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Evaluation of Rapid-Setting Cementitious Materials and Testing Protocol for Airfield Spall Repair

Monica A. Ramsey, Jeb S. Tingle, and Dr. Craig A. Rutland

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Evaluation of Rapid-Setting Cementitious Materials and Testing Protocol for Airfield Spall Repair

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Abstract

The rapid-setting cementitious material certification program is part of a research effort to assist the U.S. Air Force Civil Engineering Center in the execution of independent testing on select commercially available proprietary products to repair partial-depth spalls in airfield concrete pavements. The purpose of this research was to determine whether the existing requirements for evaluating rapid-repair products for spall repairs were sufficient or further refinement and modifications were needed. This protocol is intended to aid airfield managers and repair teams in the selection of optimal spall repair materials by maintaining a database of approved tested products.

This report presents the test methods and results of 26 cementitious rapid-setting repair products tested at the U.S. Army Engineer Research and Development Center in Vicksburg, MS, during 2013 to 2017. An evaluation of these test methods and results, along with the historic database of products tested, led to the development of an updated testing protocol for assessing a material's suitability for airfield spall repairs. Based on the revised criteria, 10 products were identified as most compatible for partial-depth airfield pavement concrete spall repairs.

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Preface

This study was conducted using MIPR F4ATA46021JWo2 under the U.S. Air Force Civil Engineer Modernization Program sponsored by the Air Force Civil Engineer Center (AFCEC) located in Tyndall Air Force Base in Panama City, FL. The AFCEC technical manager was Dr. Craig A. Rutland.

The work was performed by the Airfields and Pavements Branch (GMA) and the Concrete and Materials Branch (GMC) of the Engineering Systems and Materials Division (GM), U.S. Army Engineer Research and Development Center, Geotechnical and Structures Laboratory (ERDC-GSL). At the time of publication, Dr. Timothy W. Rushing was Chief, GMA; Mr. Christopher M. Moore was Chief, GMC; Mr. Justin S. Strickler was Chief, GM; and Mr. R. Nicholas Boone, GZT, was the Technical Director for Force Projection and Maneuver Support. The Deputy Director of the ERDC-GSL was Mr. Charles W. Ertle II, and the Director was Mr. Bartley P. Durst.

COL Teresa A. Schlosser was the Commander of ERDC, and Dr. David W. Pittman was the Director.

1 Introduction

Selecting an optimal cementitious repair product to repair spalls rapidly in airfield concrete pavements can be difficult for military personnel, considering the number of available commercial proprietary products. Most are patented under trade names, making identification of the specific cementitious agent difficult to identify. In addition, proprietary products often evolve over time with reformulations and brand name changes. Material safety data sheets and product data results available from the manufacturer often offer limited information, focused only on the product's favorable properties and neglecting its less-favorable properties.

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 could be considered to be worthy of field testing. The purpose of this report is to document the results of the products tested and to make recommendations concerning improvements that can be made in the test protocol for cementitious rapid-repair materials.

1.1 Problem statement

Rapid-repair technologies for airfield pavements have become critical to pavement repair and rehabilitation because of the demand to minimize the time in which the pavement is out of service. Rapid-repair products provide short setting times, high early-age strengths, and durability to withstand heavy loads. Due to this combination of advantageous characteristics, these materials exhibit great potential to meet the challenges of spall repairs in concrete pavements.

One potential issue with using rapid-repair products is that they can become brittle and prone to cracking, causing potential foreign object debris (FOD) damage to aircraft if a non-compatible product is used to repair the existing concrete pavement. The use of unproven products may not meet operational or mission requirements or may lead to economic losses by the government from repetitive or unscheduled repairs and application of materials that repair teams cannot effectively use. Proven products are also subject to the same risks from manufacturers' habitually repackaging or reformulating products. Unless the material has undergone

recent testing to verify its properties, engineering personnel tasked to perform or monitor repair work cannot be confident that commercially available materials will meet performance expectations.

1.2 Objectives

The primary objective of this study was to conduct independent laboratory testing on the mechanical properties (compressive strength, flexural strength, bond strength, elastic modulus, and set time) and volumetric properties (length change, restrained shrinkage, and coefficient of thermal expansion) of a variety of rapid-setting cementitious materials in an effort to determine products most compatible for DoD airfield pavement spall repairs. Results of the products tested were then to be documented on summary data sheets and published on the tri-service transportation website, which DoD users can access at <https://transportation.erdcdren.mil/cacsites/TriService/pavementrepair.aspx>.

The secondary objective of this study was to further develop and refine the laboratory testing material protocol for identifying properties most important for material selection of cementitious rapid-repair materials. This was accomplished by fully assessing and comparing the test results for all methods used to test the rapid-setting repair materials.

1.3 Scope of work

The test protocol presented in this report is applicable only to the selection of products suitable for partial depth concrete spall repairs, defined further in the next chapter. Products are limited to only cementitious rapid-repair materials with a maximum aggregate size of 0.75 in. and do not include other rapid-repair families, such as polymeric or asphaltic products, due to the extensive differences in material properties. In addition, this protocol does not apply to larger repairs, such as crater or slab replacements, and does not address any field placement or construction methods. Users are encouraged to practice strict adherence to manufacturers' guidance.

2 Background

The following section provides a background of the rapid-setting material testing program. Clarifying definitions are first provided, followed by the development of the laboratory test criteria section reprinted from ERDC TR 11-13 (Priddy 2011). Finally, the methodology for the evolution of the test protocol to identify properties of ideal rapid-repair materials is discussed.

2.1 Description of spall repairs

Spalls are described as concrete surface damage such as cracking, breaking, chipping, or fraying of the pavement that does not penetrate through the surface to the underlying layers or cause damage by upheaval of the surrounding pavement. A spall may be caused by a number of influencing factors including, but not limited to, fatigue due to impact of the aircraft, corrosion of metal joint inserts, aged joint sealant, incompressibles in the joint, misaligned dowel bars, reinforcing steel placed too near the surface, D-cracking, freeze-thaw damage, alkali-silica reaction (ASR), lack of consolidation of concrete near the joints, corrosion of reinforcing steel, or damage from munitions.

Spalls may be up to 5 ft. in diameter and typically require less than 1 ft³ of repair material. Spalls may be either partial or full depth. Partial-depth repairs require restoration to areas usually within the upper one-third of the concrete slab depth. Full-depth spall repairs are more severe, sometimes requiring complete slab replacement. Depending on critical timing and service life requirement, a spall repair may be either temporary or permanent. Expedient spall repairs are made when a return to service is critical or resources are not available to perform a permanent repair. Typically these repairs are not properly saw cut to create a rectangular shape with clean edges, as with a permanent repair described in HQ Army, Navy, Air Force (2018). The durability and long-term performance may suffer with these expedient repairs. The scope of this report is intended to treat partial-depth spalls for permanent repairs.

2.2 Development of laboratory test criteria

In order to compare repair materials and evaluate the materials for use in airfield pavement repairs, laboratory testing was necessary to determine

the basic material properties of each candidate material. Previous studies have identified numerous tests applicable for repair materials.

In 1991, the Federal Highway Administration (FHWA) identified compressive strength, flexural strength, modulus of elasticity, Poisson's ratio, bond strength, thermal compatibility, length change, resistance to freezing and thawing, and resistance to abrasion and scaling as important performance characteristics for repair materials (Wilson et al. 1999). Another study recommended testing compressive and flexural strength, set time, and shear bond (Beer et al. 1984) to evaluate material performance.

In 1992, the Waterways Experiment Station (WES) evaluated 12 cementitious and polymeric materials under the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Program to identify applicable laboratory tests and minimum test results for use in selecting repair materials (WES 1992). Testing performed under this program identified compressive strength, modulus of elasticity, shrinkage, creep, thermal compatibility, and flexural strength as applicable tests for repair materials. Out of these tests, required values were recommended for compressive strength, tensile strength, and drying shrinkage (Vaysburd et al. 1999).

In 2006, the U.S. Air Force released a draft engineering technical letter (ETL) identifying compressive strength, bond strength, thermal compatibility, shrinkage potential, and freeze-thaw resistance as the most important characteristics to evaluate in comparing cementitious, rapid-setting materials for spall repairs. The requirements set forth in GSL TR-11-13 (Priddy 2011) were based on laboratory and field testing conducted during 2005 and 2006 by personnel at ERDC. Results from the tests were compared to requirements produced under the REMR Program (WES 1992; Vaysburd et al. 1999).

2.3 Former testing protocol

The purpose of this research was to determine whether the existing requirements set forth in the ETL 08-02 (AFCEC 2008) or adapted from TR-11-13 (Priddy 2011), shown in Table 1 and Table 2, respectively, were sufficient or modifications were needed.

Table 1. Test requirements established in ETL 08-02 (AFCEC 2008).

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
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 would be $\leq 50\%$ loss in relative dynamic modulus of elasticity after 50 cycles. ² Report initial and final set times in minutes. 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.		

Table 2. Test requirements established in TR 11-13 (Priddy 2011).

Property	ASTM	Temporary Repairs		Permanent Airfield Repairs	
		Crater Repair	Expeditionary Spall Repair	Primary Runways and Taxiways	Secondary Runways, Secondary Taxiways, and Parking Aprons
Compressive strength	C 39	≥ 3,000 psi at age of 2 hr ^a ≥ 5,000 psi at age of 1 day	No laboratory requirement at this time. Requires field testing prior to approval.	≥ 3,000 psi at 2 hr or at age of opening ≥ 5,000 psi at age of 1 day	≥ 3,000 psi at specified age of opening ≥ 5,000 psi at age of 7 days and 28 days
Flexural strength	C 78	Not required	Not required	≥ 350 psi at age of 2 hr ≥ 600 psi at age of 7 days and 28 days Full-slab replacement only	≥ 350 psi at specified age of opening ≥ 600 psi at age of 7 days and 28 days Full-slab replacement only
Bond strength	C 882	≥ 1,000 psi (repair bonding to OPC mortar) ≥ 1,000 psi (repair material bonding to repair material) Test at age of 1 day.	≥ 1,000 psi (repair bonding to OPC mortar) ≥ 1,000 psi (repair material bonding to repair material) Test at age of 1 day.	≥ 1,000 psi (repair bonding to OPC mortar) ≥ 1,000 psi (repair material bonding to repair material) Test at age of 1 day.	≥ 1,000 psi (repair bonding to OPC mortar) ≥ 1,000 psi (repair material bonding to repair material) Test at age of 1 day.
Modulus of elasticity	C 469	2 × 10 ⁶ to 6 × 10 ⁶ psi Test at age 2 hr and 28 days.	2 × 10 ⁶ to 6 × 10 ⁶ psi Test at age 2 hr and 28 days.	2 × 10 ⁶ to 6 × 10 ⁶ psi Test at age 2 hr and 28 days.	2 × 10 ⁶ to 6 × 10 ⁶ psi Test at age 2 hr and 28 days.
Volumetric expansion	C 531	≤ 12 × 10 ⁻⁶ in./in./°F Test begins at age of 7 days.	≤ 12 × 10 ⁻⁶ in./in./°F Test begins at age of 7 days.	≤ 12 × 10 ⁻⁶ in./in./°F Test begins at age of 7 days.	≤ 12 × 10 ⁻⁶ in./in./°F Test begins at age of 7 days.
	C 157	<+0.03% expansion or <-0.04% shrinkage @ 28 days	<+0.03% expansion or <-0.04% shrinkage @ 28 days	<+0.03% expansion or <-0.04% shrinkage @ 28 days	<+0.03% expansion or <-0.04% shrinkage @ 28 days
Shrinkage potential	C 1581	≤ 40 microstrain at 14 days and no cracking at 28 days Test begins at time of casting.	≤ 40 microstrain at 14 days and no cracking at 28 days Test begins at time of casting.	≤ 40 microstrain at 14 days and no cracking at 28 days Test begins at time of casting.	≤ 40 microstrain at 14 days and no cracking at 28 days Test begins at time of casting.
Freeze-thaw resistance	C 666	Not required	Not required	No requirement at this time	No requirement at this time
Time of setting ^b	C 191	15 min initial set 25 to 35 min final set	Not required	15 min initial set 25 to 35 min final set	15 min initial set 25 to 35 min final set
slump	C143	Record slump	Record slump	Record slump	Record slump

¹ Field verification of material performance can be used in lieu of achievement of the test requirements. Consult https://transportation.wes.army.mil/triservice/pavement_repair.aspx for a list of approved products.

² Recommended initial and final set times of 15 min and 25 min are provided. For small repairs or spall repairs, shorter initial and final set times may be acceptable.

It is important to note the products tested and reported in TR-11-13 (Priddy 2011) were conducted for a variety of permanent and temporary repairs including spalls, small patches, large patches, and slab replacement. In addition, special testing was conducted specifically for expeditionary spall repairs. As mentioned previously, this study identified products most suitable for only permanent spall repairs. Temporary repairs and larger placements for craters were outside the scope of work for this investigation.

2.4 Historical database of approved/non-approved products

The first approach to reviewing the criteria of the existing protocol was to compile historic data for the products tested. As of January 2017, the tri-service database had published 23 approved cementitious products and 16 non-approved products as listed in Table 3 and Table 4, respectively. Upon review of summary datasheets, several of the approved products did not meet the limits of some of the existing protocol's passing criteria, and

many products had limited test data. The previous approvals of many products were based on good field performance.

Table 3. Prior approved products based on tri-service website as of January 2017.

No.	Product	Manufacturer	Year Tested
1	MasterEmaco T1060	BASF	2007
2	Rapid Set DOT Repair Mix	CTS Cement Corp.	2007
3	MasterEmaco T545HT	BASF	2007
4	MasterEmaco T545	BASF	2007
5	MasterEmaco T1061	BASF	2007
6	Pavepatch 3000	Dayton Superior Corp.	2008
7	Pavemend SLQ	CeraTech Inc.	2008
8	SikaQuick 2500	Sika Corp.	2008
9	Pavemend TR	CeraTech Inc.	2008
10	Versapace	Euclid Chemical Co.	2008
11	Ultimax Concrete Mix	Ultimax Cement	2008
12	Great White	CeraTech Inc.	2009
13	Fast Set DOT Concrete Mix	Quickcrete Companies	2010
14	Rapid Set Concrete Mix	CTS Cement Corp.	2010
15	DOTLine	Cera Tech, Inc.	2013
16	Pavepatch 3000	Dayton Superior Corp.	2013
17	MasterEmaco T1060	BASF	2013
18	Ulti-Pave3	Buzzi-Unicem USA Inc.	2014
19	HD 50	Dayton Superior Corp.	2015
20	ProSpec Premium Patch 200	H.B. Fuller Construction Products Inc.	2015
21	Rapid Set Mortar Mix	CTS Cement Corp.	2015
22	Elephant Armor DOT Industrial Grade Mortar	GST International	2016
23	FasTrac 246 Concrete	Western Material and Design LLC	2016

Table 4. Prior non-approved products based on tri-service website as of January 2017.

No.	Product	Manufacturer	Year Tested
1	Pavemend EX-H	CeraTech, Inc.	2007
2	Futura 15	W.R. Meadows	2008
3	Pavemend VR	CeraTech, Inc.	2008
4	Mainline	CeraTech, Inc.	2009
5	FasTrac	Western Material and Design, LLC	2010
6	Speedcrete 2028	Euclid Chemical Co.	2010
7	Veraspeed LS	Euclid Chemical Co.	2012
8	Pavemend SL	Cera Tech, Inc.	2013
9	Phoscrete 4 Seasons	Phoscrete Corp.	2013
10	Ardex TRM	Ardex Americas	2014
11	Fast Set Concrete Mix	Quikcrete Companies	2014
12	Rapid Road Repair	Quikcrete Companies	2014
13	Magna-Crete	Henkel Americas	2015
14	Pavemend 15	Cera Tech, Inc.	2015
15	Prospec Premium Patch 100	H.B. Fuller Construction Products	2015
16	Express Repair	Euclid Chemical Co.	NA

2.5 Continuation from previous research

It was expected that the testing protocol would evolve over time as it was put into use and data for test materials accumulated. The present study is a continuation of previous research to further improve the methods for assessing suitable materials for airfield spall repair. Some of the test methods and/or test ages have been changed or modified due to the nature of the rapid-repair materials. Any differences are noted in Chapter 4, “Description of Test Methods” and further detailed in Chapter 5, “Results and Discussion.” As a result of this continued research, an updated test protocol has emerged for cementitious rapid-setting repair materials. The products evaluated in the ERDC testing laboratory from 2013-2017 were published as summary data sheets to the tri-service pavement website upon completion and documented in Appendix A of this report.

3 Methods and Materials

Since the development of the laboratory testing criteria for evaluating cementitious, rapid-setting pavement repair materials, the majority of the laboratory testing has been conducted in accordance to the protocol requirements established in ETL-o8-o2 (AFCEC 2008) and as reported in GSL TR-11-13 (Priddy 2011).

The methods for the majority of the laboratory tests conducted from 2013 to 2017 were based on a three-tier sequence of selected tests described in this chapter. The details of the material selection, storage, and mixing procedures are also presented in this chapter. The manufacturer's technical specification sheet of each material was strictly followed for the mixture proportioning, necessary equipment, proper substrate preparation, and curing of the test specimens. Finally, a summary of the materials tested from 2013 to 2017 is provided.

3.1 Methods for tier testing of cementitious materials

Due to the cost and time requirements of the numerous tests described in the following table, a three-tiered system was used to best balance the requirements to obtain results on the maximum number of products. Table 5 details the breakdown of the cementitious material tier testing approach.

Table 5. Cementitious material tier testing approach.

Tier 1 Tests		
Test Name	Measured Property	Specification
Compressive Strength	Operational, Mechanical	ASTM C39
Flexural Strength	Operational, Mechanical	ASTM C78
Bond Strength	Mechanical	ASTM C882
Elastic Modulus	Mechanical	ASTM C469
Set Time	Workability	ASTM C191
Slump	Workability	ASTM C143
Tier 2 Tests		
Test Name	Measured Property	Specification
Coefficient of Thermal Expansion	Mechanical	ASTM C531

Length Change	Durability, Operational	ASTM C157
Restrained Shrinkage	Durability	ASTM C1581
Recommended		
Test Name	Measured Property	Specification
Freeze-Thaw	Durability	ASTM C666
Scaling	Durability	ASTM C672
Variations in Environmental Temperature	Production, Operational, Workability	--
Variation in Batch Water	Production, Operational, Workability, Mechanical	--

This three-tiered procedure was used as a performance checkpoint, where the most economical performance measures were tested first, followed by the more extensive and time-consuming laboratory testing. A product was considered for further testing if it passed tier 1 tests. The goal of the tiered procedure was to efficiently gather pertinent material performance information and filter out poorly performing materials along the course of the evaluation.

In the first tier, the repair materials' individual properties of compressive strength, flexural strength, bond strength, modulus of elasticity, time, and workability were determined by using standard ASTM test procedures. In the second tier, volumetric properties of length change, shrinkage resistance, and coefficient of thermal expansion were determined also by using standard ASTM test procedures. The third tier of testing was recommended durability tests of freeze-thaw resistance and scaling and sensitivity to temperature and water variations. Of the recommended tests, only the freeze-thaw test was performed on some of the products in this report.

3.2 Material selection

The material selection process is a collaborative effort between the ERDC and the AFCEC to review candidate proprietary products to determine their feasibility as a successful repair material. Previously tested products requiring recertification are considered for renewed testing every five years. The final number of products selected for testing each year is at the discretion of the AFCEC. Typically, three to six products are tested each year.

3.3 Material storage

Once candidate materials are selected, the products for testing ordered directly either from the manufacturer or through local construction material suppliers. Materials packaged in sealed buckets will be requested when purchased to allow for longer term storage and maximum shelf life. Many of the proprietary materials are sold only in 50-lb bags. For these products, upon arrival the testing laboratory placed the bagged product into reusable, airtight 5- to 7-gal plastic buckets for maximum humidity protection. The sealed buckets were then stored in a temperature-controlled room of $72 \pm 4^{\circ}\text{F}$.

3.4 Aggregate extension

All products were tested as extended with aggregate if allowed by the manufacturer. The quantity of extension used was the maximum of either 50 percent (by volume of product per unit) or the maximum allowed by the manufacturer if less than 50 percent. Products sold as extended products (with coarse aggregate) were tested as produced without additional aggregate added by the testing laboratory. The coarse aggregate used for extending the paste or mortar product was an ASTM C33 (2016b)-compliant #8 pea gravel local to Vicksburg, MS. The aggregate's physical properties are shown in Figure 1.

Figure 1. Properties of 3/8-in. pea gravel used to extend repair materials.

ASTM C 136: Sieve Analysis :					
Cumulative Percent					
Sieve Size	Mass Ret., g	% Ret.	Ret.	Pass	Avg
3-in.	0.0	0.00%	0.00%	100.00%	100%
1-in.	0.0	0.00%	0.00%	100.00%	100%
3/4-in.	0.0	0.00%	0.00%	100.00%	100%
1/2-in.	30.9	0.61%	0.61%	99.39%	99%
3/8-in.	1,208.4	23.76%	24.37%	75.63%	76%
No. 4	3,649.5	71.77%	96.14%	3.86%	4%
No. 8	165.1	3.25%	99.39%	0.61%	1%
No. 16	3.2	0.06%	99.45%	0.55%	1%
No. 30	0.9	0.02%	99.47%	0.53%	1%
No. 50	4.0	0.08%	99.55%	0.45%	0%
Pan	23.0	0.45%	100.00%		
Total	5,085.0	100.00%			
Fineness Modulus:			6.184		6.18
ASTM C 127: Bulk Specific Gravity & Absorption:					
SSD Mass in Air, g				3,933.8	
SSD Mass in Water, g				2,366.1	
Displaced Water, g				1,567.7	
Water Temp C				22.8	
Relative Density (Bulk Specific Gravity)(SSD)				2.5	2.51
Oven Dry Mass, g				3,810.3	
Moisture Loss, g				123.5	
Absorption				3.24%	3.2%

3.5 Mixing procedures

The mixture proportioning, mixing procedure, and mixing time were different for each repair material. Manufacturers' guidelines for producing their products at specified test temperatures and water contents were applied. However, this did not interfere with the requirements stated in ASTM C192 (2016e) used to control the production of all materials made for comparisons. All components, including mixing water, used to batch the repair material were temperature stabilized at $72 \pm 4^{\circ}\text{F}$ before being added to the mixing unit to generate an accurate strength history of the products tested.

The water content of each mixture was as prescribed by the manufacturer. Potable tap water was used as the mixing water in all of the mixtures. The mixing water was adjusted to account for the absorption of the aggregate and the moisture content of the aggregate on the day of production. The proprietary products were typically mixed one bag at a time with a drill and paddle, as shown in Figure 2, or with a small drum mixer, as shown in Figure 3.

Figure 2. Laboratory mixing conducted by using Jiffy-type drill and paddle.



Figure 3. Laboratory mixing conducted by using small drum mixer.



3.6 Materials tested 2013-2017

A total of 28 cementitious rapid-repair products listed in Table 6 were tested during 2013-2017. Datasheets containing the complete set of test results for each product are provided in Appendix A.

Table 6. Summary of products tested in the laboratory during 2013-2017.

Product Name	Manufacturer	Year Tested	Testing Tier (Tier 1/Tier 2)
Pavemend SL	Cera Tech, Inc.	2013	Tier 1/ Tier 2
DOT Line	Cera Tech, Inc.	2013	Tier 1/ Tier 2
SikaQuick 2500	Sika Corp	2013	Tier 1/ Tier 2
10-60 Repair Mortar	BASF	2013	Tier 1/ Tier 2
Pavepatch 3000	Dayton Superior Corp.	2013	Tier 1/ Tier 2
Phoscrete 4 Seasons	Phoscrete Corp.	2013	Tier 1/ Tier 2
Ulti-Pave3	Buzzi-Unicem USA, Inc.	2014	Tier 1/ Tier 2
Fast Set DOT Concrete Mix	Quikrete Companies	2014	Tier 1/ Tier 2
Ardex TRM	Ardex Americans	2014	Tier 1
Fast Set Concrete Mix	Quikrete Companies	2014	Tier 1/ Tier 2
Rapid Road Repair	Quikrete Companies	2014	Tier 1/ Tier 2
HD 50	Dayton Superior Corp.	2015	Tier 1
Pavemend 15.0	Cera Tech, Inc.	2015	Tier 1
Rapid Set Mortar Mix	CTS Cement Corp	2015	Tier 1/Tier 2
Prospec Premium Patch 100	H.B. Fuller Construction	2015	Tier 1/Tier 2
Prospec Premium Patch 200	H.B. Fuller Construction	2015	Tier 1/Tier 2
Magna-Crete	Henkel Americas	2015	Tier 1
Elephant Armor DOT	GST International	2016	Tier 1
Phoscrete HC	Phoscrete Corporation	2016	Tier 1
FasTrac 246 Concrete	Western Material & Design, LLC	2016	Tier 1
Magna-Crete	Henkel Americas	2016	Tier 2
HD 50	Dayton Superior Corp.	2016	Tier 2
Rapid Set DOT Repair	CTS Cement Corp.	2017	Tier 1
Pavemend TR	Cera Tech, Inc.	2017	Tier 1
T545 (Formerly Set 45)	BASF	2017	Tier 1
T545HT (Formerly Set 45HT)	BASF	2017	Tier 1
Rapid Set Concrete	CTS Cement Corp.	2017	Tier 1
T1061	BASF	2017	Tier 1

4 Description of Test Methods

This section summarizes the test methods employed to measure the merit of each cementitious, rapid-setting repair material addressed in this study. Any significant changes from the former test protocol are also noted.

4.1 Compressive strength

Compressive strength is important for ensuring that the repair material will not prematurely fail under wheel loads or under 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.

Compressive strength specimens were fabricated in accordance with ASTM C192 (2016e) and tested in accordance with ASTM C39 (2015a) procedures, using 4-in. × 8-in. cylinders. Compression testing using larger 6-in. × 12-in. cylinders or smaller 3-in. × 6-in. cylinders (Figure 4) is acceptable, but compression testing with 2-in. cube specimens in accordance to ASTM C109 (2016a) is not acceptable. Cube testing is intended for mortars only and often gives inflated strength values related to cylinders. The smaller 3-in. × 6-in. cylinders were often used due to the limited volume of material mixed for each product and the rapid setting time.

Timing of the strength testing was critical due to the rapid hardening of these repair materials. The cylinders were tested at different ages of 2, 3, and 24 hr and 7 and 28 days. The early 2- and 3-hr strength measurements do not have specified testing time tolerances in ASTM C39. Therefore, a tolerance of ± 15 min. was applied to this testing age to ensure true measures of strength at the specified times were collected, while balancing the laboratory's ability to collect the information in a timely manner. Triplicate cylinders were tested at each age at a loading rate of 35 psi/sec until failure. Results were reported as maximum compressive stress (psi), which equals the maximum applied load divided by the specimen's initial, unloaded cross-sectional area.

Figure 4. Concrete cylinder undergoing compression strength test.



4.2 Flexural strength

Flexural strength is important to determine the stress of the material just before it yields. Most materials fail under tensile stress before they fail under compressive stress, so the maximum tensile stress value that can be sustained before the beam fails is its flexural strength. Flexural strength specimens were fabricated and tested in accordance with ASTM C78 (2016d) procedures (Figure 5).

The test specimens were rectangular beams with dimensions of 3 in. $\times$ 3 in. $\times$ 12 in. with loading applied at third-points of the span. The beams were tested at 2 hr., 7 days, and 28 days. Triplicate beams at each test age were loaded at a specific rate to increase a stress of 150 psi/min in the bottom fiber (maximum tension) of the beam. Results were reported as the ultimate tensile stress achieved before failure, also known as the modulus of rupture.

Figure 5. Concrete beam undergoing flexural strength test.



Larger 6-in. $\times$ 6-in $\times$ 21-in. beams may be used as specified in former test protocols. However, since this repair specification limits the maximum aggregate size of extended aggregate to 1 in. and the beams are unreinforced, the 6-in.-square cross section is not necessary for testing. The smaller 3-in. $\times$ 3-in. $\times$ 12-in. beams can achieve similar results and reduce the cost of the testing by reducing the volume of material required while still abiding by the smallest 3 times the maximum nominal aggregate size rule of thumb used for slab depth flexural strength testing.

4.3 Bond strength

Bond strength is important for ensuring the material used for the spall repair will adhere to the existing concrete substrate to ensure adequate stress transfer during loading, expansion, and contraction. Bond strength specimens were fabricated and tested in accordance with ASTM C882 (2013a) procedures. This slant shear test involved the preparation of specimens in 3-in. $\times$ 6-in. cylinder molds. A bond line was produced at approximately 30 degrees from the vertical angle by first casting wedge-shaped dummy sections of either portland cement concrete (PCC) or the repair material itself.

The diagonally cast bonding area of each half-cylinder dummy sample was lightly sandblasted and submerged in water 24 hr before placement in a new 3-in. × 6-in. mold and casting to the repair material. After curing, the composite cylinder was tested in compression. The bond strength was calculated by dividing the load carried by the specimen at failure by the area of the elliptical bonding surface. Figure 6 shows an example of the PCC slant shear half-cylinder before and after bonding to a repair material.

Figure 6. Composite bond strength and slant shear specimens.



4.4 Modulus of elasticity

Modulus of elasticity is important because a spall repair material should not have stiffness significantly different from that of the parent material onto which it is applied in order to achieve a uniform load transfer across the repair section. With a higher stiffness, the repair material will assume higher stresses under wheel loading and pavement movement. If the repair material has a lower stiffness than the parent material, it will exhibit lower internal stresses; thus, the potential for cracking and delamination of the repair is reduced.

Modulus of elasticity testing was accomplished in accordance with ASTM C469 (2014c) procedures. Test specimens were either 3-in. × 6-in. or 4-in. × 8-in. cylinders instrumented with an unbounded sensing device attached to the cylinders at mid-height for the purpose of measuring vertical

deformation. The cylinders were tested at 2 hr and at 28 days. The modulus of elasticity (in psi) was calculated as change in stress divided by change in strain, where strain is calculated as vertical deformation divided by gauge length. Figure 7 shows a cylinder undergoing the modulus of elasticity test.

Figure 7. Concrete cylinder specimen undergoing modulus of elasticity test.



4.5 Set time

Set time is important because it strongly influences the workability, finishing, and load-carrying capacity of fresh concrete. Previous protocols required ASTM C191 (2013c) as the set time test method. This is a standard method for time of setting by Vicat needle based on a normal consistency of the cement paste, and many of the rapid-repair materials either contain aggregate within the proprietary product or can be extended.

The ASTM C191 method was modified to accommodate the many rapid-repair materials by wet sieving the mixed product over a #4 sieve before allowing it to form in the mold for testing to remove any aggregate that

would interfere with the 1-mm needle penetration. However, using this modified method for testing may not represent the actual performance of the product. Therefore, the time of setting was performed in accordance to ASTM C403 (2016f) which is better suited for concrete materials.

For the ASTM C403 method, periodic penetration tests were performed by using a penetrometer with an analog gauge by inserting a standardized needle of known surface area into the fresh concrete material and recording the resistance force. The penetration resistance (in psi) was calculated by dividing the recorded force (in pounds) by the bearing area of the needle (in square inches). The initial set time was the time elapsed between the initial contact of cement and water and the time when the penetration resistance equaled 500 psi. The final set time was the time elapsed between initial contact of the cement and water and the time when the penetration resistance equaled 4,000 psi. Figure 8 demonstrates both methods during testing.

Figure 8. Set time demonstrated by penetrometer and Vicat methods.



(a) Set time performed by the penetrometer method, ASTM C403.



(b) Set time performed by the Vicat method, ASTM C191.

4.6 Coefficient of thermal expansion

The coefficient of thermal expansion (CTE) of a spall repair material is important to ensure that the expansion and contraction of the repair material with changes in temperature are compatible with the parent material. If the CTE of a repair material is higher than that of the existing material, it will 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 tends to deteriorate their bond.

CTE testing was accomplished in accordance with ASTM C531 (2012a) procedures. Test bar specimens with dimensions of 1 in. $\times$ 1 in. $\times$ 11.25 in. with embedded gauge studs were fabricated from the repair material. Due to the size of the test specimen, any extended product must be sieved to meet the maximum aggregate size requirement. An initial gauge length of the bars was measured at 24 hr then daily for two weeks to determine linear shrinkage. The specimens were maintained at an ambient laboratory temperature of 73°F during the first 2 weeks. The test specimens were then exposed to environmental conditions of 210°F for 3 days, and the gauge lengths were immediately recorded. The specimens were then cooled in a desiccator box at 73°F for 24 hr and once again the

gauge length was recorded. This heating/cooling cycle of a 3-day exposure at 210°F then cooling to 73°F continued until a constant CTE was determined (Figure 9). The CTE was reported as strain per degree F, with units of in./in./°F. The procedure differed from the previous protocol ETL 08-02 requirement for the test to begin at an age of 3 days and eliminated the procedure for linear shrinkage. The current method follows the ASTM C531 with no modifications.

Figure 9. Coefficient of thermal expansion mortar bars specimens.



4.7 Workability

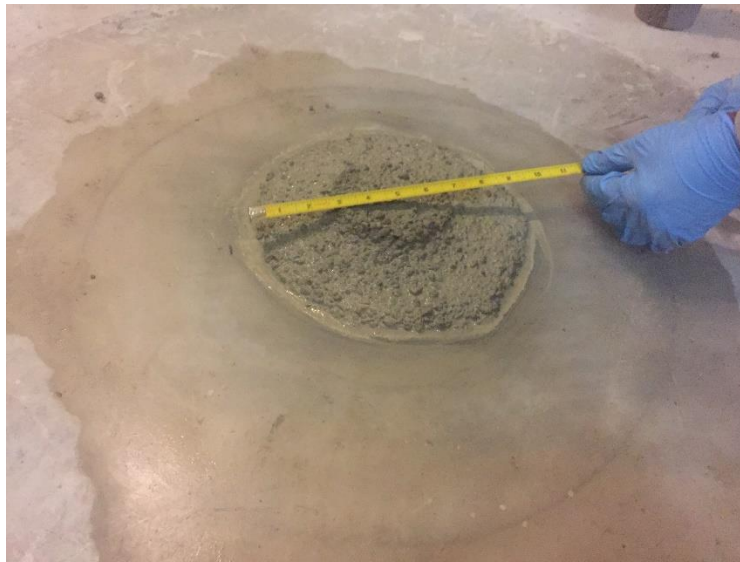
The workability is an important fresh property of concrete that is indicated by the amount of useful internal work required to fully compact the concrete without bleeding or segregation in the finished product. For most of the concretes tested, the workability was demonstrated by performing the ASTM C143 (2015d) slump test, which is the most generally accepted test to determine the consistency and workability of concrete. However, this method cautions that concretes having slumps greater than about 9 in. may not be adequately cohesive for this test to have significance. Therefore, if the slump was over 9 in., as indicated by the standard slump test, the ASTM D1611 (2014b) flow consistency test was performed.

To perform the flow consistency test, the material was placed into a cylinder with openings on both ends; the material was struck off, then the cylinder was lifted to allow the material to spread onto a non-porous surface. The diameter of the spread was immediately measured in two perpendicular directions. The slump flow consistency, like the standard slump test, is reported as the average of the diameter. Figure 10 demonstrates both methods during testing.

Figure 10. Workability demonstrated in accordance to (a) ASTM C143 and (b) ASTM C1611.



(a) Slump performed in accordance to ASTM C143.



(b) Slump flow measured in accordance to ASTM C1611.

4.8 Length change

Length change is important because excessive expansion or contraction of a spall repair 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. Length change testing was accomplished in accordance with ASTM C157 (2014a) procedures with both air and water storage curing. Test prismatic specimens with dimensions of 3 in. × 3 in. × 11.25 in. with embedded gauge studs were fabricated from the repair material with a maximum aggregate size of 0.75 in. Readings were taken during the air and water curing periods after 4, 7, 14, and 28 days and after 8, 16, 32, and 64 weeks. The length change at each age was reported as a percentage ($\text{change in length} / \text{original length} \times 100$ percent). Figure 11 shows the storage conditions for length change specimens in the air cure environment.

Figure 11. Length change specimen storage in air cure environment.



4.9 Shrinkage ring

Shrinkage potential is important because repair materials that shrink excessively are more prone to bonding problems and cracking. Shrinkage was measured by using a restraining ring device in accordance with ASTM C1581 (2016c). During this test, the ring of the repair material attempted to shrink, but the steel ring prevented its movements, resulting in the development of circumferential stresses that could lead to cracking. The maximum tensile stress was measured by strain gauges that measured cracking potential where visual cracking might not be observed. The restraining ring was constructed of structural steel pipe with a wall thickness of 0.5 in., an outside diameter of 13 in., and a height of 6 in. The repair material was cast on the outside of the restraining ring in a manner that produced a repair material ring with a height of 6 in. and a wall thickness of 1.5 in. The outer form that was used to shape the repair ring was removed after curing 24 hr while the restraining ring stayed in place throughout testing. The repair rings were cured in an environment with 50 percent relative humidity and a temperature of 73°F. A data logger recorded the microstrain for the instrumented shrinkage rings. The ring

strain at 14 days was reported and, if any cracking occurred, at 28 days. Figure 12 shows products undergoing the shrinkage ring test.

Figure 12. Shrinkage ring testing.



4.10 Freeze-thaw resistance

Resistance to damage during freezing and thawing is important to ensure the repair material can be used in cold climates that may subject the repaired surface to these environmental conditions. Freeze-thaw resistance testing was accomplished in accordance with ASTM C666, Procedure A (2015b). Test prisms with dimensions of 3 in. $\times$ 4 in. $\times$ 16 in. were moist cured for 14 days before being subjected to freeze-thaw cycles until failure (60 percent loss in dynamic modulus) or at a maximum of 300 cycles. During testing, specimens were weighed and their fundamental transverse frequency measured approximately every 36 cycles (Figure 13). Results were reported as the durability factor, which is a function of the number of cycles survived by the specimens and the relative dynamic modulus of elasticity at the time the test is terminated.

Figure 13. Freeze-thaw specimen undergoing testing for transverse frequency.



5 Results and Discussion

The following section provides a comparison of the laboratory test results from not only the laboratory tests conducted from 2013 to 2017, but also historical data extracted from datasheets from historical testing described in earlier sections published on the tri-service website. The recommendations for the new test protocol and approved products are based solely on the laboratory test results.

5.1 Compressive strength

Comparisons of the compressive strengths are detailed in Table 7 and illustrated in Figure 14. Based on these results, the following modifications for compressive strength testing are recommended.

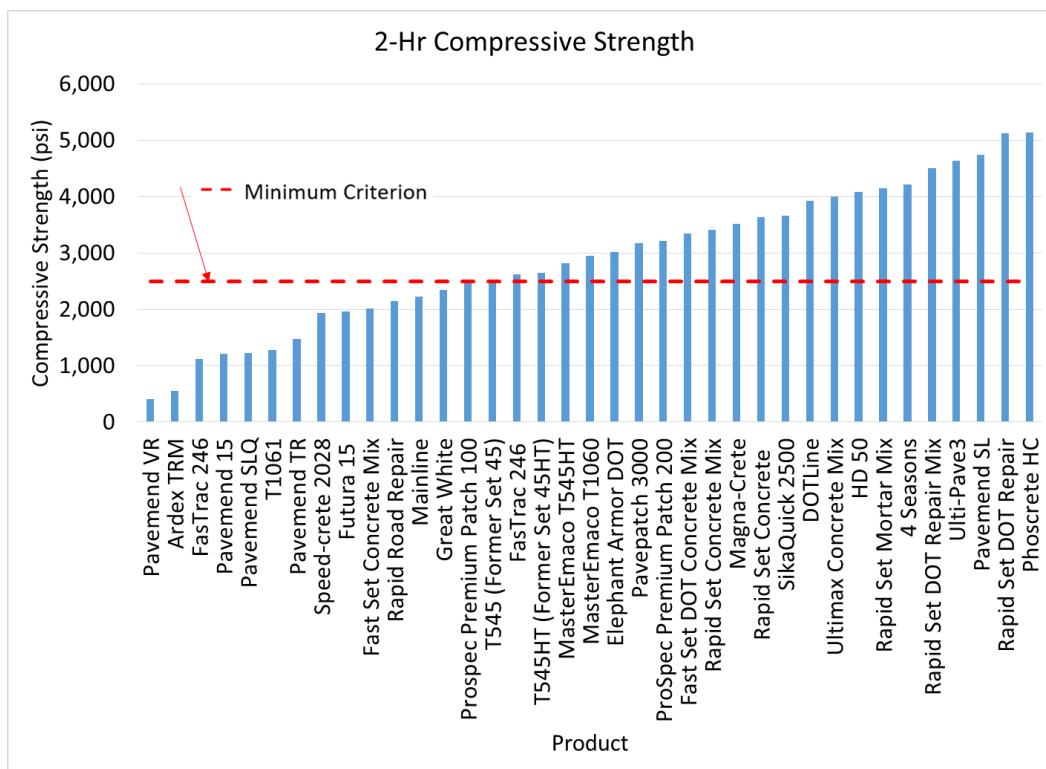
- Reduce the 2-hr pass criterion from 3,000 psi to 2,500 psi. This is based on the observation that many products do not reach 3,000 psi until 3 hr.
- No requirement was established for the 3-hr testing in previous protocols. It is recommended that products gain 3,000 psi for the 3-hr pass criterion. This is based on observations in both the test results and the 3-hr performance requirement established in ASTM C928 (2013b) for an R3 concrete.
- Reduce the 1-day requirement from 5,000 psi to 4,000 psi. This is based on the fact that the ultimate strength is 5,000 psi and most products do not reach the maximum strength requirement at 24 hr. A more appropriate strength would be 4,000 psi at this early age.
- No changes are recommended for the 7-day and 28-day pass criteria of 5,000 psi.

Table 7. Summary of compressive strength results.

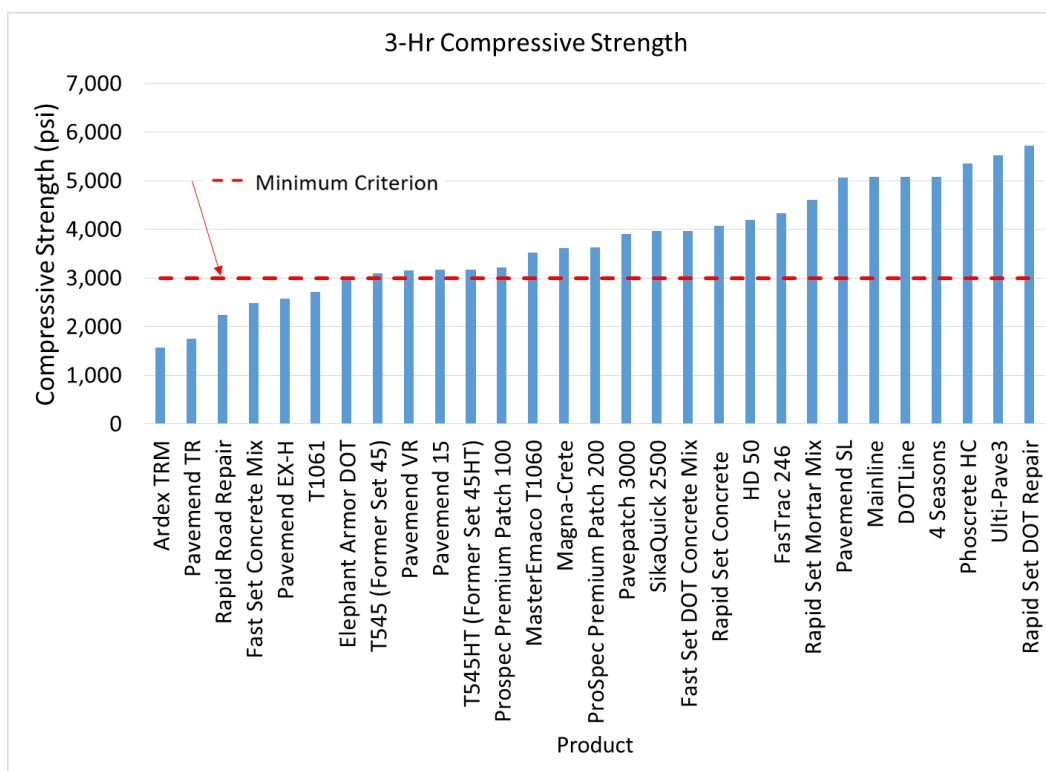
Product Name	Manufacturer	Year Tested	Compressive Strength (psi)				
			2 hrs	3 hrs	1 day	7 days	28 days
Rapid Set DOT Repair Mix	CTS Cement Corp.	2007	4,500	—	8,550	—	—
MasterEmaco T545HT	BASF	2007	2,820	—	4,430	—	—
Pavemend EX-H	Cera Tech, Inc.	2007	—	2,580	—	—	—
Pavemend SLQ	CeraTech, Inc.	2008	1,230	—	2,530	—	—
Ultimax Concrete Mix	Ultimax Cement	2008	4,000	—	6,390	—	—
Futura 15	W.R. Meadows	2008	1,960	—	4,680	—	—

Pavemend VR	Cera Tech, Inc.	2008	405	3,160	—	—	—
Great White	Cera Tech, Inc.	2009	2,340		4,195	—	—
Mainline	Cera Tech, Inc.	2009	2,223	5,074	—	—	—
Fast Set DOT Concrete Mix	Quickcrete Companies	2010	3,340	3,970	6,050	5,190	5,460
Rapid Set Concrete Mix	CTS Cement Corp.	2010	3,404		4,512	—	—
FasTrac	Western Material & Design	2010	1,117	—	4,364	—	—
Speed-crete 2028	Euclid Chemical Co.	2010	1,930	—	—	—	—
DOTLine	Cera Tech, Inc.	2013	3,920	5,080	6,420	8,290	10,170
Pavepatch 3000	Dayton Superior Corp.	2013	3,170	3,905	5,190	6,290	7,100
SikaQuick 2500	Sika Corp.	2013	3,660	3,960	5,280	7,230	8,090
MasterEmaco T1060	BASF	2013	2,950	3,520	4,590	6,170	6,290
Pavemend SL	Cera Tech, Inc.	2013	4,740	5,070	6,800	9,970	10,590
Phoscrete 4-Seasons	Phoscrete Corp.	2013	4,210	5,080	5,030	5,690	5,700
Ulti-Pave3	Buzzi-Unicem USA, Inc.	2014	4,630	5,530	7,880	8,740	9,490
Ardex TRM	Ardex Americas	2014	550	1,570	2,640	3,560	3,820
Fast Set Concrete Mix	Quikcrete Companies	2014	2,020	2,490	3,150	3,760	5,360
Rapid Road Repair	Quikcrete Companies	2014	2,140	2,240	4,570	6,050	7,980
HD 50	Dayton Superior Corp.	2015	4,080	4,200	4,700	6,370	6,980
Prospec Premium Patch 100	H.B. Fuller Construction	2015	2,460	3,220	3,620	5,400	6,550
ProSpec Premium Patch 200	H.B. Fuller Construction	2015	3,210	3,630	4,320	5,570	6,890
Rapid Set Mortar Mix	CTS Cement Corp.	2015	4,150	4,610	5,730	6,580	7,270
Magna-Crete	Henkel Americas	2015	3,510	3,620	3,870	4,440	7,270
Pavemend 15	Cera Tech, Inc.	2015	1,210	3,170	3,730	3,970	5,060
Phoscrete HC	Phoscrete Corp.	2016	5,140	5,350	6,030	7,580	7,730
Elephant Armor DOT	GST International	2016	3,020	3,030	3,270	4,150	4,520
FasTrac 246 Concrete	Western Material & Design	2016	2,620	4,340	6,070	7,290	8,160
Rapid Set DOT Repair	CTS Cement Corp.	2017	5,120	5,720	6,690	7,290	8,900
Pavemend TR	Cera Tech, Inc.	2017	1,480	1,750	3,610	3,950	4,650
T545 (Formerly Set 45)	BASF	2017	2,510	3,090	4,110	5,090	5,310
T545HT (Formerly Set 45HT)	BASF	2017	2,640	3,170	4,110	5,240	6,250
Rapid Set Concrete	CTS Cement Corp.	2017	3,630	4,080	4,530	5,040	5,710
T1061	BASF	2017	1,270	2,720	5,690	6,280	7,770

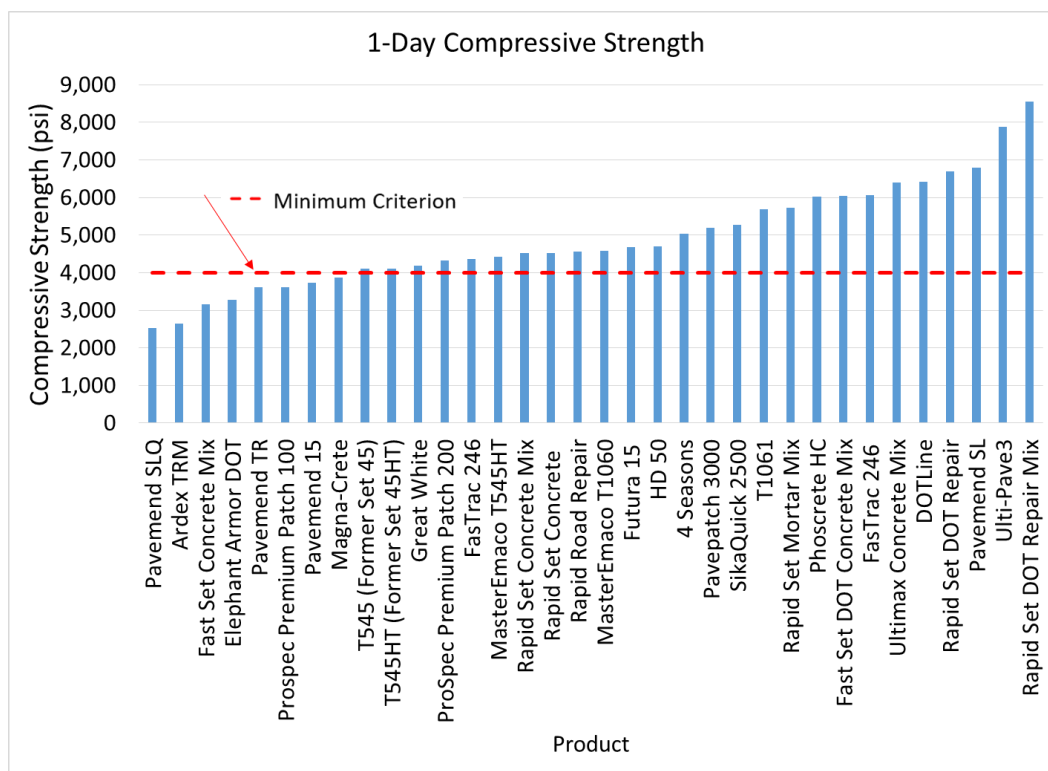
Figure 14. Summary of compressive strength product comparison by age.



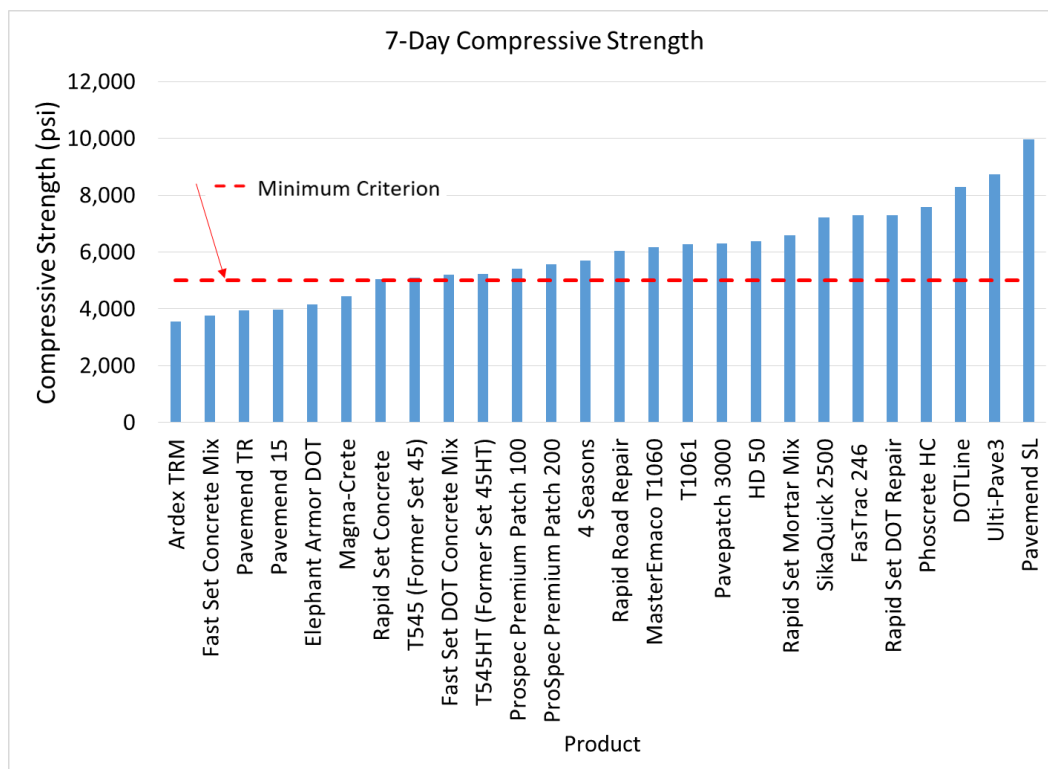
(a) Product comparison at 2-hr compressive strength.



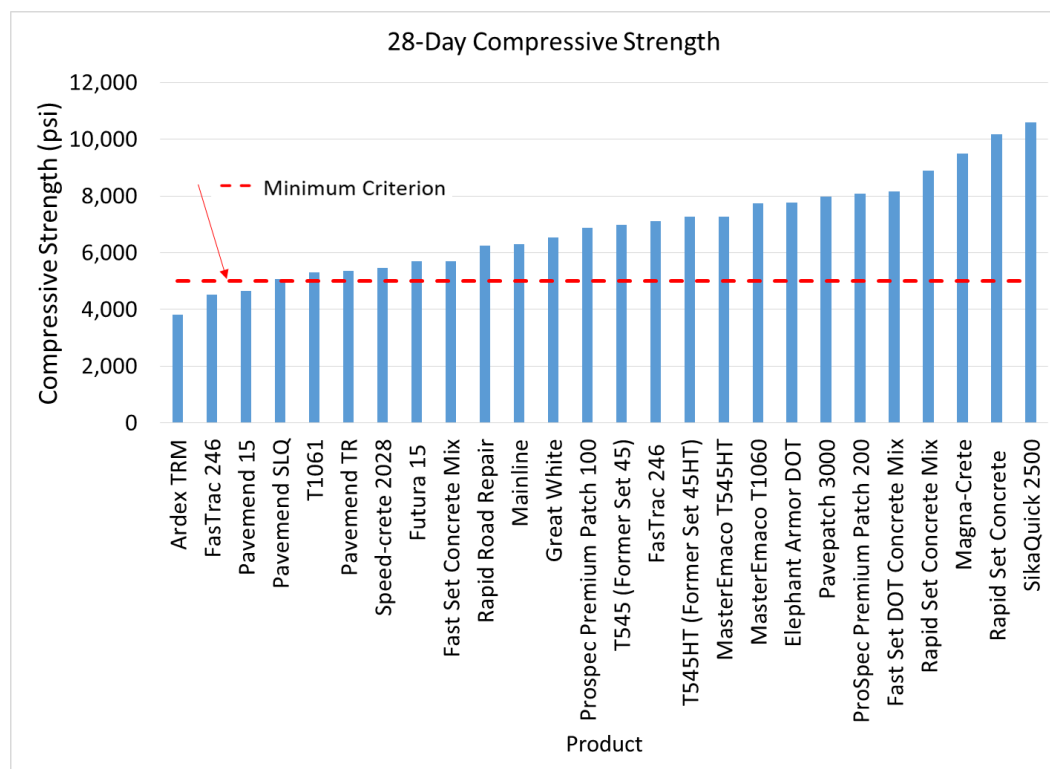
(b) Product comparison at 3-hr compressive strength.



(c) Product comparison at 1 day compressive strength.



(d) Product comparison at 7-day compressive strength.



(e) Product comparison at 28-day compressive strength.

5.2 Flexural strength

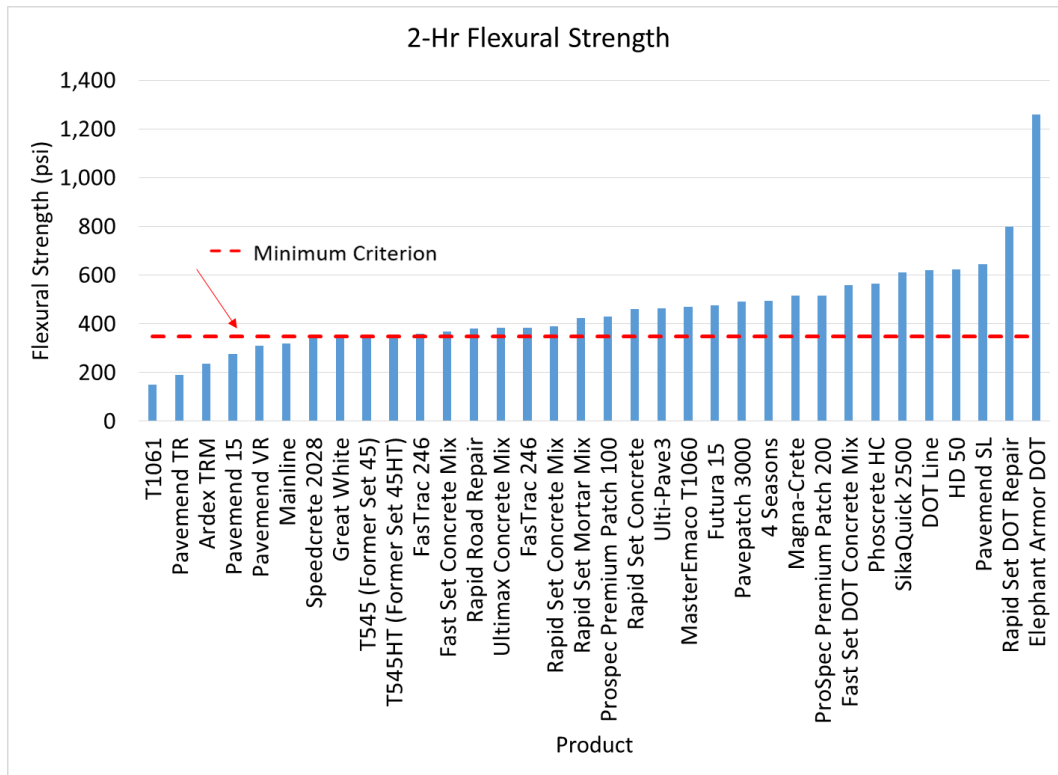
Comparisons of the flexural strengths are detailed in Table 8 and illustrated in Figure 15. Based on these results, the following modifications are recommended.

- The rate of flexural strength development was similar to the rate of strength development shown by compressive strengths.
- No changes are recommended for the current 2-hr pass criteria of 350 psi.
- It is recommended that the 7-day strength requirement decrease from 600 psi to 500 psi. This is based on the test results showing a more appropriate trend.

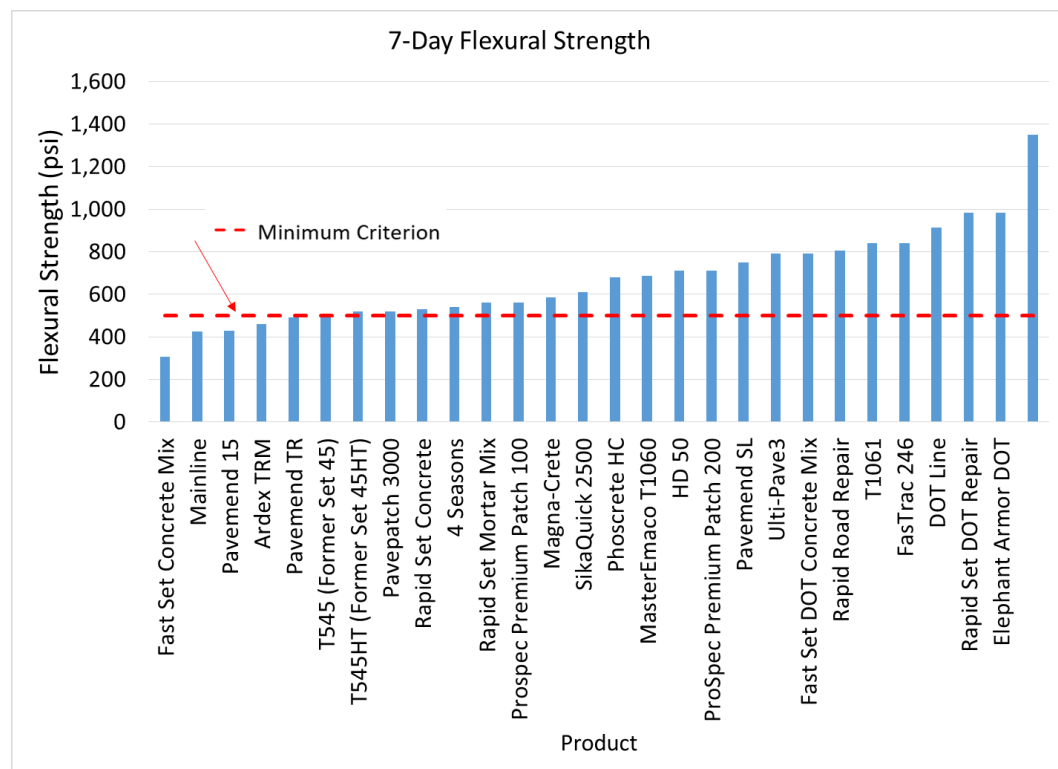
Table 8. Summary of flexural strength results.

Product Name	Manufacturer	Year Tested	Flexural Strength (psi)		
			2 hrs	7 days	28 days
Pavemend SLQ	Cera Tech, Inc.	2008	—	305	—
Ultimax Concrete Mix	Ultimax Cement	2008	385	—	—
Futura 15	W.R. Meadows	2008	475	—	—
Pavemend VR	Cera Tech, Inc.	2008	310	—	—
Great White	Cera Tech, Inc.	2009	355	—	—
Mainline	Cera Tech, Inc.	2009	320	430	—
Fast Set DOT Concrete Mix	Quickcrete Companies	2010	560	805	840
Rapid Set Concrete Mix	CTS Cement Corp.	2010	390	—	580
FasTrac	Western Material & Design	2010	385	—	—
Speedcrete 2028	Euclid Chemical Co.	2010	353	—	—
DOT Line	CeraTech, Inc.	2013	620	985	1,095
Pavepatch 3000	Dayton Superior Corp.	2013	490	530	790
SikaQuick 2500	Sika Corp.	2013	610	680	1,250
MasterEmaco T1060	BASF	2013	470	710	690
Pavemend SL	Cera Tech, Inc.	2013	645	790	2,340
Phoscrete 4 Seasons	Phoscrete Corp.	2013	495	560	545
Ulti-Pave3	Buzzi-Unicem USA, Inc.	2014	465	790	875
Ardex TRM	Ardex Americas	2014	235	490	505
Fast Set Concrete Mix	Quikcrete Companies	2014	370	425	450
Rapid Road Repair	Quikcrete Companies	2014	380	840	1,045
HD 50	Dayton Superior Corp.	2015	625	710	770
Rapid Set Mortar Mix	CTS Cement Corp.	2015	425	560	820
Magna-Crete	Henkel Americas	2015	515	610	730
Pavemend 15	Cera Tech, Inc.	2015	275	460	445
Prospec Premium Patch 100	H.B. Fuller Construction	2015	430	585	685
ProSpec Premium Patch 200	H.B. Fuller Construction	2015	515	750	815
Phoscrete HC	Phoscrete Corp.	2016	565	685	880
Elephant Armor DOT	GST International	2016	1,260	1,350	1,355
FasTrac 246 Concrete	Western Material & Design	2016	360	915	1,210
Rapid Set DOT Repair	CTS Cement Corp.	2017	800	985	875
Pavemend TR	Cera Tech, Inc.	2017	190	490	475
T545 (Formerly Set 45)	BASF	2017	355	520	610
T545HT (Formerly Set 45HT)	BASF	2017	355	520	615
Rapid Set Concrete	CTS Cement Corp.	2017	460	540	605
T1061	BASF	2017	150	840	860

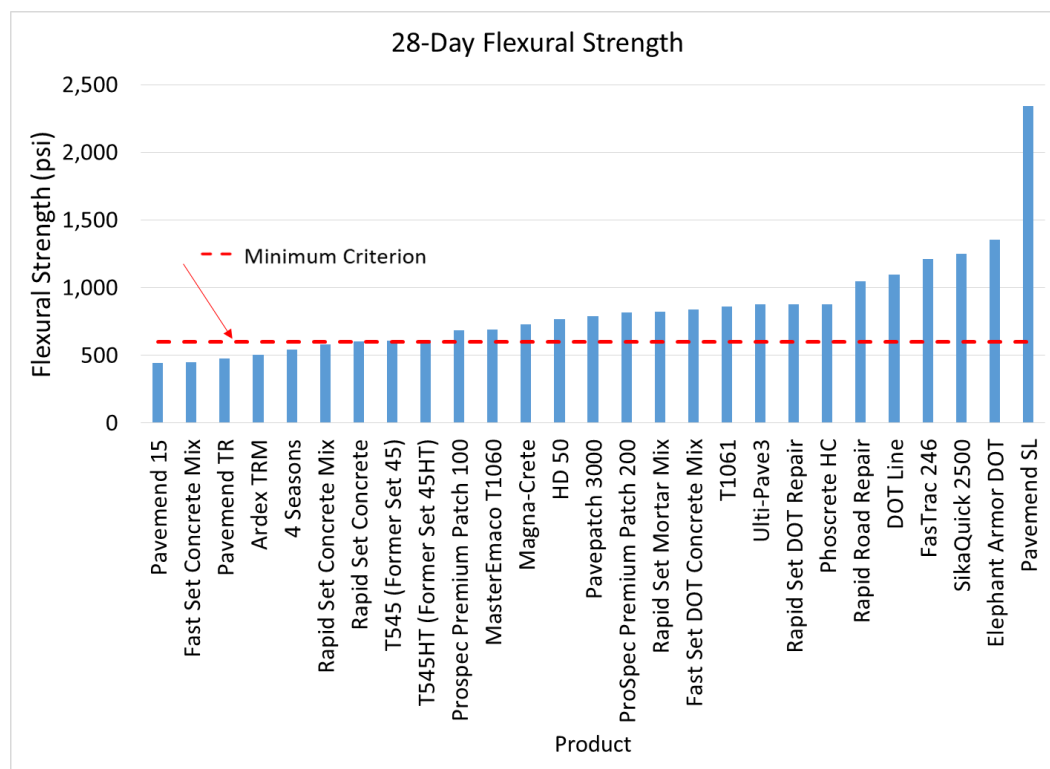
Figure 15. Summary of flexural strength product comparison by age.



(a) Product comparison at 2-hr flexural strength.



(b) Product comparison at 7-day flexural strength.



(c) Product comparison at 28-day flexural strength.

5.3 Bond strength

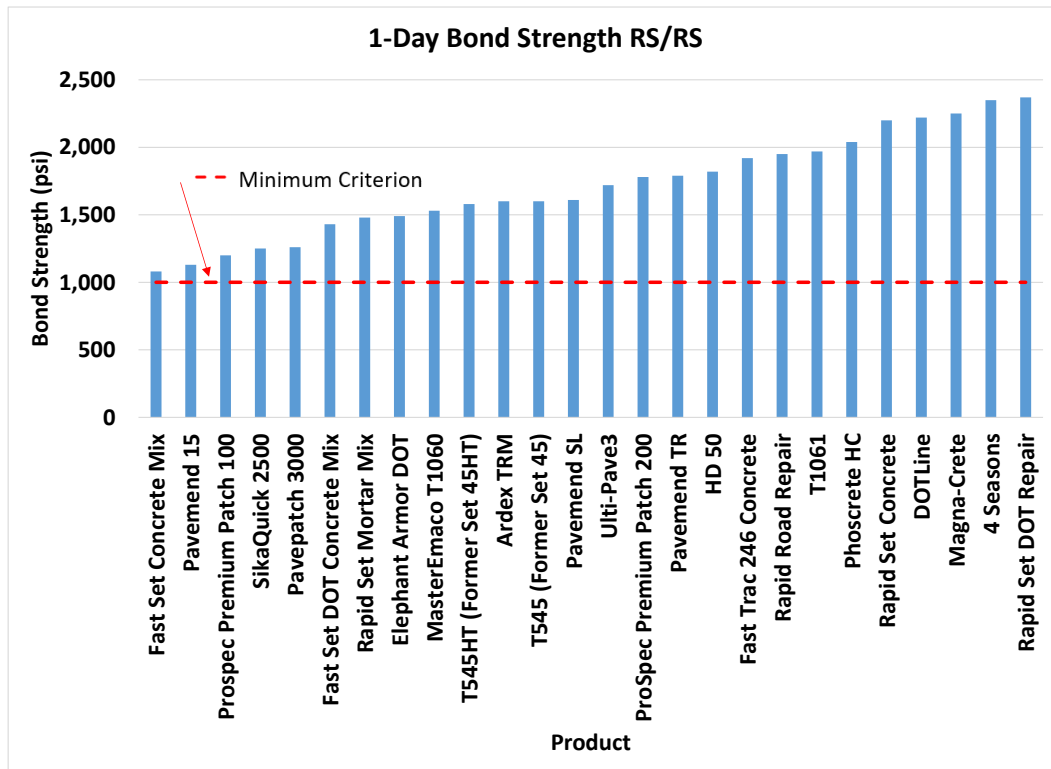
The ASTM C928 (2013b) provides a minimum performance requirement for this test of 1,000 psi at 1 day and 1,500 psi at 7 days for the rapid-setting material bonded to rapid-setting material (RS/RS). No criterion is provided in this standard for rapid-setting material bonded to portland cement concrete (PCC) material (RS/PCC). The current protocol requires a minimum of 1,000 psi for both RS/RS and RS/PCC at 1 day but no requirement at 7 days. Comparisons of the bond strengths are detailed in Table 9 and illustrated in Figure 16. Based on these results, the following modifications are recommended:

- No changes are recommended for the 1-day pass criterion of 1,000 psi on both the RS/RS and RS/PCC specimens. The majority of products meet or exceed this minimum value.
- Establish the 7-day pass criteria of 1,250 psi for the RS/ PCC specimens and 1,500 psi for RS/RS specimens.

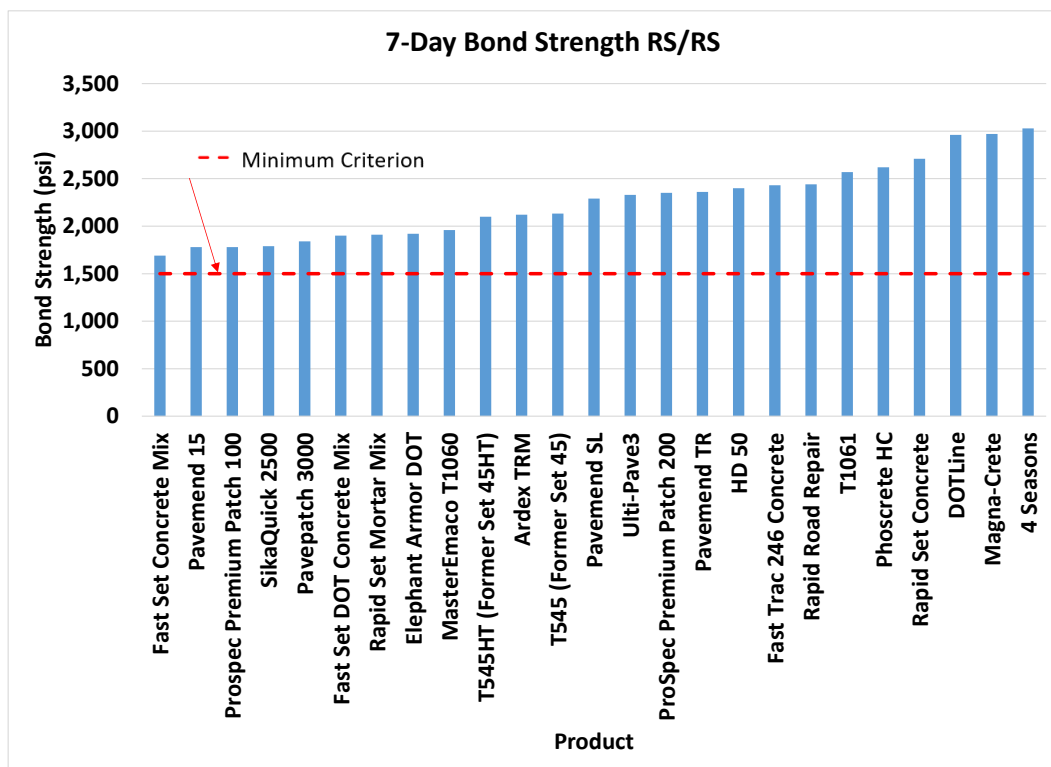
Table 9. Summary of bond strength results.

Product Name	Manufacturer	Year Tested	RS/RS (psi)		RS/PCC (psi)	
			1 day	7 days	1 day	7 days
Rapid Set DOT Repair Mix	CTS Cement Corp	2007	—	—	1,470	—
MasterEmaco T545HT	BASF	2007	—	—	1,240	—
Pavemend SLQ	Cera Tech, Inc.	2008	—	—	910	—
Ultimax Concrete Mix	Ultimax Cement	2008	—	—	1,930	—
Versapeed	Euclid Chemical Co.	2008	—	—	1,290	—
Futura 15	W.R. Meadows	2008	—	—	325	—
Pavemend VR	Cera Tech, Inc.	2008	595	—	—	—
Great White	CeraTech, Inc.	2009	—	—	891	—
Mainline	Cera Tech, Inc.	2009	—	—	1,672	—
Fast Set DOT Concrete Mix	Quickcrete Companies	2010	1,430	2,133	1,600	2,380
Rapid Set Concrete Mix	CTS Cement Corp	2010	—	—	850	—
FasTrac	Western Material	2010	—	—	2,737	—
DOTLine	CeraTech, Inc.	2013	2,220	3,030	2,030	2,420
Pavepatch 3000	Dayton Superior Corp	2013	1,260	1,900	1,030	1,470
SikaQuick 2500	Sika Corp	2013	1,250	1,840	1,170	1,410
MasterEmaco T1060	BASF	2013	1,530	1,960	1,350	1,930
Pavemend SL	Cera Tech, Inc.	2013	1,610	2,400	1,600	1,990
4 Seasons	Phoscrete Corp.	2013	2,350	2,570	1,080	1,160
Ulti-Pave3	Buzzi-Unicem USA Inc.	2014	1,720	2,360	1,390	1,740
Ardex TRM	Ardex Americas	2014	1,600	2,120	1,240	1,450
Fast Set Concrete Mix	Quikcrete Companies	2014	1,080	1,470	1,320	1,580
Rapid Road Repair	Quikcrete Companies	2014	1,950	2,970	1,350	1,520
HD 50	Dayton Superior Corp	2015	1,820	2,960	1,550	2,390
Prospec Premium Patch 100	H.B. Fuller Construction	2015	1,200	1,690	1,040	1,550
ProSpec Premium Patch 200	H.B. Fuller Construction	2015	1,780	2,350	1,820	2,150
Rapid Set Mortar Mix	CTS Cement Corp	2015	1,480	2,100	1,300	1,910
Magna-Crete	Henkel Americas	2015	2,250	2,430	1,790	2,430
Pavemend 15	Cera Tech, Inc.	2015	1,130	1,790	820	1,010
Phoscrete HC	Phoscrete Corp.	2016	2,040	2,330	1,590	1,720
Elephant Armor DOT	GST International	2016	1,490	1,910	690	770
FasTrac 246 Concrete	Western Material & Design	2016	1,920	2,290	1,870	1,945
Rapid Set DOT Repair	CTS Cement Corp.	2017	2,370	2,440	2,430	2,540
Pavemend TR	CeraTech	2017	1,790	1,920	1,560	1,770
T545 (Formerly Set 45)	BASF	2017	1,600	1,780	1,050	1,340
T545HT (Formerly Set 45HT)	BASF	2017	1,580	1,780	1,130	1,530
Rapid Set Concrete	CTS Cement Corp.	2017	2,200	2,620	1,800	2,130
T1061	BASF	2017	1,970	2,710	1,880	2,360

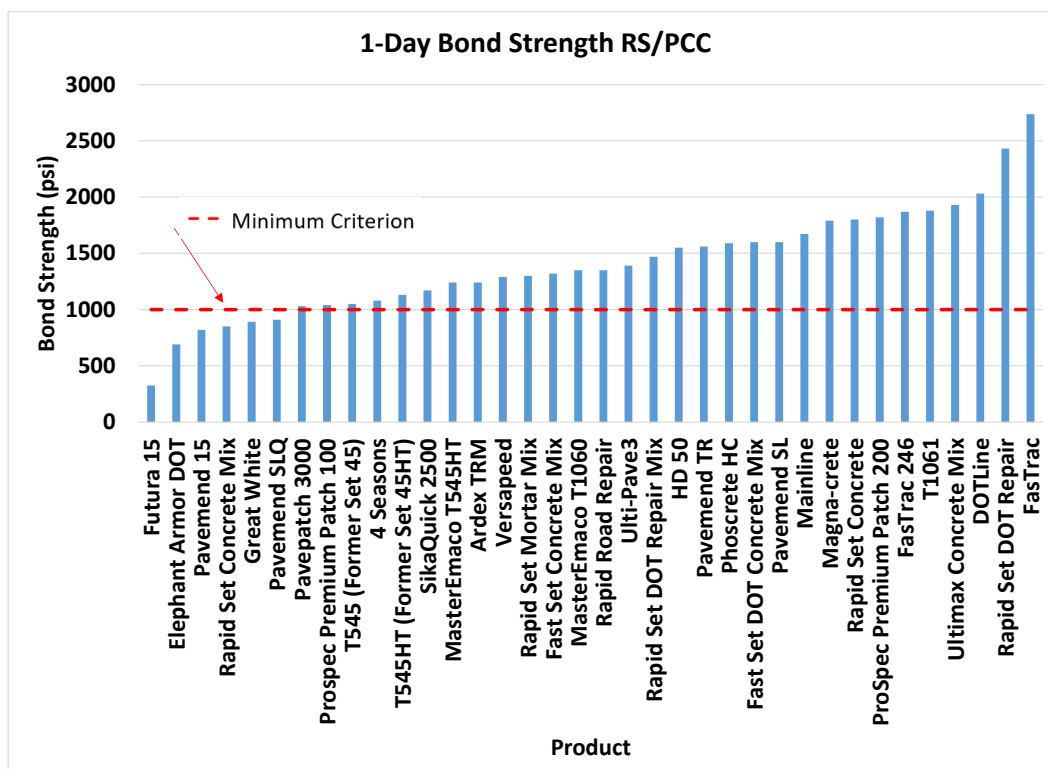
Figure 16. Summary of bond strength product comparison by age.



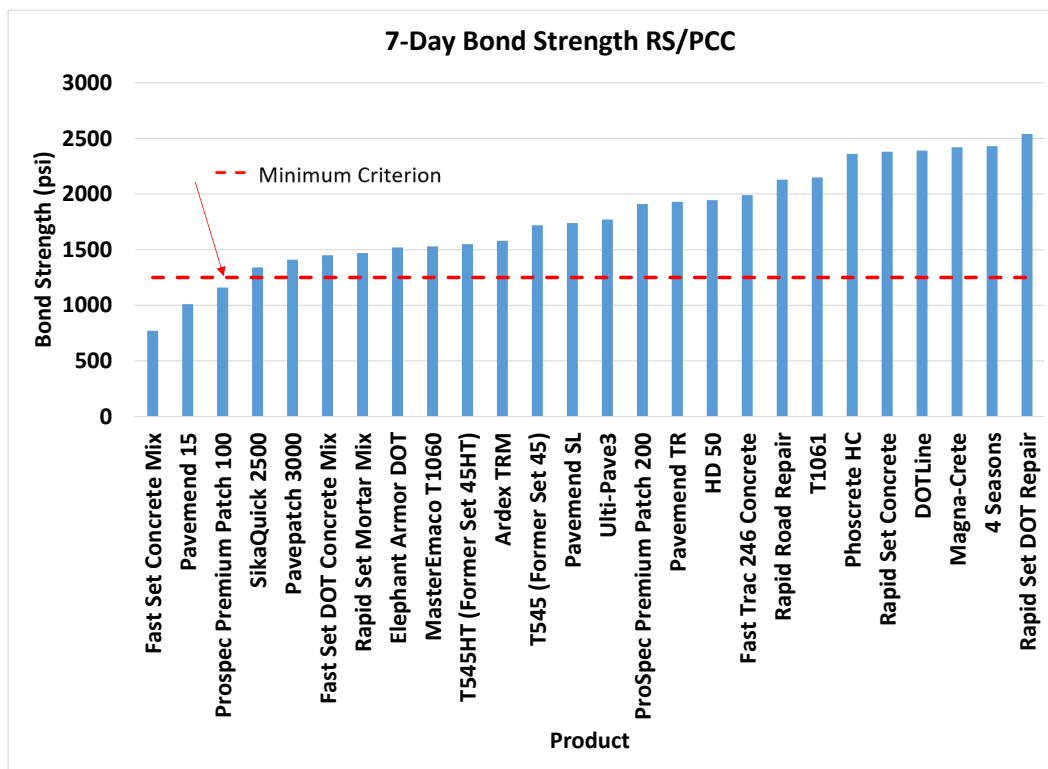
(a) Product comparison at 1-day bond strength RS/RS.



(b) Product comparison at 7-day bond strength RS/RS.



(c) Product comparison at 1-day bond strength RS/PCC.



(d) Product comparison at 7-day bond strength RS/PCC.

5.4 Modulus of elasticity

Comparisons of the modulus of elasticity results are in Table 10. Based on these results, the established limits of between 2 and 6 Mpsi at the test ages of 2 hr and 28 days appear appropriate; thus, no changes are recommended at this time.

Table 10. Summary of modulus of elasticity results.

Product Name	Manufacturer	Year Tested	Modulus of Elasticity (Mpsi)	
			2 hrs	28 days
Rapid Set DOT Repair Mix	CTS Cement Corp.	2007	5.50	—
Pavemend EX-H	Cera Tech, Inc.	2007	0.35	—
Pavemend SLQ	Cera Tech, Inc.	2008	1.50	—
Ultimax Concrete Mix	Ultimax Cement	2008	2.80	—
Great White	Cera Tech, Inc.	2009	3.60	—
Mainline	Cera Tech, Inc.	2009	2.35	—
Fast Set DOT Concrete Mix	Quickcrete Companies	2010	1.95	3.75
Rapid Set Concrete Mix	CTS Cement Corp.	2010	3.15	—
FasTrac	Western Material & Design	2010	3.5	—
DOTLine	Cera Tech, Inc.	2013	2.95	5.35
Pavepatch 3000	Dayton Superior Corp.	2013	5.05	4.85
SikaQuick 2500	Sika Corp.	2013	4.30	5.40
MasterEmaco T1060	BASF	2013	4.95	6.65
Pavemend SL	Cera Tech, Inc.	2013	3.60	6.20
Phoscrete 4 Seasons	Phoscrete Corp.	2013	2.20	3.70
Ulti-Pave3	Buzzi-Unicem USA, Inc.	2014	2.50	4.75
Ardex TRM	Ardex Americas	2014	—	3.25
Fast Set Concrete Mix	Quikcrete Companies	2014	1.95	4.00
Rapid Road Repair	Quikcrete Companies	2014	1.40	3.90
HD 50	Dayton Superior Corp.	2015	3.30	4.70
Prospec Premium Patch 100	H.B. Fuller Construction	2015	2.75	4.70
ProSpec Premium Patch 200	H.B. Fuller Construction	2015	2.95	4.40
Rapid Set Mortar Mix	CTS Cement Corp.	2015	2.20	3.10
Magna-Crete	Henkel Americas	2015	3.30	7.90
Pavemend 15	Cera Tech, Inc.	2015	0.95	2.35
Phoscrete HC	Phoscrete Corp.	2016	3.40	4.27
Elephant Armor DOT	GST International	2016	3.40	4.65
FasTrac 246 Concrete	Western Material & Design	2016	3.20	4.70

Pavemend TR	Cera Tech, Inc.	2017	3.68	4.28
T545 (Formerly Set 45)	BASF	2017	2.35	5.35
T545HT (Formerly Set 45HT)	BASF	2017	2.72	5.32
Rapid Set Concrete	CTS Cement Corp.	2017	3.34	4.08
T1061	BASF	2017	3.27	6.12

5.5 Time of setting

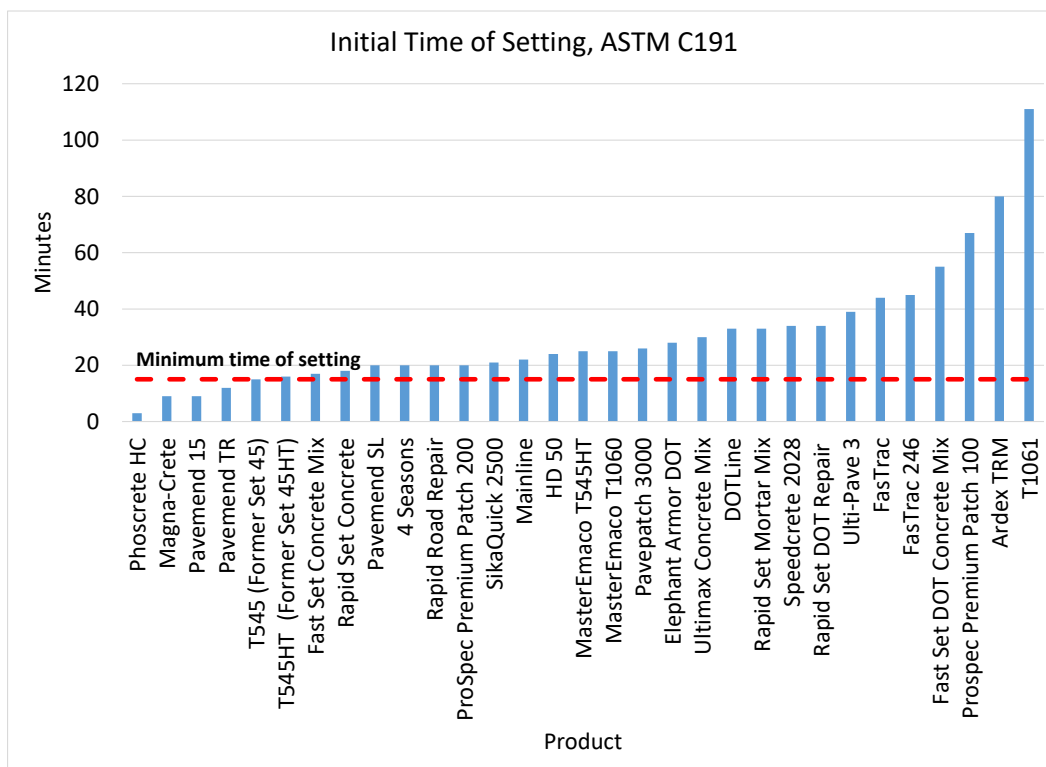
Data comparison of the times of setting is shown in Table 11. Graphs of the initial and final setting based on the ASTM C191 (2013c) and ASTM C403 (2016f) methods are illustrated in Figures 17 and 18. Based on these results, modifications are recommended on both testing requirement methods and pass/fail criteria for the initial and final set times. The current protocol recommends testing by the Vicat method of ASTM C191. However, many of the products are either extended with pea gravel or have aggregates already in the proprietary mix. The current test method is ASTM C191, which is for a cement paste only. When conducting this test on products, the aggregates are wet sieved over a No. 4 sieve before being placed in the mold and having the set time monitored. Although not in the current protocols, the ASTM C403 (2016f) time of setting of concrete mixtures by penetration resistance has also been conducted on products tested between 2013 and 2017. For some products, the time of setting deviated from the Vicat versus the penetrometer testing. It is recommended that the time of setting be conducted by the ASTM C403 procedure without sieving the aggregates to more accurately represent the field concrete placement of the rapid-repair material.

The published protocol shows no requirements for the initial and final set times, but the current pass criteria for initial set is over 15 min and for final set between 25-35 min. However, many products fail on one or both of these parameters by having a high initial set time with no upper boundary provided, and/or failing the final set time by having a set time over 35 min. It is recommended the initial set requirement be between 15 to 90 min. and the final set time be less than 2 hr, provided it meets the strength requirements at 2 hr.

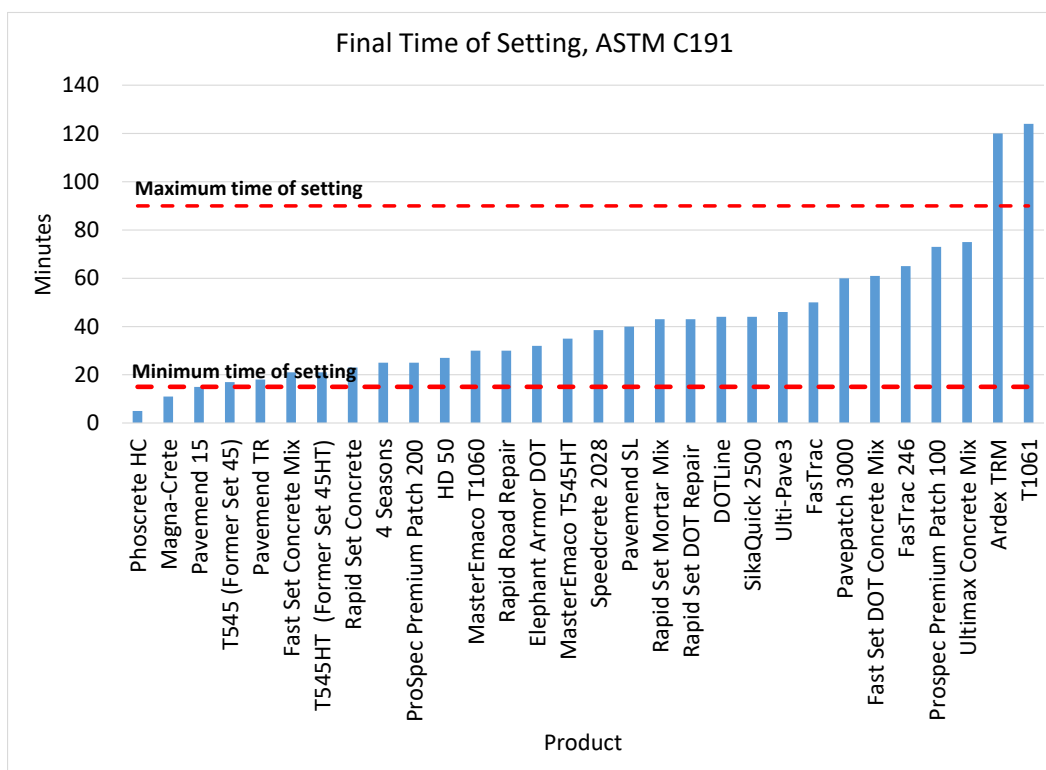
Table 11. Summary of time of setting results.

Product Name	Manufacturer	Year Tested	ASTM C191		ASTM C403	
			Initial (min)	Final (min)	Initial (min)	Final (min)
MasterEmaco T545HT	BASF	2007	25	35	—	—
Ultimax Concrete Mix	Ultimax Cement	2008	30	75	—	—
Mainline	Cera Tech, Inc.	2009	22	—	—	—
Fast Set DOT Concrete Mix	Quickcrete Companies	2010	55	61	—	—
FasTrac	Western Material & Design, LLC	2010	44	50	—	—
Speedcrete 2028	Euclid Chemical Co.	2010	34	38.5	—	—
DOTLine	CeraTech, Inc.	2013	33	44	38	40
Pavepatch 3000	Dayton Superior Corp.	2013	26	60	38	58
SikaQuick 2500	Sika Corp.	2013	21	44	21	46
MasterEmaco T1060	BASF	2013	25	30	43	47
Pavemend SL	Cera Tech, Inc.	2013	20	40	24	35
Phoscrete 4 Seasons	Phoscrete Corp.	2013	20	25	6	8
Ulti-Pave3	Buzzi-Unicem USA, Inc.	2014	39	46	25	45
Ardex TRM	Ardex Americas	2014	80	120	120	140
Fast Set Concrete Mix	Quikcrete Companies	2014	17	21	18	26
Rapid Road Repair	Quikcrete Companies	2014	20	30	25	37
HD 50	Dayton Superior Corp.	2015	24	27	23	26
Prospec Premium Patch 100	H.B. Fuller Construction	2015	67	73	65	72
ProSpec Premium Patch 200	H.B. Fuller Construction	2015	20	25	20	24
Rapid Set Mortar Mix	CTS Cement Corp.	2015	33	43	37	43
Magna-Crete	Henkel Americas	2015	9	11	8	11
Pavemend 15	Cera Tech, Inc.	2015	9	15	15	30
Phoscrete HC	Phoscrete Corp.	2016	3	5	4	5
Elephant Armor DOT	GST International	2016	28	32	30	35
FasTrac 246 Concrete	Western Material & Design, LLC	2016	45	65	48	69
Pavemend TR	CeraTech, Inc.	2017	12	18	15	20
T545 (Formerly Set 45)	BASF	2017	15	17	15	20
T545HT (Formerly Set 45HT)	BASF	2017	16	21	20	24
Rapid Set DOT Repair	CTS Cement Corp.	2017	34	43	40	44
Rapid Set Concrete	CTS Cement Corp.	2017	18	23	20	25
T1061	BASF	2017	111	124	72	88

Figure 17. Summary of time of setting product comparison based on ASTM C191.

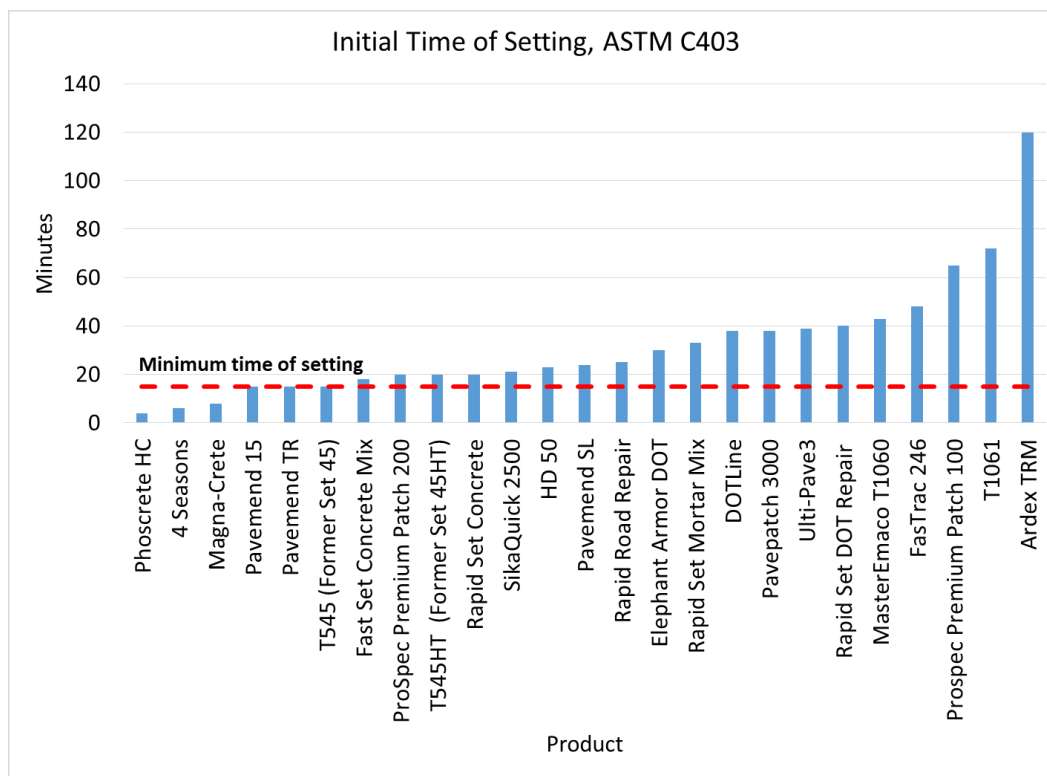


(a) Product comparison of initial time of setting based on ASTM C191.

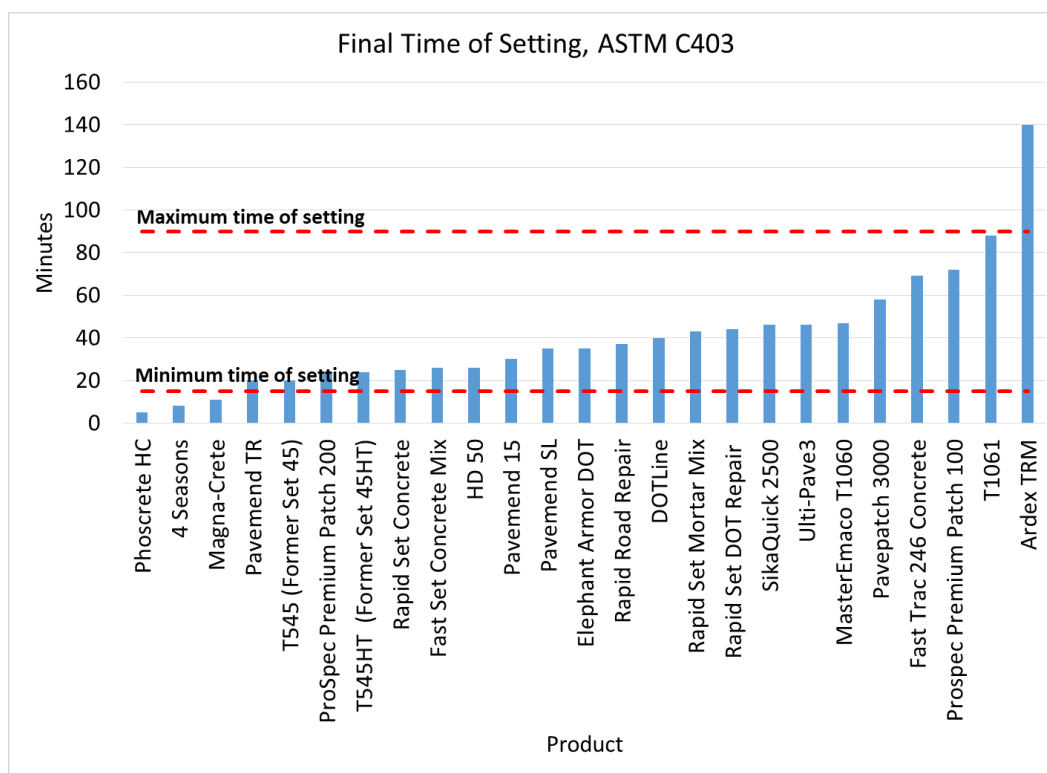


(b) Product comparison of final time of setting based on ASTM C191.

Figure 18. Summary of time of setting product comparison based on ASTM C403.



(a) Product comparison of initial time of setting based on ASTM C403.



(b) Product comparison of final time of setting based on ASTM C403.

5.6 Workability

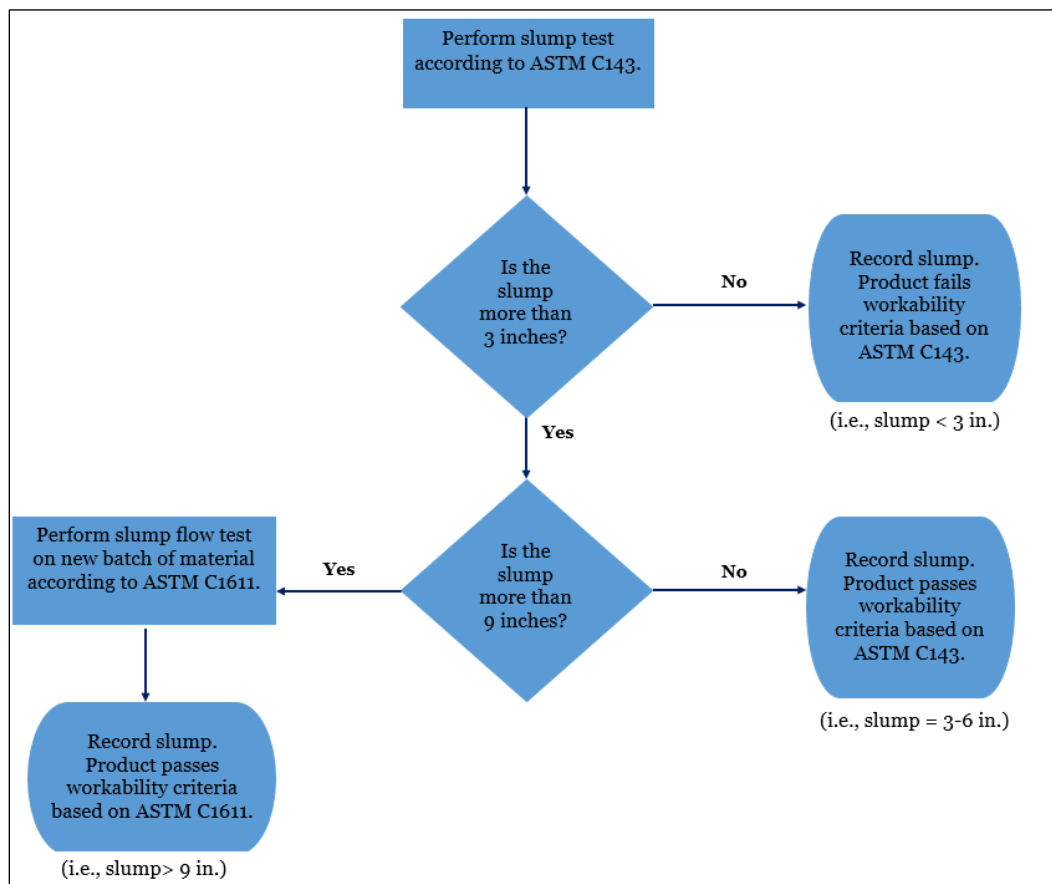
Comparisons of the workability are shown in Table 12. No slump requirement was established in the previous test protocol based on the ETL o8-02 (AFCEC 2008), and TR-11-13 (Priddy 2011) requires only that the slump be measured. The ASTM C928 (2013b) recommends a minimum slump of 3 in. for cementitious, rapid-setting materials. The same minimum criterion of 3 in. with no maximum slump or flow is suggested for the new test protocol. The standard slump from ASTM C143 (2015c) is the first test to perform within 5 min of adding the water to the material. If the concrete measures a slump greater than 9 in., the concrete may not be adequately cohesive for this test to have significance, as noted in the standard method. Therefore, a slump flow must then be measured on a new batch of material using procedures detailed in ASTM C1611 (2014b). A flowchart of the workability testing is shown in Figure 19.

Table 12. Summary of slump results.

Product Name	Manufacturer	Year Tested	Slump (in.)
Fast Set DOT Concrete Mix	Quickcrete Companies	2010	4
DOTLine	Cera Tech, Inc.	2013	5
Pavepatch 3000	Dayton Superior Corp,	2013	10
SikaQuick 2500	Sika Corp,	2013	10
MasterEmaco T1060	BASF	2013	5
Pavemend SL	Cera Tech, Inc.	2013	2.75
Phoscrete 4 Seasons	Phoscrete Corp.	2013	6
Ardex TRM	Ardex	2013	9
Ulti-Pave3	Buzzi-Unicem USA, Inc.	2014	9
Fast Set Concrete Mix	Quickcrete Companies	2014	3
Rapid Road Repair	Quickcrete Companies	2014	3
HD 50	Dayton Superior Corp,	2015	11
Prospec Premium Patch 100	H.B. Fuller Construction Products	2015	2
ProSpec Premium Patch 200	H.B. Fuller Construction Products	2015	3
Rapid Set Mortar Mix	CTS Cement Corp.	2015	4
Magna-Crete	Henkel Americas	2015	6
Pavemend 15	Cera Tech, Inc.	2015	19
Phoscrete HC	Phoscrete Corp.	2016	2
Elephant Armor DOT	GST International	2016	7
FasTrac 246 Concrete	Western Material & Design, LLC	2016	8
Rapid Set DOT Repair	CTS Cement Corp.	2017	12

Pavemend TR	Cera Tech, Inc.	2017	11
T545 (Formerly Set 45)	BASF	2017	7
T545HT (Formerly Set 45HT)	BASF	2017	8
Rapid Set DOT Repair	CTS Cement Corp.	2017	12
Rapid Set Concrete	CTS Cement Corp.	2017	3
T1061	BASF	2017	2

Figure 19. Flowchart of test requirements for workability.



5.7 Coefficient of thermal expansion

The current CTE limit is a maximum value of 12×10^{-6} (in./in./°F) with a test age of 7 days as established in ERDC TR-11-13 (Priddy 2011). Based on the CTE test data shown in Table 13 and illustrated in Figure 20, all materials tested fall well below this requirement and are more comparable to the value established in ETL o8-o2 (AFCEC 2008) of 7×10^{-6} .

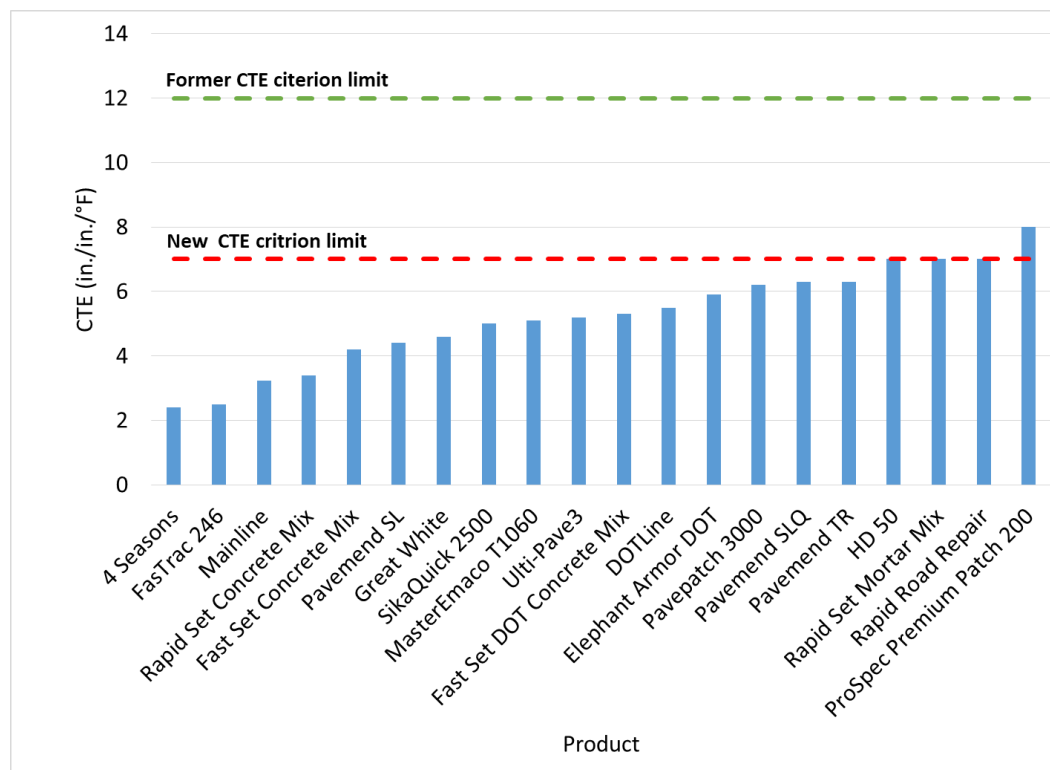
(in./in./°F). It is recommended that this test limit be reduced to an upper limit of 7×10^{-6} (in./in./°F).

The testing laboratory followed the procedure for linear shrinkage as suggested in ASTM C531 (2012a) with the frequency of measuring the mortar bars first by daily readings for 2 weeks at $73 \pm 4^\circ\text{F}$. A heating and cooling cycle of readings was then carried out on the mortar bars with the following cycle until a constant length change was measured: readings were taken on mortar bars after being stored in an oven at 210°F for 3 days; then readings were taken after the bars had been stored in a desiccator overnight and mortar bars had cooled to 73°F . The average time for a constant linear CTE to be achieved was an additional two weeks.

Table 13. Summary of CTE results.

Product Name	Manufacturer	Year Tested	CTE results
Pavemend SLQ	Cera Tech, Inc.	2008	6.3
Pavemend TR	Cera Tech, Inc.	2008	6.3
Great White	Cera Tech, Inc.	2009	4.6
Mainline	Cera Tech, Inc.	2009	3.2
Fast Set DOT Concrete Mix	Quikcrete Companies	2010	5.3
Rapid Set Concrete Mix	CTS Cement Corp.	2010	3.4
FasTrac	Western Material & Design, LLC	2010	2.5
DOTLine	Cera Tech, Inc.	2013	5.5
Pavepatch 3000	Dayton Superior Corp.	2013	6.2
SikaQuick 2500	Sika Corp.	2013	5.0
MasterEmaco T1060	BASF	2013	5.1
Pavemend SL	Cera Tech, Inc.	2013	4.4
Phoscrete 4 Seasons	Phoscrete Corp.	2013	2.4
Ulti-Pave3	Buzzi-Unicem USA, Inc.	2014	5.2
Fast Set Concrete Mix	Quikcrete Companies	2014	4.2
Rapid Road Repair	Quikcrete Companies	2014	7.0
HD 50	Dayton Superior Corp.	2015	7.0
Magna-Crete	Henkel Americas	2015	7.6
ProSpec Premium Patch 200	H.B. Fuller Construction Products, Inc.	2015	8.0
Rapid Set Mortar Mix	CTS Cement Corp.	2015	7.0
Elephant Armor DOT	GST International	2016	5.9

Figure 20. Comparison graph of CTE results and criteria limits.



5.8 Length change

The former length change testing protocol required that the 28-day minimum allowable expansion not exceed 0.03 percent when cured in water and a minimum allowance of shrinkage not exceed 0.04 percent. Based on the test results in both air and water cure environments shown in Table 14, this limit appears appropriate; and no changes to the 28-day protocol are recommended.

However, ASTM C157 (2014a) recommends this test continue until 64 weeks to determine long-term performance. Research of ultimate drying shrinkage using this method from the REMR program recommended the critical limit as a maximum of 0.1 percent at 1 year (WES 1994). No testing was conducted with specimens cured in water to determine possible ultimate expansion criteria. It is recommended that length change readings and reporting continue until 64 weeks for both air- and water-cure environments to establish an appropriate pass/fail criteria for ultimate expansion and contraction in the future.

Table 14. Summary of length change results.

Product Name	Manufacturer	Year Tested	28-day length change (in.)	
			Air Cure	Water Cure
Pavemend SLQ	Cera Tech, Inc.	2008	0.04	—
Great White	Cera Tech, Inc.	2009	0.0203	—
Mainline	Cera Tech, Inc.	2009	-0.0313	—
Fast Set DOT Concrete Mix	Quickcrete Companies	2010	0.01	0.03
Rapid Set Concrete Mix	CTS Cement Corp.	2010	0.01	0
FasTrac	Western Material & Design	2010	0.04	—
DOTLine	Cera Tech, Inc.	2013	0.032	0.028
Pavepatch 3000	Dayton Superior Corp	2013	-0.037	0.012
SikaQuick 2500	Sika Corp.	2013	-0.006	0.019
MasterEmaco T1060	BASF	2013	-0.009	0.031
Pavemend SL	Cera Tech, Inc.	2013	0.009	0.047
Phoscrete 4-Seasons	Phoscrete Corp.	2013	-0.065	0
Ulti-Pave3	Buzzi-Unicem USA, Inc.	2014	-0.015	0.015
Fast Set Concrete Mix	Quikcrete Companies	2014	0	0.01
Rapid Road Repair	Quikcrete Companies	2014	0.03	0.08
HD 50	Dayton Superior Corp	2015	-0.0055	0.017
Magna-Crete	Henkel Americas	2015	-0.028	-0.010
ProSpec Premium Patch 200	H.B. Fuller Construction	2015	-0.005	0.015
Rapid Set Mortar Mix	CTS Cement Corp.	2015	0	0.02
Elephant Armor DOT	GST International	2016	0.002	0.019

5.9 Shrinkage ring

Comparisons of shrinkage ring results are shown in Table 15. The restrained shrinkage ring test equipment was updated in FY12-FY13 to run the standard specimen dimensions and procedures in accordance with ASTM C1581 (2016c). The previous rings had an incorrect thickness and diameter. With these changes, the test criteria may not be appropriate. The 14-day requirement of a microstrain value of less than 40 is the criterion of most concern. Some products failed this 14-day requirement but passed the 28-day requirement of no cracking. Based on these results, it is recommended to record the 14-day microstrain value but have no failure criterion and also to have the 28-day microstrain value recorded and fail the product if cracking occurs. The significance in recording and reporting the microstrain values at both 14 and 28 days is to possibly establish a quantitative pass/fail limit in the future.

Table 15. Summary of shrinkage ring results.

Product Name	Manufacturer	Year Tested	14 days	28 days
			Microstrain Value	Cracking (Y/N)
Pavemend SLQ	Cera Tech, Inc.	2008	—	N
Pavemend TR	Cera Tech, Inc.	2008	—	N
Ultimax Concrete Mix	Ultimax Cement	2008	—	N
Great White	Cera Tech, Inc.	2009	40	N
Mainline	Cera Tech, Inc.	2009	51	N
Fast Set DOT Concrete Mix	Quickcrete Companies	2010	54	N
Rapid Set Concrete Mix	CTS Cement Corp.	2010	—	N
FasTrac	Western Material & Design	2010	31	N
DOTLine	Cera Tech, Inc.	2013	19	N
Pavepatch 3000	Dayton Superior Corp.	2013	0	Y
MasterEmaco T1060	BASF	2013	0	Y
Pavemend SL	Cera Tech, Inc.	2013	22	N
Phoscrete 4 Seasons	Phoscrete Corp.	2013	50	N
Ulti-Pave3	Buzzi-Unicem USA, Inc.	2014	49	N
Fast Set Concrete Mix	Quickcrete Companies	2014	27	N
Rapid Road Repair	Quickcrete Companies	2014	24	N
HD 50	Dayton Superior Corp.	2015	25.5	N
ProSpec Premium Patch 200	H.B. Fuller Construction	2015	24	N
Rapid Set Mortar Mix	CTS Cement Corp.	2015	19	N
Elephant Armor DOT	GST International	2016	34	N

5.10 Freeze-thaw resistance

Comparisons of the freeze-thaw resistance results are shown in Table 16. The ASTM C666 (2015b) Method A appears to be an extreme test for the rapid-repair products. Even though no criterion was established for a pass/fail criterion in the existing testing protocol, none of the products tested reached 300 cycles before failure, as suggested in the standard test method. Based on these results, it is recommended that new testing procedures be developed and standardized to further assess the freeze-thaw test methods for pavements.

Table 16. Summary of the freeze-thaw results.

Product Name	Manufacturer	Year Tested	Freeze-Thaw Results	
			Durability Factor	# Cycles before Failure
Fast Set DOT Concrete Mix	Quickcrete Companies	2010	41	44
DOTLine	Cera Tech, Inc.	2013	27	132
Pavepatch 3000	Dayton Superior Corp.	2013	36	189
Phoscrete 4 Seasons	Phoscrete	2013	64	200
MasterEmaco T1060	BASF	2013	27	85
SikaQuick 2500	Sika	2013	6	36
Pavemend SL	Cera Tech, Inc.	2013	4	47
Fast Set Concrete Mix	Quikrete Companies	2014	64	200
Ulti-Pave3	Buzzi-Unicem	2014	20	118
Rapid Road Repair	Quikrete Companies	2014	56	68
HD 50	Dayton Superior Corp.	2015	5	33
ProSpec Premium Patch 200	H.B. Fuller Construction	2015	9	56
Rapid Set Mortar Mix	CTS Cement Corp.	2015	5	33
Elephant Armor DOT	GST International	2016	8	44

6 Summary and Conclusions

The objective of this project was to evaluate the performance criteria for the selection of cementitious rapid-repair materials for spall repairs. This was accomplished by assembling data by individual test and age from not only the 28 products tested from 2013 to 2017 but also historical tri-service data. An analysis of the wide range of material properties of the laboratory testing results presented in this document led to the development of an updated testing protocol for cementitious rapid-repair products for airfield spall repairs. In order to achieve the best compatibility between the repair material and the original concrete surface, the recommendations for performance criteria are provided in the following section. However, it should be noted that laboratory tests are only index tests and do not necessarily predict performance. It is suggested that field tests be performed to correlate performance with the laboratory results to further validate the repair material.

6.1 Laboratory lessons learned

Based on the laboratory testing experience with the rapid-repair products, some general observations and lessons learned are summarized as follows.

- All technical data provided by the manufacturer of the product must be carefully read and strictly followed. This includes not only the mixture proportions, water recommendations, and mixing time but also the sequence of batching the components of the repair material (i.e., water, coarse aggregate, dry bagged material, etc.). Significant differences resulted in both fresh and hardened properties if, for example, the water was added first followed by mixing in the dry material versus the water added to the dry material then mixed.
- While there are some similarities between rapid-repair concrete and conventional concrete, no product should ever be approached the same. For example, Magnesium Phosphate Cement (MPC)-based products must be cured in a dry environment due to the potential of strength loss with a moist cure.
- Some materials have extremely tight working times of only a few minutes between the initial and final sets. Caution should be exercised with the quantity mixed, and personnel should be prepared for quick execution of the spall repair and cleanup of tools and equipment in the field.

- Rapid-repair materials are highly exothermic, and the use of an infrared thermometer temperature gun is recommended not only for recording the initial and final temperatures but also for use during the entire mixing time. A sudden spike in the temperature is an indication that the material is approaching the initial set time and all operations need to be finalized quickly.
- In general, rapid-repair products are sensitive to moisture due to the material's large surface area and high fineness. In efforts to keep the products from hydrating and becoming unusable, products tested in the laboratory should be stored in sealed buckets with desiccant packets to create the most airtight environment possible.
- Some allergic symptoms may be experienced when handling some products. For example, strong ammonium fumes were experienced with the Magna-Crete product, which caused mild skin, eye, and respiratory irritation. For all products, the material safety data sheet (MSDS) should always be consulted for exposure controls and personal protection. Personal protection equipment including some combination of gloves, safety glasses, and dust or ventilation masks while working in an open air ventilation environment is recommended.
- Since all testing was conducted in a strictly controlled temperature environment of $72 \pm 4^{\circ}\text{F}$, variations of high and low ranges of temperatures are recommended to evaluate the sensitivity of the product if the repairs are considered in a range outside the manufacturer's recommended installation temperature.

6.2 Summary of testing protocol

It is recommended that the updated testing protocol provided in Table 17 be used for the new selection criteria for certifying rapid-setting repair materials for spall repairs. The two-tier requirement method of testing is suggested from a cost and time requirement perspective due to the number of mechanical and volumetric property tests required. A comparison of the former and new test criteria is presented in Table 18.

Table 17. Summary of updated test protocol for cementitious materials.

Tier 1 Test Requirements			
Test Property	Test Method	Test Age	Test Criteria
Compressive Strength	ASTM C39	2 hr	$\geq 2,500$ psi
		3 hr	$\geq 3,000$ psi
		1 day	$\geq 4,000$ psi
		7 days	$\geq 5,000$ psi
		28 days	$\geq 5,000$ psi
Flexural Strength	ASTM C78	2 hr	≥ 350 psi
		7 days	≥ 500 psi
		28 days	≥ 600 psi
Bond Strength (RS/RS)	ASTM C882	1 day	$\geq 1,000$ psi
		7 days	$\geq 1,500$ psi
Bond Strength (PCC/RS)		1 day	$\geq 1,000$ psi
		7 days	$\geq 1,250$ psi
Modulus of Elasticity	ASTM C469	2 hrs	$2 \leq x \leq 6$ Mpsi
		28 days	$2 \leq x \leq 6$ Mpsi
Set Time Penetrometer Method	ASTM C403	Initial set	≥ 15 min
		Final set	15-90 min
Slump	ASTM C143	Within 5 min of added water	3-9 in. if > 9 in., perform slump flow
Slump Flow	ASTM C1611	Within 5 min of added water	≥ 9 in.
Tier 2 Test Requirements			
Test Property	Test Method	Test Age	Test Criteria
Length Change	ASTM C157	28 days Stored in air	$-0.04\% \leq x \leq +0.03\%$ at 28 days
		28 days Stored in water	Continue testing and report length change until 64 weeks
Coefficient of Thermal Expansion	ASTM C531	-	≤ 7 (in./in./°F $\times 10^{-6}$)
Shrinkage Potential	ASTM C1581	14 days	Record microstrain but no pass/fail limits at this time
		28 days	Record microstrain and fail if any ring cracked

Table 18. Comparison of former test criteria and new test criteria.

Test Property	Test Method	Test Age	Former Criteria	New Criteria
Compressive Strength	ASTM C39	2 hrs	$\geq 3,000$ psi	$\geq 2,500$ psi
		3 hr	No requirement	$\geq 3,000$ psi
		1 day	$\geq 5,000$ psi	$\geq 4,000$ psi
		7 days	$\geq 5,000$ psi	No change
		28 days	$\geq 5,000$ psi	No change
Flexural Strength	ASTM C78	2 hr	≥ 350 psi	No change
		7 days	≥ 600 psi	≥ 500 psi
		28 days	≥ 600 psi	No change
Bond Strength (RS/RS)	ASTM C882	1 day	$\geq 1,000$ psi	No change
		7 days	No requirement	$\geq 1,250$ psi
Bond Strength (PCC/RS)		1 day	≥ 1000 psi	No change
		7 days	No requirement	$\geq 1,250$ psi
Modulus of Elasticity	ASTM C469	2 hr	$2 \leq x \leq 6$ Mpsi	No change
		28 days	$2 \leq x \leq 6$ Mpsi	No change
Time of Setting Vicat Method	ASTM C191	Initial set	≥ 15 min	Remove
		Final set	25 - 35 min	Remove
Set Time Penetrometer Method	ASTM C403	Initial set	No requirement	≥ 15 min
		Final set	No requirement	15-90 min
Slump	ASTM C143	Within 5 min of added water	Record slump	3-9 in. if > 9 in., perform slump flow
Slump Flow	ASTM C1611	Within 5 min of added water	No requirement	≥ 9 in.
Length Change	ASTM C157	Stored in air	$-0.04\% \leq x \leq +0.03\%$ at 28 days	No change
		Stored in water		
Coefficient of Thermal Expansion	ASTM C531	-	≤ 12 (in./in./°F $\times 10^{-6}$)	≤ 7 (in./in./°F $\times 10^{-6}$)
Shrinkage Potential	ASTM C1581	14 days	≤ 40 $\mu\epsilon$	Record microstrain but no pass/fail limits
		28 days	No cracking	Record microstrain and fail if cracking

6.3 Summary of approved products

The products shown in Table 19 are recommended approved products based on standards set forth in the updated test protocol. Note that the four products tested in 2017 (Rapid Set Concrete Mix, Rapid Set DOT Repair Mix, MasterEmaco T545HT, and MasterEmaco T545) were tested and approved for only the tier 1 properties. Tier 2 testing is scheduled for 2018.

Table 19. Recommended approved products based on new test protocol.

Product Name	Manufacturer	Year Tested
SikaQuick 2500	Sika Corp.	2013
Ulti-Pave3	Buzzi-Unicem USA Inc.	2014
ProSpec Premium Patch 200	H.B. Fuller Construction Products Inc.	2015
Rapid Set Mortar Mix	CTS Cement Corp.	2015
HD 50	Dayton Superior Corp.	2015
FasTrac 246 Concrete	Western Material and Design, LLC	2016
Rapid Set Concrete Mix	CTS Cement Corp.	2017
Rapid Set DOT Repair Mix	CTS Cement Corp.	2017
MasterEmaco T545HT	BASF	2017
MasterEmaco T545	BASF	2017

6.4 Other testing recommendations

Limited information is available in the area of durability and long-term performance of rapid-repair materials. The following are recommendations for future research to evaluate the durability of these materials.

- The ASTM C672 (2012b) scaling test was a recommended test in the previous test protocol but was not performed on any of the rapid-repair materials tested from 2013-2017. This test method is still recommended for products that may be used for repairs in harsh environments where chloride exposure or drying and wetting can take place.
- The ASTM C666 (ASTM 2015b) freeze-thaw test was a recommended test in the previous test protocol but was integrated into Tier 2 testing for several products. As reported in the results, all products fell below a 60 percent dynamic modulus at 300 cycles as suggested in the

standard method. It is recommended that new test procedures be developed for freeze-thaw resistance methods better suited for rapid-repair materials.

- Further investigation is recommended to determine a suitable long-term limit criteria for rapid-repair materials based on long-term results from length change testing (i.e., conduct full 64-week test as per ASTM C157; 2014a).
- Limitations of the ASTM C1581 (2016c) shrinkage ring test include the inability to measure very early age shrinkage and the inability to measure the effects of expansion. It is recommended that new testing procedures be developed and standardized to assess the volumetric shrinkage and restrained stress development.

References

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- _____. 2012b. *Standard test method for scaling resistance of concrete surfaces exposed to de-icing chemicals*. Designation: C672-12. West Conshohocken, PA: ASTM International.
- _____. 2013a. *Standard test method for bond strength of epoxy-resin systems used with concrete by slant shear*. Designation: C882-13. West Conshohocken, PA: ASTM International.
- _____. 2013b. *Standard test method for packaged, dry, rapid-hardening cementitious materials for concrete repair*. Designation: C928-13. West Conshohocken, PA: ASTM International.
- _____. 2013c. *Standard test method for time of setting of hydraulic cement by vicat needle*. Designation: C191-13. West Conshohocken, PA: ASTM International.
- _____. 2014a. *Standard test method for length change of hardened hydraulic-cement mortar and concrete*. Designation: C157-14. West Conshohocken, PA: ASTM International.
- _____. 2014b. *Standard test method for slump flow of self-consolidating concrete*. Designation: C1611-14. West Conshohocken, PA: ASTM International.
- _____. 2014c. *Standard test method for static modulus of elasticity and Poisson's ratio of concrete in compression*. Designation: C469-14. West Conshohocken, PA: ASTM International.
- _____. 2015a. *Standard test method for compressive strength of cylindrical concrete specimens*. Designation C39-15. West Conshohocken, PA: ASTM International.
- _____. 2015b. *Standard test method for resistance of concrete to rapid freezing and thawing*. Designation: C666-15. West Conshohocken, PA: ASTM International.
- _____. 2015c. *Standard test method for slump of hydraulic cement concrete*. Designation: C143-15. West Conshohocken, PA: ASTM International.
- _____. 2016a. *Standard test method for compressive strength of hydraulic cement mortars using 2-in. cube specimens*. Designation: C109-16. West Conshohocken, PA: ASTM International.
- _____. 2016b. *Standard test methods for concrete aggregates*. Designation: C33-16. West Conshohocken, PA: ASTM International.

- _____. 2016c. *Standard test method for determining age at cracking and induced tensile stress characteristics of mortar and concrete under restrained shrinkage*. Designation: C1581-16. West Conshohocken, PA: ASTM International.
- _____. 2016d. *Standard test method for flexural strength of concrete (using simple beam with third-point loading)*. Designation: C78-16. West Conshohocken, PA: ASTM International.
- _____. 2016e. *Standard test method for making and curing concrete test specimens in the laboratory*. Designation: C192-16. West Conshohocken, PA: ASTM International.
- _____. 2016f. *Standard test method for time of setting of concrete mixtures by penetration resistance*. Designation: C403/403M-16. West Conshohocken, PA: ASTM International.
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Appendix A: Laboratory Testing Data Sheets

A.1 FY13 Rigid-Repair Material Evaluation Reports

See Tables A1 through A6.

Table A1. Pavement SL.

Rigid Repair Material Evaluation Report								
Product Name:		Pavement SL		Material Description:		cementitious based		
Manufacturer's Information		Name		CeraTech Inc.				
		Address		1500 N. Beauregard St. Suite 320		Alexandria, VA 22311		
		Phone		888-341-2600		Website www.ceratechinc.com		
Testing Results								
Date Received at Laboratory		April 2013		Lot Number		N/A (24 units purchased)		
Date Tested	Requirement 1		May 2013		Evaluated by		ERDC-MTC	
	Requirement 2		December 2013		Overall Result (Pass/Fail)		Requirement 1 F Requirement 2 F	
	Recommended		December 2013		Repair Classification		-----	
Testing Summary								
All tests conducted at 73°F unless specified otherwise								
Test Completed		Testing Specifics		Criteria		Mfg. Test Result Lab Test Result Pass/Fail		
Compressive Strength	ASTM C39	-		≥ 3,000 psi @ 2 hrs.		> 2,500 4,740 P		
		-		≥ 5,000 psi @ 1 day		> 5,000 6,800 P		
		-		≥ 5,000 psi @ 7 days		> 6,000 9,970 P		
		-		≥ 5,000 psi @ 28 days		> 7,000 10,590 P		
Flexural Strength	ASTM C78	-		≥ 350 psi @ 2 hrs.		> 850 (1 day) 645 P		
		-		≥ 600 psi @ 7 days		> 875 790 P		
		-		≥ 600 psi @ 28 days		> 900 2,340 P		
Bond Strength	ASTM C882	Repair Material to Repair Material		≥ 1,000 psi @ 1 day		> 1,500 1,610 P		
		Repair Material to Ordinary PCC		≥ 1,000 psi @ 1 day		> 1,500 1,600 P		
Modulus of Elasticity	ASTM C469	-		2 ≤ x ≤ 6 Mpsi @ 2 hrs.		N/A 3.60 P		
		-		2 ≤ x ≤ 6 Mpsi @ 28 days		5.20 6.20 F		
Time of Set	ASTM C191	-		Initial set: ≥ 15 min.		15 - 20 20 P		
		-		Final set: 25 - 35 min.		25 - 35 40 F		
Slump	ASTM C143	Within 5 min of added water		≥ 3 in.		N/A 2.75 F		
Length Change	ASTM C157	Stored in air		- 0.04% ≤ x ≤ +0.03% at 28 days		-0.03 0.009 P		
		Stored in water				-0.04 0.047 F		
Coeff. of Thermal Expansion	ASTM C531	Begin test @ 7 days		≤ 12·10 ⁻⁶ °F ⁻¹		5.83 4.40 P		
Shrinkage Potential	ASTM C1581	-		≤ 40 με @ 14 days		N/A 22 P		
		-		No cracking @ 28 days		N/A No cracking (3 rings) P		
Freeze-Thaw Resistance	ASTM C666	Procedure A, based on 300 cycles		No current criteria		98 @ 300 cycles 4 @ 47 cycles -		
Testing Notes and Observations								
Plastic bag units placed in sealed buckets were provided by manufacturer.								
Additional compressive strength results (psi) - 3 hr: 5,070								
Additional bond strength results (psi) - 7 days to Ordinary PCC: 1,990, 7 days to Repair Material: 2,400								
ASTM C403 results - initial set: 24 min, final set: 35 min								
Additional material ordered for C1581 testing; material from lot number SL-100CS-C used								
*Material did not pass all Requirement 1 testing; however, testing was continued since values were close to criteria limits.								
Fails minimum criteria necessary for next highest approval rating: Length Change								

Table A2. DOT Line.

Rigid Repair Material Evaluation Report							
Product Name:		DOT Line		Material Description:		cementitious based	
Manufacturer's Information		Name		CeraTech Inc.			
		Address		1500 N. Beauregard St. Suite 320		Alexandria, VA 22311	
		Phone		800-581-8397		Website www.ceratechinc.com	
Testing Results							
Date Received at Laboratory		April 2013		Lot Number		DL-342-HH (24 units purchased)	
Date Tested	Requirement 1		April 2013		Evaluated by		ERDC-MTC
	Requirement 2		December 2013		Overall Result (Pass/Fail)		Requirement 1 P*
	Recommended		December 2013		Repair Classification		Requirement 2 F**
Permanent - Primary Runways & Taxiways							
Testing Summary							
All tests conducted at 73°F unless specified otherwise							
Test Completed		Testing Specifics		Criteria		Mfg. Test Result	Lab Test Result
Compressive Strength	AS TM C 39	-		≥ 3,000 psi @ 2 hrs.		> 2,500	3,920
		-		≥ 5,000 psi @ 1 day		> 5,000	6,420
		-		≥ 5,000 psi @ 7 days		> 7,000	8,290
		-		≥ 5,000 psi @ 28 days		> 9,000	10,170
Flexural Strength	AS TM C 78	-		≥ 350 psi @ 2 hrs.		> 600 (1 day)	620
		-		≥ 600 psi @ 7 days		> 900	985
		-		≥ 600 psi @ 28 days		> 1,200	1,095
Bond Strength	AS TM C 882	Repair Material to Repair Material		≥ 1,000 psi @ 1 day		> 1,500	2,220
		Repair Material to Ordinary PCC		≥ 1,000 psi @ 1 day		> 1,500	2,030
Modulus of Elasticity	AS TM C 469	-		2 ≤ x ≤ 6 Mpsi @ 2 hrs.		N/A	2.95
		-		2 ≤ x ≤ 6 Mpsi @ 28 days		5.20	5.35
Time of Set	AS TM C 191	-		Initial set: ≥ 15 min.		20-25	33
		-		Final set: 25 - 35 min.		30-40	44
Slump	AS TM C 143	Within 5 min of added water		≥ 3 in.		N/A	5
Length Change	AS TM C 157	Stored in air		- 0.04% ≤ x ≤ +0.03% at 28 days		-0.052	0.032
		Stored in water				-0.041	0.028
Coeff. of Thermal Expansion	ASTM C 531	Begin test @ 7 days		≤ 12·10 ⁻⁶ °F ⁻¹		13.3 (TxDOT)	5.5
Shrinkage Potential	ASTM C 1581	-		≤ 40 µε @ 14 days		N/A	19
		-		No cracking @ 28 days		N/A	No Cracking (3 rings)
Freeze-Thaw Resistance	AS TM C 666	Procedure A, based on 300 cycles		No current criteria		98 @ 300 cycles	27 @ 132 cycles
Testing Notes and Observations							
Specimens air cured at laboratory environment (approximately 70°F and 50% RH) after demolding unless specific curing procedure required by individual ASTM standards							
Additional compressive strength results (psi) - 3 hr: 5,080							
Additional bond strength results (psi) - 7 days to Ordinary PCC: 2,420, 7 days to Repair Material: 3,030							
ASTM C 403 results - initial set: 38 min, final set: 40 min							
Additional material ordered for C1581 testing; material from lot number DL-342CS-AA used							
*Material did not pass all Requirement 1 testing; however, testing was continued since values were close to criteria limits.							
**Material failed Requirement 2 testing for excessive length change.							

Table A3. SikaQuick 2500.

Rigid Repair Material Evaluation Report									
Product Name:		SikaQuick 2500		Material Description:		blended portland cements			
Manufacturer's Information		Name		Sika Corporation U.S.					
		Address		30800 Stephenson Highway		Madison Heights		Michigan 48071	
		Phone		248-577-0020		Website		www.usa.sika.com	
Testing Results									
Date Received at Laboratory		April 2013		Lot Number		A0914121J (24 units purchased)		Aggregate Extension?	
Date Tested	Requirement 1		April 2013		Evaluated by		ERDC-MTC		Vicksburg, MS 39180
	Requirement 2		December 2013		Overall Result (Pass/Fail)		Requirement 1		P
	Recommended		December 2013				Requirement 2		P*
Testing Summary									
Test Completed		Testing Specifics		Criteria		Mfg. Test Result		Lab Test Result	
Compressive Strength	ASTM C39	-		$\geq 3,000$ psi @ 2 hrs.		4000 (C109)		3,660	
		-		$\geq 5,000$ psi @ 1 day		5700 (C109)		5,280	
		-		$\geq 5,000$ psi @ 7 days		7500 (C109)		7,230	
		-		$\geq 5,000$ psi @ 28 days		8500 (C109)		8,090	
Flexural Strength	ASTM C78	-		≥ 350 psi @ 2 hrs.		800 (1 day)		610	
		-		≥ 600 psi @ 7 days		1,000		625	
		-		≥ 600 psi @ 28 days		1,100		680	
Bond Strength	ASTM C882	Repair Material to Repair Material		$\geq 1,000$ psi @ 1 day		1,800		1,250	
		Repair Material to Ordinary PCC		$\geq 1,000$ psi @ 1 day		1,800		1,170	
Modulus of Elasticity	ASTM C469	-		$2 \leq x \leq 6$ Mpsi @ 2 hrs.		N/A		4.30	
		-		$2 \leq x \leq 6$ Mpsi @ 28 days		4.60		5.40	
Time of Set	ASTM C191	-		Initial set: ≥ 15 min.		12 - 24 (C266)		21	
		-		Final set: 25 - 35 min.		20 - 40 (C266)		44	
Slump	ASTM C143	Within 5 min of added water		≥ 3 in.		Not tested		10	
Length Change	ASTM C157	Stored in air		$-0.04\% \leq x \leq +0.03\%$ at 28 days		Not tested		-0.006	
		Stored in water				Not tested		0.019	
Coeff. of Thermal Expansion	ASTM C 531	Begin test @ 7 days		$\leq 12 \cdot 10^{-6}$ °F ⁻¹		2.52		5.0	
Shrinkage Potential	ASTM C1581	-		≤ 40 $\mu\epsilon$ @ 14 days		Not tested		NA	
		-		No cracking @ 28 days		Not tested		NA	
Freeze-Thaw Resistance	ASTM C666	Procedure A, based on 300 cycles		No current criteria		98 @ 300 cycles		6 @ 36 cycles	
Aggregate Extension Notes Per Unit									
Extension Allowed By Manufacturer?		Y	Supplier	Green Brothers Sand and Gravel			Pass ASTM C33?		Y
Maximum Extension Allowed (% Volume)		40-50	Quarry	Crystal Springs, MS			ASTM C128 Test Results	BSG	2.51
Product Yield (ft ³)		0.43	Material	#8 Paa Gravel				Abs	2.9%
Extension Used (% Volume)		50	Aggregate Volume (ft ³)		0.22	Nominal Weight Batched (lb)		33.67	
Moisture Corrections Applied Daily to Aggregate with ASTM D4959									
Testing Notes and Observations									
Specimens air cured at laboratory environment (approximately 70°F and 50% RH) after demolding unless specific curing procedure required by individual ASTM standards									
Additional compressive strength results (psi) - 3 hr: 3,960									
Additional bond strength results (psi) - 7 days to Ordinary PCC: 1,410, 7 days to Repair Material: 1,840									
ASTM C403 results - initial set: 21 min, final set: 46 min									
Shrinkage potential testing was conducted; but due to potential equipment error results could not be validated.									

Table A4. 10-60 Repair Mortar.

Rigid Repair Material Evaluation Report										
Product Name:		10-60 Repair Mortar		Material Description:		portland cement and cementitious based				
Manufacturer's Information		Name		BASF Chemical Corporation						
		Address		889 Valley Park Drive		Shakopee, MN 55379				
		Phone		800-243-6739		Website		http://www.buildingsystems.basf.com		
Testing Results:										
Date Received at Laboratory		May 2013		Lot Number		2J2347251 (24 units purchased)		Aggregate Extension?		Y
Date Tested	Requirement 1		June 2013		Evaluated by		ERDC-MTC		Vicksburg, MS 39180	
	Requirement 2		November 2013		Overall Result (Pass/Fail)		Requirement 1		P*	Requirement 2
	Recommended		-		Repair Classification				---	
Testing Summary										
Test Completed		Testing Specifics		Criteria		Mfg. Test Result		Lab Test Result		Pass/Fail
Compressive Strength	ASTM C39	-		$\geq 3,000 \text{ psi @ 2 hrs.}$		> 2,500		2,950		F
		-		$\geq 5,000 \text{ psi @ 1 day}$		> 5,000		4,590		F
		-		$\geq 5,000 \text{ psi @ 7 days}$		> 7,000		6,170		P
		-		$\geq 5,000 \text{ psi @ 28 days}$		> 9,000		6,290		P
Flexural Strength	ASTM C78	-		$\geq 350 \text{ psi @ 2 hrs.}$		N/A		470		P
		-		$\geq 600 \text{ psi @ 7 days}$		> 900		710		P
		-		$\geq 600 \text{ psi @ 28 days}$		> 1,200		690		P
Bond Strength	ASTM C882	Repair Material to Repair Material		$\geq 1,000 \text{ psi @ 1 day}$		> 1,500		1,530		P
		Repair Material to Ordinary PCC		$\geq 1,000 \text{ psi @ 1 day}$		> 2,000		1,350		P
Modulus of Elasticity	ASTM C469	-		$2 \leq x \leq 6 \text{ Mpsi @ 2 hrs.}$		> 4.00		4.95		P
		-		$2 \leq x \leq 6 \text{ Mpsi @ 28 days}$		5.20		6.65		F
Time of Set	ASTM C191	-		Initial set: $\geq 15 \text{ min.}$		20-25 min.		25		P
		-		Final set: 25 - 35 min.		30-40 min.		30		P
Slump	ASTM C143	Within 5 min of added water		$\geq 3 \text{ in.}$		N/A		5		P
Length Change	ASTM C157	Stored in air		$- 0.04\% \leq x \leq +0.03\% \text{ at 28 days}$		0.06 (C 596)		-0.009		P
		Stored in water				N/A		0.031		F
Coeff. of Thermal Expansion	ASTM C 531	Begin test @ 7 days		$\leq 12 \cdot 10^{-6} \text{ } ^\circ\text{F}^{-1}$		N/A		5.1		P
Shrinkage Potential	ASTM C1581	-		$\leq 40 \mu\text{s @ 14 days}$		N/A		cracked at 10 days		F
		-		No cracking @ 28 days		N/A				F
Freeze-Thaw Resistance	ASTM C666	Procedure A, based on 300 cycles		No current criteria		100 @ 200 cycles		27 @ 85 cycles		-
Aggregate Extension Notes Per Unit										
Extension Allowed By Manufacturer?		Y	Supplier	Green Brothers			Pass ASTM C33?		Y	
Maximum Extension Allowed (%_{volume})		50	Quarry	Crystal Springs			ASTM C128 Test Results		BSG	
Product Yield (ft³)		0.43	Material	3/8 Chert Pea Gravel			Abs		2.9	
Extension Used (%_{volume})		50	Aggregate Volume (ft³)		0.22	Nominal Weight Batched (lb)		33.67		
Moisture Corrections Applied Daily to Aggregate with ASTM D4959										
Testing Notes and Observations										
Specimens air cured at laboratory environment (approximately 70°F and 50% RH) after demolding unless specific curing procedure required by individual ASTM standards										
Additional compressive strength results (psi) - 3 hr: 3,520										
Additional bond strength results (psi) - 7 days to Ordinary PCC: 1,930, 7 days to Repair Material: 1,960										
ASTM C403 results- initial set: 43 min, final set: 47 min										
Will require between 2-3 hrs of cure time to generate minimum opening strength required.										
*Material did not pass all Requirement 1 testing; however, testing was continued since values were close to criteria limits.										
Fails minimum criteria necessary for next highest approval rating: 2 & 24 hrs compressive strength for permanent runway/temporary crater repairs, shrinkage potential										

Table A5. Pavepatch 3000.

Rigid Repair Material Evaluation Report								
Product Name:		Pavepatch 3000		Material Description:		cementitious, latex modified		
Manufacturer's Information		Name		Dayton Superior				
		Address		1125 Byers Road		Miamisburg, OH 45342		
		Phone		800-745-3700		Website www.daytonsuperior.com		
Testing Results								
Date Received at Laboratory		April 2013		Lot Number		A20427073B (24 units purchased)		
Date Tested	Requirement 1		April 2013		Evaluated by		ERDC-MTC	
	Requirement 2		December 2013		Overall Result (Pass/Fail)		Requirement 1 P* Requirement 2 F	
Testing Summary								
Test Completed		Testing Specifics		Criteria	Mfg. Test Result	Lab Test Result	Pass/Fail	
Compressive Strength	ASTM C39	-		$\geq 3,000$ psi @ 2 hrs.	4,000 (C109)	3,170	P	
		-		$\geq 5,000$ psi @ 1 day	5,500 (C109)	5,190	P	
		-		$\geq 5,000$ psi @ 7 days	6,100 (C109)	6,290	P	
		-		$\geq 5,000$ psi @ 28 days	8,000 (C109)	7,100	P	
Flexural Strength	ASTM C78	-		≥ 350 psi @ 2 hrs.	800	490	P	
		-		≥ 600 psi @ 7 days	800	530	F	
		-		≥ 600 psi @ 28 days	800	790	P	
Bond Strength	ASTM C882	Repair Material to Repair Material		$\geq 1,000$ psi @ 1 day	> 1,000	1,260	P	
		Repair Material to Ordinary PCC		$\geq 1,000$ psi @ 1 day	> 1,000	1,030	P	
Modulus of Elasticity	ASTM C469	-		$2 \leq x \leq 6$ Mpsi @ 2 hrs.	Not tested	5.05	P	
		-		$2 \leq x \leq 6$ Mpsi @ 28 days	Not tested	4.85	P	
Time of Set	ASTM C191	-		Initial set: ≥ 15 min.	15 - 20	26	P	
		-		Final set: 25 - 35 min.	25 - 30	60	F	
Slump	ASTM C143	Within 5 min of added water		≥ 3 in.	Not tested	10	P	
Length Change	ASTM C157	Stored in air		$-0.04\% \leq x \leq +0.03\%$ at 28 days	0.02%	-0.037	P	
		Stored in water			0.09%	0.012	P	
Coeff. of Thermal Expansion	ASTM C531	Begin test @ 7 days		$\leq 12 \cdot 10^{-6}$ °F ⁻¹	Not tested	6.2	P	
Shrinkage Potential	ASTM C1581	-		≤ 40 μ e @ 14 days	Not tested	Cracked @ 1.5 days (3 rings)	F	
		-		No cracking @ 28 days	Not tested		F	
Freeze-Thaw Resistance	ASTM C666	Procedure A, based on 300 cycles		No current criteria	100 @ 200 cycles**	36 @ 189 cycles	-	
Aggregate Extension Notes								
Extension Allowed By Manufacturer?		Y	Supplier	Green Brothers Sand and Gravel		Pass ASTM C33?		
Maximum Extension Allowed (% _{Volume})		60	Quarry	Crystal Springs		ASTM C128	BSG	
Product Yield (ft ³)		0.41	Material	#8 Pea Gravel		Test Results	Abs	
Extension Used (% _{Volume})		50	Aggregate Volume (ft ³)		0.21	Nominal Weight Batched (lb)		
Moisture Corrections Applied Daily to Aggregate with ASTM D4959								
Testing Notes and Observations								
Additional compressive strength results (psi) - 3 hr: 3,905								
Additional bond strength results (psi) - 7 days to Ordinary PCC 1,470; 7 days to Repair Material: 1,900								
ASTM C403 results- initial set: 38 min, final set: 58 min								
Additional material ordered for Requirement 2 testing, 2 months shelf life available on original material purchased; material from lot number A30926079B used								
**Manufacturer's reported freeze-thaw resistance test report based on a modified test standard in sodium chloride solution								
*Material did not pass all Requirement 1 testing; however, testing was continued since values were close to criteria limits.								
Fails minimum criteria necessary for next highest approval rating: Shrinkage potential								

Table A6. Phoscrete 4 Seasons.

Rigid Repair Material Evaluation Report											
Product Name:		Phoscrete 4 Seasons		Material Description:		magnesium phosphate based					
Manufacturer's Information		Name		Phoscrete Corp.							
		Address		7777 Glades Road, Suite 200		Boca Raton, FL 33434					
		Phone		561-504-7036		Web site www.phoscrete.com					
Testing Results											
Date Received at Laboratory		May 2013		Lot Number		323312103 (20 units purchased)					
Date Tested	Requirement 1		June 2013		Evaluated by		ERDC-MTC				
	Requirement 2		Dec-13		Overall Result (Pass/Fail)		Requirement 1 F Requirement 2 F				
Testing Summary											
Test Completed		Testing Specifics		Criteria		Mfg. Test Result		Lab Test Result		Pass/Fail	
Compressive Strength	ASTM C39	-		$\geq 3,000$ psi @ 2 hrs.		> 2,500		4,210		P	
		-		$\geq 5,000$ psi @ 1 day		> 5,000		5,030		P	
		-		$\geq 5,000$ psi @ 7 days		> 7,000		5,690		P	
		-		$\geq 5,000$ psi @ 28 days		> 9,000		5,700		P	
Flexural Strength	ASTM C78	-		≥ 350 psi @ 2 hrs.		N/A		495		P	
		-		≥ 600 psi @ 7 days		> 900		560		F	
		-		≥ 600 psi @ 28 days		> 1,200		545		F	
Bond Strength	ASTM C882	Repair Material to Repair Material		$\geq 1,000$ psi @ 1 day		> 1,500		2,350		P	
		Repair Material to Ordinary PCC		$\geq 1,000$ psi @ 1 day		> 2,000		1,080		P	
Modulus of Elasticity	ASTM C469	-		$2 \leq x \leq 6$ Mpsi @ 2 hrs.		N/A		2.20		P	
		-		$2 \leq x \leq 6$ Mpsi @ 28 days		5.20		3.70		P	
Time of Set	ASTM C191	-		Initial set: ≥ 15 min.		20-25 min.		20		P	
		-		Final set: 25 - 35 min.		30-40 min.		25		P	
Slump	ASTM C143	Within 5 min of added water		≥ 3 in.		N/A		6		P	
Length Change	ASTM C157	Stored in air		$-0.04\% \leq x \leq +0.03\%$ at 28 days		N/A		-0.065		F	
		Stored in water				N/A		0.000		P	
Coeff. of Thermal Expansion	ASTM C 531	Begin test @ 7 days		$\leq 12 \cdot 10^{-6} \text{ } ^\circ\text{F}^{-1}$		2.52		2.4		P	
Shrinkage Potential	ASTM C1581	-		$\leq 40 \mu\epsilon$ @ 14 days		N/A		50		-	
		-		No cracking @ 28 days		N/A		No Cracking (3 rings)		P	
Freeze-Thaw Resistance	ASTM C666	Procedure A, based on 300 cycles		No current criteria		N/A		64 @ 200 cycles		-	
Testing Notes and Observations											
Additional compressive strength results (psi) - 3 hr: 5,080											
Additional bond strength results (psi) - 7 days to Ordinary PCC: 1,160 7 days to Repair Material: 2,570											
ASTM C403 results- initial set: 6 min, final set: 8 min											
Requirement 1 cast specimens air cured at laboratory environment (approximately 70°F and 50% RH) after demolding unless ASTM specific curing procedure required											
Additional material ordered for ASTM C1581 testing; material from lot number 402201 (powder)/ 340222001 (liquid) was used											
*Material did not pass all Requirement 1 testing; however, testing was continued since values were close to criteria limits.											
Fails minimum criteria necessary for next highest approval rating: 7 and 28 day flexural strength for use in permanent repairs, length change in air storage											

A.2 FY14 Rigid-Repair Material Evaluation Reports

See Tables A7 through A11.

Table A7. Ulti-Pave3.

Rigid Repair Material Evaluation Report											
Product Name:		Ulti-Pave3			Material Description:		Calcium Sulfoaluminate				
Manufacturer's Information		Name		Buzzi Unicem USA Inc							
		Address		100 Brodhead Road Suite, 230			Bethlehem, PA		18017		
		Phone		610 882 5013			Website		buzziunicemusa.com		
Testing Results											
Date Received at Laboratory		November 2013		Lot Number		A1011132J (24 bags)		Aggregate Extension?		N	
Date Tested	Requirement 1		February 2014		Evaluated by		ERDC-MTC		Vicksburg, MS 39180		
	Requirement 2		October 2014		Overall Result (Pass/Fail)		Requirement 1		P*	Requirement 2	P**
	Recommended		October 2014		Repair Classification		Primary Runways and Taxiways				
Testing Summary											
All tests conducted at 73°F unless specified otherwise											
Test Completed		Testing Specifics			Criteria		Mfg. Test Result		Lab Test Result		Pass/Fail
Compressive Strength	ASTM C39	-			$\geq 3,000$ psi @ 2 hrs.		2,000		4,630		P
		-			$\geq 5,000$ psi @ 1 day		5,500		7,880		P
		-			$\geq 5,000$ psi @ 7 days		Not tested		8,740		P
		-			$\geq 5,000$ psi @ 28 days		7,500		9,490		P
Flexural Strength	ASTM C78	-			≥ 350 psi @ 2 hrs.		Not tested		465		P
		-			≥ 600 psi @ 7 days		Not tested		790		P
Bond Strength	ASTM C882	-			≥ 600 psi @ 28 days		Not tested		875		P
		Repair Material to Repair Material			$\geq 1,000$ psi @ 1 day		Not tested		1,720		P
Modulus of Elasticity	ASTM C469	Repair Material to Ordinary PCC			$\geq 1,000$ psi @ 1 day		Not tested		1,390		P
		-			$2 \leq x \leq 6$ Mpsi @ 2 hrs.		Not tested		2.50		P
Time of Set	ASTM C191	-			$2 \leq x \leq 6$ Mpsi @ 28 days		Not tested		4.75		P
		-			Initial set: ≥ 15 min.		Not tested		39		P
		-			Final set: 25 - 35 min.		Not tested		46		F
Slump	ASTM C143	Within 5 min of added water			≥ 3 in.		Not tested		9		P
Length Change	ASTM C157	Stored in air			$-0.04\% \leq x \leq +0.03\%$ at 28 days		-0.08		-0.015		P
		Stored in water					Not tested		0.015		P
Coeff. of Thermal Expansion	ASTM C 531	Begin test @ 7 days			$\leq 12 \cdot 10^{-6}$ °F ⁻¹		Not tested		5.2		P
Shrinkage Potential	ASTM C1581	-			≤ 40 $\mu\epsilon$ @ 14 days		Not tested		49		F
		-			No cracking @ 28 days		Not tested		none on 3 rings		P
Freeze-Thaw Resistance	ASTM C666	Procedure A, DF based on 300 cycles			No current criteria		Not tested		20 @ 118 cycles		-
Aggregate Extension Notes Per Unit											
Extension Allowed By Manufacturer?		N	Supplier	-			Pass ASTM C33?		-		
Maximum Extension Allowed (% _{Volume})		-	Quarry	-			ASTM C128 Test Results		BSG	-	
Product Yield (ft ³)		-	Material	-					Abs	-	
Extension Used (% _{Volume})		-	Aggregate Volume (ft ³)			-	Nominal Weight Batched (lb)		-		
Moisture Corrections Applied Daily to Aggregate with ASTM D4959											
Testing Notes and Observations											
Specimens air cured at laboratory environment (approximately 70°F and 50% RH) after demolding unless specific curing procedure required by individual ASTM standards											
Additional compressive strength results (psi) - 3 hr: 5,530											
Additional bond strength results (psi) - 7 days to Ordinary PCC: 1,740, 7 days to Repair Material: 2,360											
ASTM C403 results - initial set: 25 min. final set: 45 min.											

Table A8. Fast Set DOT Concrete Mix.

Rigid Repair Material Evaluation Report										
Product Name:		Fast Set DOT Concrete Mix (Commercial Grade)			Material Description:		Portland cement based			
Manufacturer's Information		Name	Quikrete Companies							
		Address	One Securities Centre			3490 Piedmont Rd NE Suite, 1300		Atlanta, GA 30305		
		Phone	404 634 9100		Website		quikrete.com			
Testing Results										
Date Received at Laboratory		March 2014		Lot Number		1015419 (18 bags)		Aggregate Extension?		N
Date Tested	Requirement 1	May 2014		Evaluated by		ERDC-MTC		Vicksburg, MS 39180		
	Requirement 2	July 2014		Overall Result (Pass/Fail)		Requirement 1		P*	Requirement 2	P**
	Recommended	July 2014		Repair Classification		Permanent - Primary Runways & Taxiways				
Testing Summary										
All tests conducted at 73°F unless specified otherwise										
Test Completed		Testing Specifics		Criteria		Mfg. Test Result		Lab Test Result		Pass/Fail
Compressive Strength	ASTM C39	-		≥ 3,000 psi @ 2 hrs.		3,000 (1.5 hr)		3,340		P
		-		≥ 5,000 psi @ 1 day		6,500		6,050		P
		-		≥ 5,000 psi @ 7 days		8,000		5,190		P
Flexural Strength	ASTM C78	-		≥ 5,000 psi @ 28 days		10,000		5,460		P
		-		≥ 350 psi @ 2 hrs.		Not tested		560		P
		-		≥ 600 psi @ 7 days		Not tested		805		P
Bond Strength	ASTM C882	-		≥ 600 psi @ 28 days		Not tested		840		P
		Repair Material to Repair Material		≥ 1,000 psi @ 1 day		1,200		1,430		P
		Repair Material to Ordinary PCC		≥ 1,000 psi @ 1 day		Not tested		1,600		P
Modulus of Elasticity	ASTM C469	-		2 ≤ x ≤ 6 Mpsi @ 2 hrs.		Not tested		1.95		F
		-		2 ≤ x ≤ 6 Mpsi @ 28 days		Not tested		3.75		P
		-		Initial set ≥ 15 min.		10 - 20		55		P
Time of Set	ASTM C191	-		Final set: 25 - 35 min.		20 - 45		61		F
Slump	ASTM C143	Within 5 min of added water		≥ 3 in.		3 to 4		4		P
Length Change	ASTM C157	Stored in air		- 0.04% ≤ x ≤ +0.03% at 28 days		-0.052		-0.01		P
		Stored in water				0.020		0.03		P
Coeff. of Thermal Expansion	ASTM C 531	Begin test @ 7 days		≤ 12·10 ⁻⁶ °F ⁻¹		Not tested		5.3		P
Shrinkage Potential	ASTM C1581	-		≤ 40 µε @ 14 days		Not tested		54		F
		-		No cracking @ 28 days		Not tested		None on 3 rings		P
Freeze-Thaw Resistance	ASTM C666	Procedure A, based on 300 cycles		No current criteria		78		41 @ 44 cycles		-
Aggregate Extension Notes Per Unit										
Extension Allowed By Manufacturer?		N	Supplier	-			Pass ASTM C33?		-	
Maximum Extension Allowed (% _{V_{Volume}})		-	Quarry	-			ASTM C128		BSG	-
Product Yield (ft ³)		0.57	Material	-			Test Results		Abs	-
Extension Used (% _{V_{Volume}})		-	Aggregate Volume (ft ³)		-		Nominal Weight Batched (lb)		-	
Moisture Corrections Applied Daily to Aggregate with ASTM D4959										
Testing Notes and Observations										
Specimens air cured at laboratory environment (approximately 70°F and 50% RH) after demolding unless specific curing procedure required by individual ASTM standards										
Additional compressive strength results (psi) - 3 hr: 3,970										
Additional bond strength results (psi) - 7 days to Ordinary PCC: 2,133, 7 days to Repair Material: 2,380										
ASTM C403 results (min)- initial set: 50, final set: 55										
Results shown are from the pre-extended concrete version of material										
*Material did not pass all Requirement 1 testing; however, testing was continued since values were close to criteria limits.										
**Material did not pass all Requirement 2 testing; however, testing was continued since values were close to criteria limits.										
Fails minimum criteria necessary for next highest approval rating:										

Table A9. Ardex TRM.

Rigid Repair Material Evaluation Report											
Product Name:		Ardex TRM		Material Description:		Portland cement based, mikrosilica modified					
Manufacturer's Information		Name		Ardex Americas							
		Address		400 Ardex Park Drive		Aliquippa, PA 15001					
		Phone		724 203 5000		Website		ardexamericas.com			
Testing Results											
Date Received at Laboratory		August 2014		Lot Number		4058600576 (22 bags)		Aggregate Extension? Y			
Date Tested	Requirement 1		September 2014		Evaluated by		ERDC-MTC		Vicksburg, MS 39180		
	Requirement 2		-		Overall Result (Pass/Fail)		Requirement 1		F		
	Recommended		-		Repair Classification		-		-		
Testing Summary											
All tests conducted at 73°F unless specified otherwise											
Test Completed		Testing Specifics		Criteria		Mfg. Test Result		Lab Test Result		Pass/Fail	
Compressive Strength	ASTM C39	-		≥ 3,000 psi @ 2 hrs.		3,500		550		F	
		-		≥ 5,000 psi @ 1 day		5,750		2,640		F	
		-		≥ 5,000 psi @ 7 days		7,500		3,560		F	
		-		≥ 5,000 psi @ 28 days		11,500		3,820		F	
Flexural Strength	ASTM C78	-		≥ 350 psi @ 2 hrs.		Not tested		235		F	
		-		≥ 600 psi @ 7 days		850		490		F	
		-		≥ 600 psi @ 28 days		1,100		505		F	
Bond Strength	ASTM C882	Repair Material to Repair Material		≥ 1,000 psi @ 1 day		1,250		1,600		P	
Modulus of Elasticity	ASTM C469	Repair Material to Ordinary PCC		≥ 1,000 psi @ 1 day		Not tested		1,240		P	
		-		2 ≤ x ≤ 6 Mpsi @ 2 hrs.		Not tested		No Result ¹		F	
Time of Set	ASTM C191	-		Initial set: ≥ 15 min.		10		80		P	
		-		Final set: 25 - 35 min.		15		120		F	
Slump	ASTM C143	Within 5 min of added water		≥ 3 in.		Not tested		9		P	
Length Change	ASTM C157	Stored in air		- 0.04% ≤ x ≤ +0.03% at 28 days		-0.05		-		-	
		Stored in water				-0.002		-		-	
Coeff. of Thermal Expansion	ASTM C 531	Begin test @ 7 days		≤ 12·10 ⁻⁶ °F ⁻¹		Not tested		-		-	
Shrinkage Potential	ASTM C1581	-		≤ 40 µε @ 14 days		Not tested		-		-	
		-		No cracking @ 28 days		Not tested		-		-	
Freeze-Thaw Resistance	ASTM C666	Procedure A, based on 300 cycles		No current criteria		Not tested		- @ - cycles		-	
Aggregate Extension Notes Per Unit											
Extension Allowed By Manufacturer?		Y		Supplier		Green Brothers		Pass ASTM C33?		Y	
Maximum Extension Allowed (% _{V_{cham}})		50		Quarry		Crystal Springs		ASTM C128		BSG	
Product Yield (ft ³)		0.6		Material		Pea Gravel		Test Results		Abs	
Extension Used (% _{V_{cham}})		50		Aggregate Volume (ft ³)		0.23		Nominal Weight Batched (lb)		31.50	
Moisture Corrections Applied Daily to Aggregate with ASTM D4959											
Testing Notes and Observations											
Specimens air cured at laboratory environment (approximately 70°F and 50% RH) after demolding unless specific curing procedure required by individual ASTM standards											
Manufacturer's reported testing values were of mortar constructed specimens (neat).											
Additional compressive strength results (psi) - 3 hrs. 1,570											
Additional bond strength results (psi) - 7 days to Ordinary PCC: 1,450 and 7 days to Repair Material: 2,125											
ASTM C403 results- initial set: 120 min, final set: 140 min.											
¹ No test result available. Specimens were too soft to test at time of test.											
Fails minimum criteria necessary for next highest approval rating: Fails multiple criteria points using in classification.											

Table A10. Fast Set Concrete Mix.

Rigid Repair Material Evaluation Report											
Product Name:		Fast Set Concrete Mix (Commercial Grade)		Material Description:		Portland cement based					
Manufacturer's Information		Name		Quikrete Companies							
		Address		One Securities Centre		3490 Piedmont Rd NE Suite 1300		Atlanta, GA 30305			
		Phone		404 634 9100		Website		quikrete.com			
Testing Results											
Date Received at Laboratory		March 2014		Lot Number		Not Present (18 bags)		Aggregate Extension?			
Date Tested	Requirement 1		May 2014		Evaluated by		ERDC-MTC		Vicksburg, MS 39180		
	Requirement 2		July 2014		Overall Result (Pass/Fail)		Requirement 1		F		
	Recommended		July 2014		Repair Classification		-				
Testing Summary											
All tests conducted at 73 °F unless specified otherwise											
Test Completed		Testing Specifics		Criteria		Mfg. Test Result		Lab Test Result		Pass/Fail	
Compressive Strength	ASTM C39	-		$\geq 3,000 \text{ psi @ 2 hrs.}$		3,000 (3 hr)		2,020		F	
		-		$\geq 5,000 \text{ psi @ 1 day}$		5,000		3,150		F	
		-		$\geq 5,000 \text{ psi @ 7 days}$		6,000		3,760		F	
		-		$\geq 5,000 \text{ psi @ 28 days}$		7,000		5,360		P	
Flexural Strength	ASTM C78	-		$\geq 350 \text{ psi @ 2 hrs.}$		Not tested		370		P	
		-		$\geq 600 \text{ psi @ 7 days}$		Not tested		425		F	
Bond Strength	ASTM C882	-		$\geq 600 \text{ psi @ 28 days}$		Not tested		450		F	
		Repair Material to Repair Material		$\geq 1,000 \text{ psi @ 1 day}$		1,000		1,080		P	
Modulus of Elasticity	ASTM C469	Repair Material to Ordinary PCC		$\geq 1,000 \text{ psi @ 1 day}$		Not tested		1,320		P	
		-		$2 \leq x \leq 6 \text{ Mpsi @ 2 hrs.}$		Not tested		1.95		F	
Time of Set	ASTM C191	-		$2 \leq x \leq 6 \text{ Mpsi @ 28 days}$		Not tested		4.00		P	
		-		Initial set: $\geq 15 \text{ min.}$		Not tested		17		P	
Slump	ASTM C143	Within 5 min of added water		Final set: 25 - 35 min.		25 - 45		21		F	
Length Change	ASTM C157	Stored in air		$\geq 3 \text{ in.}$		3 to 4		3		P	
		Stored in water		$-0.04\% \leq x \leq +0.03\% \text{ at 28 days}$		> -0.03		0.00		P	
Coeff. of Thermal Expansion	ASTM C 531	Begin test @ 7 days		< 0.01		Not tested		0.01		P	
Shrinkage Potential	ASTM C1581	-		$\leq 12 \cdot 10^{-6} \text{ } ^\circ\text{F}^{-1}$		Not tested		4.2		P	
		-		$\leq 40 \mu\text{e @ 14 days}$		Not tested		27		P	
Freeze-Thaw Resistance	ASTM C666	-		No cracking @ 28 days		Not tested		None for 3 rings		P	
		Procedure A, based on 300 cycles		No current criteria		Not tested		64 @ 200 cycles		-	
Aggregate Extension Notes Per Unit											
Extension Allowed By Manufacturer?		N	Supplier	-				Pass ASTM C33?		-	
Maximum Extension Allowed (% Volume)		-	Quarry	-				ASTM C128		BSG	
Product Yield (ft ³)		0.52	Material	-				Test Results		Abs	
Extension Used (% Volume)		-	Aggregate Volume (ft ³)		-		Nominal Weight Batched (lb)		-		
Moisture Corrections Applied Daily to Aggregate with ASTM D4959											
Testing Notes and Observations											
Specimens air cured at laboratory environment (approximately 70 °F and 50% RH) after demolding unless specific curing procedure required by individual ASTM standards											
Additional compressive strength results (psi) - 3 hr: 2,490											
Additional bond strength results (psi) - 7 days to Ordinary PCC: 1,580 , 7 days to Repair Material: 1,470											
ASTM C403 results- initial set: 18 min, final set: 26 min											
Fails minimum criteria necessary for next highest approval rating: Multiple Requirement 1 Criteria											

Table A11. Rapid Road Repair.

Rigid Repair Material Evaluation Report										
Product Name:		Rapid Road Repair		Material Description:		Portland cement based				
Manufacturer's Information		Name		Quikrete Companies						
		Address		One Securities Centre		3490 Piedmont Rd NE Suite, 1300		Atlanta, GA 30305		
		Phone		404 634 9100		Website		quikrete.com		
Date Received at Laboratory		March 2014		Lot Number		51019113 (24 bags)		Aggregate Extension? N		
Date Tested	Requirement 1		May 2014		Evaluated by		ERDC-MTC		Vicksburg, MS 39180	
	Requirement 2		July 2014		Overall Result (Pass/Fail)		Requirement 1 P		Requirement 2 F	
	Recommended		July 2014		Repair Classification		---			
Testing Summary										
All tests conducted at 73°F unless specified otherwise										
Test Completed		Testing Specifics		Criteria		Mfg. Test Result		Lab Test Result		Pass/Fail
Compressive Strength	ASTM C39	-		$\geq 3,000 \text{ psi @ 2 hrs.}$		2,000 (1.5 hr)		2,140		F
		-		$\geq 5,000 \text{ psi @ 1 day}$		4,000		4,570		F
		-		$\geq 5,000 \text{ psi @ 7 days}$		5,500		6,050		P
		-		$\geq 5,000 \text{ psi @ 28 days}$		6,000		7,980		P
Flexural Strength	ASTM C78	-		$\geq 350 \text{ psi @ 2 hrs.}$		550 (4 hr)		380		P
		-		$\geq 600 \text{ psi @ 7 days}$		950		840		P
		-		$\geq 600 \text{ psi @ 28 days}$		1,000		1,045		P
Bond Strength	ASTM C882	Repair Material to Repair Material		$\geq 1,000 \text{ psi @ 1 day}$		2,000		1,950		P
		Repair Material to Ordinary PCC		$\geq 1,000 \text{ psi @ 1 day}$		Not tested		1,350		P
Modulus of Elasticity	ASTM C469	-		$2 \leq x \leq 6 \text{ Mpsi @ 2 hrs.}$		Not tested		1.40		F
		-		$2 \leq x \leq 6 \text{ Mpsi @ 28 days}$		Not tested		3.90		P
Time of Set	ASTM C191	-		Initial set: $\geq 15 \text{ min.}$		17 to 25		20		P
		-		Final set: 25 - 35 min.		25 to 45		30		P
Slump	ASTM C143	Within 5 min of added water		$\geq 3 \text{ in.}$		3 to 4		3		P
Length Change	ASTM C157	Stored in air		$-0.04\% \leq x \leq +0.03\% \text{ at 28 days}$		-0.040		0.03		P
		Stored in water				0.040		0.08		F
Coeff. of Thermal Expansion	ASTM C 531	Begin test @ 7 days		$\leq 12 \cdot 10^{-6} \text{ } ^\circ\text{F}^{-1}$		4 to 9		7		P
Shrinkage Potential	ASTM C1581	-		$\leq 40 \text{ } \mu\text{s @ 14 days}$		Not tested		24		P
		-		No cracking @ 28 days		Not tested		None on 3 rings		P
Freeze-Thaw Resistance	ASTM C666	Procedure A, DF based on 300 cycles		No current criteria		96		56 @ 68 cycles		-
Aggregate Extension Notes Per Unit										
Extension Allowed By Manufacturer?		Y/N	Supplier	-			Pass ASTM C33?		-	
Maximum Extension Allowed (% _{Volume})		-	Quarry	-			ASTM C128	BSG	-	
Product Yield (ft ³)		0.6	Material	-			Test Results	Abs	-	
Extension Used (% _{Volume})		-	Aggregate Volume (ft ³)		-		Nominal Weight Batched (lb)		-	
Moisture Corrections Applied Daily to Aggregate with ASTM D4959										
Testing Notes and Observations										
Specimens air cured at laboratory environment (approximately 70°F and 50% RH) after demolding unless specific curing procedure required by individual ASTM standards										
Material with pre-added glass fiber reinforcement tested										
Additional compressive strength results -(psi) 3 hr: 2,240										
Additional bond strength results (psi) - 7 days to Ordinary PCC: 1,520 , 7 days to Repair Material: 2,970										
ASTM C403 results- initial set: 25 min. final set: 37 min.										
*Material did not pass all Requirement 1 testing; however, testing was continued since values were close to criteria limits.										
Fails minimum criteria necessary for next highest approval rating: Length Change										

A.3 FY15 Rigid-Repair Material Evaluation Reports

See Tables A12 through A17.

Table A12. HD 50.

Rigid Repair Material Evaluation Report									
Product Name:		HD 50		Material Description:		Portland cement, latex modified, fiber reinforced			
Manufacturer's Information		Name		Dayton Superior Corp.					
		Address		1125 Byers Road		Miamisburg, OH 45342			
		Phone		888 977 9600		Website		www.daytonsuperior.com	
Date Received at Laboratory		January 2014		Lot Number		A4082005B		Aggregate Extension? Y	
Date Tested	Requirement 1		March 2015		Evaluated by		ERDC-MTC		
	Requirement 2		-		Overall Result (Pass/Fail)		Requirement 1		*P
	Recommended		-		Repair Classification		Requirement 2		FY16
Testing Summary									
All tests conducted at 73°F unless specified otherwise									
Test Completed		Testing Specifics		Criteria		Mfg. Test Result		Lab Test Result	
Compressive Strength	ASTM C39	-		$\geq 3,000 \text{ psi @ 2 hrs.}$		2000 (C109 @ 1 hr)		4,080	
		-		$\geq 5,000 \text{ psi @ 1 day}$		6145 (C109)		4,700	
		-		$\geq 5,000 \text{ psi @ 7 days}$		7000 (C109)		6,370	
		-		$\geq 5,000 \text{ psi @ 28 days}$		7990 (C109)		6,980	
Flexural Strength	ASTM C78	-		$\geq 350 \text{ psi @ 2 hrs.}$		Not tested		625	
		-		$\geq 600 \text{ psi @ 7 days}$		Not tested		710	
		-		$\geq 600 \text{ psi @ 28 days}$		Not tested		770	
Bond Strength	ASTM C882	Repair Material to Repair Material		$\geq 1,000 \text{ psi @ 1 day}$		2,000		1,820	
		Repair Material to Ordinary PCC		$\geq 1,000 \text{ psi @ 1 day}$		Not tested		1,550	
Modulus of Elasticity	ASTM C469	-		$2 \leq x \leq 6 \text{ Mpsi @ 2 hrs.}$		Not tested		3.30	
		-		$2 \leq x \leq 6 \text{ Mpsi @ 28 days}$		Not tested		4.70	
Time of Set	ASTM C191	-		Initial set: $\geq 15 \text{ min.}$		15-20		24	
		-		Final set: 25 - 35 min.		25-30		27	
Slump	ASTM C143	Within 5 min of added water		$\geq 3 \text{ in.}$		Not tested		11	
Length Change	ASTM C157	Stored in air		$-0.04\% \leq x \leq +0.03\%$ at 28 days		-0.11		-	
		Stored in water				0.06		-	
Coeff. of Thermal Expansion	ASTM C 531	Begin test @ 7 days		$\leq 12 \cdot 10^{-6} \text{ }^{\circ}\text{F}^{-1}$		Not tested		-	
Shrinkage Potential	ASTM C1581	-		$\leq 40 \text{ } \mu\text{e @ 14 days}$		Not tested		-	
		-		No cracking @ 28 days		Not tested		-	
Freeze-Thaw Resistance	ASTM C666	Procedure A, DF based on 300 cycles		No current criteria		No Mass Loss		-	
Aggregate Extension Notes Per Unit									
Extension Allowed By Manufacturer?		Y	Supplier	Green Brothers		Pass ASTM C33?		Y	
Maximum Extension Allowed (% _{Volume})		60	Quarry	Crystal Springs		ASTM C128		BSG	
Product Yield (ft ³)		0.42	Material	Pea Gravel		Test Results		Abs	
Extension Used (% _{Volume})		50	Aggregate Volume (ft ³)		0.20	Nominal Weight Batched (lb)		31.61	
Moisture Corrections Applied Daily to Aggregate with ASTM D4959									
Testing Notes and Observations									
Specimens air cured at laboratory environment (approximately 70°F and 50% RH) after demolding unless specific curing procedure required by individual ASTM standards									
Additional compressive strength results (psi) - 3 hr: 4,200									
Additional bond strength results (psi) - 7 days to Ordinary PCC: 2,390 psi 7 days to Repair Material: 2,960 psi									
ASTM C403 results- initial set: 23 min. final set: 26 min.									
*Material did not pass all Requirement 1 testing; however, testing was continued since other test times before and after met or close to criteria limits.									

Table A13. Pavemend 15.0

Rigid Repair Material Evaluation Report										
Product Name:		Pavemend 15.0		Material Description:		cementitious				
Manufacturer's Information		Name		Ceratech Inc.						
		Address		1500 N. Beauregard St.		Suite 320		Alexandria, VA 22311		
		Phone		800 581 8397		Website		www.ceratechinc.com		
Testing Results										
Date Received at Laboratory		September 2015		Lot Number		15.0-100 (24 units)		Aggregate Extension?		
Date Tested	Requirement 1		October 2015		Evaluated by		ERDC-MTC		Vicksburg, MS 39180	
	Requirement 2		-		Overall Result (Pass/Fail)		Requirement 1		F	
	Recommended		-		Repair Classification		-		-	
Testing Summary										
All tests conducted at 73°F unless specified otherwise										
Test Completed		Testing Specifics		Criteria		Mfg. Test Result		Lab Test Result		Pass/Fail
Compressive Strength	ASTM C39	-		$\geq 3,000 \text{ psi @ 2 hrs.}$		3,500		1,210		F
		-		$\geq 5,000 \text{ psi @ 1 day}$		5,750		3,730		F
		-		$\geq 5,000 \text{ psi @ 7 days}$		7,500		3,970		F
		-		$\geq 5,000 \text{ psi @ 28 days}$		11,500		5,060		P
Flexural Strength	ASTM C78	-		$\geq 350 \text{ psi @ 2 hrs.}$		Not tested		275		F
		-		$\geq 600 \text{ psi @ 7 days}$		850		460		F
		-		$\geq 600 \text{ psi @ 28 days}$		1,100		445		F
Bond Strength	ASTM C882	Repair Material to Repair Material		$\geq 1,000 \text{ psi @ 1 day}$		1,250		1,130		P
		Repair Material to Ordinary PCC		$\geq 1,000 \text{ psi @ 1 day}$		Not tested		820		F
Modulus of Elasticity	ASTM C469	-		$2 \leq x \leq 6 \text{ Mpsi @ 2 hrs.}$		Not tested		0.95		F
		-		$2 \leq x \leq 6 \text{ Mpsi @ 28 days}$		3.8		2.35		P
Time of Set	ASTM C191	-		Initial set: $\geq 15 \text{ min.}$		10		9		P
		-		Final set: 25 - 35 min.		15		15		F
Slump	ASTM C143	Within 5 min. of added water		$\geq 3 \text{ in.}$		Not tested		19		P ¹
Length Change	ASTM C157	Stored in air		$-0.04\% \leq x \leq +0.03\%$ at 28 days		-0.05		-		-
		Stored in water				-0.002		-		-
Coeff. of Thermal Expansion	ASTM C 531	Begin test @ 7 days		$\leq 12 \cdot 10^{-6} \text{ }^{\circ}\text{F}^{-1}$		Not tested		-		-
Shrinkage Potential	ASTM C1581	-		$\leq 40 \mu\text{e @ 14 days}$		Not tested		-		-
		-		No cracking @ 28 days		Not tested		-		-
Freeze-Thaw Resistance	ASTM C666	Procedure A, based on 300 cycles		No current criteria		Not tested		- @ - cycles		-
Aggregate Extension Notes Per Unit										
Extension Allowed By Manufacturer?		N	Supplier	-		Pass ASTM C33?		-		
Maximum Extension Allowed (% _{Volume})		-	Quarry	-		ASTM C128		BSG		
Product Yield (ft ³)		0.42	Material	-		Test Results		Abs		
Extension Used (% _{Volume})		-	Aggregate Volume (ft ³)		-		Nominal Weight Batched (lb)		-	
Moisture Corrections Applied Daily to Aggregate with ASTM D4959										
Testing Notes and Observations										
Specimens air cured at laboratory environment (approximately 70°F and 50% RH) after demolding unless specific curing procedure required by individual ASTM standards										
Manufacturer's reported testing values were are of mortar constructed specimens (neat)										
Additional compressive strength results (psi) - 3 hr: 3,170										
Additional bond strength results (psi) - 7 days to Ordinary PCC: 1,790, 7 days to Repair Material: 1,010										
ASTM C403 results- initial set: 15 min. final set: 30 min.										
Product produced on 15 August 2014										
Test result reported by ASTM C1611 since no slump could be measured, value is the average of measurements of the diameter.										
Fails minimum criteria necessary for next highest approval rating: Fails multiple criteria points using in classification.										

Table A14. Rapid Set Mortar Mix.

Rigid Repair Material Evaluation Report										
Product Name:		Rapid Set Mortar Mix			Material Description:		Calcium Sulfoaluminate			
Manufacturer's Information		Name		CTS Cement Manufacturing						
		Address		11065 Knott Ave, Suite A		Cypress, CA 90630				
		Phone		714 379 8260		Website		www.ctscement.com		
Date Received at Laboratory		December 2014		Lot Number		65507304 (30 units)		Aggregate Extension?		
Date Tested	Requirement 1		January 2015		Evaluated by		ERDC-MTC		Vicksburg, MS 39180	
	Requirement 2		February-April 2015		Overall Result (Pass/Fail)		Requirement 1		P*	
	Recommended		February-March 2015		Repair Classification		Requirement 2		P	
Testing Summary										
All tests conducted at 73°F unless specified otherwise										
Test Completed		Testing Specifics		Criteria		Mfg. Test Result		Lab Test Result		
Compressive Strength	ASTM C39	-		$\geq 3,000$ psi @ 2 hrs.		3,000 (1.5 hr)		4,150		
		-		$\geq 5,000$ psi @ 1 day		6,500		5,730		
		-		$\geq 5,000$ psi @ 7 days		8,000		6,580		
		-		$\geq 5,000$ psi @ 28 days		10,000		7,270		
Flexural Strength	ASTM C78	-		≥ 350 psi @ 2 hrs.		Not tested		425		
		-		≥ 600 psi @ 7 days		Not tested		560		
		-		≥ 600 psi @ 28 days		Not tested		820		
Bond Strength	ASTM C882	Repair Material to Repair Material		$\geq 1,000$ psi @ 1 day		1,200		1,480		
		Repair Material to Ordinary PCC		$\geq 1,000$ psi @ 1 day		Not tested		1,300		
Modulus of Elasticity	ASTM C469	-		$2 \leq x \leq 6$ Mpsi @ 2 hrs.		Not tested		2.20		
		-		$2 \leq x \leq 6$ Mpsi @ 28 days		Not tested		3.10		
Time of Set	ASTM C191	-		Initial set: ≥ 15 min.		10 - 20		33		
		-		Final set: 25 - 35 min.		20 - 45		43		
Slump	ASTM C143	Within 5 min of added water		≥ 3 in.		3 to 4		4		
		-		-		-		-		
Length Change	ASTM C157	Stored in air		$-0.04\% \leq x \leq +0.03\%$ at 28 days		-0.052		0.00		
		Stored in water		-		0.020		0.02		
Coeff. of Thermal Expansion	ASTM C 531	Begin test @ 7 days		$\leq 12 \cdot 10^{-6}$ °F ⁻¹		Not tested		7		
		-		≤ 40 $\mu\epsilon$ @ 14 days		Not tested		19		
Shrinkage Potential	ASTM C1581	-		No cracking @ 28 days		Not tested		none on 3 rings		
		-		-		-		-		
Freeze-Thaw Resistance	ASTM C666	Procedure A, DF based on 300 cycles		No current criteria		78		5 @ 33 cycles		
		-		-		-		-		
Aggregate Extension Notes Per Unit										
Extension Allowed By Manufacturer?		-	Supplier	-			Pass ASTM C33?		-	
Maximum Extension Allowed (% _{volume})		-	Quarry	-			ASTM C128		BSG	
Product Yield (ft ³)		-	Material	-			Test Results		Abs	
Extension Used (% _{volume})		-	Aggregate Volume (ft ³)		-	Nominal Weight Batched (lb)		-		
Moisture Corrections Applied Daily to Aggregate with ASTM D4959										
Testing Notes and Observations										
Specimens air cured at laboratory environment (approximately 70°F and 50% RH) after demolding unless specific curing procedure required by individual ASTM standards										
Results shown are from the non-extended mortar version of material.										
Additional compressive strength results (psi) - 3 hr: 4,610										
Additional bond strength results (psi) - 7 days to Ordinary PCC: 1,910 psi ; 7 days to Repair Material: 2,100 psi										
ASTM C403 results (min)- initial set: 37; final set: 43										
*Material did not pass all Requirement 1 testing; however, testing was continued since other test times before and after met or close to criteria limits.										
Fails minimum criteria necessary for next highest approval rating:										

Table A15. Prospec Premium Patch 100.

Rigid Repair Material Evaluation Report									
Product Name:		Prospec Premium Patch 100			Material Description:		Portland cement, polymer modified, fiber reinforced		
Manufacturer's Information		Name		H.B. Fuller Construction Products Inc.					
		Address		1105 South Frontenac St.		Aurora, IL 60504			
		Phone		800-552-6225		Website		www.prospec.com	
Testing Results									
Date Received at Laboratory		January 2015		Lot Number		611034103		Aggregate Extension?	
Date Tested	Requirement 1		March 2015		Evaluated by		ERDC-MTC		
	Requirement 2		-		Overall Result (Pass/Fail)		Requirement 1		F
	Recommended		-		Repair Classification		-		
Testing Summary									
All tests conducted at 73°F unless specified otherwise									
Test Completed		Testing Specifics		Criteria		Mfg. Test Result		Lab Test Result	
Compressive Strength	ASTM C39	-		$\geq 3,000 \text{ psi @ 2 hrs.}$		2770 (1 hr)		2,460	
		-		$\geq 5,000 \text{ psi @ 1 day}$		4,570		3,620	
		-		$\geq 5,000 \text{ psi @ 7 days}$		5,550		5,400	
		-		$\geq 5,000 \text{ psi @ 28 days}$		9270 (C109)		6,550	
Flexural Strength	ASTM C78	-		$\geq 350 \text{ psi @ 2 hrs.}$		700 (4 hr)		430	
		-		$\geq 600 \text{ psi @ 7 days}$		Not tested		585	
		-		$\geq 600 \text{ psi @ 28 days}$		Not tested		685	
		-		$\geq 1,000 \text{ psi @ 1 day}$		1,580		1,200	
Bond Strength	ASTM C882	Repair Material to Repair Material		$\geq 1,000 \text{ psi @ 1 day}$		Not tested		1,040	
Modulus of Elasticity	ASTM C469	-		$2 \leq x \leq 6 \text{ Mpsi @ 2 hrs.}$		Not tested		2.75	
		-		$2 \leq x \leq 6 \text{ Mpsi @ 28 days}$		4.06		4.70	
Time of Set	ASTM C191	-		Initial set: $\geq 15 \text{ min.}$		37		67	
		-		Final set: 25 - 35 min.		46		73	
Slump	ASTM C143	Within 5 min of added water		$\geq 3 \text{ in.}$		3.5		2	
Length Change	ASTM C157	Stored in air		$-0.04\% \leq x \leq +0.03\%$ at 28 days		-0.094		-	
		Stored in water				0.038		-	
Coeff. of Thermal Expansion	ASTM C 531	Begin test @ 7 days		$\leq 12 \cdot 10^{-6} \text{ }^{\circ}\text{F}^{-1}$		5.9		-	
Shrinkage Potential	ASTM C1581	-		$\leq 40 \mu\epsilon \text{ @ 14 days}$		Not tested		-	
		-		No cracking @ 28 days		Not tested		-	
Freeze-Thaw Resistance	ASTM C666	Procedure A, DF based on 300 cycles		No current criteria		92 (RDM, Pro. B)		-	
Aggregate Extension Notes Per Unit									
Extension Allowed By Manufacturer?		Y	Supplier	Green Brothers				Pass ASTM C33?	
Maximum Extension Allowed (% V_{volume})		60	Quarry	Crystal Springs				ASTM C128	BSG
Product Yield (ft ³)		0.4	Material	Pea Gravel				Test Results	Abs
Extension Used (% V_{volume})		50	Aggregate Volume (ft ³)		0.20	Nominal Weight Batched (lb)		31.61	
Moisture Corrections Applied Daily to Aggregate with ASTM D4959									
Testing Notes and Observations									
Specimens air cured at laboratory environment (approximately 70°F and 50% RH) after demolding unless specific curing procedure required by individual ASTM standards									
Manufacturer's reported testing values are a mix of mortar (neat) or aggregate extended constructed specimens. Known specimen type results are indicated as shown.									
Additional compressive strength results (psi) - 3 hr: 3,220									
Additional bond strength results (psi) - 7 days to Ordinary PCC: 1,550psi 7 days to Repair Material: 1,690 psi									
ASTM C403 results- initial set: 65 min. final set: 72 min.									
*Material did not pass all Requirement 1 testing; however, testing was continued since other test times before and after met or close to criteria limits.									
**Material did not pass all Requirement 2 testing; however, testing was continued since values were close to criteria limits.									

Table A16. Prospec Premium Patch 200.

Rigid Repair Material Evaluation Report									
Product Name:		Prospec Premium Patch 200		Material Description:		Portland cement, polymer modified, fiber reinforced			
Manufacturer's Information		Name		H.B. Fuller Construction Products Inc.					
		Address		1105 South Frontenac St.		Aurora, IL 60504			
		Phone		800-552-6225		Website		www.prospec.com	
Date Received at Laboratory		January 2015		Lot Number		611034103		Aggregate Extension?	
Date Tested	Requirement 1		March 2015		Evaluated by		ERDC-MTC		
	Requirement 2		October 2015		Overall Result (Pass/Fail)		Requirement 1		*P
	Recommended		-		Repair Classification		-		
Testing Summary									
All tests conducted at 73°F unless specified otherwise									
Test Completed		Testing Specifics		Criteria		Mfg. Test Result		Lab Test Result	
Compressive Strength	ASTM C39	-		≥ 3,000 psi @ 2 hrs.		3800 (C109 @ 3 hr)		3,210	
		-		≥ 5,000 psi @ 1 day		5400 (C109)		4,320	
		-		≥ 5,000 psi @ 7 days		7500 (C109)		5,570	
		-		≥ 5,000 psi @ 28 days		9100 (C109)		6,890	
Flexural Strength	ASTM C78	-		≥ 350 psi @ 2 hrs.		Not tested		515	
		-		≥ 600 psi @ 7 days		> 1100 (C348)		750	
		-		≥ 600 psi @ 28 days		> 1200 (C348)		815	
Bond Strength	ASTM C882	Repair Material to Repair Material		≥ 1,000 psi @ 1 day		1,500		1,780	
		Repair Material to Ordinary PCC		≥ 1,000 psi @ 1 day		Not tested		1,820	
Modulus of Elasticity	ASTM C469	-		2 ≤ x ≤ 6 Mpsi @ 2 hrs.		Not tested		2.95	
		-		2 ≤ x ≤ 6 Mpsi @ 28 days		3.8		4.40	
Time of Set	ASTM C191	-		Initial set: ≥ 15 min.		18		20	
		-		Final set: 25 - 35 min.		20		25	
Slump	ASTM C143	Within 5 min of added water		≥ 3 in.		Not tested		3	
Length Change	ASTM C157	Stored in air		- 0.04% ≤ x ≤ +0.03% at 28 days		-0.094		-0.005	
		Stored in water				0.038		0.0153	
Coeff. of Thermal Expansion	ASTM C 531	Begin test @ 7 days		≤ 12 · 10 ⁻⁶ °F ⁻¹		Not tested		8	
Shrinkage Potential	ASTM C1581	-		≤ 40 µε @ 14 days		Not tested		24	
		-		No cracking @ 28 days		Not tested		none on 3 rings	
Freeze-Thaw Resistance	ASTM C666	Procedure A, DF based on 300 cycles		No current criteria		Not tested		9 @ 56 cycles	
Aggregate Extension Notes Per Unit									
Extension Allowed By Manufacturer?		Y	Supplier	Green Brothers			Pass ASTM C33?		Y
Maximum Extension Allowed (%V _{volume})		50	Quarry	Crystal Springs			ASTM C128		BSG
Product Yield (ft ³)		0.4	Material	Pea Gravel			Test Results		Abc
Extension Used (%V _{volume})		50	Aggregate Volume (ft ³)		0.21	Nominal Weight Batched (lb)		32.98	
Moisture Corrections Applied Daily to Aggregate with ASTM D4959									
Testing Notes and Observations:									
Specimens air cured at laboratory environment (approximately 70°F and 50% RH) after demolding unless specific curing procedure required by individual ASTM standards									
Manufacturer's reported testing values were are of mortar constructed specimens (neat).									
Additional compressive strength results (psi) - 3 hr: 3,630									
Additional bond strength results (psi) - 7 days to Ordinary PCC: 2,150 psi 7 days to Repair Material: 2,350 psi									
ASTM C403 results- initial set: 20 min. final set: 24 min.									
**Material did not pass all Requirement 1 testing; however, testing was continued since values were close to criteria limits.									
Fails minimum criteria necessary for next highest approval rating: 1 day compressive strength									

Table A17. Magna-Crete.

Rigid Repair Material Evaluation Report								
Product Name:		Magna-Crete		Material Description:		Magnesium Phosphate		
Manufacturer's Information		Name		Henkel Americas (Locite)				
		Address		One Henkel Way, Rocky Hill, CT 06067				
		Phone		1-860-571-5100		Website http://www.henkel.com/		
Date Received at Laboratory		January 2014		Testing Results		Lot Number L04108501		
Date Tested	Requirement 1		March 2015		Evaluated by		ERDC-MTC	
	Requirement 2		-		Overall Result (Pass/Fail)		Requirement 1 F	
	Recommended		-		Repair Classification		-	
Testing Summary								
All tests conducted at 73°F unless specified otherwise								
Test Completed		Testing Specifics		Criteria		Mfg. Test Result		
Compressive Strength	ASTM C39	-		$\geq 3,000 \text{ psi @ 2 hrs.}$		2500-3500		
		-		$\geq 5,000 \text{ psi @ 1 day}$		4000-6000 (3 day)		
		-		$\geq 5,000 \text{ psi @ 7 days}$		Not tested		
		-		$\geq 5,000 \text{ psi @ 28 days}$		7000-8000		
Flexural Strength	ASTM C78	-		$\geq 350 \text{ psi @ 2 hrs.}$		700 (4 hr)		
		-		$\geq 600 \text{ psi @ 7 days}$		Not tested		
		-		$\geq 600 \text{ psi @ 28 days}$		Not tested		
Bond Strength	ASTM C882	Repair Material to Repair Material		$\geq 1,000 \text{ psi @ 1 day}$		Not tested		
		Repair Material to Ordinary PCC		$\geq 1,000 \text{ psi @ 1 day}$		Not tested		
Modulus of Elasticity	ASTM C469	-		$2 \leq x \leq 6 \text{ Mpsi @ 2 hrs.}$		Not tested		
		-		$2 \leq x \leq 6 \text{ Mpsi @ 28 days}$		Not tested		
Time of Set	ASTM C191	-		Initial set $\geq 15 \text{ min.}$		3-11		
		-		Final set: 25 - 35 min.		15-22		
Slump	ASTM C143	Within 5 min of added water		$\geq 3 \text{ in.}$		5		
Length Change	ASTM C157	Stored in air		$-0.04\% \leq x \leq +0.03\%$ at 28 days		Not tested		
		Stored in water				Not tested		
Coeff. of Thermal Expansion	ASTM C 531	Begin test @ 7 days		$\leq 12 \cdot 10^{-6} \text{ } ^\circ\text{F}^{-1}$		4-9		
Shrinkage Potential	ASTM C1581	-		$\leq 40 \mu\epsilon \text{ @ 14 days}$		Not tested		
		-		No cracking @ 28 days		Not tested		
Freeze-Thaw Resistance	ASTM C666	Procedure A, DF based on 300 cycles		No current criteria		Not tested		
Aggregate Extension Notes Per Unit								
Extension Allowed By Manufacturer?		Y	Supplier	Green Brothers		Pass ASTM C33?		
Maximum Extension Allowed (% _{Volume})		25	Quarry	Crystal Springs		ASTM C128	BSG	
Product Yield (ft ³)		0.45	Material	Pea Gravel		Test Results	Abs	
Extension Used (% _{Volume})		25	Aggregate Volume (ft ³)		0.20	Nominal Weight Batched (lb)		
Moisture Corrections Applied Daily to Aggregate with ASTM D4959								
Testing Notes and Observations								
Specimens air cured at laboratory environment (approximately 70°F and 50% RH) after demolding unless specific curing procedure required by individual ASTM standards								
Manufacturer's reported testing values are a mix of mortar (neat) or aggregate extended constructed specimens. Known specimen type results are indicated as shown.								
Additional compressive strength results (psi) - 3 hr: 3,620								
Additional bond strength results (psi) - 7 days to Ordinary PCC: 2,050 psi 7 days to Repair Material: 2,430 psi								
ASTM C403 results- initial set: 8 min. final set: 11 min.								
*High safety concern as product emits a strong, toxic ammonia fume when mixed								
*Material did not pass all Requirement 1 testing; however, testing was continued since other test times before and after met or close to criteria limits.								

A.4 FY16 Rigid-Repair Material Evaluation Reports

See Tables A18 through A22.

Table A18. Elephant Armor DOT.

Rigid Repair Material Evaluation Report							
Product Name:		Elephant Armor DOT Industrial Grade Mortar		Material Description:		calcium sulfoaluminate, cementitious, fiber reinforced	
Manufacturer's Information		Name		GST International			
		Address		994 Packer Way		Telephone	
		Sparks, NV 89431		Website		1-775-829-2626 www.gstinternational.com	
Testing Results							
Date Received at Laboratory		January, 2016		Lot Number		IH-T0430-01 (70577)	
Date Tested	Requirement 1	March, 2016		Evaluated by		ERDC-MTC	
	Requirement 2	June, 2016		Overall Result (Pass/Fail)		Requirement 1 F Requirement 2 P	
Testing Summary							
All tests conducted at 73°F unless specified otherwise							
Test Completed		Testing Specifics		Criteria		Mfg. Test Result Lab Test Result Pass/Fail	
Compressive Strength	ASTM C39	-		≥ 3,000 psi @ 2 hrs.		N/A 3,020 P	
		-		≥ 5,000 psi @ 1 day		4420 (C109) 3,270 F	
		-		≥ 5,000 psi @ 7 days		6040 (C109) 4,150 F	
		-		≥ 5,000 psi @ 28 days		7837 (C109) 4,520 F	
Flexural Strength	ASTM C78	-		≥ 350 psi @ 2 hrs.		N/A 1,260 P	
		-		≥ 600 psi @ 7 days		1,439 1,350 P	
		-		≥ 600 psi @ 28 days		N/A 1,355 P	
Bond Strength	ASTM C882	Repair Material to Repair Material		≥ 1,000 psi @ 1 day		N/A 1,490 P	
		Repair Material to Ordinary PCC		≥ 1,000 psi @ 1 day		N/A 690 F	
Modulus of Elasticity	ASTM C469	-		2 ≤ x ≤ 6 Mpsi @ 2 hrs.		N/A 3.40 P	
		-		2 ≤ x ≤ 6 Mpsi @ 28 days		N/A 4.65 P	
Time of Set	ASTM C191	-		Initial set: ≥ 15 min.		20-30 28 P	
		-		Final set: 25 - 35 min.		60-90 32 P	
Slump	ASTM C143	Within 5 min of added water		≥ 3 in.		N/A 7 P	
Length Change	ASTM C157	Stored in air		- 0.04% ≤ x ≤ +0.03% at 28 days		-0.06 0.002 P	
		Stored in water				N/A 0.019 P	
Coeff. of Thermal Expansion	ASTM C 531	Begin test @ 7 days		≤ 12·10 ⁻⁶ °F ⁻¹		N/A 5.88 P	
Shrinkage Potential	ASTM C1581	-		≤ 40 με @ 14 days		N/A 34 P	
		-		No cracking @ 28 days		N/A none on 3 rings P	
Freeze-Thaw Resistance	ASTM C666	Procedure A, based on 300 cycles		No current criteria		N/A 8 @ 44 cycles -	
Testing Notes and Observations							
Mixing was performed with a dual paddle mixer at a ratio of 1.6 gallons of water per 50 lbs of dry material							
Specimens air cured at laboratory environment (approximately 70°F and 50% RH) after demolding unless specific curing procedure required by individual ASTM standards							
Additional compressive strength results 3,030 (psi) - 3 hr:							
Additional bond strength results 770 (psi) - 7 days to Ordinary PCC							
Additional bond strength results 1,910 (psi) - 7 days to Repair Material							
ASTM C403 results- initial set: 30 min. final set: 35 min.							

Table A19. Phoscrete HC.

Rigid Repair Material Evaluation Report							
Product Name	Phoscrete HC		Material Description:	Very Rapid Hardening MALP (Magnesium Aluminosilicate Liquid Phosphate)			
Manufacturer's Information	Name			Phoscrete Corporation			
	Address	265 S Federal Hwy, Suite 320		Telephone	(561) 420-0595		
		Deerfield Beach, FL 33441		Website	http://www.phoscrete.com/		
Testing Results							
Date Received at Laboratory		September, 2016	Lot Number	623609		Aggregate Extension?	No
Date Tested	Requirement 1	December, 2016	Evaluated by	ERDC-MTC		Vicksburg, MS 39180	
	Requirement 2	-	Overall Result (Pass/Fail)	Requirement 1	F	Requirement 2	-
Requirement 1							
Test Completed		Testing Specifics		Criteria	Mfg. Test Result	Lab Test Result	Pass/Fail
Compressive Strength	ASTM C39	-		$\geq 2,500$ psi @ 2 hrs.	NA	5,140	P
		-		$\geq 3,000$ psi @ 3 hrs.	NA	5,350	P
		-		$\geq 4,000$ psi @ 1 day	6,500	6,030	P
		-		$\geq 5,000$ psi @ 7 days	NA	7,580	P
		-		$\geq 5,000$ psi @ 28 days	8,000	7,730	P
Flexural Strength	ASTM C78	-		≥ 350 psi @ 2 hrs.	500	565	P
		-		≥ 500 psi @ 7 days	NA	685	P
		-		≥ 600 psi @ 28 days	700	880	P
Bond Strength	ASTM C882	Repair Material to Repair Material		$\geq 1,000$ psi @ 1 day	1,500	2,040	P
		Repair Material to Repair Material		$\geq 1,250$ psi @ 7 days	2,000	2,330	P
		Repair Material to Ordinary PCC		$\geq 1,000$ psi @ 1 day	1,750	1,590	P
		Repair Material to Ordinary PCC		$\geq 1,250$ psi @ 7 days	2,500	1,720	P
Modulus of Elasticity	ASTM C469	-		$2 \leq x \leq 6$ Mpsi @ 2 hrs.	NA	3.40	P
		-		$2 \leq x \leq 6$ Mpsi @ 28 days	3	4.27	P
Time of Set	ASTM C191	-		Initial Set: ≥ 15 min.	18 ¹	3	F
		-		Final Set: 15 - 90 min.	28 ¹	5	F
Time of Set	ASTM C403	-		Initial Set: ≥ 15 min.	18 ¹	4	F
		-		Final Set: 15 - 90 min.	28 ¹	5	F
Slump	ASTM C143	Within 5 min of added water		≥ 3 in.	6	2	F
Requirement 2							
Test Completed		Testing Specifics		Criteria	Mfg. Test Result	Lab Test Result	Pass/Fail
Length Change	ASTM C157	Stored in air		$-0.04\% \leq x \leq +0.03\%$ @ 28 days	NA	-	-
		Stored in water			NA	-	-
Coeff. of Thermal Expansion	ASTM C 531	Begin test @ 7 days		$\leq 7 \cdot 10^{-6}$ °F ⁻¹	7.15	-	-
Shrinkage Potential	ASTM C1581	-		No cracking @ 28 days	NA	-	-
Testing Notes and Observations							
Mixing ratio of 1 50-lb bag to 1 jug in packaged kit from manufacturer.							
Product was mixed using phoscrete's urethane auger paddle for 1 minute. Product consistently set at extremely rapid set times with low workability.							
¹ Manufacturer testing results based on ASTM C266 Gilmore modified							

Table A20. FasTrac 246 Concrete.

Rigid Repair Material Evaluation Report								
Product Name:		FastTrac 246		Material Description:		cementitious		
Manufacturer's Information		Name		Western Material and Design LLC				
		Address		P.O. Box 1157, 1612 East Elm St		Telephone		
		Harrisonville, MO 64701		Website		1-800-451-0173 www.wmdus.com		
Testing Results								
Date Received at Laboratory		October, 2015		Lot Number		41003851		
Requirement 1		February, 2016		Evaluated by		ERDC-MTC		
Date Tested	Requirement 2		-		Overall Result (Pass/Fail)		Requirement 1 *Pass	
	Recommended		-		Repair Classification		*Material did not pass all criteria limits, but does pass updated protocol.	
Testing Summary								
All tests conducted at 73°F unless specified otherwise								
Test Completed		Testing Specifics		Criteria		Mfg. Test Result		
Compressive Strength		ASTMC39		-		≥ 3,000 psi @ 2 hrs.		
				-		≥ 5,000 psi @ 1 day		
				-		≥ 5,000 psi @ 7 days		
				-		≥ 5,000 psi @ 28 days		
Flexural Strength		ASTMC78		-		≥ 350 psi @ 2 hrs.		
				-		≥ 600 psi @ 7 days		
				-		≥ 600 psi @ 28 days		
Bond Strength		ASTMC882		Repair Material to Repair Material		≥ 1,000 psi @ 1 day		
				Repair Material to Ordinary PCC		≥ 1,000 psi @ 1 day		
Modulus of Elasticity		ASTMC469		-		2 ≤ x ≤ 6 Mpsi @ 2 hrs.		
				-		2 ≤ x ≤ 6 Mpsi @ 28 days		
Time of Set		ASTMC191		-		Initial set: ≥ 15 min.		
				-		Final set: 25 - 35 min.		
Slump		ASTMC143		Within 5 min of added water		≥ 3 in.		
Length Change		ASTMC157		Stored in air		N/A		
				Stored in water		N/A		
Coeff. of Thermal Expansion		ASTMC 531		Begin test @ 7 days		≤ 12·10 ⁻⁶ °F ⁻¹		
Shrinkage Potential		ASTMC1581		-		≤ 40 µε @ 14 days		
				-		No cracking @ 28 days		
Freeze-Thaw Resistance		ASTMC666		Procedure A, based on 300 cycles		No current criteria		
Testing Notes and Observations								
Specimens air cured at laboratory environment (approximately 70°F and 50% RH) after demolding unless specific curing procedure required by individual ASTM standards								
Manufacturer's reported testing values were are of mortar constructed specimens (neat) *manufacturer reported compressive strength at 3 hr 3,500 psi								
Additional compressive strength results at 3 hr: 4,340 psi								
Additional bond strength results (psi) - 7 days to Ordinary PCC: 1,945 psi , 7 days to Repair Material: 2,290 psi								
ASTMC403 results- initial set: 48 min. final set: 69 min.								

Table A21. Magna-Crete.

Rigid Repair Material Evaluation Report							
Product Name:		Magna-Crete		Material Description:		Magnesium Phosphate	
Manufacturer's Information		Name		Henkel Americas (Locite)			
		Address		One Henkel Way, Rocky Hill		Telephone 1-860-571-5100	
		Rocky Hill, CT 06067		Website http://www.henkel.com/			
Testing Results							
Date Received at Laboratory		January 2014		Lot Number		L04108501	
Date Tested		Requirement 1		Evaluated by		ERDC-MTC	
		Requirement 2		Overall Result (Pass/Fail)		Requirement 1 F Requirement 2 P	
		Recommended		Repair Classification		-	
Testing Summary							
All tests conducted at 73°F unless specified otherwise							
Test Completed		Testing Specifics		Criteria		Pass/Fail	
Compressive Strength	ASTM C39	-		≥ 3,000 psi @ 2 hrs.		P	
		-		≥ 5,000 psi @ 1 day		F	
		-		≥ 5,000 psi @ 7 days		F	
		-		≥ 5,000 psi @ 28 days		P	
Flexural Strength	ASTM C78	-		≥ 350 psi @ 2 hrs.		P	
		-		≥ 600 psi @ 7 days		P	
		-		≥ 600 psi @ 28 days		P	
Bond Strength	ASTM C882	Repair Material to Repair Material		≥ 1,000 psi @ 1 day		P	
		Repair Material to Ordinary PCC		≥ 1,000 psi @ 1 day		P	
Modulus of Elasticity	ASTM C469	-		2 ≤ x ≤ 6 Mpsi @ 2 hrs.		P	
		-		2 ≤ x ≤ 6 Mpsi @ 28 days		F	
Time of Set	ASTM C191	-		Initial set: ≥ 15 min.		F	
		-		Final set: 25 - 35 min.		F	
Slump	ASTM C143	Within 5 min of added water		≥ 3 in.		P	
Length Change	ASTM C157	Stored in air		- 0.04% ≤ x ≤ +0.03% at 28 days		P	
		Stored in water		Not tested		P	
Coeff. of Thermal Expansion	ASTM C 531	Begin test @ 7 days		≤ 12·10 ⁻⁶ °F ⁻¹		P	
Shrinkage Potential	ASTM C1581	-		≤ 40 µε @ 14 days		P	
		-		No cracking @ 28 days		P	
Freeze-Thaw Resistance	ASTM C666	Procedure A, DF based on 300 cycles		No current criteria		P	
Aggregate Extension Notes Per Unit							
Extension Allowed By Manufacturer?		Y	Supplier	Green Brothers		Pass ASTM C33?	
Maximum Extension Allowed (% _{Volume})		25	Quarry	Crystal Springs		ASTM C128 BSG 2.51	
Product Yield (ft ³)		0.45	Material	Pea Gravel		Test Results Abs 2.9%	
Extension Used (% _{Volume})		25	Aggregate Volume (ft ³)		0.20	Nominal Weight Batched (lb) 12.50	
Moisture Corrections Applied Daily to Aggregate with ASTM D4959							
Testing Notes and Observations:							
Specimens air cured at laboratory environment (approximately 70°F and 50% RH) after demolding unless specific curing procedure required by individual ASTM standards							
Manufacturer's reported testing values are a mix of mortar (neat) or aggregate extended constructed specimens. Known specimen type results are indicated as shown.							
Additional compressive strength results (psi) - 3 hr: 3,620							
Additional bond strength results (psi) - 7 days to Ordinary PCC: 2,050 psi 7 days to Repair Material: 2,430 psi							
ASTM C403 results- initial set: 8 min. final set: 11 min.							
*High safety concern as product emits a strong, toxic ammonia fume when mixed							
*Material did not pass all Requirement 1 testing; however, testing was continued since other test times before and after met or close to criteria limits.							

Table A22. HD 50.

Rigid Repair Material Evaluation Report							
Product Name:		HD 50		Material Description:		Portland cement, latex modified, fiber reinforced	
Manufacturer's Information		Name		Dayton Superior Corp.			
		Address		1125 Byers Road		Telephone 1-888- 977-9600	
		Miamisburg, OH 45342		Website www.daytonsuperior.com			
Testing Results							
Date Received at Laboratory		January 2014		Lot Number		A4082005B	
Date Tested	Requirement 1		March 2015		Evaluated by		
	Requirement 2		January 2016		Overall Result (Pass/Fail)		
	Recommended		-		Repair Classification		
Testing Summary							
All tests conducted at 73°F unless specified otherwise							
Test Completed		Testing Specifics		Criteria	Mfg. Test Result	Lab Test Result	Pass/Fail
Compressive Strength	ASTM C39	-		$\geq 3,000 \text{ psi @ 2 hrs.}$	2,000 (C109 @ 1 hr)	4,080	P
		-		$\geq 5,000 \text{ psi @ 1 day}$	6,145 (C109)	4,700	F
		-		$\geq 5,000 \text{ psi @ 7 days}$	7,000 (C109)	6,370	P
		-		$\geq 5,000 \text{ psi @ 28 days}$	7,990 (C109)	6,980	P
Flexural Strength	ASTM C78	-		$\geq 350 \text{ psi @ 2 hrs.}$	Not tested	625	P
		-		$\geq 600 \text{ psi @ 7 days}$	Not tested	710	P
		-		$\geq 600 \text{ psi @ 28 days}$	Not tested	770	P
Bond Strength	ASTM C882	Repair Material to Repair Material		$\geq 1,000 \text{ psi @ 1 day}$	2,000	1,820	P
		Repair Material to Ordinary PCC		$\geq 1,000 \text{ psi @ 1 day}$	Not tested	1,550	P
Modulus of Elasticity	ASTM C469	-		$2 \leq x \leq 6 \text{ Mpsi @ 2 hrs.}$	Not tested	3.30	P
		-		$2 \leq x \leq 6 \text{ Mpsi @ 28 days}$	Not tested	4.70	P
Time of Set	ASTM C191	-		Initial set $\geq 15 \text{ min.}$	15-20	24	P
		-		Final set: 25 - 35 min.	25-30	27	P
Slump	ASTM C143	Within 5 min of added water		$\geq 3 \text{ in.}$	Not tested	11	P
Length Change	ASTM C157	Stored in air		$-0.04\% \leq x \leq +0.03\% \text{ at 28 days}$	-0.11	-0.0055	P
		Stored in water			0.06	0.0165	P
Coeff. of Thermal Expansion	ASTM C 531	Begin test @ 7 days		$\leq 12 \cdot 10^{-6} \text{ } ^\circ\text{F}^{-1}$	Not tested	7	P
Shrinkage Potential	ASTM C1581	-		$\leq 40 \text{ } \mu\text{e @ 14 days}$	Not tested	25.55	P
		-		No cracking @ 28 days	Not tested	none on 3 rings	P
Freeze-Thaw Resistance	ASTM C666	Procedure A, DF based on 300 cycles		No current criteria	No Mass Loss	5 @ 33 cycles	-
Aggregate Extension Notes Per Unit							
Extension Allowed By Manufacturer?		Y	Supplier	Green Brothers		Pass ASTM C33?	
Maximum Extension Allowed (% _{Volume})		60	Quarry	Crystal Springs		ASTM C128	BSG
Product Yield (ft ³)		0.42	Material	Pea Gravel		Test Results	Abs
Extension Used (% _{Volume})		50	Aggregate Volume (ft ³)		0.20	Nominal Weight Batched (lb)	
31.61							
Moisture Corrections Applied Daily to Aggregate with ASTM D4959							
Testing Notes and Observations							
Specimens air cured at laboratory environment (approximately 70°F and 50% RH) after demolding unless specific curing procedure required by individual ASTM standards							
Additional compressive strength results (psi) - 3 hr: 4,200							
Additional bond strength results (psi) - 7 days to Ordinary PCC: 2,390 psi 7 days to Repair Material: 2,960 psi							
ASTM C403 results- initial set: 23 min. final set: 26 min.							
*Material did not pass all Requirement 1 testing; however, testing was continued since other test times before and after met or close to criteria limits.							
Fails minimum criteria necessary for next highest approval rating:							

A.5 FY17 Rigid-Repair Material Evaluation Reports

See Tables A23 through A28.

Table A23. Rapid Set DOT Repair Mix.

Rigid Repair Material Evaluation Report								
Product Name:		Rapid Set DOT Repair Mix		Material Description:		Cementitious		
Manufacturer's Information		Name		CTS Cements Manufacturing Corp.				
		Address		11065 Knott Ave., Suite A		Telephone		
		Cypress, CA 90630		Website		1-800-929-3030 http://www.ctscement.com		
Testing Results								
Date Received at Laboratory		March, 2017		Lot Number		5300825612		
Date Tested	Requirement 1		April, 2017		Evaluated by		ERDC-MTC	
	Requirement 2		-		Overall Result (Pass/Fail)		Requirement 1 Pass Requirement 2 -	
Requirement 1								
Test Completed		Testing Specifics		Criteria		Mfg. Test Result		
Compressive Strength	ASTM C39	-		$\geq 2,500 \text{ psi @ 2 hrs.}$		4,600 ¹		
		-		$\geq 3,000 \text{ psi @ 3 hrs.}$		NA		
		-		$\geq 4,000 \text{ psi @ 1 day}$		6,800		
		-		$\geq 5,000 \text{ psi @ 7 days}$		7,200		
		-		$\geq 5,000 \text{ psi @ 28 days}$		9,000		
Flexural Strength	ASTM C78	-		$\geq 350 \text{ psi @ 2 hrs.}$		400 ²		
		-		$\geq 500 \text{ psi @ 7 days}$		650		
		-		$\geq 600 \text{ psi @ 28 days}$		850		
Bond Strength	ASTM C882	Repair Material to Repair Material		$\geq 1,000 \text{ psi @ 1 day}$		1,200		
		Repair Material to Repair Material		$\geq 1,250 \text{ psi @ 7 days}$		1,800		
		Repair Material to Ordinary PCC		$\geq 1,000 \text{ psi @ 1 day}$		NA		
		Repair Material to Ordinary PCC		$\geq 1,250 \text{ psi @ 7 days}$		NA		
Modulus of Elasticity	ASTM C469	-		$2 \leq x \leq 6 \text{ Mpsi @ 2 hrs.}$		NA		
		-		$2 \leq x \leq 6 \text{ Mpsi @ 28 days}$		4.50		
Time of Set	ASTM C191	-		Initial Set: $\geq 15 \text{ min.}$		10 minutes ³		
		-		Final Set: 15 - 90 min.		25 minutes ³		
Time of Set	ASTM C403	-		Initial Set: $\geq 15 \text{ min.}$		10 minutes ³		
		-		Final Set: 15 - 90 min.		25 minutes ³		
Slump	ASTM C143	Within 5 min of added water		$\geq 3 \text{ in.}$		6		
Requirement 2								
Test Completed		Testing Specifics		Criteria		Mfg. Test Result		
Length Change	ASTM C157	Stored in air		$-0.04\% \leq x \leq +0.03\% \text{ @ 28 days}$		NA		
		Stored in water				NA		
Coeff. of Thermal Expansion	ASTM C 531	Begin test @ 7 days		$\leq 8 \cdot 10^{-6} \text{ } ^\circ\text{F}^{-1}$		7.15		
Shrinkage Potential	ASTM C 1581	-		No cracking @ 28 days		NA		
Testing Notes and Observations								
¹ Manufacturer results at 3 hrs.								
² Manufacturer results at 4 hrs.								
³ Manufacturer documents the working time as 10 to 25 min.								
Mixing was performed with a drill-mounted mixer at a ratio of 4.5 quarts of water per 55 lb. of dry material with 50% extended pea gravel aggregate.								
Specimens moist cured at laboratory environment (approximately 70°F and 50% RH) after demolding.								

Table A24. Pavemend TR.

Rigid Repair Material Evaluation Report								
Product Name:		Pavemend TR		Material Description:		Magnesium Phosphate Cement		
Manufacturer's Information		Name		CeraTech				
		Address		1500 N. Beauregard St. Suite, 320		Telephone		
		Alexandria, VA 22311		Website		1-800-581-8397 www.ceratechinc.com		
Testing Results								
Date Received at Laboratory		March 2017		Lot Number		100215		
Date Tested	Requirement 1		June 2017		Evaluated by		ERDC-MTC	
	Requirement 2		-		Overall Result (Pass/Fail)		Requirement 1 F Requirement 2 -	
Requirement 1								
Test Completed		Testing Specifics		Criteria		Mfg. Test Result		
Compressive Strength	ASTM C39	-		$\geq 2,500 \text{ psi @ 2 hrs.}$		N/A		
		-		$\geq 3,000 \text{ psi @ 3 hrs.}$		NA		
		-		$\geq 4,000 \text{ psi @ 1 day}$		>3,000 psi		
		-		$\geq 5,000 \text{ psi @ 7 days}$		>3,000 psi		
		-		$\geq 5,000 \text{ psi @ 28 days}$		>3,000 psi		
Flexural Strength	ASTM C78	-		$\geq 350 \text{ psi @ 2 hrs.}$		N/A		
		-		$\geq 500 \text{ psi @ 7 days}$		N/A		
		-		$\geq 600 \text{ psi @ 28 days}$		N/A		
Bond Strength	ASTM C882	Repair Material to Repair Material		$\geq 1,000 \text{ psi @ 1 day}$		NA		
		Repair Material to Repair Material		$\geq 1,250 \text{ psi @ 7 days}$		NA		
		Repair Material to Ordinary PCC		$\geq 1,000 \text{ psi @ 1 day}$		NA		
		Repair Material to Ordinary PCC		$\geq 1,250 \text{ psi @ 7 days}$		NA		
Modulus of Elasticity	ASTM C469	-		$2 \leq x \leq 6 \text{ Mpsi @ 2 hrs.}$		N/A		
		-		$2 \leq x \leq 6 \text{ Mpsi @ 28 days}$		N/A		
Time of Set	ASTM C191	-		Initial Set: $\geq 15 \text{ min.}$		N/A		
		-		Final Set: 15 - 90 min.		N/A		
Time of Set	ASTM C403	-		Initial Set: $\geq 15 \text{ min.}$		N/A		
		-		Final Set: 15 - 90 min.		N/A		
Slump	ASTM C143	Within 5 min of added water		$\geq 3 \text{ in.}$		N/A		
Requirement 2								
Test Completed		Testing Specifics		Criteria		Mfg. Test Result		
Length Change	ASTM C157	Stored in air		$-0.04\% \leq x \leq +0.03\% \text{ @ 28 days}$		NA		
		Stored in water				NA		
Coeff. of Thermal Expansion	ASTM C 531	Begin test @ 7 days		$\leq 7 \cdot 10^{-6} \text{ } ^\circ\text{F}^{-1}$		7.15		
Shrinkage Potential	ASTM C1581	-		No cracking @ 28 days		NA		
Testing Notes and Observations								
Bucket mixing was performed with a drill and paddle mixer.								
50% aggregate extention mixed with 3/8" clean washed pea gravel								

Table A25. T545 (Formerly Set 45).

Rigid Repair Material Evaluation Report								
Product Name:		T 545 (Formerly Set 45)		Material Description:		Very rapid-setting chemical action mortar		
Manufacturer's Information		Name		Master Builder Solutions by BASF				
		Address		889 Valley Park Drive		Telephone 1-800-243-6739		
		Shakopee, MN 55379		Website www.master-builders-solutions.basf.us				
Testing Results								
Date Received at Laboratory		March, 2017		Lot Number		67008799		
Date Tested	Requirement 1		June, 2017		Evaluated by		ERDC-MTC	
	Requirement 2		-		Overall Result (Pass/Fail)		Requirement 1 P Requirement 2 -	
Requirement 1								
Test Completed		Testing Specifics		Criteria		Mfg. Test Result		
Compressive Strength	ASTM C39	-		$\geq 2,500 \text{ psi @ 2 hrs.}$		2000 ¹		
		-		$\geq 3,000 \text{ psi @ 3 hrs.}$		NA		
		-		$\geq 4,000 \text{ psi @ 1 day}$		6,000		
		-		$\geq 5,000 \text{ psi @ 7 days}$		NA		
		-		$\geq 5,000 \text{ psi @ 28 days}$		8,500		
Flexural Strength	ASTM C78	-		$\geq 350 \text{ psi @ 2 hrs.}$		NA		
		-		$\geq 500 \text{ psi @ 7 days}$		NA		
		-		$\geq 600 \text{ psi @ 28 days}$		NA		
Bond Strength	ASTM C882	Repair Material to Repair Material		$\geq 1,000 \text{ psi @ 1 day}$		NA		
		Repair Material to Repair Material		$\geq 1,250 \text{ psi @ 7 days}$		NA		
		Repair Material to Ordinary PCC		$\geq 1,000 \text{ psi @ 1 day}$		NA		
		Repair Material to Ordinary PCC		$\geq 1,250 \text{ psi @ 7 days}$		NA		
Modulus of Elasticity	ASTM C469	-		$2 \leq x \leq 6 \text{ Mpsi @ 2 hrs.}$		4.9		
		-		$2 \leq x \leq 6 \text{ Mpsi @ 28 days}$		5.25		
Time of Set	ASTM C191	-		Initial Set: $\geq 15 \text{ min.}$		9-15 ²		
		-		Final Set: 15 - 90 min.		10-20 ²		
Time of Set	ASTM C403	-		Initial Set: $\geq 15 \text{ min.}$		9-15 ²		
		-		Final Set: 15 - 90 min.		10-20 ²		
Slump	ASTM C143	Within 5 min. of added water		$\geq 3 \text{ in.}$		NA		
Requirement 2								
Test Completed		Testing Specifics		Criteria		Mfg. Test Result		
Length Change	ASTM C157	Stored in air		$-0.04\% \leq x \leq +0.03\% \text{ @ 28 days}$		NA		
		Stored in water				NA		
Coeff. of Thermal Expansion	ASTM C 531	Begin test @ 7 days		$\leq 7 \cdot 10^{-6} \text{ } ^\circ\text{F}^{-1}$		7.15		
Shrinkage Potential	ASTM C1581	-		No cracking @ 28 days		NA		
Testing Notes and Observations								
¹ Manufacturer testing results at 3 hours								
² Manufacturer testing results based on ASTM C266 Gikmore modified								
Mixing was performed with a single paddle mixer for 1 1/2 minutes at a ratio of 4 pints of water per 50 lbs of dry material and 50% pea gravel aggregate extension								
Specimens dry cured at laboratory environment (approximately 70°F and 50% RH) after demolding								

Table A26. T545T (Formerly Set 45HT).

Rigid Repair Material Evaluation Report										
Product Name:		T 545HT (Formerly Set 45HT)			Material Description:		Very rapid-setting chemical action mortar			
Manufacturer's Information		Name		Master Builder Solutions by BASF						
		Address		889 Valley Park Drive		Telephone		1-800-243-6739		
				Shakopee, MN 55379		Website		www.master-builders-solutions.basf.us		
Testing Results										
Date Received at Laboratory		March, 2017		Lot Number		67008800		Aggregate Extension?		Yes, 50%
Date Tested	Requirement 1		June, 2017		Evaluated by		ERDC-MTC		Vicksburg, MS 39180	
	Requirement 2		-		Overall Result (Pass/Fail)		Requirement 1		P	Requirement 2
Requirement 1										
Test Completed		Testing Specifics		Criteria		Mfg. Test Result		Lab Test Result		Pass/Fail
Compressive Strength	AS TM C39	-		$\geq 2,500$ psi @ 2 hrs.		3,000 ¹		2,640		P
		-		$\geq 3,000$ psi @ 3 hrs.		NA		3,170		P
		-		$\geq 4,000$ psi @ 1 day		6,000		4,110		P
		-		$\geq 5,000$ psi @ 7 days		NA		5,240		P
		-		$\geq 5,000$ psi @ 28 days		8,500		6,250		P
Flexural Strength	AS TM C78	-		≥ 350 psi @ 2 hrs.		NA		355		P
		-		≥ 500 psi @ 7 days		NA		520		P
		-		≥ 600 psi @ 28 days		NA		615		P
Bond Strength	AST M C 882	Repair Material to Repair Material		$\geq 1,000$ psi @ 1 day		NA		1,580		P
		Repair Material to Repair Material		$\geq 1,250$ psi @ 7 days		NA		1,780		P
		Repair Material to Ordinary PCC		$\geq 1,000$ psi @ 1 day		NA		1,130		P
		Repair Material to Ordinary PCC		$\geq 1,250$ psi @ 7 days		NA		1,530		P
Modulus of Elasticity	AST M C 469	-		$2 \leq x \leq 6$ Mpsi @ 2 hrs.		4.9		2.72		P
		-		$2 \leq x \leq 6$ Mpsi @ 28 days		5.25		5.32		P
Time of Set	AST M C 191	-		Initial Set: ≥ 15 min.		9-15 ²		16		P
		-		Final Set: 15 - 90 min.		10-20 ²		21		P
Time of Set	AST M C 403	-		Initial Set: ≥ 15 min.		9-15 ²		20		P
		-		Final Set: 15 - 90 min.		10-20 ²		24		P
Slump	AST M C 143	Within 5 min of added water		≥ 3 in.		NA		8		P
Requirement 2										
Test Completed		Testing Specifics		Criteria		Mfg. Test Result		Lab Test Result		Pass/Fail
Length Change	AST M C 157	Stored in air		$-0.04\% \leq x \leq +0.03\%$ @ 28 days		NA		-		-
		Stored in water				NA		-		-
Coeff. of Thermal Expansion	AST M C 531	Begin test @ 7 days		$\leq 7 \cdot 10^{-6}$ °F ⁻¹		7.15		-		-
Shrinkage Potential	AST M C1581	-		No cracking @ 28 days		NA		-		-
Testing Notes and Observations										
¹ Manufacturer testing results at 3 hours										
² Manufacturer testing results based on ASTM C266 Gilmore modified										
Mixing was performed with a single paddle mixer for 1 1/2 minutes at a ratio of 4 pints of water per 50 lbs of dry material and 50% pea gravel aggregate extension										
Specimens dry cured at laboratory environment (approximately 70°F and 50% RH) after demolding										

Table A27. Rapid Set Concrete Mix.

Rigid Repair Material Evaluation Report							
Product Name:		Rapid Set Concrete Mix		Material Description:		Cementitious	
Manufacturer's Information		Name	CTS Cements Manufacturing Corp.				
		Address	11065 Knott Ave., Suite A		Telephone	1-800-929-3030	
		Cypress, CA 90630		Website	http://www.ctscement.com		
Testing Results							
Date Received at Laboratory		March, 2017	Lot Number	5301012614		Aggregate Extension?	No
Date Tested	Requirement 1	April, 2017	Evaluated by	ERDC-MTC		Vicksburg, MS 39180	
	Requirement 2	-	Overall Result (Pass/Fail)	Requirement 1	P*	Requirement 2	-
*The following data summary for the CTS Concrete Mix represent test specimen fabricated from the manufacturer's lowest recommended water content of 3.5 quarts per 60 lb. bag. The product passed all requirements except the slump criteria.							
Requirement 1							
Test Completed		Testing Specifics		Criteria	Mfg. Test Result	Lab Test Result	Pass/Fail
Compressive Strength	ASTM C39	-		$\geq 2,500 \text{ psi @ 2 hrs.}$	3,600 ¹	3,630	P
		-		$\geq 3,000 \text{ psi @ 3 hrs.}$	NA	4,080	P
		-		$\geq 4,000 \text{ psi @ 1 day}$	4,500 psi	4,530	P
		-		$\geq 5,000 \text{ psi @ 7 days}$	5,500 psi	5,040	P
		-		$\geq 5,000 \text{ psi @ 28 days}$	6,000 psi	5,710	P
Flexural Strength	ASTM C78	-		$\geq 350 \text{ psi @ 2 hrs.}$	NA	460	P
		-		$\geq 500 \text{ psi @ 7 days}$	500 psi	540	P
		-		$\geq 600 \text{ psi @ 28 days}$	550 psi	605	P
Bond Strength	ASTM C882	Repair Material to Repair Material		$\geq 1,000 \text{ psi @ 1 day}$	1,200	2,200	P
		Repair Material to Repair Material		$\geq 1,250 \text{ psi @ 7 days}$	NA	2,620	P
		Repair Material to Ordinary PCC		$\geq 1,000 \text{ psi @ 1 day}$	NA	1,800	P
		Repair Material to Ordinary PCC		$\geq 1,250 \text{ psi @ 7 days}$	NA	2,130	P
Modulus of Elasticity	ASTM C469	-		$2 \leq x \leq 6 \text{ Mpsi @ 2 hrs.}$	NA	3.34	P
		-		$2 \leq x \leq 6 \text{ Mpsi @ 28 days}$	4.55	4.08	P
Time of Set	ASTM C191	-		Initial Set: $\geq 15 \text{ min.}$	NA	18	P
		-		Final Set: 15 - 90 min.	NA	23	P
Time of Set	ASTM C403	-		Initial Set: $\geq 15 \text{ min.}$	15 min.	20	P
		-		Final Set: 15 - 90 min.	35 min.	25	P
Slump	ASTM C143	Within 5 min of added water		$\geq 3 \text{ in.}$	4	3	P
Requirement 2							
Test Completed		Testing Specifics		Criteria	Mfg. Test Result	Lab Test Result	Pass/Fail
Length Change	ASTM C157	Stored in air		$-0.04\% \leq x \leq +0.03\% \text{ @ 28 days}$	NA	-	-
		Stored in water			NA	-	-
Coeff. of Thermal Expansion	ASTM C 531	Begin test @ 7 days		$\leq 7 \cdot 10^{-6} \text{ }^{\circ}\text{F}^{-1}$	7.15	-	-
Shrinkage Potential	ASTM C1581	-		No cracking @ 28 days	NA	-	-
Testing Notes and Observations							
¹ Manufacturer Data at 3 hrs.							
Mixing was performed with a single paddle mixer at a lowest recommended water content of 3.5 quarts of water per 60 lbs of dry material							

Table A28. T1061 (Formerly 10-61 Rapid Mix).

Rigid Repair Material Evaluation Report											
Product Name:		T 1061 (Formerly 10-61 Rapid Mortar)			Material Description:		Rapid-setting cement based concrete repair mortar				
Manufacturer's Information		Name		Master Builder Solutions by BASF							
		Address		889 Valley Park Drive		Telephone		1-800-243-6739			
				Shakopee, MN 55379		Website		www.master-builders-solutions.basf.us			
Testing Results											
Date Received at Laboratory		March, 2017		Lot Number		67008791		Aggregate Extension?		Yes, 50%	
Date Tested	Requirement 1		June, 2017		Evaluated by		ERDC-MTC		Vicksburg, MS 39180		
	Requirement 2		-		Overall Result (Pass/Fail)		Requirement 1		F	Requirement 2	-
Requirement 1											
Test Completed		Testing Specifics			Criteria		Mfg. Test Result		Lab Test Result		Pass/Fail
Compressive Strength	AS TMC39	-			$\geq 2,500$ psi @ 2 hrs.		3,000 ^{1,2}		1,270		F
		-			$\geq 4,000$ psi @ 1 day		4,000		5,690		P
		-			$\geq 5,000$ psi @ 7 days		NA		6,280		P
		-			$\geq 5,000$ psi @ 28 days		8,000		7,770		P
Flexural Strength	AS TMC78	-			≥ 350 psi @ 2 hrs.		NA		150		F
		-			≥ 500 psi @ 7 days		NA		840		P
		-			≥ 600 psi @ 28 days		850		860		P
Bond Strength	AS TMC882	Repair Material to Repair Material			$\geq 1,000$ psi @ 1 day		2,300		1,970		P
		Repair Material to Repair Material			$\geq 1,250$ psi @ 7 days		NA		2,710		P
		Repair Material to Ordinary PCC			$\geq 1,000$ psi @ 1 day		NA		1,880		P
		Repair Material to Ordinary PCC			$\geq 1,250$ psi @ 7 days		NA		2,360		P
Modulus of Elasticity	AS TMC469	-			$2 \leq x \leq 6$ Mpsi @ 2 hrs.		NA		3.27		P
		-			$2 \leq x \leq 6$ Mpsi @ 28 days		4.60		6.12		F
Time of Set	AS TMC191	-			Initial Set: ≥ 15 min.		50		111		F
		-			Final Set: 15 - 90 min.		80		124		F
Time of Set	AS TMC403	-			Initial Set: ≥ 15 min.		NA		72		F
		-			Final Set: 15 - 90 min.		NA		88		F
Slump	AS TMC143	Within 5 min of added water			≥ 3 in.		NA		2		F
Requirement 2											
Test Completed		Testing Specifics			Criteria		Mfg. Test Result		Lab Test Result		Pass/Fail
Length Change	AS TMC157	Stored in air			$-0.04\% \leq x \leq +0.03\%$ @ 28 days		NA		-		-
		Stored in water					NA		-		-
Coeff. of Thermal Expansion	AS TMC 531	Begin test @ 7 days			$\leq 7 \cdot 10^{-6}$ °F ⁻¹		7.15		-		-
Shrinkage Potential	AS TMC1581	-			No cracking @ 28 days		NA		-		-
Testing Notes and Observations											
¹ Manufacturer testing results at 3 hours											
² Manufacturer testing results based on ASTM C109 cubes											
Mixing was performed with a single paddle mixer for 3 minutes at a ratio of 5 1/2 pints of water per 50 lbs of dry material and 50% pea gravel aggregate extension											
Specimens dry cured at laboratory environment (approximately 70°F and 50% RH) after demolding											

Unit Conversion Factors

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
cubic yards	0.7645549	cubic meters
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
inches	0.0254	meters
ounces (mass)	0.02834952	kilograms
ounces (U.S. fluid)	2.957353 E-05	cubic meters
pints (U.S. liquid)	4.73176 E-04	cubic meters
pints (U.S. liquid)	0.473176	liters
pounds (force)	4.448222	newtons
pounds (force) per foot	14.59390	newtons per meter
pounds (force) per inch	175.1268	newtons per meter
pounds (force) per square foot	47.88026	pascals
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.45359237	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic meter
pounds (mass) per cubic inch	2.757990 E+04	kilograms per cubic meter
pounds (mass) per square foot	4.882428	kilograms per square meter
pounds (mass) per square yard	0.542492	kilograms per square meter
quarts (U.S. liquid)	9.463529 E-04	cubic meters
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters

REPORT DOCUMENTATION PAGE

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14. ABSTRACT The rapid-setting cementitious material certification program is part of a research effort to assist the U.S. Air Force Civil Engineering Center in the execution of independent testing on select commercially available proprietary products to repair partial-depth spalls in airfield concrete pavements. The purpose of this research was to determine whether the existing requirements for evaluating rapid-repair products for spall repairs were sufficient or further refinement and modifications were needed. This protocol is intended to aid airfield managers and repair teams in the selection of optimal spall repair materials by maintaining a database of approved tested products. This report presents the test methods and results of 26 cementitious rapid-setting repair products tested at the U.S. Army Engineer Research and Development Center in Vicksburg, MS, during 2013 to 2017. An evaluation of these test methods and results, along with the historic database of products tested, led to the development of an updated testing protocol for assessing a material's suitability for airfield spall repairs. Based on the revised criteria, 10 products were identified as most compatible for partial-depth airfield pavement concrete spall repairs.					
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