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TRI-SERVICE PAVEMENTS WORKING GROUP (TSPWG) MANUAL

TESTING PROTOCOL FOR RAPID-SETTING RIGID REPAIR MATERIALS

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TEST PROTOCOL FOR RAPID-SETTING RIGID REPAIR MATERIALS

Indicate the preparing activity beside the Service responsible for preparing the document.

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER CENTER (Preparing Activity)

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Change No.	**Date**	**Location**

This manual supersedes TSPWG M 3-270-01.08-2, *Test Protocol for Rapid-Setting Rigid Repair Materials*, dated 28 February 2017.

FOREWORD

This Tri-Service Pavements Working Group Manual supplements guidance found in other Unified Facilities Criteria, Unified Facilities Guide Specifications, Defense Logistics Agency Specifications, and Service-specific publications. All construction outside of the United States is governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and, in some instances, Bilateral Infrastructure Agreements (BIA). Therefore, the acquisition team must ensure compliance with the most stringent of the TSPWG Manual, the SOFA, the HNFA, and the BIA, as applicable. This manual guides the acceptance testing protocol and establishes limits for identification and use of materials, with minimal risk, in partial-depth spall repairs of rigid pavements in locations subject to high operations tempo and where time to return the area to aircraft traffic is limited. The information in this manual is referenced in technical publications found on the Whole Building Design Guide. It is not intended to take the place of Service-specific doctrine, technical orders (TOs), field manuals, technical manuals, handbooks, Tactic Techniques or Procedures (TTPs), or contract specifications but should be used along with these to help ensure pavements meet mission requirements.

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- Whole Building Design Guide web site http://dod.wbdg.org/.

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TRI-SERVICE PAVEMENTS WORKING GROUP MANUAL (TSPWG M) REVISION SUMMARY SHEET

Document: TSPWG M 3-270-01.08.2, *Test Protocol for Rapid-Setting Rigid Repair Materials*

Superseding: TSPWG M 3-270-01.08-2, *Test Protocol for Rapid-Setting Rigid Repair Materials*, dated 28 February 2017

Description: This manual provides a protocol for the acceptance of rapid-setting rigid materials used to repair spalls on rigid airfield pavements. This protocol consists of a series of tests and limits that ensure lasting spall repairs that can support aircraft within two hours. The Defense Logistics Agency (DLA) uses this protocol and that found in TSPWG M 3-270-01.08-4, *Testing Protocol for Polymeric Spall Repair Materials*, to identify products for filling orders under National Stock Number (NSN) 5610-01-564-7710.

Reasons for Document:

- This manual was revised to reflect changes in the testing protocol limits.
- This manual provides test protocols and limits to ensure engineers at remote airfields with high operational tempos can rapidly generate durable repairs.

Impact: There is no cost impact. The following benefits should be realized.

- Supplemental information on the operation, maintenance, and repair of pavements, as well as airfield damage repair, will be available to all services and the DLA.
- Maintenance and/or upgrading of this supplemental information will include inputs from all Services and DLA.

Unification Issues: None

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TABLES

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CHAPTER 1 INTRODUCTION

1-1 BACKGROUND.

There are many options when selecting a material for repairing spalls. Materials can be generalized into three categories: cementitious, asphaltic, and polymeric. Within each of these categories there are many products to choose from and some products blur the categorical boundaries (e.g., polymer-modified asphalt and polymer-modified concrete). Proprietary products often evolve as manufacturers attempt to address concerns or problems expressed by field personnel. The testing protocol presented herein is necessary for DOD organizations to eliminate materials that have a low probability of success in the field. The field success of materials that pass this testing protocol cannot be guaranteed but such materials are considered worthy of field testing. This testing protocol is limited to cementitious products (portland cement or other cementitious products) that exhibit elastic moduli greater than 1,000,000 pounds per square inch (psi) in their hardened state. This testing protocol is also limited to concrete materials with a maximum aggregate size of 0.75-in. (19 mm). This manual does not address the proper application of any materials in the field. Users are encouraged to strictly adhere to manufacturers' guidelines.

1-2 PURPOSE AND SCOPE.

1-2.4 This manual provides a testing protocol for acceptance of rapid-setting rigid repair materials intended for airfield and roadway pavements previously constructed with ordinary portland cement (OPC) concrete.

1-2.1 This manual provides a suite of laboratory tests, with their acceptable limits, that can be utilized to evaluate rigid spall repair materials used in portland cement concrete (PCC) pavements to produce repairs capable of supporting aircraft traffic within a couple of hours of placement. Rigid materials are those that have elastic moduli higher than approximately 1,000,000 psi. They are designed to exhibit properties similar to PCC pavements. These materials may contain OPC or they may contain other modern hydrating or cementing minerals, such as magnesium phosphate. Rigid materials do not include most polymers, particularly those considered to produce "elastomeric concrete." Spalls in PCC pavements consist of damage that does not penetrate through the pavement surface to the underlying layers. Spalls may be up to 5 ft (1.5 m) in diameter and typically require less than 1 ft^3 (0.028 m^3) of repair material. However, larger spalls resulting from exploding munitions can occur in contingency environments.

1-2.2 This protocol identifies materials which, based upon material and mechanical properties, will likely result in a durable partial-depth spall repair in a PCC pavement subjected to short-term aircraft traffic. Repairs using these materials can fail to meet mission needs or expected performance when the repair area is not properly prepared; the materials are not properly proportioned or mixed; the materials are used in temperatures outside the manufacturers' recommended weather conditions; the materials are not properly placed, consolidated, finished, isolated or sealed; or the joints or cracks within or next to the repair are not properly re-established. Each test and limit identified in this protocol is intended to diminish the risk and uncertainty of the material compatibility with the parent substrate and the ability of the material to withstand the stress and strain of applied loads without failure. Materials that do not meet the limits contained herein may still result in durable repairs; however, there is an increased risk that some aspects of the repair performance will need to be mitigated. For example, repairs made with materials mix designs based on type I cement can result in long-lasting repairs but will not meet the strength requirements in the required timeframes of this protocol. These materials often require several weeks before they reach the required strengths. Therefore, the use of such materials will require diverting traffic away from the repair area for up to 28 days to mitigate the risk of premature failure.

1-3 APPLICABILITY.

This manual is used by DLA to acquire materials for National Stock Number (NSN) 5610-01-564-7710. Installations can use materials that do not meet the limits of this manual's protocol; however, testing materials by using this protocol will help identify what risks, if any, the installation may be taking when using certain materials.

1-4 GLOSSARY.

Appendix A contains acronyms, abbreviations, and terms.

1-5 REFERENCES.

Appendix B contains a list of references used in this manual. The publication date of the code or standard is not included in this manual. Unless otherwise specified, the most recent edition of the referenced publication applies.

CHAPTER 2 TESTING PROTOCOL

2-1 DESCRIPTION OF TESTS.

2-1.1 Compressive Strength.

Compressive strength is important for ensuring the spall repair will not crush under wheel loads or due to stresses caused by environmentally induced pavement movements. It is generally accepted that the repair material should have a compressive strength similar to that of the existing concrete substrate. Evaluate compressive strength by testing in accordance with ASTM C39 procedures, using a minimum cylinder size of 3 in. x 6 in. (76 mm x 152 mm). Larger 4-in. x 8-in. (102 mm x 203 mm) or 6-in. x 12-in. (152 mm x 305 mm) cylinders are acceptable, but compression testing using 2-in. (50 mm) cubes in accordance with ASTM C109 is not acceptable. Cube testing is intended only for mortar and often gives inflated strength values for cylindrical specimens. Smaller 3-in. x 6-in. (76 mm x 152 mm) cylinders are recommended due to the limited volume of material mixed for each product and the rapid setting time. Curing durations before testing are 2, 3, and 24 hours and 7 and 28 days. The curing duration is the time elapsed from the final finishing of a compression specimen to the time of testing, not the time elapsed from the initial set of the material to the time of testing. Report results as maximum compressive stress (psi), which equals maximum force divided by the initial, unloaded cross-sectional area of the specimen.

2-1.2 Flexural Strength.

In addition to resisting crushing forces, durable spall repair materials also resist bending forces or flexure. Flexural strength is the limiting bending stress of the material before it yields, an important property since most pavement materials fail in flexure before they fail in compression. Although flexural strength can be correlated from compressive strength, it is recommended that flexural strength be established from testing according to ASTM C78 procedures. Each beam specimen shall have a test span three times its depth (± 2%) and with sides at right angles to its top and bottom. Flexural testing using 3-in. x 3-in. x 12-in. (76 mm x 76 mm x 305 mm) rectangular beams is acceptable. Larger 6-in. x 6-in. x 21-in. (152 mm x 152 mm x 533 mm) beams may also be used. However, since the maximum aggregate size is 0.75 in. (19 mm) and the beams are unreinforced, the larger 6-in. (152 mm) -square cross-section is not necessary for testing. The smaller beams can achieve similar results and reduce the cost of testing by reducing the volume of material required while still abiding by the rule of thumb used for slab depth flexural strength testing, which is that the smallest specimen dimension is at least three times the nominal maximum aggregate size. Curing durations before testing are 2 hours, 7 days, and 28 days. Report results as the ultimate bending stress before failure, also known as the modulus of rupture, in psi.

2-1.3 Bond Strength.

Bond strength is important to ensure the spall repair material will adhere to the existing concrete substrate to ensure adequate stress transfer during loading, expansion, and contraction. Perform bond strength tests in accordance with ASTM C882 procedures.

This procedure uses 3-in. x 6-in. (76 mm x 152 mm) cylindrical molds. A bond line is produced at approximately 30 degrees from vertical by first making wedge-shaped dummy sections of either OPC mortar or the repair material itself. Lightly sandblast the slant faces before placing the dummy section inside new molds and casting the repair material to the specimens. After curing for 1 day and 7 days, the composite cylinder, produced with repair material bonded either to the OPC mortar or to itself, is tested in compression. Report results as maximum bond stress, which is calculated as the maximum load divided by the area of the elliptical bonding surface, in units of psi.

2-1.4 Modulus of Elasticity.

The use of rigid repair materials with a modulus of elasticity that is significantly greater than that of the parent material will increase stress in the repair, which will lead to premature failure. Use only rigid spall repair materials with a modulus of elasticity, or stiffness, between 2 x 106 psi and 6 x 106 psi after 2 hours and 28 days of curing. For the same amount of strain under load, a stiff repair material will develop high internal stresses compared to a parent material of lesser stiffness. Conversely, if the repair material has a lower modulus of elasticity than the parent material, lower internal stresses will develop; thus, the potential for cracking and delamination of the repair will be reduced. Perform modulus of elasticity tests in accordance with ASTM C469 procedures using minimum size 3-in. x 6-in. (76 mm x 152 mm) cylinders. In this method, a bonded or unbonded sensing device is attached to the cylinder at mid-height to measure vertical deformation. Use a gauge length for the measurement that is at least three times the maximum aggregate size and not more than one-half the specimen height. The modulus of elasticity is calculated as change in stress divided by change in strain, where strain is calculated as vertical deformation divided by gauge length. Report modulus of elasticity in units of psi. The calculation, as specified in ASTM C469, produces a “chord modulus of elasticity.” Conduct the test after the specimens have cured 2 hours and after 28 days.

2-1.5 Volumetric Expansion or Contraction.

Excessive expansion and contraction of a spall repair, due to either internal or external forces, will result in a loss of bond to the parent material. Additionally, if the spall repair is large, excessive expansion can result in deterioration of the surrounding pavements.

2-1.5.1 Coefficient of Thermal Expansion.

The coefficient of thermal expansion of the spall repair material is important for reasons similar to those for the modulus of elasticity. A repair material with a coefficient of thermal expansion that is significantly greater than the parent material will experience greater volume changes with changes in temperature (volumetric expansion due to externally applied forces). The differential movement between the repair and the parent material will tend to deteriorate the bond between the materials. Perform the coefficient of thermal expansion tests in accordance with ASTM C531 procedures. Prismatic specimens with dimensions of 1 in. x 1 in. x 10 in. (25 mm x 25 mm x 254 mm) are embedded with metal gauge studs to facilitate length measurements. Specimens are measured at 24 hours then daily for two weeks to determine linear shrinkage. Next, the specimens are held at a temperature of 210 °F (98.8 °C) for 3 days after which the gauge length is measured. The specimens are then cooled to 73 °F (22.7 °C) for 24 hours and the gauge length is measured. This heating/cooling cycle is continued until a constant coefficient of thermal expansion is determined. Calculate the coefficient of thermal expansion as strain per degree F, with units of in./in./°F.

2-1.5.2 Length Change.

Volumetric change of spall repair materials can occur due to various factors other than applied force or temperature changes. Measuring the length change is important because the success of any repair depends largely on overcoming the tendency of the repair material to shrink or expand after placement. Deterioration of the bond with the parent material will occur if the spall repair material experiences length increases greater than 0.03% or length decreases greater than 0.04%. Assess the potential expansion or contraction of a repair material in accordance with ASTM C157 procedures, with modified length change methods detailed in ASTM C928. Fabricate triplicate 3-in. x 3-in. x 11.25-in. (76 mm x 76 mm x 286 mm) prism sets embedded with metal gauge studs for both water- and air-curing conditions. Remove specimens from molds at 2.5 hours then take initial readings at 3 hours. Immediately store one set of prisms for air curing and one set for water curing. Store air-curing specimens in a drying room maintained at a temperature of 73 °F ± 3 °F (23 °C ± 2 °C) and a relative humidity of 50% ± 4%. Prisms should be spaced 1 in. (25 mm) on all sides. Immerse water-curing specimens in untreated tap water at 73 °F ± 1 °F (23 °C ± 0.5 °C). Take measurements using a length comparator at 28 days. Calculate the length change as a percentage (change in length/original length x 100%). Report separate results for air- and water-cured specimens—do not average the two together.

2-1.6 Shrinkage Potential.

Shrinkage potential includes drying shrinkage, thermal shrinkage, and autogenous shrinkage, all of which occur during hydration. Shrinkage potential is important because repair materials that shrink excessively are more prone to bonding problems and shrinkage-related cracking.

Shrinkage in this protocol is measured using a restraining ring device in accordance with ASTM C1581. During this test, a ring of repair material attempts to shrink but a steel ring prevents its movements, resulting in the development of circumferential stresses that can lead to cracking. Strain gauges measure maximum tensile stress, which indicates cracking potential where cracking may not be visually observed. The restraining ring is constructed of structural steel pipe with a wall thickness of 0.5 in. (12 mm), an outside diameter of 13 in. (330 mm), and a height of 6 in. (152 mm). Repair material is cast on the outside of the restraining ring in a manner that produces a repair material ring with a height of 6 in. (152 mm) and a wall thickness of 1.5 in. (38 mm). The repair ring is moist-cured at 73.5 °F (23 °C) for 24 hours. The outer form used to shape the repair ring is then removed and the top of the repair ring is sealed so all drying occurs on the outer circumference of the repair ring. The restraining ring stays in place during the entire test. The repair ring cures in an environment with 50% relative humidity and a temperature of 73.5 °F (23 °C) for 28 days, during which the ring is monitored for cracking and the circumferential strain on the inside of the restraining ring is measured. Report the ring strain at the end of moist curing, the age at the time of the first crack (if cracking occurs), and the ring strain at either the age at the time of the first crack or 28 days if cracking never occurs. The ages are computed from the time of casting the repair ring.

2-1.7 Freeze-Thaw Resistance.

Resistance to damage during freezing and thawing is important to ensure the repair material can be used in cold climates. Unfortunately, for a wide range of materials, a reasonably rapid and well-correlated laboratory test method does not exist. Therefore, although a freeze-thaw test is recommended to continue to develop a database of laboratory results, there is no pass/fail requirement for these test results. The test method recommended by this testing protocol is ASTM C666, Procedure A. The test specimens are prisms or cylinders with widths and depths or diameters of 3 to 5 in. (76 to 127 mm) and lengths of 11 to 16 in. (279 to 406 mm). During freezing and thawing cycles, the prisms are monitored for changes in relative dynamic modulus of elasticity, which is calculated via fundamental transverse frequency measurements. The prisms are subjected to 300 cycles or until the relative dynamic modulus of elasticity decreases to less than 60% of its initial value. Testing begins after the prisms have moist-cured 14 days. Results are presented as a “durability factor,” which is a function of the number of cycles survived by the specimen and the relative dynamic modulus of elasticity at the time the test is terminated.

2-1.8 Workability.

Workability is an important consideration for selecting a repair material due to the short working times associated with rapid-setting products. The material must have a consistency to easily place, consolidate, and finish the repair rapidly. The working time for this protocol is defined by the time elapsed from the contact of water and the repair material to the initial set of the material. The final set must be achieved to ensure the repair can support traffic within two hours of placement.

2-1.8.1 Time of Setting.

The recommended test method is a modified version of ASTM C403. Follow ASTM C403, except do not remove the large aggregates (if present) before the test, as this best represents the actual material placed in the pavement repair. Begin timing as soon as the mixing water meets the product. Perform periodic tests using a penetrometer with an analog gauge by inserting the penetrometer needle of known surface area into the fresh concrete material. Record the penetration resistance (in psi), which is calculated by dividing the force (in pounds) by the bearing area of the needle (in square inches). The initial set time is the time elapsed between the initial contact of water and the product and the time when the penetration resistance equals 500 psi. The final set time is the time elapsed between initial contact of the water and the product and the time when the penetration resistance equals 4000 psi.

2-1.8.2 Slump.

For most repair materials, determine the slump in accordance with ASTM C143 within five minutes of adding water. This is the most generally accepted test to determine the consistency and workability of concrete. However, this method cautions that concretes having slumps greater than 9 in. (229 mm) may not be adequately cohesive for this test to have significance. Therefore, if the slump is over 9 in. (229 mm), as indicated by the standard slump test, the ASTM C1611 flow consistency test is required. Perform this test within five minutes of mixing the repair material. The ASTM C1611 procedure uses a mold conforming with ASTM C143 placed on a non-porous surface. Fill the mold, strike the repair material off with a straight-edge metal trowel, and then lift the mold so the material spreads over the non-porous surface. Measure the diameter of the spread in two perpendicular directions. Report the slump flow as the average diameter (inch).

2-1.9 Curing Methods.

Test specimens must be properly cured to produce accurate results. Always follow the manufacturer’s recommended procedures. When in doubt, air-cure specimens at room temperature and 50% relative humidity to impose less than optimal, but realistic, field curing conditions. Most importantly, report the curing conditions with the test results. To reflect field performance, curing durations in this protocol, unless specifically noted, are the times elapsed from the final finishing of a test specimen to the time of testing, not the times elapsed from the initial set of the material to the time of testing.

2-1.10 Replicates.

Three replicates are required for each test described in this protocol. The average result of the three replicates is compared to the requirements presented in Table 2-1. The average of only two replicates is not acceptable. Fabrication of additional specimens is encouraged in case a problem occurs during testing. Report any discarded test results believed to be outliers and explain the reason the data is considered invalid.

Table 2-1 Requirements for Test Results.

Property	ASTM	Requirement
Compressive strength	C39	≥ 2,500 psi at age of 2 hours ≥ 3,000 psi at age of 3 hours ≥ 4,000 psi at age of 1 day ≥ 5,000 psi at age of 7 days ≥ 5,000 psi at age 28 days
Flexural strength	C78	≥ 350 psi at age of 2 hours ≥ 500 psi at age of 7 days ≥ 600 psi at age of 28 days
Bond strength	C882	Repair slant material bonded to repair slant material (RS/RS) ≥ 1,000 psi at age of 1 day ≥ 1,500 psi at age of 7 days
		OPC mortar bonded to repair slant material (OPC/RS) ≥ 1,000 psi at age of 1 day ≥ 1,250 psi at age of 7 days
Modulus of elasticity	C469	≥ 2 $x10^6$ psi and ≤ 6 $x10^6$ psi Test at ages of 2 hours and 28 days
Volumetric expansion	C531	≤ 7 x 10^{-6} in/in/°F The test begins at the age of 14 days
	C157	Length change ≤ +0.03% and ≥ -0.04% @ 28 days Positive is expansion. Negative is shrinkage. Store specimens in air and store separate specimens in water All samples must pass regardless of how they are stored
Shrinkage potential	C1581	No cracks at 28 days. The test begins at the time of casting.
Freeze-thaw resistance	C666	No requirement at this time[1]
Time of setting	C403	Initial set ≥ 15 minutes Final set ≥ 15 minutes and ≤ 90 minutes Test begins immediately
Slump	C143 or C1611	≥ 3 inches within 5 minutes of added water

[1] Depending on results gathered for the database, a possible requirement designed to eliminate materials that are extremely susceptible to freeze-thaw damage is ≤ 60% loss in relative dynamic modulus of elasticity after 50 cycles.

2-1.11 Product Information and Test Results.

Information on products that have undergone testing by this protocol is available at https://transportation.erdc.dren.mil/cacsites/TriService/pavement_repair.aspx.

2-2 ADDITIONAL REPORTING REQUIREMENTS.

When reporting results on material after it has been tested in accordance with this testing protocol, include the following information to help reveal any differences between testing conducted by different testing agencies. Include information that is important for material selection but not directly related to the test result requirements presented in Table 2-1.

- Type of packaging (including quantity) for the material
- Manufacturer-reported shelf life and any problems related to material hydrating in package
- Safety/hazardous chemical issues, including the repair material and cleanup
- Method of mixing
- Volumes of material mixed in each batch
- Any notes concerning ease of use and mixing/consolidation characteristics
- Air temperature and sunlight conditions during mixing and casting
- Curing conditions
- Method of capping cylinders, where applicable
- Number of replicates used in calculating test results
- Anomalies or problems that occurred during testing
- Any eliminated data, along with justification

2-3 EVOLVING PROTOCOL.

This testing protocol and the associated material requirements will evolve as it is put to use and material test results are accumulated.

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APPENDIX A GLOSSARY

°C	Celsius
°F	Fahrenheit
ASTM	American Society for Testing and Materials
DLA	Defense Logistics Agency
DOD	Department of Defense
ft	foot
ft^3	cubic foot
in.	inch
m	meter
m^3	cubic meter
mm	millimeter
NSN	National Stock Number
OPC	ordinary portland cement
PCC	portland cement concrete
psi	pounds per square inch

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APPENDIX B REFERENCES

ARMY

Technical Report REMR-CS-62, *Performance Criteria for Concrete Repair Materials*, Phase II Summary Report, U.S. Army Waterways Experiment Station, Vicksburg, Mississippi, https://www.dtic.mil/DTIC Online/downloadPdf.search?collectionId=tr&docId=ADA362896

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

https://www.astm.org/

ASTM C39, *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*

ASTM C78, *Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third Point Loading)*

ASTM C109, *Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)*

ASTM C157, *Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete*

ASTM C403, *Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance*

ASTM C469, *Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression*

ASTM C531, *Standard Test Method for Linear Shrinkage and Coefficient of Thermal Expansion of Chemical-Resistant Mortars, Grouts, Monolithic Surfacings, and Polymer Concretes*

ASTM C617, *Standard Practice for Capping Cylindrical Concrete Specimens*

ASTM C666, *Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing*

ASTM C882, *Standard Test Method for Bond Strength of Epoxy-Resin Systems Used with Concrete by Slant Shear*

ASTM C928, *Standard Test Method for Packaged, Dry, Rapid-Hardening Cementitious Materials for Concrete Repairs*

ASTM C1231, *Standard Practice for Use of Unbonded Caps in Determination of Compressive Strength of Hardened Concrete Cylinders*

ASTM C1581, *Standard Test Method for Determining Age at Cracking and Induced Tensile Stress Characteristics of Mortar and Concrete Under Restrained Shrinkage*

ASTM C1611, *Standard Test Method for Slump Flow of Self-Consolidating Concrete*