular material into an empty 60 mL syringe with the plunger removed (fig. 4.2.1).
2. Hold the syringe in a vertical position and tap the side of it 10 times with a finger while slowly rotating the syringe.
3. Inject 20 mL grout from the 20 mL syringe into a 60 mL syringe (fig. 4.2.2) while holding the 60 mL syringe in a vertical position or while supporting the syringe by placing it in a clear rigid plastic tube or graduated cylinder standing upright.
4. Start measuring the time.
5. Repeat steps 1 and 2 using the second 60 mL syringe.
6. If damp medium is used, pour 100 mL of distilled water into the syringe partially filled with granular material and let the excess water drain for 5 minutes.

Figure 4.2.1 Pouring 20 mL crushed brick into a 60 mL syringe.

Figure 4.2.2 Injecting 20 mL grout into a 60 mL syringe. Note that the syringe with grout and granular material is held vertically and supported by a rigid plastic tube.

Results

1. Classify the flow of the grout as: easy (E)—if grout flows through the tip of the syringe in 5 minutes or less; feasible (F)—if grout reaches the tip of the syringe but does not flow through it in 5 minutes; difficult (D_L)—if grout halts before reaching the tip of the syringe in 5 minutes (fig. 4.2.3). Record the distance reached by the grout (L) in millimeters.
2. Repeat the test for the same medium until two experimental runs providing the same classification are obtained. For the grouts classified as difficult, the average level reached by the grout is calculated from the levels reached by two independent runs. The average level reached in the syringe of the two runs should not differ more than 25% from the individual results; otherwise, the test should be repeated.
3. Record results on a data collection sheet; see figure 4.2.4 for an example.

Figure 4.2.3 Grout penetrating into crushed travertine. No grout has flowed out within 5 minutes; therefore, this grout is classified as difficult.

FLOW WITH SYRINGE

Grout name	
Grout proportions	
Operator	
Date	

EASY (E): If grout flows through the tip of the syringe in 5 minutes

FEASIBLE (F): If grout reaches the tip of the syringe but does not flow through it in 5 minutes

DIFFICULT (D_L): If grout halts before reaching the tip of the syringe in 5 minutes; record the distance reached (L) in mm

	Travertine-wet		Travertine-dry		Brick-wet		Brick-dry	
	1	2	1	2	1	2	1	2
Classification								

Figure 4.2.4 Data collection sheet for the flow with syringe test method.

4.3. Flow on Plastered Tile

Aim

The aim of this field test is to compare the ability of different grouts to flow within a vertical crevice in plaster. The distance a specific grout flows is an indication of how far it can flow through a network of cracks or voids. This test can be used in the field as a simple way of comparing the flow behavior of different grouts to determine which grout to use on a case-by-case basis.

Description

A fixed volume of grout is poured into a vertical crevice created in a coarse plastered tile, and the distance it flows is determined. This test can also be used for testing nonhydraulic injection grouts.

Notes

Mortar used for repairs on site can be used to plaster the reverse of the tile for this test. The following mortar proportions and ingredients, given here as a reference, were used at the GCI to prepare the plaster.

Equipment and Materials

- standard sand (EN 196-1)
- superventilated pozzolana
- lime putty
- mixing bowl or large plastic container to mix the plaster
- mortar mixer if available
- trowel
- glazed or unglazed ceramic tile (33 × 25 × about 1 cm thick)
- spray bottle
- distilled water
- pointed cutting tool for creating flow paths (e.g., wood tool for ceramics)
- ruler in millimeters
- 10 mL syringe
- thermometer
- humidity gauge
- plastic bag or moist cabinet larger than the size of the ceramic tile

Preparation of Plastered Tile

1. Pour 2.5 parts (by volume) standard sand and 0.5 parts (by volume) superventilated pozzolana into a container and mix with mortar mixer or trowel.
2. Add 1 part (by volume) lime putty and mix thoroughly with the mortar mixer at low speed, or mix manually with a trowel.
3. Using the spray bottle, prewet the reverse of the tile with water.
4. Spread plaster over the reverse of the tile to a thickness of 3–4 cm.
5. Smooth the surface with the trowel.
6. While the plaster is still wet, use the ruler and a cutting tool to make parallel V-shaped channels approximately 0.5 cm wide and 2–3 cm apart (fig. 4.3.1).

Figure 4.3.1 Making parallel V-shaped channels using a ruler and cutting tool.

Figure 4.3.2 Prepared flow tile after setting.

Figure 4.3.3 Injecting 10 mL grout into a channel.

7. Store the plastered tile in a tightly closed plastic bag (or in a moist cabinet at RH greater than 95%) at 20°C ± 5°C for 2 weeks.
8. At the end of 2 weeks, remove the plastered tile from the plastic bag (or from the moist cabinet) and keep it near the location where the grouting will be executed for at least 2 more weeks and until it is strong enough to be placed on its edge. Record the maximum and minimum RH and temperature weekly.

Procedure

1. Set the plastered tile on its edge so that the channels are vertical (fig. 4.3.2).
2. Record the temperature and humidity.
3. Using the 10 mL syringe, inject 10 mL grout into the top of a channel, as shown in figure 4.3.3.

Results

1. Once the grout has stopped flowing, use a ruler to measure the distance (L) the grout has flowed down the channel in millimeters. The flow of the grout can also be classified according to the measured distance: low (L)—if grout flows a distance less than 100 mm; medium (M)—if grout flows a distance less than 200 mm; high (H)—if grout flows a distance more than 200 mm. Note if grout is collected at the bottom of the channel (fig. 4.3.4). The farther down the channel the grout travels, the better the flow.
2. Repeat the test until two experimental runs providing the same classification are obtained. The average of two independent measurements is the average flow distance. Average distance should not differ more than 25% from each measured value; otherwise, the test should be repeated.
3. Record results on a data collection sheet; see figure 4.3.5 for an example.

Figure 4.3.4 The distance the grout has flowed is recorded. In this case, grout demonstrated high flow and accumulated at the bottom of the tile.

FLOW ON PLASTERED TILE

Grout name	
Grout proportions	
Operator	
Date	

	Week no.	Temperature (°C)		RH (%)	
		Max	Min	Max	Min
Plaster	1				
	2				

L (mm): Distance traveled by grout

LOW (L): If grout flows a distance less than 100 mm
MEDIUM (M): If grout flows a distance less than 200 mm
HIGH (H): If grout flows a distance more than 200 mm. Note if grout is collected at the bottom of the channel.

Specimen no.	Temperature (°C)	RH (%)	L (mm)	Classification
1				
2				

L, average = ______ mm

Classification ______

Figure 4.3.5 Data collection sheet for the flow on plastered tile test method.

4.4. Expansion and Bleeding

Aim

This test is used in the field to determine the amount of expansion and accumulation of bleed water that forms over time at the surface of freshly mixed grout. Grouts that are well formulated and properly proportioned should not segregate or bleed visibly. Excessive segregation or bleeding of a grout will change its properties and cause clogging during injection. A suggested final bleeding should be less than 0.4%.

Description

This test follows ASTM C 940—Expansion and Bleeding of Freshly Mixed Grouts for Preplaced-Aggregate Concrete in the Laboratory—and the laboratory procedure for the expansion and bleeding of grouts (section 2.2 in this volume), with the exception of sample volume, which has been modified for field use. Grout is placed in a graduated cylinder, and the change in total volume and the rate of accumulation of bleed water on the surface of the grout are measured over a period of time. The volume of bleed water with respect to the total volume of grout is an indication of the separation of the liquid and solid phases. It is important to determine the expansion of a lime-based hydraulic grout when the injection grout includes additives that facilitate expansion. This test can also be used for testing nonhydraulic injection grouts.

Adaptations for Testing Injection Grouts for the Conservation of Architectural Surfaces in the Field

The volume of grout used is reduced from 800 ± 10 mL, as specified in ASTM C 940, to 80 ± 10 mL. All test equipment and materials are stored in closed containers in the location where the test will be run.

Equipment and Materials

- 100 mL plastic or glass graduated cylinder reading to 1 mL
- 25 mL plastic or glass graduated cylinder reading to 1 mL
- 10 mL syringe with cannula (#20 or higher)
- stopwatch
- thermometer
- Parafilm or thin plastic wrap (e.g., food wrap)

Figure 4.4.1 Grout in a graduated cylinder.

Figure 4.4.2 Bleed water at the top of the 100 mL graduated cylinder.

Procedure

1. Place the 100 mL graduated cylinder on a level surface free of vibration.
2. Mix the grout and record the ambient temperature.
3. Pour the grout into the graduated cylinder until the volume of the sample is 80 ± 10 mL (fig. 4.4.1). Volume measurements should begin within 3 minutes after the grout is mixed.
4. Cover the top with Parafilm or plastic wrap to prevent evaporation of the bleed water.
5. Record the total initial volume of the sample (V_0).
6. Record the volume at the upper surface of the bleed water layer (V_t) and at the upper surface of the grout (V_g), to the nearest 1 mL at 15 minute intervals for the first 60 minutes; thereafter, do this at hourly intervals until two successive readings show no further change in volume of the grout.
7. At the end of the test, transfer the bleed water (fig. 4.4.2) into a 25 mL graduated cylinder by tilting the cylinder and drawing the water off with a

syringe. Record the final volume of the bleed water (V_w) to the nearest 0.5 mL.

Results

1. Calculate the expansion of the grout (E) to the nearest 1% for each prescribed interval:

$$E = \frac{V_g - V_0}{V_0} \times 100 \tag{4.4.1}$$

   where V_0 is the volume of the sample at the beginning of the test, and V_g is the volume of the grout portion of the sample at prescribed intervals, measured at the upper surface of the grout, both in milliliters.

2. Calculate the combined expansion of the grout (CE) to the nearest 1% for each prescribed interval:

$$CE = \frac{V_t - V_0}{V_0} \times 100 \tag{4.4.2}$$

   where V_0 is the volume of the sample at the beginning of the test, and V_t is the volume of the sample at prescribed intervals, measured at the upper surface of the water layer, both in milliliters.

3. Calculate the bleeding of the grout (B) to the nearest 1% for each prescribed interval:

$$B = \frac{V_t - V_g}{V_0} \times 100 \tag{4.4.3}$$

   where V_0 is the volume of the sample at the beginning of the test; V_t is the volume of the sample at prescribed intervals, measured at the upper surface of the water layer; and V_g is the volume of the grout portion of the sample at prescribed intervals, measured at the upper surface of the grout, all in milliliters.

4. Calculate the final bleed water (FB) as a percentage of the initial volume of the grout, to the nearest 1%:

$$FB = \frac{V_w}{V_0} \times 100 \tag{4.4.4}$$

   where V_0 is the volume of the sample at the beginning of the test, and V_w is the volume of decanted bleed water, both in milliliters.

5. The average of two independent measurements is stated as E, CE, and B at each interval, and the average of two independent measurements is stated as FB. The average value should not differ more than 10% from each measured value; otherwise, the test should be repeated.

6. An example data collection sheet for this procedure is given in figure 4.4.3.

EXPANSION AND BLEEDING

Grout name		**Ambient temperature (°C)**	
Grout proportions			
Operator		**Date**	

V_0 (mL): Volume of the sample at the beginning of the test
V_t (mL): Volume of the sample at prescribed intervals, measured at the upper surface of the water layer
V_g (mL): Volume of grout portion of sample at prescribed intervals, measured at the upper surface of grout
V_w (mL): Volume of decanted bleed water

EQUATIONS

Expansion, E (%) = $\frac{V_g - V_0}{V_0} \times 100$	Combined expansion, CE (%) = $\frac{V_t - V_0}{V_0} \times 100$
Bleeding, B (%) = $\frac{V_t - V_g}{V_0} \times 100$	Final bleeding, FB (%) = $\frac{V_w}{V_0} \times 100$

	Test 1					**Test 2**				
Hour:min	**V_t (mL)**	**V_g (mL)**	**E (%)**	**CE (%)**	**B (%)**	**V_t (mL)**	**V_g (mL)**	**E (%)**	**CE (%)**	**B (%)**
0:15										
0:30										
0:45										
1:00										
2:00										
3:00										
4:00										
5:00										
6:00										
7:00										
8:00										

	Test 1	**Test 2**
V_0 (mL)		
V_w (mL)		
FB (%)		

Figure 4.4.3 Data collection sheet for the expansion and bleeding test method.

4.5. Wet Density

Aim

This test is used in the field to determine the wet density of a grout. Wet density becomes an important parameter if added weight as a result of grouting might cause structural instability or failure of the architectural surfaces. Examples of this would be the grouting of large voids behind architectural surfaces on ceilings and vaults.

Description

This test follows the procedure of ASTM C 185—Standard Test Method for Air Content of Hydraulic Cement Mortar (section 9.4)—and the laboratory procedure for wet density (section 2.3 in this volume), with the exception of sample volume, which has been modified for field use. A syringe is filled with grout and weighed. The volume of the syringe and the measured weight of the grout are used to calculate the wet density. This test can also be used for testing nonhydraulic injection grouts.

Equipment and Materials

- two 5 mL syringes
- balance accurate to within 0.1 g
- paper towel(s)

Procedure

1. Tare the balance with an empty 5 mL syringe.
2. Pull 5 mL grout into the syringe and remove air bubbles by tapping with finger (fig. 4.5.1) until all air bubbles are removed.
3. Clean the tip of the syringe and wipe off all grout and water adhering to the outside of the syringe.
4. Weigh the filled syringe (M_g) (fig. 4.5.2).

Figure 4.5.1 A syringe filled with grout is tapped to remove air bubbles.

Results

1. Calculate the wet density of the grout (ρ_{wet}) in grams per cubic centimeter ($g{\cdot}cm^{-3}$) using the following formula:

$$\rho_{wet} = \frac{M_g}{5} \qquad (4.5.1)$$

   where M_g is the weight of the grout in grams.
2. The average of two independent measurements is stated as the average wet density. The average value should not differ more than 10% from each measured value; otherwise, the test should be repeated.
3. An example data collection sheet for this procedure is given in figure 4.5.3.

Figure 4.5.2 A grout-filled syringe is weighed.

WET DENSITY

Grout name	
Grout proportions	
Operator	
Date	

M_g (g): Weight of the grout in syringe
ρ_{wet} ($g \cdot cm^{-3}$): Wet density of the grout

EQUATION

$$\rho_{wet} = \frac{M_g}{5}$$

Specimen no.	M_g	ρ_{wet} ($g \cdot cm^{-3}$)
1		
2		

ρ_{wet}, **average =** ______ $g \cdot cm^{-3}$

Figure 4.5.3 Data collection sheet for the wet density test method.

4.6. Drying Shrinkage

Aim

This test is used in the field to determine the change of volume of a grout after drying. Volumetric stability of an injection grout is an important parameter directly affecting adhesion and durability. This test also provides information on the water content of the grout leading to volumetric instability. While increased water content may appear to improve some properties, such as injectability, it will decrease volumetric stability and lead to the formation of cracks, which in turn will cause loss of the bond between the grout and the substrate layers and loss of grout strength.

Description

A container is filled with grout, and the dimensional changes, including cracking, of the grout are observed as the grout cures. During the testing, the grout-filled containers are placed near the location where the grouting will be conducted. This test can also be used for testing nonhydraulic injection grouts.

Notes

The experiment can be run by injecting grout directly into weighing boats or similar shallow trays, or by injecting grout into prepared "mortar cups" (described below). The second setup aims to address the effect of absorption by the substrate on early drying shrinkage, in addition to the effect of evaporation on shrinkage, which is not taken into account if a nonporous setup (weighing boat) is used. The following procedure explains how to determine and classify shrinkage by the use of mortar cups. Mortar used for repairs on site can be employed to make mortar cups. The following mortar proportions and ingredients were used at the GCI to prepare the mortar cups and are given here as a reference.

Equipment and Materials

- standard sand (EN 196-1)
- superventilated pozzolana
- lime putty
- mixing bowl or large plastic container for mixing mortar
- mortar mixer or trowel
- spatula
- plastic tube approximately 50 mm in diameter
- two weighing boats or similar shallow 30–50 mm deep containers at least 20 mm larger in diameter than the plastic tube described above
- 20 mL syringe
- thermometer
- humidity gauge
- caliper, ruler in millimeters, or a crack comparator card
- wristwatch
- plastic bags or moist cabinet

Preparation of Mortar Cups

Prepare a minimum of two mortar cups per grout as follows:

1. Pour 2.5 parts (by volume) standard sand and 0.5 parts (by volume) superventilated pozzolana into a container and mix with mortar mixer or trowel.
2. Add 1 part (by volume) lime putty and mix thoroughly with a mortar mixer at low speed, or mix manually with a trowel.
3. Pour the mortar into a small plastic weighing boat or container, fill approximately 30 mm deep, and smooth the surface with a spatula (fig. 4.6.1).
4. Press one end of the plastic tube halfway (approx. 15 mm deep) into the mortar (not all the way to the bottom), and rotate it to hollow out a cylindrical cavity in the mortar (fig. 4.6.2).
5. Remove the plastic tube and remove excess mortar from inside the cylindrical cavity with the spatula to create a flat bottom (fig. 4.6.3). Reuse the plastic tube to prepare as many mortar cups as needed.

Figure 4.6.1 A weighing boat or shallow container filled with mortar.

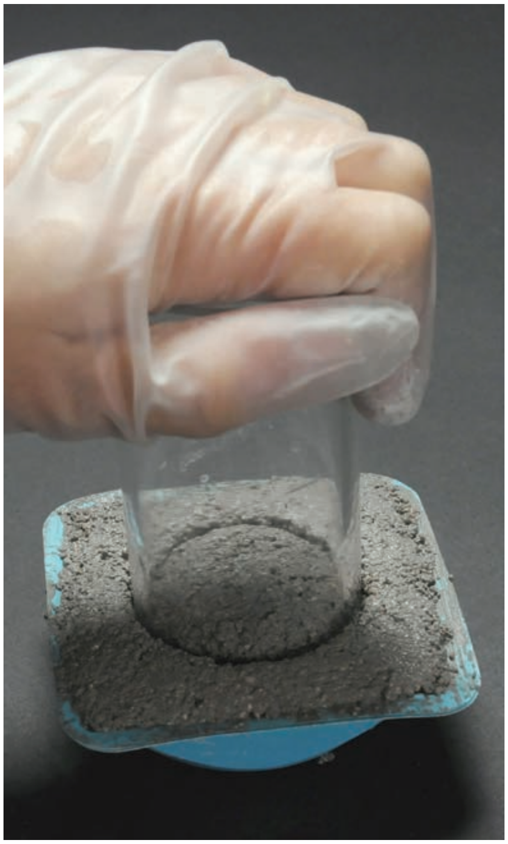


Figure 4.6.2 Plastic tube being pressed and rotated to approximately half the depth of the mortar in the cup.

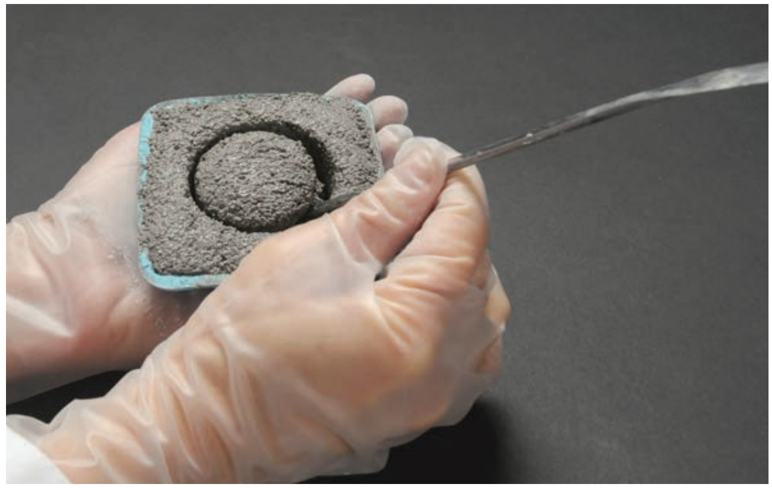


Figure 4.6.3 Removing excess mortar from the cavity.

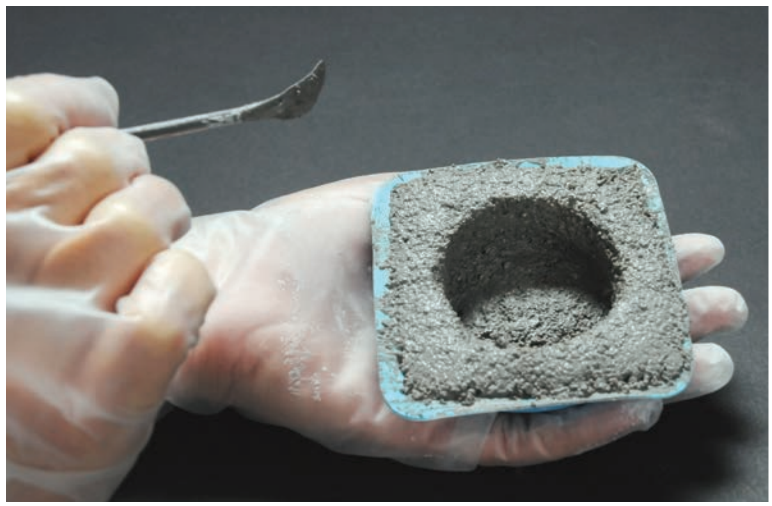


Figure 4.6.4 Fresh mortar cup.

6. Store the mortar cups (fig. 4.6.4) in tightly closed plastic bags (or in the moist cabinet at RH greater than 95%) at 20°C ± 10°C for 2 weeks.
7. At the end of 2 weeks, remove the mortar cups from plastic bags (or from the moist cabinet) and keep them near the location where the grouting will be conducted for at least 2 more weeks.

Procedure

1. Using a syringe without a cannula, inject 20 mL grout into shallow plastic container or mortar cup cavity (fig. 4.6.5).
2. Tap the container 10 times to spread the grout, and remove any entrapped air by slowly hitting the container on the counter.
3. Prepare a second specimen following steps 1 and 2; a total of two specimens per grout are needed.

Figure 4.6.5 Grout being injected into a mortar cup.

4. Record the time and date of preparation.
5. Leave the grout-filled plastic containers or mortar cups in the area where the grouting will take place. Record the RH and ambient temperature.
6. Wait at least 24 hours.
7. Measure the gap between the grout sample and the sides of the plastic container or cylindrical mortar cup cavity. Record the maximum measured gap.
8. If any cracking has occurred in the grout itself, measure the maximum crack size.
9. Record the time and date of measurements and the ambient temperature and RH. It is recommended that the process of obtaining measurements be continued until two successive measurements are the same.

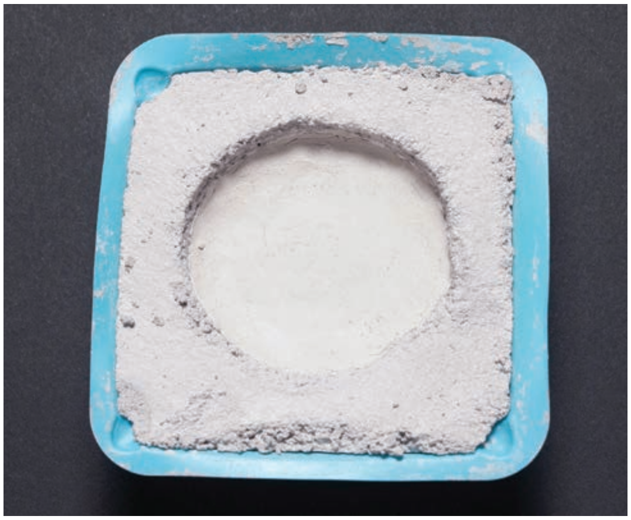


Figure 4.6.6 Specimen exhibiting no drying shrinkage (NS).

Results

1. Classify the shrinkage of the grout as: no drying shrinkage (NS)—no visible separation between grout and mortar and no visible cracking in the grout (fig. 4.6.6); medium drying shrinkage (MS)—a separation of less than 0.5 mm between grout and mortar and/or a maximum crack size of less than 0.5 mm in the grout (fig. 4.6.7); or high drying shrinkage (HS)—a separation of more than 0.5 mm between grout and mortar and/or a maximum crack size of more than 0.5 mm in the grout (fig. 4.6.8).
2. Report the drying shrinkage classification when both specimens provide the same classification; otherwise, the test should be repeated with two other specimens.
3. Report all temperature and humidity measurements.
4. Record measurements and results on a data collection sheet; see figure 4.6.9, for example.

Figure 4.6.7 Specimen exhibiting medium drying shrinkage (MS).

Figure 4.6.8 Specimen exhibiting high drying shrinkage (HS).

DRYING SHRINKAGE

Grout name	
Grout proportions	
Operator	

NO DRYING SHRINKAGE (NS): No separation between grout and mortar and no visible cracking in the grout

MEDIUM DRYING SHRINKAGE (MS): Separation of less than 0.5 mm between grout and mortar and/or a maximum crack size of less than 0.5 mm in the grout

HIGH DRYING SHRINKAGE (HS): Separation of more than 0.5 mm between grout and mortar and/or a maximum crack size of more than 0.5 mm in the grout

Test 1				Test 2			
Date	Time	RH (%)	Temperature (°C)	Date	Time	RH (%)	Temperature (°C)

Test 1			Test 2		
Separation size (mm)	Crack size (mm)	Classification	Separation size (mm)	Crack size (mm)	Classification

Figure 4.6.9 Data collection sheet for the drying shrinkage test method.

4.7. Final Setting Time

Aim

This test is used in the field to determine the final setting time of a grout. The time of setting is of interest particularly in situations where a fairly rapid set may be desired (e.g., fragile plasters, vaults, large areas of loss) or cases in which it is necessary to know when supports can be removed. Desirable setting time should be determined on a case-by-case basis, depending on the type of voids or cracks to be grouted.

Description

This test defines the final setting time of a grout as the time at which it becomes rigid enough to resist penetration by a cannula. Grout is injected into a container, and the time of final setting is determined by periodic insertion of a cannula into the grout until the cannula can no longer penetrate it. During the measurement, the grout-filled containers are placed near the location where the grouting will be executed. Final setting time, as measured here, is different from the laboratory test for setting time with Vicat needle, as it takes into account the effects of drying due to a loss of water to the substrate and to evaporation. The results of this field test will be closer to those that will be observed in the field than those measured in the laboratory.

Note

The experiment can be run by injecting grout directly into weighing boats or similar shallow trays, or by injecting grout into prepared "mortar cups" (described below). The second setup aims to address the effect of absorption by the substrate on final setting time, which is not taken into account if nonporous weighing boats or trays are used. The following procedure explains how to measure final setting time in mortar cups. Mortar used for repairs on site can be used to make mortar cups. The following mortar proportions and ingredients, given here as a reference, were used at the GCI to prepare these cups.

Equipment and Materials

- standard sand (EN 196-1)
- pozzolan
- lime putty
- mixing bowl or large plastic container for mixing the mortar
- mortar mixer or trowel
- spatula
- plastic tube approximately 50 mm in diameter
- two weighing boats or similar shallow 30–50 mm deep containers at least 20 mm larger in diameter than the plastic tube described above
- 20 mL syringe
- 60 mL syringe
- 14 gauge stainless steel blunt cannula (dispensing needle) (outer diameter, 2.1 mm; inner diameter, 1.70 mm; length, 25.4 mm)
- 100 g granular material (2 mm minimum aggregate size)
- wristwatch
- thermometer
- humidity gauge
- plastic bags or moist cabinet

Preparation of Mortar Cups

Prepare a minimum of two mortar cups per grout as follows:

1. Pour 2.5 parts (by volume) standard sand and 0.5 parts (by volume) pozzolan into a container and mix with a mortar mixer or trowel.
2. Add 1 part (by volume) lime putty and mix thoroughly with the mortar mixer at low speed, or mix manually with a trowel.
3. Pour the mortar mixture into a small plastic weighing boat or container, fill approximately 30 mm deep, and smooth the surface with a spatula (fig. 4.7.1).
4. Press one end of the plastic tube halfway (approx. 15 mm deep) into the mortar (not all the way to

Figure 4.7.1 A weighing boat or shallow container filled with mortar.

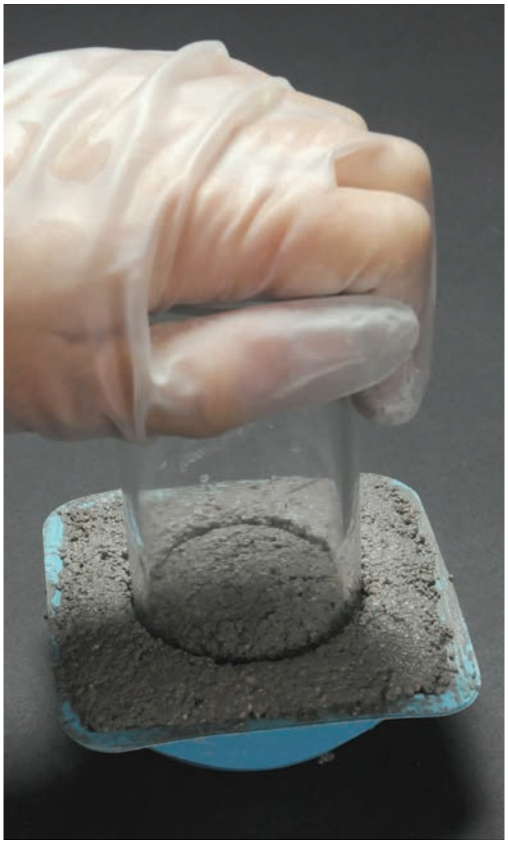


Figure 4.7.2 Plastic tube being pressed and rotated to approximately half the depth of the mortar in the cup.

the bottom), and rotate it to hollow out a cylindrical cavity in the mortar (fig. 4.7.2).

5. Remove the plastic tube and remove excess mortar from inside the cylindrical cavity with the spatula to create a flat bottom (fig. 4.7.3). Reuse the plastic tube to prepare as many mortar cups as needed.
6. Store the mortar cups (fig. 4.7.4) in tightly closed plastic bags (or in a moist cabinet at RH greater than 95%) at 20ºC ± 10ºC for 2 weeks.
7. At the end of 2 weeks, remove the mortar cups from the plastic bags (or from the moist cabinet) and keep them near the location where the grouting will be conducted for at least 2 more weeks.

Procedure

1. Using a syringe without a cannula, inject 20 mL grout into a plastic container or mortar cup cavity (fig. 4.7.5).

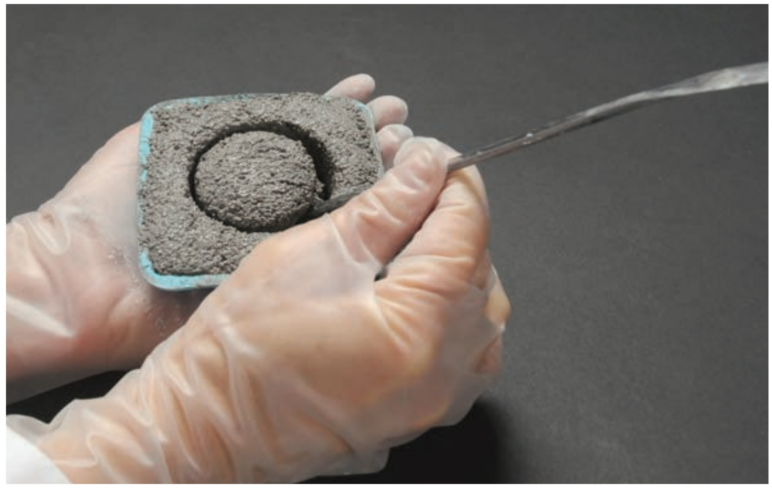


Figure 4.7.3 Removing excess mortar from the cavity.

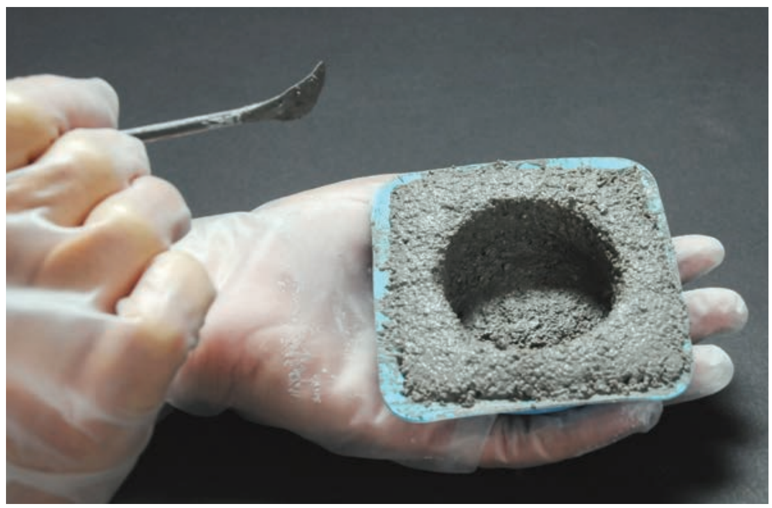


Figure 4.7.4 Fresh mortar cup.

Figure 4.7.5 Grout being injected into a mortar cup.

2. Tap the sides of the container 10 times to spread the grout, and remove any entrapped air by slowly hitting the container on the counter.
3. Prepare a second specimen following steps 1 and 2; a total of two specimens per grout are needed.
4. Record the time (t_o).
5. Leave the grout-filled plastic containers or mortar cups next to the area where the grouting will take place. Record the RH and ambient temperature.
6. Fill the 60 mL syringe (without a plunger) with 100 g granular material and attach the cannula.
7. After 1 hour, while holding the syringe vertically, position the tip of the cannula as close as possible to the surface of the grout specimen without touching it. The location of the first penetration hole should be at least 10 mm away from the wall of the mortar cup. Release the syringe and, using your fingers, guide it to fall directly into the grout (fig. 4.7.6).
8. Record the RH and temperature to monitor the effect of evaporation on final setting.
9. Repeat steps 7 and 8 every hour until the cannula no longer penetrates the grout (fig. 4.7.7). The space between two penetration holes should be at least 10 mm. The cannula should be cleaned, both inside and outside, after each measurement.

Figure 4.7.6 Syringe with cannula filled with 100 g of sand being dropped into the grout.

Figure 4.7.7 Final setting, reached after five penetrations.

Results

1. Final setting time is the time when the cannula no longer penetrates the grout.
2. The average of two independent measurements is the average final setting time obtained under field conditions. Two measurements should not differ from each other by more than 2 hours; otherwise, the test should be repeated.
3. Record results, including all temperature and humidity measurements, on a data collection sheet; see figure 4.7.8 for an example.

FINAL SETTING TIME

Grout name	
Grout proportions	
Operator	
Date	

t_0: Time the specimen is prepared

t_{final}: Time at which the cannula does not penetrate grout specimen

	Time (t)			Ambient	
	Date	**Hour**	**Min**	**Temperature (°C)**	**RH (%)**
(t_0)					
Specimen 1					
(t_0)				4	
Specimen 2					

Specimen no.	t_{final} (h)
1	
2	

t_{final}, average = ______ **h**

Figure 4.7.8 Data collection sheet for the final setting time test method.

4.8. Capillary Water Absorption

Aim

This test is used to estimate the water absorption behavior of hardened grout under field conditions by a gravimetric method. The absorption of water in a hardened grout should correspond to that of the materials being grouted to ensure compatibility of original and intervention materials.

Description

The method uses the sample size requirements of NORMAL 11/85—Capillary Water Absorption and Capillary Absorption Coefficient—and the procedure of RILEM test no. II.6—Water Absorption Coefficient (Capillarity)—and it follows the laboratory procedure for capillary water absorption (section 2.7 in this volume), with the exception of the processes of specimen preparation and oven drying, which have been altered for field testing. A syringe with a cannula is used to fill an empty transparent plastic tube through a taped, sealed end. The plastic tube is held vertically, and grout is injected through the tape into the bottom of the tube. After curing, the grout specimens are pushed out of the tube, or removed by cutting the plastic tube with a saw. Specimens are set on a perforated stand placed in a tray filled with water. The weight change of the specimen over time is used to calculate the amount of absorbed water.

Adaptations for Testing Injection Grouts for the Conservation of Architectural Surfaces in the Field

One of the most important modifications to this test method is that the specimens are not dried in the oven at 40°C ± 1°C, as was the case for the laboratory test method. Therefore, obtained A_{field} is to be used only for comparing water absorption capacity of the grouts tested at the same time under the same field conditions. The selected shape (cylindrical) and size (22 mm in diameter and 100 mm in height) of the grout specimens are meant to minimize cracking of specimens during curing, demolding, and drying. The selected dimensions are also suitable for testing brittle and heterogeneous injection grouts by providing a large enough sample volume and a surface area to volume ratio of 2.0 (NORMAL 11/85).

Equipment and Materials

- plastic container with a surface area more than 20 times larger than the inflow surface area of the specimen and deep enough to cover the perforated stand and the upright specimen
- plastic lid fitting the container
- distilled water
- perforated stainless steel metal or plastic stand
- balance accurate to within 0.01 g
- transparent rigid plastic (e.g., polymethyl methacrylate, PMMA) tube with 22.00 ± 0.05 mm inner diameter and around 1.75 mm wall thickness
- adhesive tape
- 60 mL syringe
- 14 gauge stainless steel blunt cannula (dispensing needle) with outer diameter, 2.1 mm; inner diameter, 1.70 mm; length, 25.4 mm
- ruler in millimeters
- stopwatch
- lint-free cloth
- tile or manual saw with a PMMA cutting blade or PMMA cutting knife
- V-shaped holder (metal or wood)

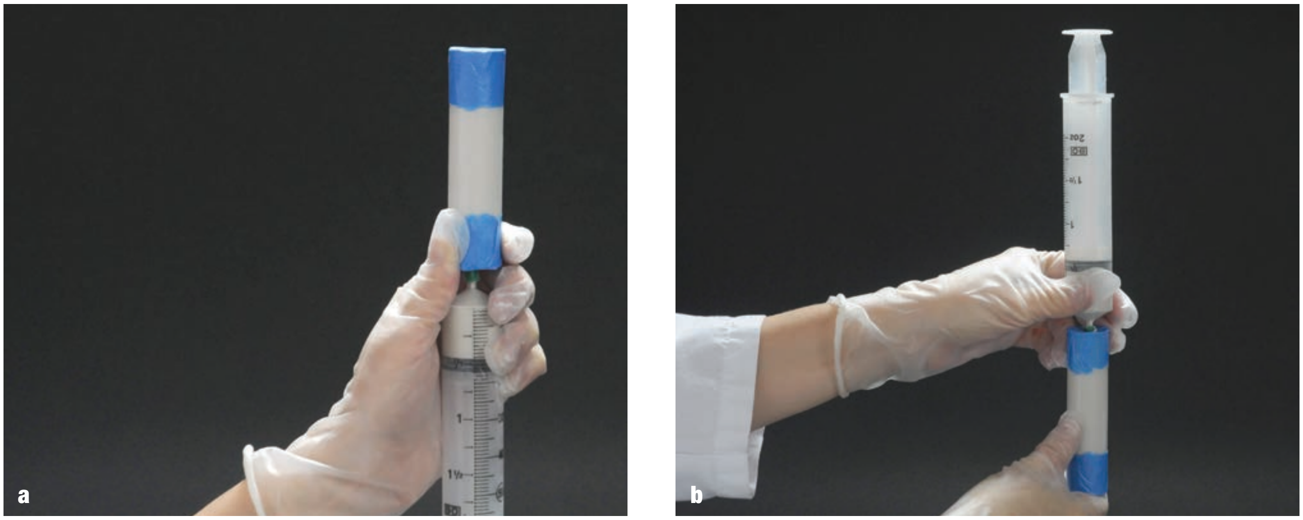
Column Preparation

1. Cut transparent rigid plastic tube into columns 100 mm in length.
2. Prepare three columns for each grout.
3. Seal one end of the columns with tape.

Specimen Preparation

1. Prepare the grout.
2. Pull 50 mL grout into the syringe and remove air bubbles by tapping with your finger.
3. Attach the cannula to the syringe and insert the cannula through the taped bottom end of the column (fig. 4.8.1).

Figure 4.8.1 The column is filled with a syringe inserted from the taped bottom of the column.

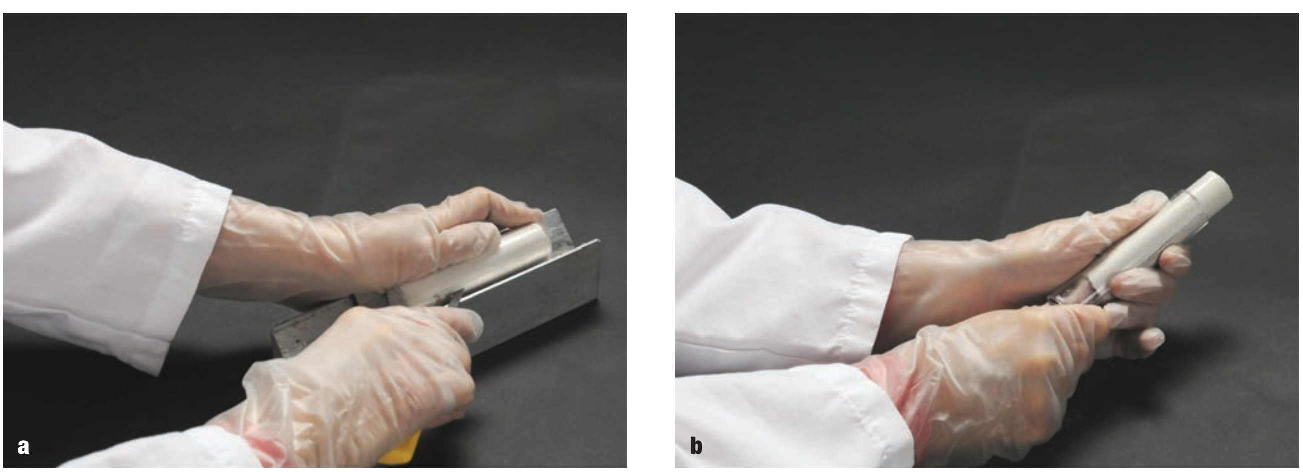


Figures 4.8.2a and 4.8.2b The top of the column sealed with adhesive tape (a), and the column turned upside down (b).

4. Push the plunger; holding the column vertically, slowly fill the column to the top with grout.
5. Seal the top end of the column with adhesive tape (fig. 4.8.2a). Turn the column upside down, remove the cannula, and reseal the end with fresh tape (fig. 4.8.2b).
6. Prepare three specimens for each grout.
7. Store the columns vertically (injection end down) for at least 2 weeks.
8. Extrude each specimen from the column by sawing the plastic tube covering the cylindrical specimen along the length without making any saw marks on the specimen (fig. 4.8.3a) and simply push the specimen with a finger from one end. Pushing the specimen with a finger from one end without sawing the plastic tube may also work (fig. 4.8.3b).

Procedure

1. Place the specimens near the location where the grouting will be conducted and leave for 2 weeks. Record the maximum and minimum RH and the ambient temperature weekly.
2. Measure the length (l) and diameter (d) of each specimen.
3. Weigh the specimen to the nearest 0.01 g (M_0).
4. Fill the tray with distilled water until the water level is 2 mm above the perforated stand. During testing, the water level in the tray is kept constant by the addition of water as needed.
5. Place the specimen on the stand and start the stop-watch (fig. 4.8.4).
6. Stop the stopwatch after 30 seconds and simultane-ously remove the specimen from the stand. Lightly blot the wet face with a damp cloth to remove



Figures 4.8.3a and 4.8.3b Slitting of a cylindrical plastic tube with a PMMA cutter (a), and removing the cured grout specimen (b).

Figure 4.8.4 Specimen absorbing water after being placed in a water-filled container. The level of water absorbed is indicated by the darker area at the bottom of the grout specimen.

Figure 4.8.5 Test setup before covering with a lid. The cover minimizes evaporation of the water in the tray.

surface water, and weigh the specimen (M_t) with the wet surface at the top. Place the specimen back on the stand as quickly as possible; start the stopwatch again.

7. Take measurements at 1, 2, 5, 10, 15, and 30 minutes.
8. The test setup is covered with a plastic lid to control the RH of the surroundings (fig. 4.8.5).

Results

1. The amount of absorbed water after time t (ΔM_t), in grams, is calculated with

$$\Delta M_t = M_t - M_0 \tag{4.8.1}$$

where M_t is the weight of the specimen at time t in grams, and M_0 is the weight of the specimen at $t = 0$ in grams.

2. The weight of water absorbed per unit area (m) in kilograms per square meter is calculated with

$$m = \frac{\Delta M_t}{\pi \times \left(\frac{d}{2}\right)^2} \times 10^3 \tag{4.8.2}$$

where ΔM_t is the amount of absorbed water after time t, in grams, and d is the diameter of the grout specimen in millimeters.

3. Calculate the water absorption coefficient in the field, A_{field}, in kilograms per square meter per square root of seconds ($kg \cdot m^{-2} \cdot s^{-1/2}$) using the results at 1 minute and 15 minutes, as follows:

$$A_{field} = \frac{m_{15min} - m_{1min}}{\sqrt{t_{15min}} - \sqrt{t_{1min}}} = \frac{m_{15min} - m_{1min}}{\sqrt{900} - \sqrt{60}} \tag{4.8.3}$$

where m_{15min} is the weight of water absorbed per unit area at 15 minutes, and m_{1min} is the weight of water absorbed per unit area at 1 minute, both in kilograms per square meter. The value t_{15min} is the time at 15 minutes, and t_{1min} is the time at 1 minute, both in seconds.

4. Calculate the average water absorption coefficient using the results of three specimens. Discard any individual result if the average and the individual result differ more than 25% from each other. The average water absorption coefficient should be obtained by at least two individual results; otherwise, the test should be repeated.
5. An example data collection sheet is given in figure 4.8.6.

CAPILLARY WATER ABSORPTION

Grout name	
Grout proportions	
Operator	
Date	

l (mm): Length of the specimen
d (mm): Diameter of the specimen
M_0 (g): Weight of the specimen at time t = 0
t: Time
M_t (g): Weight of the specimen at time t
ΔM_t (g): Weight of absorbed water after time t
m ($kg \cdot m^{-2}$): Weight of absorbed water per unit area
A_{field} ($kg \cdot m^{-2} \cdot s^{-1/2}$): Water absorption coefficient measured in the field

EQUATIONS

$$\Delta M_t = M_t - M_0$$

$$m = \frac{\Delta M_t}{\pi \times \left(\frac{d}{2}\right)^2} \times 10^3$$

$$A_{field} = \frac{m_{15\,min} - m_{1\,min}}{\sqrt{t_{15\,min}} - \sqrt{t_{1\,min}}} = \frac{m_{15\,min} - m_{1\,min}}{\sqrt{900} - \sqrt{60}}$$

Specimen no.	l (mm)	d (mm)	M_0 (g)
1			
2			
3			

Week no.	Temperature (°C)		RH (%)	
	max	min	max	min
1				
2				

		Specimen 1			Specimen 2			Specimen 3		
t (min)	t (s)	M_t (g)	ΔM_t (g)	m ($kg \cdot m^{-2}$)	M_t (g)	ΔM_t (g)	m ($kg \cdot m^{-2}$)	M_t (g)	ΔM_t (g)	m ($kg \cdot m^{-2}$)
0.5	30									
1	60									
2	120									
5	300									
10	600									
15	900									
30	1800									

Specimen no.	A_{field} ($kg \cdot m^{-2} \cdot s^{-1/2}$)
1	
2	
3	

A_{field}, average = ______ $kg \cdot m^{-2} \cdot s^{-1/2}$

Figure 4.8.6 Data collection sheet for the capillary water absorption test method.

4.9. Water Vapor Transmission Rate by the Wet Cup Method

Aim

This test estimates the passage of water vapor through hardened injection grouts under field conditions. The rate of water vapor transmission of a grout should be similar to the rate of water vapor transmission of the original material to be grouted, in order to ensure passage of water vapor through the original and intervention layers.

Description

The method uses the sample size requirements of NORMAL 21/85—Water Vapor Permeability—and loosely follows the procedure of ASTM E 96—Standard Test Methods for Water Vapor Transmission of Materials—as well as following the laboratory procedure for water vapor transmission by the wet cup method (section 2.8 in this volume), with the exceptions of controlled environmental conditions and dry cup correction, which have been modified for the field. A grout specimen is sealed to the open mouth of a test cup partially filled with distilled water and placed in the area where the grouting will be carried out. Periodic weighings of the cup and specimen determine the rate of water vapor movement (i.e., water vapor transmission rate—$WVTR_{field}$) through the specimen from the inside of the cup to the atmosphere.

Adaptations for Testing Injection Grouts for the Conservation of Architectural Surfaces in the Field

The specimen dimension requirements of NORMAL 21/85, including the requirements that the thickness be at least twice the size of the largest aggregate and the diameter be at least three times the thickness of the specimen, are followed. The selected shape (discs) and size (44 mm diameter and 10.0 mm thick) of the grout specimens are designed to minimize cracking of the specimen during curing and demolding. Furthermore, the disc shape simplifies the lateral sealing, and the selected dimensions ensure that the specimen is representative of the material being tested. One of the most important modifications applied to this test method is that the test is conducted under field conditions (i.e., in varying relative RH and temperature). Therefore, the obtained $WVTR_{field}$ is to be used only for comparing water vapor transmission rates of the grouts tested at the same time under the same field conditions. It is also recommended that RH and temperature ranges during the measurements be recorded.

Notes

The experiment can be run by preparing specimens on nonporous (e.g., glass or tile) surfaces or on porous substrates (e.g., plastered tile, brick, or stone). The second setup takes into account the effect of water loss due to the absorption by the substrate on the water vapor transmission rate of grouts. To prepare the plastered tile, mortar used for repairs on site can be employed. The following proportions and ingredients were used at the GCI to prepare the plastered tile, and they are given here as a reference.

Equipment and Materials

- standard sand (EN 196-1)
- superventilated pozzolana
- lime putty
- mixing bowl or large plastic container to mix the plaster
- mortar mixer, if available
- trowel
- glazed or unglazed ceramic tile (33 × 25 × about 1 cm thick)
- spray bottle
- distilled water
- three ring molds cut from rigid plastic tubing (approximately 44.0 mm inner diameter and 10.0 mm thick) (fig. 4.9.1)
- hot glue gun and glue sticks, or plasticine
- three plastic cups with maximum 50 mm mouth diameter (fig. 4.9.2)
- thin screen or cheesecloth
- 10 mL syringe
- sealing gum or cord (e.g., Permagum sealing cord)
- balance accurate to within 0.01 g
- metric caliper
- thermometer
- humidity gauge
- wristwatch
- plastic bag or moist cabinet larger than the size of the ceramic tile

Preparation of Plastered Tile

1. Pour 2.5 parts (by volume) standard sand and 0.5 parts (by volume) superventilated pozzolana into a container and mix with mortar mixer or trowel.

2. Add 1 part (by volume) lime putty and mix thoroughly with the mortar mixer at low speed, or mix manually with a trowel.
3. Using the spray bottle, prewet the reverse of the tile with water.
4. Spread plaster over the reverse of the tile to a thickness of 3–4 cm.
5. Smooth the surface with the trowel.
6. Store the plastered tile in a tightly closed plastic bag (or in a moist cabinet at RH greater than 95%) at 20°C ± 5°C for 2 weeks.
7. At the end of 2 weeks, remove the plastered tile from the plastic bag (or from the moist cabinet) and keep it near the location where the grouting will be executed for at least 2 more weeks. Record the maximum and minimum RH and temperature weekly.

Specimen Preparation

1. Place the mold on the plastered tile, brick, or stone covered with a thin screen (or cheesecloth), as shown in figure 4.9.1.
2. Hold the ring mold down and attach the bottom of the mold to the plastered tile by gluing it around the bottom edge with hot glue or plasticine.
3. Prepare a total of three molds for each grout.
4. Fill the ring molds with grout flush with the top within 2 minutes after mixing (fig. 4.9.1). Strike off the grout with the edge of a trowel.
5. Store the specimen assembly in a tightly closed plastic bag (or in a moist cabinet at RH greater than 95%) at 20°C ± 1°C for 2 weeks.
6. At the end of the first week, remove the specimen assembly from plastic bag (or from the moist cabinet). Carefully remove the hot glue around the mold and separate the specimens and the molds from the plaster by pulling the screen horizontally. Replace the specimen assembly in a tightly closed plastic bag (or in a moist cabinet) for one more week.
7. At the end of second week, remove the specimen assembly from plastic bag (or from the moist cabinet). Leave the specimens in the molds uncovered in the area where grouting will be conducted, out of direct sunlight and wind, for 24 hours before demolding.
8. Demold the specimens. First separate the specimen and the mold from the screen, if needed.
9. Keep specimens near the location where the grouting will be conducted for another 13 days, or until test is performed.
10. Record the maximum and minimum RH and temperature weekly.

Procedure

1. Label three plastic cups for each grout.
2. Measure the diameter (d) and the thickness (δ) of the specimens.
3. Pour 10 mL distilled water into the cups.

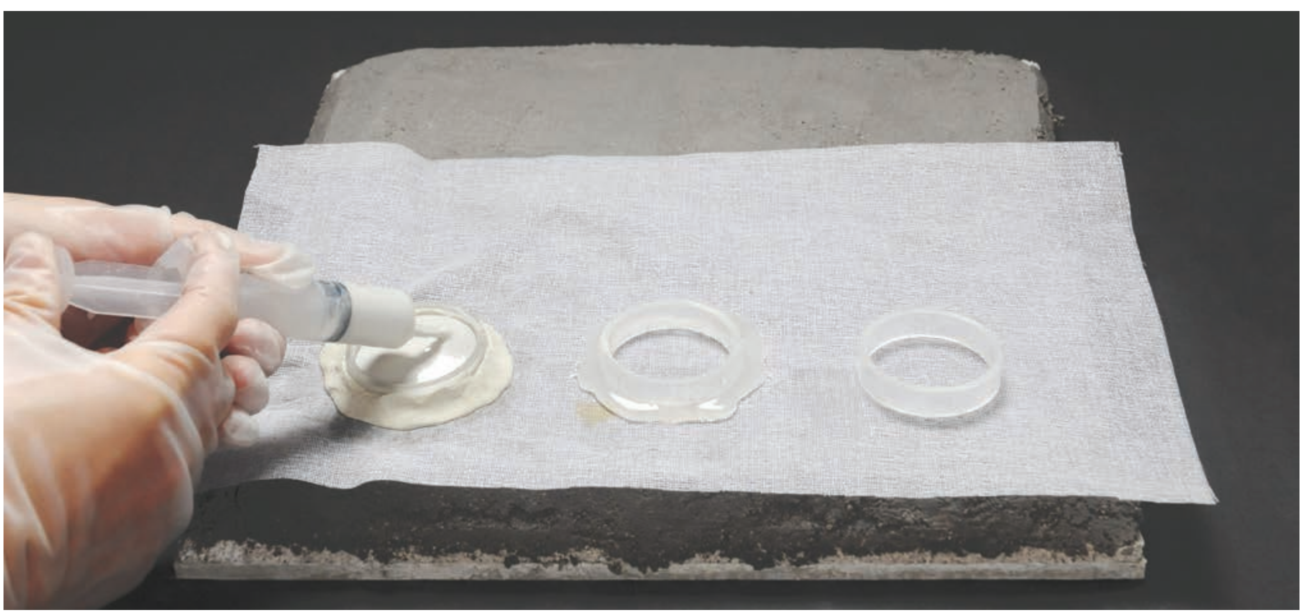


Figure 4.9.1 Molds attached to plastered tile being filled with grout.

Figure 4.9.2 Cup with cured specimen after sealing.

4. Place the sealing gum or cord around the specimen, and place the specimen in the cup. Gently push the specimen, being careful not to apply excessive pressure, so as to avoid cracking the specimen or pushing the sealing gum underneath the specimen.
5. Continue to fill the space between the grout sample and the cup with sealant to cover the sides of the specimen (fig. 4.9.2).
6. Weigh the cup and specimen assembly (M_0).
7. Place the cups near the location where the grouting will be conducted.
8. Weigh the cups (M) every day for 2 weeks. Record the RH and ambient temperature at each weighing.

Results

1. Calculate the surface area of the specimen (a) in square meters using

$$a = \frac{\pi \times d^2}{4 \times 10^6} \tag{4.9.1}$$

where d is the diameter of the specimen in millimeters.

2. Calculate the weight loss (ΔM) of each specimen and cup assembly for each measurement, in grams, using

$$\Delta M = M - M_0 \tag{4.9.2}$$

where M is the weight of the specimen and cup, and M_0 is the initial weight of the specimen and cup, both in grams.

3. Calculate the rate of water vapor transmission ($WVTR_{field}$) in grams per hour per square meter ($g \cdot h^{-1} \cdot m^{-2}$), using the results at 2 days and 14 days, as follows:

$$WVTR_{field} = \frac{\Delta M_{day\,14} - \Delta M_{day\,2}}{288 \times a} \tag{4.9.3}$$

where $\Delta M_{day\,14}$ is the weight loss of the specimen and cup at 14 days, in grams, $\Delta M_{day\,2}$ is the weight loss of the specimen and cup at 2 days, in grams, and a is the surface area of the specimen in square meters. The most common way of expressing WVTR is in grams per day (24 hours) per square meter ($g \cdot 24h^{-1} \cdot m^{-2}$). For the best use of $WVTR_{field}$ values, record the RH and the ambient temperature ranges during the measurement. The thickness of the specimens should also be indicated.

4. Calculate average $WVTR_{field}$ from the results of three specimens. Discard any result if the average and the independent result differ more than 25%. Average $WVTR_{field}$ should be obtained by at least two individual results; otherwise, the test should be repeated.
5. An example data collection sheet is given in figure 4.9.3.

WATER VAPOR TRANSMISSION RATE BY THE WET CUP METHOD

Grout name	
Grout proportions	
Operator	
Date	

d (mm): Diameter of mouth area of the cup
δ (mm): Thickness of the specimen
M_0 (g): Initial weight of the the specimen and cup
t: Time
M (g): Weight of the specimen and cup at time t
a (m^2): Area of the specimen
ΔM (g): Weight loss of the specimen and cup assembly at time t
ΔM_{day14} (g): Weight loss of the specimen and cup at 14 days
ΔM_{day2} (g): Weight loss of the specimen and cup at 2 days
$WVTR_{field}$ ($g \cdot h^{-1} \cdot m^{-2}$): Rate of water vapor transmission

	Week no.	Temperature (°C)		RH (%)	
		Max	Min	Max	Min
Plaster	1				
	2				
Specimen	1				
	2				

EQUATIONS

$$a = \frac{\pi \times d^2}{4 \times 10^6}$$

$$\Delta M = M_t - M_0$$

$$WVTR_{field} = \frac{M_{day\ 14} - M_{day\ 2}}{288 \times a}$$

Specimen no.	d (mm)	δ (mm)	M_0 (g)	a (m^2)
1				
2				
3				

Time (t)			Temp.	RH	M (g)			ΔM (g)		
Date	Hour	Min	(°C)	(%)	1	2	3	1	2	3

	Temp. (°C)	RH (%)
Maximum		
Minimum		

Specimen no.	$WVTR_{field}$ ($g \cdot h^{-1} \cdot m^{-2}$)
1	
2	
3	

$WVTR_{field}$, average = ________ $g \cdot h^{-1} \cdot m^{-2}$

Figure 4.9.3 Data collection sheet for the water vapor transmission rate test method.

Appendix A: List of Standards

The following list of standard and recommended tests is meant as a reference for the different tests that were modified for this manual. Some laboratory procedures described here closely follow one or another standard. Others loosely follow a given standard, and still others were derived from two or more standards and/or recommendations, and modified according to different material properties and performance characteristics of injection grouts from those materials for which these tests were developed.

The test methods are designated by the following acronyms, which specify either the organizations that promulgated the standards (e.g., ASTM, DIN, EN, UNI, etc.) or a specific category of testing recommendations offered by an organization (e.g., RILEM, NORMAL, etc.).

ASTM	ASTM International (formerly American Society for Testing and Materials)
DIN	Deutsches Institut für Normung (German Institute for Standardization)
EN	European standard approved by European Committee for Standardization (CEN)
NORMAL	Commissione Normativa Manufatti Lapidei (NORMAL) (Italian Committee for Normalization of Procedures on Stone Materials)
RILEM	Réunion Internationale des Laboratoires d'Essais et de Recherches sur les Materiaux et des Constructions (International Union of Testing and Research Laboratories for Materials and Structures)
UNI	Ente Nazionale Italiano di Unificazione (Italian Organization for Standardization)

ASTM C 185	Standard Test Method for Air Content of Hydraulic Cement Mortar
ASTM C 191	Standard Test Method for Time of Setting of Hydraulic Cement by Vicat Needle
ASTM C 192-07	Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory
ASTM C 474	Standard Test Methods for Joint Treatment Materials for Gypsum Board Construction
ASTM C 496	Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens
ASTM C 939	Standard Test Method for Flow of Grout for Preplaced-Aggregate Concrete (Flow Cone Method)
ASTM C 940	Expansion and Bleeding of Freshly Mixed Grouts for Preplaced-Aggregate Concrete in the Laboratory
ASTM C 953	Standard Test Method for Time of Setting of Grouts for Preplaced-Aggregate Concrete in the Laboratory
ASTM C 1506	Standard Test Method for Water Retention of Hydraulic Cement-Based Mortars and Plasters
ASTM D 905	Standard Test Method for Strength Properties of Adhesive Bonds in Shear by Compression Loading
ASTM D 4327	Standard Test Method for Anions in Water by Chemically Suppressed Ion Chromatography

ASTM E 96	Standard Test Methods for Water Vapor Transmission of Materials
DIN 18 555, part 7	Testing of Mortars Containing Mineral Binders: Determination of Water Retentivity of Freshly Mixed Mortar by the Filter Plate Method to Determine the Water Retention Value
EN 196-1	Methods of Testing Cement—Part 1: Determination of Strength
EN 445	Grout for Prestressing Tendons—Test Method
EN 1771	Determination of Injectability Using the Sand Column Test
NORMAL 11/85	Capillary Water Absorption and Capillary Absorption Coefficient
NORMAL 21/85	Water Vapour Permeability
RILEM test no. II.6	Water Absorption Coefficient (Capillarity)
UNI 11152	Water Suspensions of Hydraulic Binders for Grouting: Characteristics and Test Methods

Appendix B: Laboratory Instruments and Manufacturers

Company name, type (model)	Address	Telephone	Website
Caframo Mixer (Stirrer BDC 3030)	501273 Grey Road 1 RR 2, Wiarton, Ontario, N0H 2T0, Canada	+1 800 567 3556	www.caframo.com
Dionex Ion chromatograph, autosampler (DX 500, AS 3500)	1228 Titan Way, P.O. Box 3603, Sunnyvale, CA 94088-3603, USA	+1 408 737 0700	www.dionex.com
Humboldt Manufacturing Co. Water retention apparatus (H-3630A)	3801 North 25th Ave., Schiller Park, IL 60176, USA	+1 408 737 0700	www.humboldtmfg.com
IGM Injectability apparatus (I07 760)	4, rue Pablo Picasso, 78114 Magny les Hameaux, France	+33 1 30 47 10 65	www.igm.fr
IKA Flat stirrer (KS250 basic)	2635 North Chase Pkwy. SE, Wilmington, NC 28405-7419, USA	+1 910 452 7059	www.ika.com
Instron Universal testing machine (5885H)	825 University Ave., Norwood, MA 02062-2643, USA	+1 800 877 6674	www.instron.us
Julabo Refrigerated/heating circulator (F25)	884 Marcon Blvd, Allentown, PA 18109, USA	+1 610 231 0250	www.julabo.de/de
Matest Cement setting tester (Vicatronic)	Via delle Industrie, 25, 24048 Treviolo (Bg), Italy	+39 035 2055011	www.matest.com
MK Diamond Products Tile saw (MK 101)	1315 Storm Pkwy., Torrance, CA 90501, USA	+1 800 421 5830	www.mkdiamond.com
Thermo Viscosity tester (Haake Viscotester 550)	81 Wyman St., Waltham, MA 02454, USA	+1 781 622 1000	www.thermofisher.com

Glossary

The following terms have been used throughout this manual. They were taken from different sources describing related materials, parameters, and test methods.

The following publications were consulted in the preparation of this glossary: *Use of Nomenclature in Dispersion Science and Technology* by V. A. Hackley and C. F. Ferraris, National Institute of Standards and Technology (NIST) Special Publication 960-3 (Springfield, VA: NIST, 2001); and *Concrete,* 2d ed., edited by S. Mindess, J. F. Young, and D. Darwin (Upper Saddle River, NJ: Prentice Hall, 2003). Also consulted were the following standards from ASTM International: ASTM C 11, Standard Terminology Relating to Gypsum and Related Building Materials and Systems; ASTM C 125, Standard Terminology Relating to Concrete and Concrete Aggregates; and ASTM C 219, Standard Terminology Relating to Hydraulic Cement.

A selection of definitions has been reprinted with permission from *Glossary of Terms and Definitions Used in Grouting: Proposed Definitions and Preferred Usage,* Project Report 61 (London: CIRIA, 1997), ISBN: 978-0-86017-861-3; www.ciria.org.

Adhesion
The tendency of dissimilar materials and/or surfaces to bond to one another.

Aliquot
A small quantitative sample taken from a larger volume of a solution.

Apparent Bingham yield stress
A critical shear stress value of a nonideal Bingham plastic fluid, defined as the extrapolation of the flow curve from the linear, high shear rate region (plastic region) to the stress axis (shear rate of 0).

Batch
A quantity of material (e.g., grout) mixed at one time.

Bingham plastic fluid
A fluid that behaves as a solid at low stresses and as a viscous fluid at high stresses and exhibits rheological properties based on initial yield stress and plastic viscosity.

Bleeding
The separation of mixing water within, or its emergence from, a newly placed suspension (e.g., grout), caused by the settlement of the solid materials of the suspension.

Bond strength
The relative resistance to sliding or separation of a material (e.g., grout) from another material with which it is in contact. It is a collective expression of the effect of all forces between two surfaces, such as adhesion, friction, and mechanical interlock.

Cannula
A small-diameter metal or plastic tube (e.g., a hypodermic needle) for insertion into a cavity, as for draining off fluid or introducing medication. Used in these procedures for the injection of fresh grouts, for prewetting of surfaces, and for draining off surface water in some test procedures.

Capillary water absorption
The quantity of water absorbed by a porous material (e.g., hardened grout) in contact with a free water surface, by capillary action.

Capillary water absorption coefficient
The mass of water absorbed per unit surface area per square root of time. It corresponds to the slope of the initial straight segment of the capillary absorption curve.

Capillary water absorption curve
A curve that shows the change in the mass of water absorbed per unit surface area of a porous material (e.g., hardened grout), as a function of the square root of time under standard conditions.

Consistency
A qualitative expression of the relative mobility or ability of a freshly mixed suspension (e.g., grout) to flow.

Curing
For a lime-based grout, the maturing of the material by the hydration of its cementitious and/or pozzolanic materials and/or by the carbonation of lime components.

Curing time
For a grout, the time interval between the mixing of ingredients and the development of the ultimate solid properties of the material.

Differential viscosity
The derivative of shear stress with respect to shear rate.

Drying shrinkage
A reduction in dimensions of a material (e.g., grout) caused by drying.

Eluent
The mobile phase that transports the chemical through the column of chromatography.

Expansion
The increase in the volume of a suspension (e.g., grout), generally expressed as a percentage of the original volume of the material.

Filtration
The process of separating solids from fluids (liquids or gases) by placing a porous material (such as a filter) through which only the fluid can pass. The filter retains the suspended solid

particles, a process that may result in the deposition of a filter cake.

Final bleed water
The maximum percentage of the water phase released from a suspension (e.g., grout) during gravity settling, expressed as a percentage of the original volume.

Final set
A degree of stiffening (e.g., of a grout) greater than the initial set, generally stated as an empirical value indicating the time, in hours and minutes, that is required for stiffening that is sufficient to resist the penetration of a weighted test needle.

Flow cone
A device for measuring the consistency of a grout by measuring the time of efflux of a predetermined volume of grout to flow through a precisely sized orifice from a cone with standardized dimensions, used to indicate consistency.

Flow curve
A graphic representation of the behavior of flowing materials, in which shear stress is plotted as a function of shear rate.

Grout
A fluid material used to fill cracks, crevices, and cavities in soil, rock formations, and architectural and structural systems by force of gravity, injecting, or flooding, which gels, stiffens, or sets with time and consolidates the soil, rock, or wall, and/or reattaches layers in the architectural system. See "injection grout for architectural surfaces."

Grout mix
The components of a grout mixture, including dry ingredients (binders, aggregates, pozzolans, etc.) and water, expressed by weight.

Hardening
The development in a material of useful and measurable strength after setting.

Hydration
The chemical reaction between the hydraulic compounds and water (e.g., in a grout) that results in the formation of new compounds, most of which have strength-producing properties.

Hydraulic binder
A finely ground inorganic material or a blend of finely ground inorganic materials that when mixed with water sets and hardens, even under water, by means of hydration and/or pozzolanic reactions.

Initial set
A degree of stiffening (e.g., of a grout) generally stated as an empirical value indicating the time, in hours and minutes, that is required for stiffening that is sufficient to resist a predetermined penetration depth of a weighted test needle.

Injectability
The ability of a grout, under constant pressure, to fill a crack or capillary network created by granular material.

Injectability curve
The curve obtained by plotting the distance attained by a grout into a column filled with granular material as a function of time during an injectability test.

Injection grout for architectural surfaces
A bulked fluid material, composed of a binder, aggregate, water, and frequently admixtures, that can be injected behind a plaster, wall painting, or mosaic to fill cracks and voids and reestablish adhesion between delaminated layers.

Ion chromatography
A form of liquid chromatography, in which ions and polar molecules are separated based on their charge during their transport through a column, most commonly through ion exchange. After separation, each substance is quantified by a suitable means of detection.

Laminar flow
Flow across a surface in which all of the fluid particles proceed along parallel paths at the same velocity, and in which there is no transverse component of velocity.

Marsh funnel
See "flow cone."

Maximum aggregate size
The smallest sieve opening through which the entire sample (i.e., dry grout) can be passed.

Mortar
A combination of one or more binders (earth, gypsum, lime, or cement), aggregates, and water, with or without admixtures and fibrous reinforcements, used in or applied to masonry. In comparison with injection grouts, mortars typically have higher viscosity, contain aggregates of greater particle size, and have lower binder-water ratios.

Newtonian fluid
An ideal fluid that exhibits constant viscosity at all rates of shear.

Non-Newtonian fluid
A fluid that exhibits varying viscosity with different rates of shear and exhibits yield stress. See also "Bingham fluid."

Particle size distribution
A listing of percentages of all particle sizes in a sample, as determined by sieve analysis of dry granular materials for large particles, and determined by laser refractometry or sedimentation test for a suspension of small particles in a fluid. When measured by sieve analysis, it is usually expressed in terms of cumulative weight percentages of larger particles (retained) or smaller particles (passed).

Plastic viscosity
A parameter of the Bingham plastic model of fluids, the differential viscosity in the linear region of a flow curve—that is, the slope of the shear stress/shear rate curve above the yield point.

Preplaced-aggregate concrete
Concrete produced by placing coarse aggregate within a form or shutter and injecting a cementitious or resin grout to fill the interstices between the aggregate particles.

Rheology
The study of the deformation and flow of matter.

Rotary viscometer
An instrument for measurement of the viscosity of a fluid from the relationship between torque needed to rotate an

object submerged in fluid and rotation speed (shear gradient). The viscosity is derived from the ratio of shear stress related to torque to shear rate related to rotation speed.

Sedimentation
The accumulation of particles in a suspension at the bottom of a container as a result of gravitational forces.

Separator column
An ion exchange column used to separate ions in a solution according to their retention characteristics on the column packing material prior to quantification.

Set
A change of phase from a fluid to a solid. For a suspension, this condition is reached when it has lost plasticity to an arbitrary degree (i.e., the onset of rigidity), usually measured in terms of resistance to penetration or deformation; *initial set* refers to the first stiffening, and *final set* refers to an attainment of significant rigidity.

Setting time
The elapsed time required for a material to attain a specified rigidity after its components are mixed.

Shear
The relative movement resulting from the application of forces that causes, or tends to cause, two contiguous parts of a material to slide relative to one another in a direction parallel to their plane of contact.

Shear bond strength
The stress at which the bond between two different materials can no longer resist an applied shear force, and failure occurs.

Shear rate
The rate at which shear is applied, as a function of time.

Shear strength
The stress at which a single material can no longer resist an applied shear force, and failure occurs.

Shear stress
The component of an applied stress that causes successive parallel layers of a material body to move, in their own planes (i.e., the plane of shear), relative to one another.

Shrinkage
A reduction in volume of a material.

Splitting tensile strength test (Brazilian test)
An indirect way of measuring the tensile strength of a material. A load is applied on the side of a cylindrical specimen in diametric compression, leading to splitting of the specimen across the vertical diameter.

Stress
Force per unit area of a surface in a specimen on which internal forces act.

Suspension
A heterogeneous fluid containing solid particles that are either sufficiently large and settle due to gravitational forces, or small enough that they remain suspended in the fluid (colloidal particles).

Tensile strength
The stress at which a material can no longer resist an applied tensile force, and failure occurs.

Thixotropy
A reversible, time-dependent decrease in viscosity at a particular shear rate.

Turbulent flow
Flow in which the progression of fluid particles is irregular, and there is a seemingly haphazard interchange of particle positions. Individual particles are subject to fluctuating transverse velocities, so that the motion is eddying and sinuous rather than rectilinear.

Viscometer
An instrument for measuring the viscosity of fluids.

Viscoplastic
A hybrid property of a material that behaves like a solid below some critical stress value (the yield stress) but flows like a viscous liquid when this stress is exceeded. It is often associated with highly aggregated suspensions.

Viscosity
The property of a fluid that resists the forces tending to make it flow.

Water retention capacity
The ability of a suspension (i.e., freshly mixed grout) to retain its water under suction created by contact with a porous body.

Water retention value
The mass of water retained in a suspension after a specified amount of suction is applied for a specified period of time. Expressed as a percentage of the original water content.

Water vapor permeability
The time rate of water vapor transmission through unit area of a flat material of unit thickness, induced by unit vapor pressure difference between two specific surfaces, under specified temperature and humidity conditions.

Water vapor transmission rate
The steady water vapor flow through a porous material (e.g., grout) in unit time through unit area, normal to specific parallel surfaces, under specific conditions of temperature and humidity at each surface.

Wet density
The weight per unit volume of a freshly mixed suspension (e.g., grout).

Yield stress
A critical shear stress value below which an ideal plastic or viscoplastic material behaves like a solid, and above which a plastic material yields (i.e., deforms plastically), while a viscoplastic material flows like a liquid.

Abbreviations

$\dot{\gamma}$	shear rate (s^{-1})
δ	thickness (mm)
η_{pl}	plastic viscosity (Pa · s)
ρ_{dry}	dry density ($g{\cdot}cm^{-3}$)
ρ_{wet}	wet density ($g{\cdot}cm^{-3}$)
σ	shear stress (Pa)
σ_B^*	apparent Bingham yield stress (Pa)
ω	water to grout ratio by weight

a	area (m^2)
A	water absorption coefficient ($kg{\cdot}m^{-2}{\cdot}s^{-1/2}$)
A_{field}	water absorption coefficient measured in the field ($kg{\cdot}m^{-2}{\cdot}s^{-1/2}$)
B	bleeding (%)
CE	combined expansion (%)
d	diameter (mm)
d_{max}	maximum aggregate size (mm)
ΔM	weight change (g or %)
ΔP	vapor pressure difference (Pa)
E	expansion of grout (%)
f	splitting tensile strength ($N{\cdot}mm^{-2}$)
func( )	function
F	breaking load (N)
f_{sb}	shear bond strength ($N{\cdot}mm^{-2}$)
FB	final bleed water (%)
h	height of the grout in the column (mm)
l	length (mm)
L	distance (mm)
m	weight of water absorbed per unit area ($kg{\cdot}m^{-2}$)
M	weight (g or kg)
r	radius (mm)
R^2	coefficient of determination
RH	relative humidity (%)
S	drying shrinkage (%)
S_{vp}	saturation vapor pressure (Pa)
t	time (s or h)
T_i	thixotropy index
V	volume (mL)
w	width (mm)
W	water content (g or %)
WRV	water retention value (%)
WVP	water vapor permeability ($g{\cdot}h^{-1}{\cdot}Pa^{-1}{\cdot}m^{-1}$)
WVTR	rate of water vapor transmission ($g{\cdot}h^{-1}{\cdot}m^{-2}$)
$WVTR_{field}$	rate of water vapor transmission measured in the field ($g{\cdot}h^{-1}{\cdot}m^{-2}$)