

TRI-SERVICE PAVEMENTS WORKING
GROUP (TSPWG) MANUAL

**TESTING PROTOCOL FOR RAPID
SETTING RIGID REPAIR MATERIALS**



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U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER CENTER (Preparing Activity)

Record of Changes (changes are indicated by \1\ ... /1/)

Change No.	Date	Location

FOREWORD

This Tri-Service Pavements Working Group Manual supplements guidance found in other Unified Facilities Criteria, Unified Facility Guide Specifications, Defense Logistics Agency Specifications, and Service specific publications. All construction outside of the United States is also governed by Status of forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA.) Therefore, ensure compliance with the more stringent of these documents, protocols, agreements, specification and criteria, as applicable. This manual provides guidance on acceptance testing protocol and limits to identify materials for use, 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. This protocol and the material identified by the process are 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. Use this manual along with these other documents to help ensure pavement repairs meet mission requirements.

TSPWG Manuals are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction, maintenance, repair, or operations. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of this document. Technical content of this TSPWG Manual is the responsibility of the Tri-Service Pavements Working Group (TSPWG). Contact the preparing activity for document interpretation. Send recommended changes with supporting rationale to the respective service TSPWG member.

TSPWG Manuals are effective upon issuance and are distributed only in electronic media from the following source:

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

Check hard copies of TSPWG Manuals printed from electronic media against the current electronic version prior to use to ensure that they are current.

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

Description of Changes: This update converts USAF ETL 08-2, Testing Protocol for Rigid Spall Repair Materials into a TSPWG Manual. Content was reorganized for ease of understanding and locating information.

Reasons for Changes: To ensure the material is available to all services.

Impact: There is no cost impact. This publication results in the following benefits:

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

Note: The use of the name or mark of any specific manufacturer, commercial product, commodity, or service in this publication does not imply endorsement by the Department of Defense (DOD).

CONTENTS

	<u>Page</u>
CHAPTER 1 INTRODUCTION	1
1-1 BACKGROUND.....	1
1-2 PURPOSE.....	1
1-3 SCOPE.....	2
1-4 REFERENCES.....	2
CHAPTER 2 TESTING PROTOCOL.....	3
2-1 DESCRIPTION OF TESTS.....	3
2-2 ADDITIONAL REPORTING REQUIREMENTS.....	9
2-3 EVOLVING PROTOCOL.....	9
GLOSSARY	10
APPENDIX A REFERENCES.....	11

TABLES

<u>Table</u>	<u>Title</u>	
2-1	Requirements for Test Results	8

CHAPTER 1

INTRODUCTION

1-1 BACKGROUND.

When military personnel attempt to select a material for repairing spalls, they encounter a tremendous number of options. 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 over time as manufacturers attempt to address concerns or problems expressed by field personnel. The testing protocol presented herein is necessary for DOD organizations to eliminate from consideration for use those 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 to be 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 psi in their hardened state. This testing protocol is also limited to concrete materials that have a maximum aggregate size of 0.75 inch (19 millimeters). This TSPWG Manual does not address the proper application of any materials in the field. Users are encouraged to practice strict adherence to manufacturers' guidelines.

1-2 PURPOSE.

This TSPWG Manual provides a suite of laboratory tests, with their acceptable limits, which can be utilized to evaluate rigid spall repair materials used in portland cement concrete (PCC) pavements. Rigid materials are considered to be those that have elastic moduli higher than approximately 1,000,000 pounds per square inch (psi). They are designed to exhibit properties similar to ordinary portland cement (OPC) concrete. These materials may themselves 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 that are 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 caused by weapons may be up to 5 feet (1.5 meters) in diameter. Typical pavement spalls require less than 1 cubic foot (0.028 cubic meter) of repair material, although larger spalls resulting from exploding munitions can occur in contingency environments.

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 aircraft traffic in a short period of time. Repairs using these materials can fail to meet the mission needs or expected performance when: the repair area is not properly prepared; the materials are not properly proportions 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 within this protocol is intended to remove or diminish risk and uncertainty associated with the materials bond to and compatibility with the pavement being repaired as well as the repair's ability to withstand the environmentally, material and mechanically induced loads (stress and strains). Use of materials which do not meet the acceptance limits contained herein may result in durable repairs. However, there will be 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 this protocol's strength requirements in the timeframes required. These materials often require several weeks before they reach the required strengths. Therefore, 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 SCOPE.

This TSPWG Manual provides a testing protocol for the acceptance of rapid setting rigid repair materials intended for use on both airfield and roadway pavements that were previously constructed with Ordinary Portland cement (OPC) concrete.

1-4 REFERENCES.

[Appendix A](#) contains the list of references used in this TSPWG Manual.

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 easily under wheel loads or under stresses caused by environmentally induced pavement movements. Accomplish compressive strength testing in accordance with ASTM C39 procedures. Most cementitious spall repair materials can be evaluated using 3-inch by 6-inch (76-millimeter by 152-millimeter) cylinders. This TSPWG Manual is limited to concrete materials that have a maximum aggregate size of 0.75 inch (19 millimeters). Do not consider the material for use in spall repair if the repair material has a large coarse aggregate content and compaction in the 3-inch by 6-inch (76-millimeter by 152-millimeter) molds is difficult. The material may, however, still be useful for larger repairs where the minimum dimension of the repair volume is 6 inches (152 millimeters) or greater. Compression testing using 6-inch by 12-inch (152-millimeter by 304-millimeter) cylinders is acceptable, but compression testing with 2-inch (50-millimeter) cubes (ASTM C109) is not acceptable as part of this protocol because cubes often give inflated strength values relative to cylinders. Curing and capping methods are addressed in paragraph 2-1.9. Curing durations, prior to testing, include both 2-hour and 1-day durations as a minimum. These curing durations are 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. Results are reported as maximum compressive stress (psi), which equals maximum force divided by cross-sectional area.

2-1.2 Flexural Strength.

In addition to resisting crushing forces, durable spall repair materials also resist bending forces or flexure. Although flexural strength can be correlated to compressive strength, it is recommended that flexural strength testing be accomplished according to ASTM C78 procedures. Use beam specimens with a test span within 2% of being three times its depth as tested and with sides of the specimen at right angles with the top and bottom. Curing durations, prior to testing, include both 2-hour and 1-day durations as a minimum. Results are reported as the modulus of rupture (psi).

2-1.3 Bond Strength.

Bond strength is important for ensuring the spall repair will not easily become dislodged from the parent material onto which the repair was applied. Perform bond strength tests in accordance with ASTM C882 procedures. This procedure involves the use of 3-inch by 6-inch (76-millimeter by 152-millimeter) cylinder 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. After curing, these wedge-shaped sections slide into the bottom of the cylinder molds. The repair material is then placed on top of the dummy section. After curing for 1 day, the composite cylinder, produced with repair material bonded either to OPC mortar or to itself, is tested in compression. Curing and capping methods are addressed in paragraph 2-1.9. Results are reported as maximum bond stress (psi), which is calculated as maximum force divided by the area of the elliptical bonding surface.

2-1.4 Modulus of Elasticity.

Use of rigid repair materials with a modulus of elasticity that is significantly greater than that of the parent material being repaired will increase stress in the repair which will lead to a premature failure. Use only rigid spall repair materials that have a modulus of elasticity that is less than or equal to 3×10^6 psi after 2 hours of curing or 4×10^6 psi after 3 days of curing. With a higher stiffness, the repair material would assume higher stresses under wheel loading and pavement movement. Perform modulus of elasticity tests in accordance with ASTM C469 procedures. Use cylinders that are either 3 inches by 6 inches (76 millimeters by 152 millimeters) or 6 inches by 12 inches (152 millimeters by 304 millimeters). In this method, a bonded or unbonded sensing device is attached to the cylinder at mid-height for the purpose of measuring vertical deformation. Use a gage 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 (with units of psi) is calculated as change in stress divided by change in strain, where strain is calculated as vertical deformation divided by gage length. 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 3 days. Curing and capping methods are addressed in paragraph 2-1.9.

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 the deterioration of the surrounding pavements.

2-1.5.1 Coefficient of Thermal Expansion.

The spall repair material's coefficient of thermal expansion 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 would experience greater volume changes with changes in temperature (volumetric expansion due to externally applied forces). The difference in movements for the repair versus the parent material would tend to deteriorate their bond. Perform coefficient of thermal expansion

tests in accordance with ASTM C531 procedures. These procedures involve the production of prismatic bars (1 inch by 1 inch by 10 inches [25 millimeters by 25 millimeters by 254 millimeters]) with metal studs on each end. The studs facilitate length measurements. The lengths of the bars are measured at both 73 °F (22.7 °C) and 210 °F (98.8 °C). The coefficient of thermal expansion is calculated as strain per degree F, with units of in/in/°F. Begin testing after the prisms have cured 3 days.

2-1.5.2. Length Change.

Because volumetric expansion of spall repair materials can occur due to various causes other than applied force or temperature changes, testing for expansion due to internal forces needs to be accomplished according to ASTM C157 procedures. If a spall repair material experiences length changes greater than 0.03%, this will result in deterioration of the bond with the parent material and deterioration of the parent material itself. Following ASTM C157 procedures, test specimens are prismatic bars with dimensions based on maximum aggregate size. Use prismatic bars that are 3 inches by 3 inches by 11.25 inches (76 millimeters by 76 millimeters by 285 millimeters) with metal studs on each end for spall repair materials with maximum aggregate size of 0.75 inch (19 millimeters). The studs facilitate length measurements. The bars are then cured in either water at 73 °F (22.7 °C) or air storage at 73 °F (22.7 °C) with a 50% relative humidity. Readings are taken during curing after 4, 7, 14, and 28 days and after 8, 16, 32, and 64 weeks. The length change at each age is calculated as a percentage (change in length/original length x 100%).

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. While this procedure is slightly more involved than the traditional linear bar shrinkage test, which can be accomplished in conjunction with the coefficient of thermal expansion test (ASTM C531), the use of restraint is an attempt to capture all components of shrinkage listed above. The linear bar shrinkage test is limited to measuring only drying shrinkage. The restraining ring is constructed of structural steel pipe with a wall thickness of 0.5 inch (12 millimeters), an outside diameter of 13 inches (330 millimeters), and a height of 6 inches (152 millimeters). 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 inches (152 millimeters) and a wall thickness of 1.5 inches (38 millimeters). The repair ring is moist cured at 73.5 °F (23 °C) for 24 hours. Then the outer form that was used to shape the repair ring is removed and the top of the repair ring is sealed so that all drying occurs on the outer circumference of the repair ring. The restraining ring stays in place during the entire test. The repair ring now 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. Measure, record and compare to the requirement in Table 2-1, the ring strain at 14 days. Results to be reported include ring strain at the end of moist curing, age at the time of first crack (if cracking occurs), and ring strain at either the age at the time of 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, it is generally accepted that there is no reasonably rapid laboratory test method that correlates well with field freeze–thaw performance for a wide range of material types. Therefore, although a freeze–thaw test is recommended for the purpose of continuing to develop a database of laboratory results that can be related to field performance, there is no material 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 inches (76 to 127 millimeters) and lengths of 11 to 16 inches (279 to 406 millimeters). 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 percent of its initial value. Begin testing after the prisms have cured 3 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 Time of Setting.

Because of the short working times associated with rapid setting materials typically used for spall repairs, it is an important consideration in the selection of a specific material to accomplish a repair. Working time for this protocol will be defined by the time elapsed between initial contact of water and the repair material and the initial set of the material. The test method recommended by this testing protocol is ASTM C191. For this method, a paste is proportioned and mixed to normal consistency and molded. Periodic penetration tests are performed on this paste by allowing a 1-millimeter Vicat needle to settle into this paste. The initial time of setting is the time elapsed between the initial contact of cement and water and the time when the penetration is measured or calculated to be 25 millimeters (1 inch). The Vicat final time of setting is the time elapsed between initial contact of the cement and water and the time when the needle does not leave a complete circular impression in the paste surface. Time of setting is reported in minutes. Begin testing immediately after the paste is mixed due to very fast set times associated with these repair materials.

2-1.9 Curing and Capping Methods.

Although the curing and capping of laboratory specimens are not tests, they are important considerations for the purpose of accomplishing an accurate and consistent testing protocol.

2-1.9.1 Curing affects all tests described above. Cure the specimens in accordance with ASTM C1581 for the restraining ring shrinkage test. For the other tests, cure in the manner recommended by the repair material's manufacturer for curing materials in field placements or that represent the curing that will be used in field placements. When in doubt about the anticipated field procedures, air cure at room temperature and 50% relative humidity to impose less than optimal, but realistic, 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 time elapsed from the final finishing of a test specimen to the time of testing, not the time elapsed from the initial set of the material to the time of testing.

2-1.9.2 Capping affects compressive strength, bond strength, and modulus of elasticity testing. Capping is necessary for providing flat and perpendicular ends for the cylinders during compression loading. Capping complements additional flatness and perpendicularity requirements for the uncapped specimens. Cap cylinder specimens with bonded materials in accordance with ASTM C617 or use unbonded pad caps in accordance with ASTM C1231. For this protocol, use either bonded or unbonded caps for compressive strength and bond strength testing. Modulus of elasticity testing requires the use of bonded caps. Report the capping method(s) with the test results.

2-1.10 Replicates.

Three replicates are required for each of the tests described as being part of this protocol. The average result, calculated from the three replicates, is compared to the requirements presented in Table 2-1. The average of only two replicates is not acceptable, so those conducting the tests are encouraged to make extra specimens in case a problem occurs during testing. Report, with the other test results, any test results that are thrown out because they are 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	$\geq 3,000$ psi Test at age of 2 hours $\geq 5,000$ psi Test at age of 1 day
Flexural Strength	C78	≥ 350 psi Test at ages of 2 hours and 1 day
Bond Strength	C882	≥ 850 psi (repair bonding to OPC mortar) $\geq 1,000$ psi (repair material bonding to repair material) Test at age of 1 day
Modulus of Elasticity	C469	$\leq 3 \times 10^6$ psi Test at age of 2 hours $\leq 4 \times 10^6$ psi Test at age of 3 days
Volumetric Expansion	C531	$\leq 7 \times 10^{-6}$ in/in/°F Test begins at age of 3 days
	C157	$< 0.03\%$ Test begins at age of 4 days
Shrinkage Potential	C1581	≤ 40 microstrain at 14 days <u>and</u> no cracking at 28 days Test begins at time of casting
Freeze–Thaw Resistance	C666	No requirement at this time ¹ Test begins at age of 3 days
Time of Setting	C191	No requirement at this time ² Test begins immediately
<p>¹ Depending on results that are gathered for the database, a possible requirement designed to eliminate materials that are extremely susceptible to freeze–thaw damage is $\leq 50\%$ loss in relative dynamic modulus of elasticity after 50 cycles.</p> <p>² Report initial and final set times in minutes.</p> <p>Note: Some requirements were adapted from those produced by research conducted under the Repair, Evaluation, Maintenance, and Rehabilitation Research Program. Reference: Vaysbur, A.M., Emmons, P.H., McDonald, J.E., Poston, R.W., and Kesner, K.E. (1999). <i>Performance Criteria for Concrete Repair Materials, Phase II Summary Report</i>, Technical Report REMR-CS-62, U.S. Army Waterways Experiment Station, Vicksburg, MS.</p>		

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 a 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
- Rate of freeze–thaw cycles (i.e., number of cycles per day)

2-3 EVOLVING PROTOCOL.

This testing protocol and the associated material requirements will evolve over time as it is put to use and material test results are accumulated. One area of testing that has not been addressed in this protocol but which has recently received a lot of attention is the ability for repair materials to be used with non-potable forms of water, including seawater and gray (shower) water. The effects of non-potable water can be quantified by repeating the compressive strength tests with several “standardized” forms of non-potable water.

GLOSSARY

Acronyms and Abbreviations

AFCEC – Air Force Civil Engineer Center

AFPD – Air Force Policy Directive

ASTM – American Society for Testing and Materials

C – Celsius

DOD – Department of Defense

ETL – engineering technical letter

F – Fahrenheit

in – inch

OPC – ordinary portland cement

PCC – portland cement concrete

Prime BEEF – Prime Base Engineer Emergency Force

psi – pounds per square inch

RED HORSE – Rapid Engineers Deployable - Heavy Operations Repair Squadron

APPENDIX A

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, available at

<https://www.dtic.mil/DTICOnline/downloadPdf.search?collectionId=tr&docId=ADA362896>.

American Society for Testing and Materials (ASTM):

Annual Book of ASTM Standards, available at <http://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 C191, Standard Test Methods for Time of Setting of Hydraulic Cement by Vicat Needle

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 Surfacing, 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 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