Review of Current Standards and Patching Products for Rapid Setting Partial Depth Repairs used on Concrete Pavements and Bridge Decks

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ABSTRACT

Partial depth concrete repairs are an extremely common way to fix parts of deteriorating concrete infrastructure and structural components. Concrete pavements and bridge decks are in need of quick fixes that are durable and long-lasting so more time and effort can be put into replacing or rebuilding our country's main method of transportation. This literature review examines the current standards of practice for partial depth concrete repairs through current agency specifications and specific state practices. The details and laboratory testing specifications of the products used in concrete repairs are investigated to see what qualities of partial depth repair materials they reflect. Combinations of products and materials are explored to see what they have to offer the concrete partial depth repair industry.

INTRODUCTION

The objective of this literature review was to examine the current agency specifications for partial depth repairs, compare five states approved products lists, see what ASTM specifications govern the properties that partial depth repair materials possess, and analyze what materials are successful. The three agencies examined are the Federal Highway Administration, the American Concrete Pavement Association, and the National Concrete Pavement Technology Center for their vast involvement and research into partial depth repairs. The five states, California, Illinois, Iowa, Minnesota, and Missouri, were chosen due to the their abundance of concrete roadways and impressive state highway departments. This literature review summarizes the key findings of each agency, state, and ASTM standard, then analyzes the most effective partial depth repair materials available, and finally, questions the possibility of creating a newer and more powerful partial depth repair materials through the use of existing products.

CURRENT AGENCY SPECIFICATIONS

Definition of a Partial Depth Repair

Federal Highway Administration. The Federal Highway Administration defines a partial depth repair as the removal of concrete and replacement of a repair material on a shallow, deteriorated area of a concrete structure (Smith and Harrington 2014). They are mainly used in areas where the deterioration of the pavement structure is less than one-third to one-half of the total depth of the pavement layer (Smith and Harrington 2014). Partial depth repairs can last up to 15 or more years when constructed correctly, but can fail in as little as two to three years if done improperly (Smith and Harrington 2014). Successful and long-term partial depth repairs depend on the existing condition of the pavement, the materials used for the repair, and the equipment and construction techniques used (Smith and Harrington). Some examples of where partial depth repairs have been effective can be found in *Concrete Pavement Preservation Guide, Second Edition* by Smith and Harrington.

American Concrete Pavement Association. The American Concrete Pavement Association defines a partial depth repair as a rehabilitation technique to restore areas of spalling, deterioration, and distress around areas of joints and cracks in the upper one-third to one-half of a pavement slab (ACPA 1998). These partial depth repairs are small in nature, only covering about 1.2 square yards (1 sq. m) and only reaching about two to three inches (50-75 mm) into a pavement slab (ACPA 1998). Once spalls and deterioration on the surface begin, the constant loading that the pavement slab receives in that area will continue to make the failure worse, possibly resulting in a full depth repair (ACPA 1998). To fix these pavement failures with a partial depth repair, four basic steps are taken, removing and examining the area of the repair, cleaning the existing concrete, placing the repair material and any other additional materials, and reestablishing the joints (ACPA 1998).

National Concrete Pavement Technology Center. The National Concrete Pavement Technology Center defines partial depth repairs as the removal and replacement of small areas of deteriorated concrete pavement, that either slow down and eliminate the spreading of spalling and distresses caused by traffic loading and weather conditions (Frentress and Harrington 2012). These repairs significantly improve the quality of riding and driving on the road surface, they rebuild the structural integrity of the slab, and they extend the service life of the concrete pavement for up to 10-15 years when the proper materials are chosen (Frentress and Harrington 2012). According to the National Concrete Pavement Technology Center, it was originally believed that partial depth repairs were only limited to the top one-third of a pavement slab, that was however, until several colder weather states tried using partial depth repairs as deep as one-half of the slab thickness. Because of success with partial depth repairs at this depth into the slab, most states have amended to this rule (Frentress and Harrington 2012).

Types of Partial Depth Repairs

Federal Highway Administration. The Federal Highway Administration has separated partial depth repairs into three different categories:

Type 1: Spot Repairs of Cracks, Joints, and Spalls (Smith and Harrington 2014)

- Repairs that address small areas where pavement has failed
- Work well for the following types of repairs:
    - Joint spalling
    - Mid-slab surface spalling or cracking
    - Severe surface scaling
    - Joint reservoir issues
- The removal of concrete for these types of repairs involves sawing the damaged area and then jackhammering out the old concrete
- Removal can also be done used a milling machine to mill the concrete

Type 2: Joint Crack Repairs (Smith and Harrington 2014)

- These repairs are done along longitudinal or transverse joints where the cracked concrete is longer than six feet (1.8 m) and the maximum depth is no more than one-half of the depth of the slab
- For transverse joint crack repairs it is important to saw down to the joint at its full depth with an additional 0.25 to one inch (6-25 mm)
- For longitudinal joint repairs, the repair material only needs to be installed on the surface of the crack

Type 3: Bottom Half Repairs (Smith and Harrington)

- Best when fixing the edges of a slab that has failure deeper than one-half of the slab thickness
- Similar to a full depth repairs, but only used to fix the corners and edges of a pavement slab
- These types of partial depth repairs should be limited to a length of 18 inches (460 mm)
- Full depth repairs are recommended to be used when the repair is longer than 18 inches (460 mm) and when the crack extends into lanes on either side of the longitudinal joint

American Concrete Pavement Association. The American Concrete Pavement Association categorizes partial depth repairs in two different forms, repairs from spalling and repairs from cracking. The first form, repairs from spalling, involves the spalling of concrete, or, the complete breaking apart of concrete (ACPA 1998). One common place for spalling to occur is along a transverse joint where the joint is prevented from closing due to blockages between the joints. These blockages can be rocks, sand, and other material fragments that fit between the joints when they are open in cooler weather (ACPA 1998). Another cause of spalling at a joint is from plastic inserts that help to form the joints when the concrete is first set. The paste at the top of the slab can become spalled and scaled when these inserts bring water to the surface of the slab, altering the water-cementitious materials ratio, which causes

the paste to spall (ACPA 1998). Similarly to plastic inserts, metal inserts can also cause failure at the slab surface in the form of spalling. The rising water reacts with the metal inserts to create corrosion, which then breaks down to cause fragments that lodge between joints to cause breaking and spalling of the concrete (ACPA 1998). Any spall larger than two inches (50 mm) in length is considered to cause an affect to the riding quality of the pavement slab, and should be fixed with a partial depth repair (ACPA 1998).

The second form of partial depth repairs is a repair caused by cracking. Cracking is defined as the chipping and fraying of concrete at joints and edges that is within about two inches (50 mm) (ACPA 1998). These types of cracks typically run as a fracture through the whole slab, therefore, full depth repairs are used majority of the time for repairs caused by cracking. However, the determination between a full depth repair and a partial depth repair is still dependent on the condition and circumstances of the crack itself (ACPA 1998). A partial depth repair caused by cracking would most likely be used in a scenario where a combination of spalling and cracking is present (ACPA 1998).

National Concrete Pavement Technology Center. The National Concrete Pavement Technology Center groups partial depth repairs into three categories:

Spot Repairs of Joints, Cracks, and Spalls (Frentress and Harrington 2012)

- Used mostly with small, isolated areas of failure that are not intended to be long and continuous
- Repairs joint spalling, mid-slab surface spalling or cracking, severe scaling, and is used to restore joint reservoirs
- Normally with pavement slabs where the existing load transferring devices are still functioning
- Any repairs that are considered as spot repairs and are closer than two feet from each other can be combined to create one spot repair

Extended Length Repairs (Frentress and Harrington 2012)

- The two types of repairs within this category are longitudinal joints and transverse joints
- Typically always longer than six feet in length, and will reach as deep as one-half of the slab thickness
- The first step towards repairing extended length joints is to reconstruct the joint by sawing

Bottom-Half Spot Repairs (Frentress and Harrington 2012)

- Even though bottom-half repairs are typically at locations where failure has reached deeper than one-half of the slab thickness, they occur on the outer edges of the pavement, allowing for a partial depth repair to effectively repair the damage
- For bottom half repairs to become full depth repairs, they must be wider than 18 inches (457 mm) at the bottom of the repair or longer than 18 inches (457 mm) transversely. However, bottom half partial depth repairs can be longer than 18 inches (457 mm) along a centerline.

Material Selection of Partial Depth Repairs

Federal Highway Administration. The Federal Highway Administration recommends choosing a more expensive repair material with higher performance qualities that will not be covered, and will be exposed to traffic and climate right away (Wilson et al. 1999). There are a number of factors to consider when choosing the right repair material for a partial depth repair. These factors can include, but are not limited to available curing time, placement conditions (such as ambient temperature and moisture levels), material properties (such as shrinkage, coefficient of thermal expansion, and bond strength), material costs, placement costs, location of nearest ready-mix plant (may need to use a portable mixer), compatibilities between the repair material and existing pavement, size and depth of the repair, performance capabilities of the materials, and project size (Smith and Harrington 2014, Johnson et al. 1980). Specifically, when comparing costs of repair materials, it is important to think about the material, installation, equipment, labor, and time (Wilson et al. 1999).

The Federal Highway Administration believes there are two parameters that should be made a priority when selecting the right repair material. The first parameter is the available curing time of the material. This is highly considered due to the fact that roadway may have a specific reopening timeframe that must be met (Smith and Harrington 2014). The other parameter is the drying shrinkage of the repair material. This is important because drying shrinkage of a repair material can induce a tensile stress of up to 1,000 pounds per square foot (6,900 kPa) compared to that of normal concrete (Smith et al. 2008).

The Federal Highway Administration also requires some documentation of the material before it is chosen for repair. They require that it be verified that it is obtained from an approved source off of the Qualified Products List from the contract documents of the project, that it be sampled and tested prior to installation, and that if there is a bonding agent to be used between the existing concrete and repair material, that it meets the correct specifications (FHWA 2005).

American Concrete Pavement Association. The American Concrete Pavement Association reviews the process for material selection with three categories, circumstantial factors, material qualities, and material properties. Circumstantial factors are the factors that change from project to project that can affect the performance of the concrete depending on the material chosen. Material qualities are the qualities that determine the way the concrete will behave dependent on material selection. And lastly, material properties are the measureable quantities that aid in choosing the right repair material for the job.

Circumstantial Factors (ACPA 1998):

- Time and availability before opening to traffic
- Air temperature during construction
- Funding
- Desired service life
- Size and depth of the patches

Material Qualities (ACPA 1998):

- Good workability
- Quick mixing time
- Fast setting time
- Rapid strength development
- Low shrinkage
- Strong bond capability
- Good long-term strength and durability
- Thermal compatibility with existing concrete
- Reasonable cost

Material Properties (ACPA 1998):

- Strength gain
- Modulus of elasticity
- Bond strength
- Freeze-thaw resistance
- Scaling resistance
- Sulfate resistance
- Abrasion resistance
- Coefficient of thermal expansion
- Shrinkage (volume changes)

National Concrete Pavement Technology Center. According to the National Concrete Pavement Technology Center, the most widely used parameter when selecting a partial depth repair material is the compressive strength of the mixture at any given time during the existence of the repair. This is because the existing concrete of the pavement slab carries tensile stresses, and the repair material only carries compression stresses (Frentress and Harrington 2012). The recommended minimum amount of strength required for no further damage of the concrete is between 1,600 psi and 1,800 psi (11 MPa to 12.5 MPa) (Frentress and Harrington 2012).

When selecting a repair material it is also very important to consider allowable lane closure time, shrinkage characteristics coefficient of thermal expansion, ambient temperature, cost, size of the repair, and estimated performance of the repair (Frentress and Harrington 2012). The coefficient of thermal expansion and shrinkage of the repair material are important characteristics to compare with the existing concrete because if they are not compatible to the concrete already in place, then the repair will ultimately experience an early failure (Frentress and Harrington 2012). Early failure of a partial depth repair can also be caused by incompatibility between the joint bond breaker and the joint sealant, inadequate cure time prior to opening the repair to traffic, incompatibilities between the climate conditions and the materials or procedures used, and extreme climate conditions during the life of the repair that may be beyond the control of the repair material (Frentress and Harrington 2012). Freeze-thaw durability must also be considered when choosing a rapid strength gaining material because of the material's susceptibility to durability with its short curing time (Frentress and Harrington 2012).

Recommended Repair Materials

Federal Highway Administration. The Federal Highway Administration recommends the following materials as sufficient for partial depth repairs:

Concrete Materials

- Portland Cement Concrete
    - Cement types I, II, and III are used with coarse aggregate not larger than one-half the repair depth (Smith et al. 2008)
    - Type I is most commonly used because of its low cost, abundant availability, and ease of use (Smith and Harrington 2014)
    - Should be air entrained with a low slump an a maximum water-cementitious materials ratio of 0.44 (Smith and Harrington 2014)
    - Typical minimum compressive strength values are between 1,600 and 1,800 pounds per square inch (11-12.5 MPa) to support traffic with no deterioration (Smith and Harrington 2014)
- Gypsum-Based Cement Concrete
    - Because of its calcium sulfate content, this cement is good for pavements that need to be reopened quickly with its low setting times of 20-40 minutes (Smith and Harrington 2014)
    - Should only be used in temperatures above freezing and requires dry ambient conditions during placement (Smith and Harrington 2014)
    - With its high calcium sulfate content, it should not be used for repairing reinforced pavements for the prevention of steel corrosion from the free sulfates in gypsum (Smith et al. 2008)
- Calcium Aluminate Concrete
    - Generally have low shrinkage during curing, good bonding properties, gains strength rapidly, and has good resistance to freezing and thawing cycles and deicing chemicals (Smith and Harrington 2014)
    - Work well for low temperature pavement repairs because it can still contribute early strength (Smith and Harrington 2014)
    - Not recommended for high temperature pavement repairs because of the potential for strength loss during curing (Smith et al. 2008)
- Magnesium Phosphate Concrete
    - Can be classified as a one- or two-component system. The one-component system is a magnesium and phosphate mixed as a powdered form that is added to water. The two-component system is a magnesium powder and aggregate combined with a phosphate liquid solution (Smith and Harrington 2014)
    - Yields a high early strength and sets very quickly (Smith and Harrington 2014)
    - It is an impermeable material that bonds well with clean and dry surfaces (Smith and Harrington 2014)
    - This mixture can set in as little as 10-15 minutes when in hot weather where the temperature is above 90 °F (32 °C) (Smith et al. 2008)

Polymer-Based Concrete Materials

- Polyurethane-Based Concrete
  - In general, this concrete consists of a two-part polyurethane resin that is combined with aggregate (Wilson et al. 1999)
  - Even though they have a high coefficient of thermal expansion and display high amounts of initial shrinkage, this concrete is usually flexible and fast setting in about 90 seconds (Smith and Harrington 2014)
  - Some mixtures of this concrete can be placed on existing concrete that is wet without any adverse effects to the quality of the concrete (Smith et al. 2008)
- Epoxy Polymer Concrete
  - Classified as a one-component system consisting of a liquid epoxy resin mixed with a curing agent (Smith and Harrington 2014)
  - This concrete has great impermeability and adhesive properties (Smith and Harrington 2014)
  - Has an extensive range of setting times, application temperatures, and bonding conditions (Smith and Harrington 2014)
  - Required to be compatible with the existing concrete pavement due to its high coefficient of thermal expansion (Smith and Harrington 2014)
- Methyl Methacrylate Concrete
  - It is a volatile substance that can be a health hazard to those who are exposed to its fumes for an extended period of time during placement (Smith et al. 2008)
  - Have high compressive strengths, long working times, and good adhesion (Smith et al. 2008)
  - Can be placed in temperatures from 40 to 130 °F (4 to 54 °C) (Smith et al. 2008)
- Polyester-Styrene Concrete
  - Very similar to Methyl Methacrylate Concrete and its properties, however the rate of strength gain is much slower, limiting reopening times (Smith et al. 2008)
  - More cost-effective than Methyl Methacrylate Concrete, so it is generally used more frequently (Smith et al. 20080

Bituminous Materials

- Conventional Bituminous Materials
  - Mainly considered only as a temporary or emergency repair material (Smith and Harrington 2014)
  - Low in cost, widely available, easy to handle, and have very low cure times (Smith and Harrington 2014)
  - They can be used anywhere and in all climate types (Wilson et al. 1999)
- Proprietary and Modified Bituminous Materials
  - Perform better than Conventional Bituminous Materials, however they are more expensive (Smith and Harrington 2014)

- Can be placed along transverse joints without reforming the joint, therefore speeding up the replacement process (Smith and Harrington 2014)

American Concrete Pavement Association. The American Concrete Pavement Association recommends the following materials as sufficient for partial depth repairs:

Cementitious Repair Materials

- Normal Concrete
  - It is best to use normal concrete mixes with Type I cement when the pavement slab can be closed for more than 24 hours to traffic (ACPA 1998)
  - When selecting aggregate for a normal concrete mix, the aggregate size cannot be greater than one-half of the depth of the partial depth repair (ACPA 1998)
  - Normal concrete should never be placed in ambient temperatures below 40 °F (4 °C), but can be placed at ambient temperatures below 55 °F (13 °C) with a longer curing period (ACPA 1998)
- High-Early Strength Portland Cement Concrete (PCC)
  - This concrete can be open to traffic in as little as four hours with a an early strength of 3000 psi (21 MPa) due to the use of Type III cement (ACPA 1998)
- Gypsum-Based (Calcium Sulfate) Cement
  - Gypsum-based cement is best used where ambient temperatures are above freezing, but no more than 110 °F (43 °C) (ACPA 1998)
- Magnesium Phosphate Cement and Magnesium Ammonium Phosphate Cement
  - Normal setting mixes are made in small batches and mixed quickly because of their relatively short setting time (ACPA 1998)
  - Retarded setting mixes consist of magnesium ammonium phosphate cement, which was originally created for hot summer days where the ambient temperatures can reach about 85 °F (29 °C) (ACPA 1998)
  - Intermediate setting mixes also consist of magnesium ammonium phosphate cement, but range in between normal and retarded mixtures for setting time (ACPA 1998)
  - Normal, retarded, and intermediate setting mixes are all sensitive to the moisture content of the existing concrete, and cannot be used with pavement slabs known to have used limestone aggregates (ACPA 1998)
  - These cements have a great bond strength to any clean and dry surface (ACPA 1998)
- Alumina Powder
  - Best used with Type I and Type III cements because of their higher shrinkage compared to other repair materials (ACPA 1998)

    - Can decrease bond strength and abrasion resistance because of a decreased density of the paste created (ACPA 1998)

Polymer Concretes

- Epoxy-Resin Mortars or Epoxy Concretes
    - They have great adhesive properties, and low permeability, but are not great with their wide range of setting times, placement temperatures, strengths, bond capabilities, and abrasion resistance (ACPA 1998)
    - Early failure can be caused by their lack of thermal compatibility with many types of existing concrete (ACPA 1998)
    - Epoxy will speed up corrosion with reinforcing steel, so it is recommended to not use epoxy concretes for repairs from spalling (ACPA 1998)
- Methyl-Methacrylate Concrete
    - This concrete has a wide ambient temperature placement range of 40 to 130°F (4 to 54°C), but are hazardous to those working with it because can easily ignite if exposed to a spark (ACPA 1998)
    - They can adhere to any clean and dry surface, can achieve a working time between 30 and 60 minutes, and can gain high compressive strengths (ACPA 1998)
- Polyester-Styrene Concretes
    - Extremely similar to methyl-methacrylate concrete, but have a slower strength gain, so they are not recommended to be used as a repair material on a project with a short closure period (ACPA 1998)
- Polyurethane Concretes
    - This type of material is created by a combination of aggregates and a two-part polyurethane resin that sets quickly (ACPA 1998)
    - One type of polyurethane concrete is moisture sensitive and will foam when it comes in contact with water, the other type is moisture resistant, which allows it to be placed on wet surfaces (ACPA 1998)

Bituminous Materials

- Bituminous materials are known to deteriorate rapidly, so it is recommended that they are used only as temporary repair materials (ACPA 1998)

National Concrete Pavement Technology Center. The National Concrete Pavement Technology Center recommends sticking to conventional Portland Cement Concrete for partial depth repairs. Cement types I, II, and III are the most commonly used materials as they are the most widely accepted (Frentress and Harrington 2012). Type I is best used without any admixtures because it is inexpensive, available, and easy to use. Type III (HE) cement repairs can be opened to traffic sooner than Type I cement, so it is generally used with faster turn around times to get traffic back on the roadway (Frentress and Harrington 2012).

Another material that can allow traffic to be opened in just 4 to 12 hours is Portland Cement Concrete with accelerating admixtures. These mixes are designed so they do not give up their long term durability, however, using admixtures and designing for a higher early strength can lead to a higher risk of failure (Frentress and Harrington 2012). Rapid-setting and high early strength materials can also be used to

open traffic sooner because of the flexible and semi-rigid properties. When using lower early strength mixtures, the number of equivalent single axle loads must be calculated to determine the total closure time of the roadway (Frentress and Harrington 2012).

STATE APPROVED PRODUCTS REVIEW

Qualified Products Findings

The following five tables list all of the qualified products that are permitted to be used as partial depth repair materials for California (Caltrans), Illinois (IDOT), Iowa (IOWADOT), Minnesota (MnDOT), and Missouri (MoDOT). These states have excellent knowledge and resources to complete partial depth repairs on their roadways, which are mainly made of concrete pavement slabs.

Table 1. Caltrans Qualified Products

Product Name	*Product Manufacturer*	*Product Application*
10-60 Mortar	BASF Construction Chemicals/Master Builders	Dry, Rapid-Hardening Cementitious Materials for Surface Spalls, Honeycomb and Minor Defects
10-61 Mortar	BASF Construction Chemicals/Master Builders	Dry, Rapid-Hardening Cementitious Materials for Surface Spalls, Honeycomb and Minor Defects
Elephant Armor DOT Industrial Grade Mortar	GST International	Dry, Rapid-Hardening Cementitious Materials for Surface Spalls, Honeycomb and Minor Defects
SikaQuick 1000	Sika Corporation	Dry, Rapid-Hardening Cementitious Materials for Surface Spalls, Honeycomb and Minor Defects
SikaQuick 2500	Sika Corporation	Dry, Rapid-Hardening Cementitious Materials for Surface Spalls, Honeycomb and Minor Defects
Express Repair	The Euclid Chemical Company	Dry, Rapid-Hardening Cementitious Materials for Surface Spalls, Honeycomb and Minor Defects
EMACO T415	BASF Construction Chemical/Master Builders	Dry, Rapid-Hardening Cementitious Materials for In Depth Repairs
Elephant Armor DOT Industrial Grade Mortar	GST International	Dry, Rapid-Hardening Cementitious Materials for In Depth Repairs
SikaCrete 321FS	Sika Corporation	Dry, Rapid-Hardening Cementitious Materials for In Depth Repairs

(Ref. Caltrans 2017 Materials List)

Table 2. IDOT Qualified Products

Product Name	*Product Manufacturer*	*Product Application*
Formflo P-51	JE Tomes & Associates	Packaged, Dry, Formed Concrete Repair Mixture
Quikrete Quick Setting Cement	Quikrete	R1 Mortar for Packaged, Dry, Rapid Hardening Cementitious

		Materials
HD-50 Heavy Duty Concrete Patch,	Dayton Superior Corporation	R2 Mortar for Packaged, Dry, Rapid Hardening Cementitious Materials
Quikrete Commercial Grade Fastest Repair Mortar	Quikrete	R2 Mortar for Packaged, Dry, Rapid Hardening Cementitious Materials
Speccopatch RS	Specco Industries	R2 Mortar for Packaged, Dry, Rapid Hardening Cementitious Materials
SikaQuick 1000	Sika Corporation	R2 Mortar for Packaged, Dry, Rapid Hardening Cementitious Materials
SikaQuick 2500	Sika Corporation	R2 Mortar for Packaged, Dry, Rapid Hardening Cementitious Materials
Utilibond	Utilicor Technologies, Inc.	R2 Mortar for Packaged, Dry, Rapid Hardening Cementitious Materials
Masteremaco T 545	BASF Corporation-Building Systems	R3 Mortar for Packaged, Dry, Rapid Hardening Cementitious Materials
Rapid Set Mortar Mix	CTS Cement Mfg. Co./ Rapid Set Products	R3 Mortar for Packaged, Dry, Rapid Hardening Cementitious Materials
Rapid Set DOT Repair Mix	CTS Cement Mfg. Co./ Rapid Set Products	R3 Mortar for Packaged, Dry, Rapid Hardening Cementitious Materials
Rapid Set Cement All	CTS Cement Mfg. Co./ Rapid Set Products	R3 Mortar for Packaged, Dry, Rapid Hardening Cementitious Materials
Chemspeed 65	ChemMasters	R3 Mortar for Packaged, Dry, Rapid Hardening Cementitious Materials
Pave Patch 3000	Dayton Superior	R3 Mortar for Packaged, Dry, Rapid Hardening Cementitious Materials
Express Repair	The Euclid Chemical Company	R3 Mortar for Packaged, Dry, Rapid Hardening Cementitious Materials
Planitop 18	MAPEI Corporation	R3 Mortar for Packaged, Dry, Rapid Hardening Cementitious Materials
Planitop 18 ES	MAPEI Corporation	R3 Mortar for Packaged, Dry, Rapid Hardening Cementitious Materials

Futura - 15	W.R. Meadows	R3 Mortar for Packaged, Dry, Rapid Hardening Cementitious Materials
Quikrete Commercial Grade Fastest Nonshrink Grout	The Quikrete Companies	R3 Mortar for Packaged, Dry, Rapid Hardening Cementitious Materials
Repcon 928	SpecChem	R3 Mortar for Packaged, Dry, Rapid Hardening Cementitious Materials
Speccrete Highway Repair 928	Specco Industries, Inc.	R3 Mortar for Packaged, Dry, Rapid Hardening Cementitious Materials
Speccrete Phastpatch D.O.T.	Specco Industries, Inc.	R3 Mortar for Packaged, Dry, Rapid Hardening Cementitious Materials
Rapid Setting Concrete Mix	CTS Cement Mfg. Co./ Rapid Set Products	R3 Concrete for Packaged, Dry, Rapid Hardening Cementitious Materials

(Ref. IDOT 2017 Formed, IDOT 2017 Rapid Hardening)

Table 3. IOWADOT Qualified Products

Product Name	*Product Manufacturer*	*Product Application*
Delpatch	D.S. Brown	Elastomeric Concrete for Concrete Repair
Blendcrete	Bonsal American	Fast-Setting Repair Mortars for Structural Components
Fastrac 220 FQ	Western Material and Design LLC	Fast-Setting Repair Mortars for Structural Components
Fastrac 300	Western Material and Design LLC	Fast-Setting Repair Mortars for Structural Components
FlexKrete	FlexKrete	Fast-Setting Repair Mortars for Structural Components
HD 50	Dayton Superior	Fast-Setting Repair Mortars for Structural Components
MasterEmaco T 415	BASF Construction Chemicals – Building Systems	Fast-Setting Repair Mortars for Structural Components
MasterEmaco T 430	BASF Construction Chemicals – Building Systems	Fast-Setting Repair Mortars for Structural Components
Meadow – Crete GPS	W.R. Meadows, Inc.	Fast-Setting Repair Mortars for Structural Components
Pavemend 15.0	Ceratech, Inc.	Fast-Setting Repair Mortars for Structural Components
Pavemend TR	Ceratech, Inc.	Fast-Setting Repair Mortars for Structural Components

Pavemend VR	Ceratech, Inc.	Fast-Setting Repair Mortars for Structural Components
Phoscrete Four Season	Phoscrete Corporation	Fast-Setting Repair Mortars for Structural Components
Phoscrete VO-Plus	Phoscrete Corporation	Fast-Setting Repair Mortars for Structural Components
Planitop 15	Mapei Americas	Fast-Setting Repair Mortars for Structural Components
Planitop 18 ES	Mapei Americas	Fast-Setting Repair Mortars for Structural Components
Precast Patch	SpecChem	Fast-Setting Repair Mortars for Structural Components
Precast Patch 5	SpecChem	Fast-Setting Repair Mortars for Structural Components
RM800PC	Hilti, Inc.	Fast-Setting Repair Mortars for Structural Components
RepCon V/O	SpecChem	Fast-Setting Repair Mortars for Structural Components
Sika Repair SHB	Sika Corporation	Fast-Setting Repair Mortars for Structural Components
SikaQuick VOH	Sika Corporation	Fast-Setting Repair Mortars for Structural Components
Speed Repair	Right Pointe	Fast-Setting Repair Mortars for Structural Components
US Spec Quickset	US Mix Co.	Fast-Setting Repair Mortars for Structural Components
US Spec Quickset V/O Patch	US Mix Co.	Fast-Setting Repair Mortars for Structural Components
Ulti-Grout	Buzi Unicem USA	Fast-Setting Repair Mortars for Structural Components
DOT Line	Ceratech, Inc.	Inspection and Acceptance for Rapid-Setting Concrete Patching Materials
Durapatch Hiway	L&M Construction Chemicals, Inc.	Inspection and Acceptance for Rapid-Setting Concrete Patching Materials
Euco Speed Mp	Euclid Chemical Company	Inspection and Acceptance for Rapid-Setting Concrete Patching Materials
Fastrac 220 FQ	Western Material and Design LLC	Inspection and Acceptance for Rapid-Setting Concrete Patching Materials
Fastrac 246	Western Material and Design LLC	Inspection and Acceptance for Rapid-Setting Concrete Patching Materials
Fastrac 300	Western Material and Design LLC	Inspection and Acceptance for Rapid-Setting Concrete Patching Materials
Futura 15	W.R. Meadows, Inc.	Inspection and Acceptance for Rapid-Setting Concrete Patching Materials
HD 15	Dayton Superior	Inspection and Acceptance for Rapid-

		Setting Concrete Patching Materials
MG Krete	IMCO Technologies, Inc.	Inspection and Acceptance for Rapid-Setting Concrete Patching Materials
MasterEmaco T 1060	BASF Construction Chemicals – Building Systems	Inspection and Acceptance for Rapid-Setting Concrete Patching Materials
Pave Patch 3000	Dayton Superior	Inspection and Acceptance for Rapid-Setting Concrete Patching Materials
Pavemend SL	Ceratech, Inc.	Inspection and Acceptance for Rapid-Setting Concrete Patching Materials
Pro Traffic Patch	Ash Grove Packaging Corp.	Inspection and Acceptance for Rapid-Setting Concrete Patching Materials
RM800PC	Hilti, Inc.	Inspection and Acceptance for Rapid-Setting Concrete Patching Materials
Rapid Set Concrete Mix	CTS Cement Manufacturing Corp.	Inspection and Acceptance for Rapid-Setting Concrete Patching Materials
Rapid Set DOT Concrete Mix	CTS Cement Manufacturing Corp.	Inspection and Acceptance for Rapid-Setting Concrete Patching Materials
RepCon 928	SpecChem	Inspection and Acceptance for Rapid-Setting Concrete Patching Materials
RepCon 928 DBR	SpecChem	Inspection and Acceptance for Rapid-Setting Concrete Patching Materials
SikaQuick 2500	Sika Corporation	Inspection and Acceptance for Rapid-Setting Concrete Patching Materials
Speccrete Highway Repair 928	Specco Industries, Inc.	Inspection and Acceptance for Rapid-Setting Concrete Patching Materials
Superior Pave Patch 3000	Dayton Superior	Inspection and Acceptance for Rapid-Setting Concrete Patching Materials

(Ref. IOWADOT 2017 MAPLE, IOWADOT 2017 Inspection)

Table 4. MnDOT Qualified Products

Product Name	*Product Manufacturer*	*Product Application*
Renupave Ultra	ABC Cement LLC	Packaged, Dry Rapid Hardening Cementitious Material
Rapid Patch Concrete Surface Repair	Akona Manufacturing LLC	Packaged, Dry Rapid Hardening Cementitious Material
ProSpec Rapid Patch Commerical DOT Repair	Akona Manufacturing LLC	Packaged, Dry Rapid Hardening Cementitious Material
ProSpec Rapid Patch Horizontal Repair	Akona Manufacturing LLC	Packaged, Dry Rapid Hardening Cementitious Material
Ardex TRM	Ardex Engineered Cements	Packaged, Dry Rapid Hardening Cementitious Material
10-60 Rapid Mortar	BASF Construction Chemical	Packaged, Dry Rapid Hardening Cementitious Material

10-61 Rapid Mortar	BASF Construction Chemical	Packaged, Dry Rapid Hardening Cementitious Material
Set 45 HW	BASF Construction Chemical	Packaged, Dry Rapid Hardening Cementitious Material
Rapid Patch - VR	Bonsal	Packaged, Dry Rapid Hardening Cementitious Material
Fast Set Cement Mix	Bonsal	Packaged, Dry Rapid Hardening Cementitious Material
Fast Patch 928	Burke	Packaged, Dry Rapid Hardening Cementitious Material
Pavemend SL	Ceratech, Inc.	Packaged, Dry Rapid Hardening Cementitious Material
DOTLine	Ceratech, Inc.	Packaged, Dry Rapid Hardening Cementitious Material
MainLine	Ceratech, Inc.	Packaged, Dry Rapid Hardening Cementitious Material
Pavemend SLQ (Low temp.)	Ceratech, Inc.	Packaged, Dry Rapid Hardening Cementitious Material
ChemSpeed 65	ChemMasters	Packaged, Dry Rapid Hardening Cementitious Material
Tectonite	CFB	Packaged, Dry Rapid Hardening Cementitious Material
Pave Patch 3000	Dayton Superior	Packaged, Dry Rapid Hardening Cementitious Material
HD 50	Dayton Superior	Packaged, Dry Rapid Hardening Cementitious Material
Rapid Set Cement All	CTS Cement Manufacturing	Packaged, Dry Rapid Hardening Cementitious Material
Rapid Set Mortar Mix	CTS Cement Manufacturing	Packaged, Dry Rapid Hardening Cementitious Material
Rapid Set Cement Mix	CTS Cement Manufacturing	Packaged, Dry Rapid Hardening Cementitious Material
Rapid Set DOT Repair Mix	CTS Cement Manufacturing	Packaged, Dry Rapid Hardening Cementitious Material
Re-Crete 20 Minute Set	Dayton Superior	Packaged, Dry Rapid Hardening Cementitious Material
Five Star Highway Patch	Dayton Superior	Packaged, Dry Rapid Hardening Cementitious Material
Phoscrete VO	Phoscrete Corporation	Packaged, Dry Rapid Hardening Cementitious Material
Phoscrete HC	Phoscrete Corporation	Packaged, Dry Rapid Hardening Cementitious Material
SikaQuick 1000	Sika Corporation	Packaged, Dry Rapid Hardening Cementitious Material
SikaQuick 2500	Sika Corporation	Packaged, Dry Rapid Hardening Cementitious Material

Sikacrete 321FS	Sika Corporation	Packaged, Dry Rapid Hardening Cementitious Material
RepCon 928	SpecChem	Packaged, Dry Rapid Hardening Cementitious Material
Highway Patch 928	Specco Industries, Inc.	Packaged, Dry Rapid Hardening Cementitious Material
Speccopatch RS	Specco Industries, Inc.	Packaged, Dry Rapid Hardening Cementitious Material
Speed Crete 2028	Tamms Industries	Packaged, Dry Rapid Hardening Cementitious Material
Speed Crete Greenline	Tamms Industries	Packaged, Dry Rapid Hardening Cementitious Material
Speed Crete Express Repair	Tamms Industries	Packaged, Dry Rapid Hardening Cementitious Material
Uni Rod Repair DOT	Universal Form Clamp	Packaged, Dry Rapid Hardening Cementitious Material
Polypatch	US Mix Products	Packaged, Dry Rapid Hardening Cementitious Material
Transpatch	US Mix Products	Packaged, Dry Rapid Hardening Cementitious Material
Transpatch Concrete	US Mix Products	Packaged, Dry Rapid Hardening Cementitious Material
Transpatch EXT	US Mix Products	Packaged, Dry Rapid Hardening Cementitious Material
Polypatch FR	US Mix Products	Packaged, Dry Rapid Hardening Cementitious Material
STR Mortar	US Mix Products	Packaged, Dry Rapid Hardening Cementitious Material
Futura	W.R. Meadows	Packaged, Dry Rapid Hardening Cementitious Material
Fastrac 220 FQ	Western Materials and Design LLC	Packaged, Dry Rapid Hardening Cementitious Material
Fastrac 246	Western Materials and Design LLC	Packaged, Dry Rapid Hardening Cementitious Material

(Ref. MnDOT 2017)

Table 5. MoDOT Qualified Products

Product Name	*Product Manufacturer*	*Product Application*
Conspec Pave Patch 3000	Dayton Superior	Rapid Set Concrete Patching Material (Horizontal)
DOT Patch HD	Symons Corporation	Rapid Set Concrete Patching Material (Horizontal)
EcoFix	United States Gypsum Co.	Rapid Set Concrete Patching Material (Horizontal)
Fastrac 246 Rapid Setting Concrete	Western Materials and Design LLC	Rapid Set Concrete Patching Material (Horizontal)

Fastrac 300 Rapid Setting Cement	Western Materials and Design LLC	Rapid Set Concrete Patching Material (Horizontal)
HD-50	Dayton Superior	Rapid Set Concrete Patching Material (Horizontal)
MasterEmaco T 1060	BASF Corporation Construction Systems	Rapid Set Concrete Patching Material (Horizontal)
Mono-Patch	Bindan Corporation	Rapid Set Concrete Patching Material (Horizontal)
Quikrete Commercial Grade Fast Set DOT Mix	The Quikrete Companies	Rapid Set Concrete Patching Material (Horizontal)
Phoscrete HC	Phoscrete Corp.	Rapid Set Concrete Patching Material (Horizontal)
Rapid Set Concrete Mix	CTS Manufacturing Corp.	Rapid Set Concrete Patching Material (Horizontal)
Rapid Set DOT Concrete Mix	CTS Manufacturing Corp.	Rapid Set Concrete Patching Material (Horizontal)
Rapid Set DOT Repair Mix	CTS Manufacturing Corp.	Rapid Set Concrete Patching Material (Horizontal)
RepCon 928	SpecChem	Rapid Set Concrete Patching Material (Horizontal)
Road Patch	Degussa Building Systems	Rapid Set Concrete Patching Material (Horizontal)
Sika Set Roadway Patch	Sika Chemical Corp.	Rapid Set Concrete Patching Material (Horizontal)
SikaTop 122 Plus	Sika Chemical Corp.	Rapid Set Concrete Patching Material (Horizontal)
Speedcrete 2028	Tamms Industries	Rapid Set Concrete Patching Material (Horizontal)
MasterEmaco N424	BASF Building Systems	Rapid Set Concrete Patching Material (Vertical & Overhead)
SikaTop 122	Sika Chemical Corporation	Rapid Set Concrete Patching Material (Vertical & Overhead)
SikaTop 122 Plus	Sika Chemical Corporation	Rapid Set Concrete Patching Material (Vertical & Overhead)
SikaTop 123 Plus	Sika Chemical Corporation	Rapid Set Concrete Patching Material (Vertical & Overhead)

(Ref. MoDOT 2016 Concrete, MoDOT 2015)

Specifications for Approval

The following table describes the basic requirements a producer or supplier must provide, or the steps they must take, to have their product approved for the qualified products list in California, Illinois, Iowa, Minnesota, and Missouri.

Table 6. Approval Requirements for Repair Materials by State

Document/Material	*States which Require it*
Company name, address, and contact information	CA, IL
Name of the repair product or brand name or product number	CA, IL, IA
Material Safety Data Sheet	CA, IL, IA, MN, MO
Technical Data Sheet	IL, MN
Copy of the test report for the product from the National Transportation Product Evaluation Program (NTPEP)	IA
Certificate of compliance stating proposed material complies with the tests on the material data sheet	CA
Material data sheet that at a minimum contains test results for compliance requirements	CA
Laboratory test results showing the water soluble chloride ion content	IL, IA
The ASTM C882 tested shear strength by an independent laboratory	IA
Independent laboratory test results performed according to ASTM C928	MN
A signed letter stating that the product will not be changed without written notification by the Department	IL
List of projects where the product has been used successfully, including reports or photographs if possible	CA
Manufacturers recommended procedures for use and mixing instructions	CA, IL, IA
Limitations on use of product	CA
Shelf life of the product and storage requirements	CA, IA
Supply two prepackaged bags of approximately 100 pounds of a sample taken from the same batch of material that was used for compliance testing	CA
Submit a sufficient amount of the product to mix 1 cubic foot for testing purposes	IL, IA, MO
Provide a copy of MoDOT's New Product Evaluation Form	MO
Product specifications, certification, literature, test data, and warranty	MO

(Ref. Caltrans 2017 Authorization, IDOT 2017 Formed, IOWADOT 2017 Elastomeric, IOWADOT 2017 Fast-Setting, IOWADOT 2017 Inspection, MnDOT 2008, MnDOT 2016 New)

The following tables summarize the requirements each supplier or producer must provide in addition to those list in Table 6. Some of these requirements are accompanied with standard values and test results in order to achieve approval.

Table 7. Caltrans Specific Test Result Requirements for Repair Materials

Requirement	*Value*	*Standard*
Minimum 7- day compressive strength	4000 psi	ASTM C39 or C109
Minimum 28-day bond strength	1500 psi	ASTM C882 as modified by C928
Maximum 28-day length change	-0.15%	ASTM C157
Maximum soluble chlorides by weight	0.05%	AASHTO T260

(Ref. Caltrans 2017 Authorization)

Table 8. IDOT Additional Product Requirements

Requirement	*Material Application*
Individual weight of cement and finely divided minerals (hundredweight per cubic yard)	Packaged, dry, formed concrete repair mixture
Type of cement, class of fly ash or grade of ground granulated blast-furnace slag	Packaged, dry, formed concrete repair mixture
Maximum size of coarse aggregate	Packaged, dry, formed concrete repair mixture
Brand name of ASTM C494, Type F admixture used	Packaged, dry, formed concrete repair mixture
Recommended water dosage for 5-7 inch slump (w/c ratio shall not exceed 0.46)	Packaged, dry, formed concrete repair mixture

(Ref. IDOT 2017 Formed)

Table 9. IOWADOT Additional Product Requirements

ASTM C109/C579 Method B Requirements	*Value*
Minimum compressive strength after curing three 2 inch cubes for 24 hours at 73 ± 4° F	2000 psi
ASTM C882 Requirements	*Value*
Time to soak in dummy section	24 hours
Before blasting the surface, the time to allow the dummy section to air dry	15 minutes
After applying primer, time to allow the dummy section to cure	30 minutes
Minimum compressive strength after curing for 24 hours at 73 ± 4° F	300 psi

(Ref. IOWADOT 2017 Elastomeric)

ASTM SPECIFICATION DETAILS

The following American Society for Testing and Materials (ASTM) Standards are the most commonly used standards when considering the parameters used in selection and testing of concrete used for partial depth repair materials. They have proven to demonstrate consistent results for a number of different parameters and qualities that must be taken into account when choosing and using concrete partial depth repair materials.

C39/C39M. ASTM C39/C39M tests a concrete's compressive strength, by applying a load compressively until failure. The compressive strength of the concrete cylinder is then calculated by dividing the maximum load of the specimen, before failure, by it's cross sectional area (ASTM 2017 Compressive). The obtained results vary because they depend on the size and shape of the cylinder, how the batch of concrete was batched and mixed, the method of sampling, the molding conditions, the age of the specimen, the temperature of the specimen, and the moisture conditions (ASTM 2017 Compressive). These results are mainly used for future quality control by understanding how concrete proportioning, mixing, and placing effect its compressive strength. This test is also used to see if the concrete specimen complies with specifications that are set for its intended use (ASTM 2017 Compressive).

C157/C157M. ASTM C157/C157M tests the change in length that occurs because of factors other than those of externally applied forces, temperature changes, and moisture changes (ASTM 2014 Length). This test is considered important when choosing a concrete partial depth repair material because it evaluates the potential for volumetric expansion or contraction once the new concrete repair material is bonded to the existing concrete (ASTM 2014 Length). It is most helpful to those choosing a repair material to use this test with concrete partial depth repair products that are produced with nonstandard mixing, placing, handling, and curing practices or procedures (ASTM 2014 Length).

C469/C469M. ASTM C469/C469M determines the Young's modulus of elasticity and Poisson's ratio of concrete using cylindrical concrete specimens, with results presenting themselves as a ratio of lateral to longitudinal strain for the hardened specimen at whatever age is desired for the testing (ASTM 2014 Static). To complete the test for each parameter, a compressometer is used when testing for Young's modulus, and an extensometer is the best device to use when testing for Poisson's ratio (ASTM 2014 Static). When considering partial depth repairs, it is helpful to determine Young's modulus and Poisson's ratio to understand the elastic behavior that the repair material will have, compared to the existing concrete. If the cylindrical specimen is loaded rapidly, the results will yield a higher moduli than standard, showing that its behavior will be more elastic, and if it is loaded slowly, the results will yield lower moduli than standard, making its behavior less elastic (ASTM 2014 Static).

C531/C531M. ASTM C531/C513M measures the linear shrinkage during setting and curing, and measures the coefficient of thermal expansion of chemical-resistant mortars, grouts, monolithic surfacings, and polymer concretes (ASTM 2012). This test is performed using a concrete bar with a square cross section where the change in length is measured after curing using measuring studs that mold into the ends of the bar as it cures (ASTM 2012). The coefficient of thermal expansion is then calculated by measuring that change in length at a certain elevated temperature. The results of this procedure are important to compare with existing concrete that will be bonded to a concrete repair material because if the coefficients of thermal expansion are different, the repair will fail quickly due to differential expansion (ASTM 2012).

C666/C666M. ASTM C666/C666M tests the resistance of concrete specimens to rapidly repeated cycles of freezing and thawing, completed using two different procedures: Rapid Freezing and Thawing in Water, and Rapid Freezing in Air and Thawing in Water (ASTM 2015). The procedures are both used to determine the differences in the properties of concrete from the resistance of the concrete to freezing and thawing cycles, as stated in the procedure, however the procedures do not provide a measurement of service life expectancy from any specific type of concrete (ASTM 2015). This specification assumes that the testing will have no damaging effects on frost-resistant concrete because of its resistant aggregates and adequate air void system that prevents saturation (ASTM 2015). When it comes to choosing between rapid freezing and thawing in water, or rapid freezing in air and thawing in water, the decision is mainly based upon the user's application and suitability to their project to best determine the freeze-thaw conditions of the partial depth repair material (ASTM 2015)

C882/C882M. ASTM C882/C882M determines the bond strength of epoxy-based bonding systems to be used with Portland cement concrete, and it covers the bonding system between freshly mixed or hardened concrete to hardened concrete (ASTM 2013 Bond). To determine this bond's strength, two equal sections of a 3-inch by 6-inch (75 mm by 150 mm) cylinder made of Portland cement mortar are first bonded together. Then a compressive strength test (C39/C39M) is performed on the composite cylinder to measure the compressive strength (ASTM 2013 Bond). The reason this test is performed for concrete partial depth repairs is so that the correct bonding agent can be chosen to be placed between the existing concrete and the repair material that will not cause the repair to fail.

C928/C928M. ASTM C928/C928M tests the compressive strength, length change, scaling resistance, and slant shear bond strength of packaged, dry, cementitious mortar or concrete materials used for rapid repairs to hardened hydraulic cement concrete pavements and structures (ASTM 2013 Packaged). The compressive strength of the repair materials is tested using the procedures of ASTM C39/C39M, the length change of the repair material is tested using the procedures of C157/C157M, the scaling resistance of the repair material is tested using the procedures of C672/C672M (not discussed in this section), and the slant shear bond strength of the repair material is tested using the procedures of C882/C882M (ASTM

2013 Packaged). The packaged, dry, concrete repair materials must contain aggregates where more than 5% by mass of the total mixture is retained on the 3/8 inch (9.5 mm) sieve, whereas the packaged, dry, mortar repair material must contain less (ASTM 2013 Packaged). Overall, this standard can effectively explore the basic properties of any packaged, dry, cementitious mortar or concrete materials to aid in selection for partial depth repairs. However, the purchaser of the repair concrete or mortar has the right to reject any material that fails any part of the testing in this standard, which then must be reported in writing to the product producer or supplier (ASTM 2013 Packaged).

C1581/C1581M. The ASTM C1581/C1581M test procedure uses concrete or mortar specimens under restrained shrinkage to determine their relative age at cracking and their induced tensile stress characteristics (ASTM 2016). This standard is only used to relatively compare materials, and is not used to define the actual age of cracking of mortar or concrete and is only applicable to mixtures with a nominal maximum aggregate size (NMAS) of 0.5 inches (13 mm) or less (ASTM 2016). The actual age of cracking and tendency of cracking depend on the type structure, degree of restraint, rate of property development, construction and curing methods, and the environmental conditions (ASTM 2016). When considering the induced tensile stress of the concrete and mortar, this test can determine the relative effects of material variations such as aggregate source, aggregate gradation, cement type, cement content, water content, supplementary cementitious materials, or chemical admixtures (ASTM 2016). The use of this test is best suited for estimating the likelihood that a concrete mixture would have early-aged cracking under restrained shrinkage, and is helpful in aiding the selection of the proper cement-based repair material for a partial depth repair (ASTM 2016).

C1583.C1583M. ASTM C1583/C1583M determines the near-surface tensile strength of the substrate as an indicator of the adequacy of the surface preparation before the overlay material is applied to a repair, it determines the bond strength of the repair itself or the overlay material on top of the substrate, and it determines the tensile strength of the repair itself or the overlay material or the adhesive used in the repair after being applied to the surface (ASTM 2013 Tensile). When testing for the bond strength to the substrate or the tensile strength of the overlay or substrate, the outcome will result in whichever is weaker (ASTM 2013 Tensile). When testing on the surface of a material that has been applied to the substrate, the strength that is measured is controlled by its failure mechanism that requires the least amount of stress. This means that it is unknown what strength is measured until failure occurs, so the failure mode must be reported with each test completed (ASTM 2013 Tensile).

ANALYSIS AND DISCUSSION

After defining and characterizing a partial depth repair, and understanding the ASTM specifications partial depth repair products must conform to, it is best to analyze which of the listed products has shown to be more successful than others. Without the material specifications and usage information of each product, this will be concluded by determining which approved products and producers appear to be the most common on the qualified products lists of the states of interest. After all, these five states were chosen to be studied due to their abundance of concrete pavement infrastructure, and their strong state highway department.

There are two manufacturers of partial depth repair products that have approved products in all five states studied. Those two companies are Sika Corporation and BASF Construction Chemicals/Master Builders. The materials listed, produced by Sika Corporation, are rapid hardening cementitious materials used for in-depth repairs and surface spalls on structural components. They can be used for vertical and horizontal applications, depending on which product is used. Based upon these qualities, and that nine of their products appear multiple times on the qualified products lists of the identified states, it is safe to assume without any other product information, that Sika Corporation manufactures more successful partial depth repair materials than other companies listed.

The second company that has partial depth products approved on every state's qualified products list, is BASF Construction Chemicals/Master Builders. Their materials are also rapid hardening cementitious materials used mainly for surface spalls and repairs to structural components, but the majority of their products are defined as mortars to be used for partial depth repairs. It is also safe to assume that BASF Construction Chemicals/Master Builders manufactures better products than other companies on each qualified products list because of their abundance, and their wide range of use for partial depth repairs. Two other manufacturers that would qualify as being more successful than most producers of partial depth repair materials are Dayton Superior and CTS Cement Manufacturing Company. These two manufacturers have qualified products listed in four out of five states studied, combining for a total of 11 approved products for partial depth repairs.

Another interesting question to consider is, can any of these approved products be combined in to create a partial depth repair material that performs better than existing materials, or that can be used for more specialized repairs? Based on the types of materials used by the Federal Highway Administration, the American Concrete Pavement Association, and the National Concrete Pavement Technology Center, it would be realistic to assume that various materials may be combined to create a repair product that would benefit all sorts of repair conditions. For example, if a gypsum-based cement concrete was combined with a calcium aluminate concrete, the resulting repair material would have low setting times caused by the gypsum-based cement concrete, but would also have low shrinkage, good bonding properties, and can be used in low temperature repairs because of the presence of calcium aluminate concrete. More research into the adverse side effects of combining certain chemicals and cements would need to be tested and considered first.

These sorts of combinations can also be advantageous to the location or type of placement desired. Looking at the current product lists, some repairs materials can only be used for horizontal applications, and some can only be used for vertical and overhead applications. If possible, a combination of two types of repair materials could create a more diverse use for repairs that require horizontal, and vertical and overhead applications. Based upon the information gathered, and more study and research, it is possible to combine existing materials in many ways to create better and more effective partial depth repair materials.

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