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Selection of High Performance Repair Materials for Pavements and Bridge Decks

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SELECTION OF HIGH PERFORMANCE REPAIR MATERIALS FOR PAVEMENTS AND BRIDGE DECKS

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ABSTRACT

The Ohio Department of Transportation has identified the need to specify durable, more permanent high performing pavement and bridge deck patching materials. These materials need to allow for expedited pavement and bridge deck wearing surface repair for worker and user safety. Currently, either temporary or generally specified in-kind or like materials are being used to perform pavement patching. Usually, the Department provides generically specified cementitious or cold mix asphalt materials for patching wearing surfaces with varied performance characteristics. Current products used for these repairs are generally those that have been used for many decades for which competition exists. However, new or proprietary products are difficult to specify unless incorporated into a construction project for research purposes, an approved equal is permitted, or procurement of the product complies with the Department's direct purchasing requirements. Consequently, this creates a situation where the desired product is precluded from use.

The objective of this study was to specify durable, more permanent high performing pavement and bridge deck patching products that allow for expediting pavement and bridge deck wearing surface repair for worker and user safety. Aspects examined in this

study include: history on causes of pavement patching failures, comparison of laboratory and field testing criteria from other organizations, product classifications based on material properties, analysis of available patching products, and identifying products to be tested based on previous research.

The products chosen for the winter patching project were FlexSet and MG Krete. They have been placed in the field already and were chosen due to their excellent low temperature range, compliance of most ODOT and ASTM 928 laboratory standards and great previous field testing results from ERDC and NTPEP. The other four products recommended for summer placement are Delpatch, RepCon 928, SR-2000 and Optimix. They displayed characteristics desirable for further testing and represent a range of material classifications.

Recommended laboratory standards were specified based on current ODOT requirements and past research and are listed in this thesis. Field recommendations consisted of having the product representative present on site during placement and to document all conditions of the patch hole, surrounding pavement and weather conditions.

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INTRODUCTION AND RESEARCH OBJECTIVES

1.1 ODOT Problem Statement

There is a need to specify durable, more permanent high performing pavement and bridge deck patching products that allow for expediting pavement and bridge deck wearing surface repair for worker and user safety. The current specification and supplemental specifications are out of step with the transition from prescriptive format, such as mixture proportions, to performance based specifications. Thus, in the current format, it is difficult to make use of new materials and emerging technologies. Many of the current products have been in use for many decades but have competitive alternatives that could or would perform better. However, new or proprietary products are difficult to specify unless incorporated into a construction project for research purposes, an approved equal is permitted, or procurement of the product complies with the Department's direct purchasing requirements. Consequently, this creates a situation in which the desired product is precluded from use.

1.2 Research Context

Repair is a complex problem. The general principle is to repair with like materials, that is to say, concrete with cementitious materials, and asphalt with hot mix or cold patch materials. However, some materials are difficult to supply in small quantities. Asphalt repair materials may be difficult to compact effectively in small patches. In addition, rapid hardening cementitious materials are preferred over conventional concrete to reduce traffic interruptions. Furthermore, durable repairs demand different material properties from initial construction. For example, bond strength and dimensional stability, such as limits on shrinkage or expansion, may be much more significant than compressive strength. High early strength cementitious materials may also have high stiffness (modulus of elasticity), which can lead to stress concentrations and early patch failure. In many instances, products that perform well in the laboratory turn out to not perform nearly so well in the field.

Installation procedures also have a significant effect on performance. Removal of existing distressed material must be carried out carefully in order to prevent undue damage to the remaining pavement or bridge deck or to reinforcing steel. Patch holes should be clean and dry, and may need to have tack coat or some other bonding agent applied for some materials. Curing of cementitious materials may be difficult to carry out on a small scale, but may also be critical to long term performance of repairs.

Two valuable resources to this study are the National Transportation Product Evaluation Program (NTPEP), which has published four reports documenting two year test results for Rapid Set Concrete Patching Materials, and the U.S. Army Engineer Research and Development Center (ERDC), which has published two recent reports evaluating materials for repairing concrete airport pavements, using both laboratory and field testing with a focus on commercially available repair materials and two reports on asphalt patching on airfield and highway pavements.

Although ERDC has developed protocols for evaluation of these materials, its approach may not be appropriate for adoption by ODOT. Materials developed for short term repairs in a military theater of operations may not have the long term durability required by ODOT. In particular, freeze-thaw durability may be more of an issue for ODOT than for ERDC. The ERDC labs are in Vicksburg, Mississippi, which makes freeze thaw field testing impractical. That said, the ERDC testing program was extensive, and therefore the findings were looked at in detail.

These reports from both NTPEP and ERDC were consulted when determining the candidate repair products for this research.

1.3 Study Objectives

The goals and objectives of this study were to investigate laboratory testing methods, to develop acceptable field performance criteria of new and existing rapid setting concrete and asphalt pavement and bridge deck patching products for comparative analysis, and to determine their suitability for field placement. Previous research from numerous resources was used to identify these methods. The selected products were to be used in the field testing stages of this research. To fulfill these objectives the following goals were identified:

- Identify and compare previous laboratory and field testing criteria being used by other organizations.
- Identify and determine acceptable laboratory and field performance criteria for comparative analysis of selected products.
- Compare and investigate previous products tested and their results.
- Determine product classifications based on product material make-up.
- Identifying products to be tested based on previous research.
- Define product laboratory and field testing criteria.

1.4 Research Plan

To achieve the objectives of this study, the following steps were performed and are summarized below.

1. Perform initial review of literature to obtain history on causes of pavement patching failures and previous patching material studies and reports.
2. Determine product classifications based on material composition.
3. Define product laboratory testing criteria.
4. Define product field testing criteria.
5. Identify previously tested products and their performance.
6. Identify rapid setting pavement repair/patching products for field testing based on previous research.

Based on the research plan, the first task started on month one, August 2013 and continued through to task nine which ended in Month eight, March 2014.

1.5 Field Details

There will be approximately 100 test patches installed by the Great Lakes Construction Company. To achieve a comprehensive study and to evaluate material performance in cold weather, approximately 14 patches were installed at Month eight, March 2014. The remaining patches will be installed in Year one, Month 11 or 12, estimated to be June or July 2014. It is essential to install the products no later than the first summer of the project to allow for two winters of field exposure over the course of the study.

Installing 100 test patches should remove any potential effect of different installation practices, and therefore the performance differences would be due to differences in material properties. However, the materials should also be suitable for installation by ODOT maintenance personnel. Therefore, additional test patches are projected to be installed by ODOT District Eight personnel over Year two. This will document how difficult the materials are to use.

Field observations and nondestructive evaluations will be used at periodic intervals to assess performance. Approximately one month after patch installation, a thorough visual inspection will be conducted of all patches, supplemented by UPV and impact-echo for cementitious materials and potentially SASW and impulse-response.

Following this baseline evaluation, visual observations will be made approximately every two months to document pavement condition. The research team will visually inspect and evaluate each repair, with respect to pavement or bridge deck related distresses for each patching material and each substrate type, with consideration given to pavement section or bridge deck composition and seasonal limitations. Visual inspection procedures will make use of ACI 201.1R-08, *Guide for Conducting a Visual Inspection of Concrete in Service* (ACI Committee 201) for concrete pavements and bridge decks and of the *DISTRESS IDENTIFICATION MANUAL for the Long-Term Pavement Performance Program* (Miller et. al, 2003) for asphalt and concrete pavements. If deterioration is found, such as delamination or spalling, more frequent visual inspections will be done to document the speed of deterioration.

At three intervals during the project, following each winter season and near the conclusion of the project, the visual observations will be supplemented by thorough nondestructive evaluation.

At the conclusion of the project, cores may be extracted from approximately 20% of the patches with respect to patch and pavement type. NDE equipment will be used to select some patches that appear to be sound for core extraction, as well as those that show some indication of damage or debonding. If the cores appear to indicate good bond to substrate, pull-off testing will be used to evaluate bond strength. Cores that are extracted with patch fully bonded to substrate can also be subsequently tested in shear in the laboratory.

As a part of this task, laboratory testing of the patch materials will be carried out at the Cleveland State University research laboratories. This will include tests determined in the literature review along with other NDE tests in the field. ERDC, NTPEP and product fact sheets will provide insight into the appropriate testing to complete.

At the conclusion of this task, the research team will provide data and data analysis for all applicable measurable physical and/or chemical material performance characteristics and physical substrate bond properties.

1.5.1 Field Performance Criteria

When determining acceptable field performance criteria there were some key conditions that needed to be checked. Two of these areas were stability and durability.

At the conclusion of the study, acceptable materials should be fully bonded to the substrate without surface damage or internal cracking within the patches. The patches should still be in excellent condition, with no indications of the initiation of distress.

Since the chosen materials needed to be high performing, the characteristics of early strength, high durability and installation efficiency were also important. The ERDC and NTPEP research provided valuable insight about material characteristics that are associated with satisfactory field performance.

1.5.2 Location

The site location for March 2014 included pavement and bridge deck sections along USR 35 in Greene County, Ohio. Future patch locations include Route 71 and 74 in Hamilton County, Route 73 in Warren County and Route 71 in Clinton County. Exact locations will be selected in coordination with ODOT. Product location/layout details, number of patches, and patch dimensions were determined in the field based on site conditions**.** Appendix A shows detail about the patch locations.

1.5.3 Field Installation

The project installation subcontractor, the Great Lakes Construction Company, installed selected rapid setting and ODOT standard products at multiple asphalt and concrete pavement and concrete bridge deck locations. Substrate preparation was consistent with ODOT and Manufacturer's requirements in the identified pavement sections for side – by – side product evaluation.

The Great Lakes Construction Company has a long history of satisfactory work for ODOT, as well as long standing collaboration with the Cleveland State University Department of Civil and Environmental Engineering.

1.5.4 Observing Installation

The installation process was observed and documented by the research team to ensure that proper procedures were followed and to note any potential anomalies. Observations were made of the condition of the pavement or bridge deck repair substrate along with the placement procedure.

1.6 Benefits and Potential Application of Research Results

"ODOT's largest asset is our transportation infrastructure, such as roads, bridges, intermodal facilities, railways and ports. Through usage and the passage of time, the system degrades and can become inadequate for both current and projected travel demands. Maintenance of the infrastructure presents many challenges as well as opportunities for improvements. Developing methods to better utilize resources and integrate advances in science, technology, and construction techniques will assist ODOT in efforts to both modernize and support our system." (Strategic Research Plan 2012-2014, 2012)

By investing in appropriate research on pavement patching based on performance rather than prescription, there will be a reduction in re-patching of pavements and improved longevity of patches as appropriate, proven materials will be used. This in turn will save ODOT time, money and reduce the extent of construction on Ohio roads. This research relates to ODOT's mission of "Make our system work better." It directly addresses the Strategic Focus Research Area of Transportation Asset Management viewed above. This represents an example of "Developing methods to better utilize resources and integrate advances in science, technology, and construction techniques." The research is expected to benefit ODOT and Ohio through extended service life, reduction in maintenance repair costs and improved safety for highway crews working on location. Longer lasting repairs will extend the life and reduce disruption to the traveling public.

1.7 Organization of this Thesis

This thesis consists of six chapters, beginning with this introduction. The second chapter reviews concrete material classifications. It examines the different composition of materials, which in turn determines their classification. The third chapter is the background and literature review of concrete repair. The fourth chapter is the background and literature review of asphalt repair. The fifth chapter provides details of the shortlisted materials. The sixth and final chapter offers final product recommendations, recommended laboratory tests, field placement recommendations, and follow-on research and conclusions.

CHAPTER II

CEMENTITIOUS MATERIAL CLASSIFICATIONS

Rapid setting cementitious materials are characterized by short setting times. Some may exhibit rapid strength development with compressive strengths in excess of 17MPa (2400 psi) within three hours.

One advantage to rapid setting cements is the accelerated strength development that allows the repaired pavement or bridge deck to be placed into service more quickly than conventional repair materials. From this, there are lower traffic-control costs and improved safety. There are also limitations to this type of concrete. Although most rapid-setting materials are as durable as concrete, some, due to their constituents, may not perform well in a specific service environment. Some of these materials may also contain high levels of alkali or aluminate to provide expansion, so their exposure to sulfates and reactive aggregates should be limited. ASTM C928 is the standard used to cover packaged, dry, cementitious mortar or concrete materials for rapid repairs to hardened hydraulic-cement concrete pavements and structures.

The classification given to the rapid setting repair materials is determined by composition, and is the main factor determining what type of patching material is suitable to use. The categories in this section comprise of cementitious concrete including portland cement and high alumina cement; polymer modified concrete including magnesium phosphate and latex modifiers; and polymer concretes including epoxies.

2.1 Cementitious Concrete

Cementitious mortars include portland cement and High-Alumina cement.

2.1.1 Portland Cement

Portland cement is the chief ingredient in cement paste - the binding agent in portland cement concrete (PCC). It is a hydraulic cement that, when combined with water, hardens into a solid mass. Interspersed in an aggregate matrix it forms PCC. As a material, portland cement has been used for well over 175 years and its behavior is well-understood. Chemically, portland cement is a complex substance whose mechanisms and interactions have yet to be fully defined. Portland cement is readily available, economical, has similar properties to the parent concrete, and is relatively easy to produce, place, finish, and cure. Generally, concrete mixtures can be proportioned to match the properties of the underlying concrete; therefore, conventional concrete is applicable to a wide range of repairs. Conventional concrete should not be used in repairs where the aggressive environment that caused the original concrete to deteriorate has not been eliminated, unless a reduced service life is acceptable (ACI Committee 546, 2004).

2.1.2 Ultrafine Portland Cement

Ultrafine portland cement materials are based on traditional portland cement. The portland cement is ground to an ultrafine level, resulting in a larger available surface area for faster hydration upon mixing with water. This provides the mechanism by which the hydration proceeds more rapidly than a traditional portland cement chemical reaction (ERDC, 2011).

2.1.3 High Alumina Cement

High-alumina materials use monocalcium aluminate ($CaO\text{-}Al_2O_3$) as the primary agent producing rapid strength gain in the paste. These types of cements have also shown ultra-high strengths upon placement, compared to conventional portland cement concrete pastes made with Type I or II portland cements. Evaluations performed as part of the Corps of Engineers’ Repair, Evaluation, Maintenance, and Rehabilitation Research Program (REMR) in 1992 found that these materials generally continue hydration well beyond the 3-hr mark, doubling their strength after 7 days of curing. However, these materials have been shown to produce less strength when subjected to significant moisture and high temperatures (Neville 1975). (ERDC, 2011)

2.2 Polymer Modified Concrete

Polymer modified concrete (PMC) may be divided into two classes: polymer impregnated concrete (PIC) and polymer cement concrete. PIC consists of impregnation of precast hardened portland cement concrete with a monomer that is subsequently converted to solid polymer. For this study, PIC is not used, as damaged concrete is replaced, not repaired. PMC includes magnesium phosphate and latex modifiers.

PMC is still essentially dependent upon the portland cement binder for its structural integrity. Both types of PMC have higher strength, lower water permeability, better resistance to chemicals and greater freeze-thaw stability than conventional concrete. (Beaudoin & Blaga, 1985), Polymer modified concretes are typically less expensive than polymer concretes and are often used for concrete restoration work when construction time is limited. (Polymer Concrete vs Polymer Modified Concrete, 2008)

2.2.1 Polymer Cement Concrete

For polymer cement concrete, part of the cement binder of the concrete mix is replaced by polymer (often in latex form). It has, at times, been called polymer portland cement concrete (PPCC) and latex-modified concrete (LMC). It is identified as portland cement and aggregate combined, at the time of mixing, with organic polymers that are dispersed or re-dispersed in water. This dispersion is called a latex. Latexes commonly used include polymers and co-polymers of vinyl acetate. Polymer dispersions are added to the concrete mixture to improve the properties of the final product. These properties include improved bond strength to concrete substrates, increased flexibility and impact resistance, improved resistance to penetration by water and by dissolved salts, and improved resistance to freezing and thawing. (ACI Committee 548, 2009)

Polymer cement concrete overlays have exhibited excellent long-term performance. Properly installed overlays are highly resistant to freezing-and-thawing damage, and exhibit minimal bond failure after many years of service. LMC overlays installed on severely deteriorated bridge decks, after proper surface preparation, continue to perform many years after installation. (ACI Committee 548, 2009)

Latexes commonly used, include polymers and copolymers of vinyl acetate. When emulsified and mixed with concrete, epoxies provide excellent freezing and thawing resistance, significantly reduced permeability, and improved chemical resistance.

Polymer cement concrete also has limitations; the temperature at which the material should be placed is 45 to 85 °F (7 to 30 °C), longer mixing times result in an increase in the total air content with subsequent reductions in compressive strength, so mixing time should be limited to 3 min. Handling, placing, and finishing of PCC is limited to less than 30 min.

2.2.2 Magnesium Phosphate Concrete

Magnesium phosphate concrete (MPC) is a hydraulic cement based system different from portland cement. Unlike portland and some polymer cement concrete, which require moist curing for optimum property development, these systems produce their best properties with air curing, similar to epoxy concrete. The materials use a blend of magnesium oxide (MgO) and ammonium di-hydrogen phosphate ($NH_4H_2PO_4$) as the base for the paste. Upon mixing with water, these compounds react rapidly, gaining strength and producing large amounts of heat, although retarded versions are available that produce less heat. These materials have been used in repairs to concrete since the mid 1970's and are cost effective for rapid repairs when a short down time is important. Historical testing has shown that these products can achieve compressive strengths well in excess of 3,000 psi (21 MPa) within two hours (Popovics and Rajendran 1988). These materials are generally self-leveling and set quickly. Repair in a cold-weather environment is an important application. Due to the exothermic nature of the reaction, heating the materials and the substrates is not usually necessary, unless the temperature is below freezing. (ERDC, 2011)

Some other advantages of MPC are; early setting times of 10 to 20 min at room temperatures, a retarded version that has extended setting times of 45 to 60 min at room temperature, and it can be placed at temperatures as low as 32 °F (0 °C), or lower if the mixing water and material are heated. It has a scaling resistance similar to air entrained portland cement based concrete materials, has low permeability, good bond strength to portland cement, and performs better for thin patches, because they do not require a moist cure.

There are some limitations of MPC. It should be extended only with non-calcareous aggregates such as silica, basalt, granite, trap rock, and other hard rocks. This is because the bond can be weakened when the carbonated surface reacts with the phosphoric acid, producing carbon dioxide which weakens the paste aggregate bond. Because of the short interval between initial and final setting times, MPC generally is not hard troweled. The mixing water typically has a tolerance of only ±10%. Any variation of the water content from that specified by the manufacturer reduces both the strength and the durability of the MPC mortar.

The neat or extended magnesium phosphate mortar develops a very rapid exothermic reaction that can produce relatively high temperatures; therefore it should not be placed at temperatures above 80 °F (27 °C) or in the sunlight within the temperature ranges of 60 to 80 °F (15 to 27 °C). Hot weather formulas are available for use in warm ambient conditions. In a hardened state, MPC quickly produces high strength and high modulus of elasticity. Therefore, it is not flexible and does not have the toughness that is typically found with organic-modified mortars and is susceptible to fracturing from impact loads. With the normal setting formulations of MPC, high heat peaks are encountered. (ACI Committee 546, 2004)

2.3 Polymer Concrete

Polymer concrete (PC) is a composite material in which aggregate is held together in a dense matrix with a polymer binder. The polymer binder is formed by polymerizing a mixture of a monomer and aggregate (no other bonding material) to use in place of portland cement. The rest of the mixture consists of water, fine aggregates or sand and fiber. PC is mixed, placed, and consolidated in a manner that is similar to conventional concrete and exhibits rapid curing; high tensile, flexural, and compressive strengths; good adhesion to most surfaces; good freezing-and-thawing resistance; low permeability to water and aggressive solutions; and good chemical resistance. PC also has rapid curing at ambient temperatures from 0 to 104 degrees Fahrenheit (-18 to 40 degrees Celsius), good resistance against corrosion, is light weight, has increased ductility for some products, low shrinkage during curing, and may be vibrated to fill voids. ASTM C 881 (2013) is the standard that covers two-component, epoxy-resin bonding systems for application to PCC.

There are a wide variety of prepackaged polymer products available, and these make use of many different polymers. A polymer is a chemical compound or mixture of compounds formed by polymerization, and consisting essentially of repeating structural units. Polymer Concretes include; furan and sulfur concretes, polyester, vinyl ester, vinyl ester novolac polymer concretes, epoxy and epoxy-novolac polymer concretes, potassium silicate, etc. Most of the work on polymer concretes has been with methyl methacrylate, epoxies, and polyester-styrene resin systems. (Poston et. al, 2001)

These resinous polymer concretes generally achieve compressive strengths significantly higher than polymer modified concrete. Potassium silicate polymer concretes are more like PCC in that they achieve compressive strengths in the 3,500-4,500 psi (21 to 28 MPa) range and have a certain degree of absorption. Polymers with high elongation and low modulus of elasticity are particularly suited for bridge overlays.

PC overlays are especially well suited for use in areas where concrete is subject to chemical attack.

Application and performance of PC is dependent upon the specific polymeric binder as well as the type of aggregate and its gradation. Co-polymerization techniques allow the production of a variety of binders with a wide range of physical properties. Many factors affect the performance of these materials so it is essential that the manufacturer's recommendations be carefully followed. Aggregates composed primarily of silica, quartz, granite, good limestone, and other high-quality material have been used successfully in the production of polymer concrete, but must be dry and free of dirt and other organic materials. If they are not, the moisture can reduce the bond strength between the monomers and epoxies and the aggregate. (ACI Committee 548, 2009)

Limitations of PC include that organic solvents are required to clean equipment when using polyesters and epoxies, working times for these materials are variable and depending on ambient temperatures, they may range from less than 15 min to more than one hour, therefore rapid curing generally means less time for placing and finishing operations. Retarders and accelerators can often be added to help control the working and curing times. Some epoxy systems are custom batched at the factory to accommodate a specific ambient temperature range. The coefficients of thermal expansion of polymer materials are variable from one product to another, and are significantly higher than conventional concrete. (ACI Committee 546, 2004)

Most of the polymer concretes considered for repairing pavement spalls are very ductile, but still hard enough to wear well. Generally speaking, the more resin-rich repair matrix gives more elastomeric properties, and filling the matrix with more clean, dry sand or coarse aggregate makes it more rigid. It is important to note that polymers cost much more than portland cement, but their ability to bond and stay in the repair without cracking may make them very cost effective. So, initial material costs in a labor intensive job may not be nearly as important for repairs as for new construction (Fowler et. al, 2008).

2.3.1 Epoxy Compounds

Epoxy compounds are generally formulated in two or more parts. Part A is most often the portion containing the resin, and Part B is usually the hardener system. Epoxy systems are formulated for specific uses so the proper epoxy must be selected for the specific job requirements. The ratio of resin to hardener varies considerably with the formulation of the epoxies. The range of curing temperatures also varies depending on the specific formulation. (UFC, 2001) Curing can take place at temperatures varying from 140 to 5 °F (60 to –15 °C) or below. Epoxy resins are generally high in cost, but offer advantages, such as low shrinkage, while some formulations bond to damp surfaces that do not require a primer.

CHAPTER III

BACKGROUND AND LITERATURE REVIEW OF CONCRETE PAVEMENT AND BRIDGE DECK REPAIR

This chapter addresses the repair process, factors in determine a good concrete pavement repair material, along with areas to avoid and cautions. It also reviews common causes of partial depth repair failure, classes of repair materials and types of testing previously done on rapid setting materials by NTPEP and ERDC. Results of that testing are reviewed along with an overview of current ODOT specifications for patching.

The use of rapid-setting materials for concrete pavements is not new. Much research has been focused on the development of methods of evaluating the wide spectrum of materials being marketed to state departments of transportation (DOTs) over that last 20 years. Field testing of these materials has resulted in identification of problems with short working times at both ambient and high temperatures, with excessive shrinkage cracking, and with batching quantities needed for repairs (Macadam et al. 1984; Parker et al. 1985; Ramey et al. 1985; Popovics and Rajendran 1988).

These problems have been alleviated by a newer generation of products with modern cementing components. Unfortunately, repackaging and reformulation of these products by manufacturers have resulted in serious pavement repair failures with some of the products, despite previous good repair results with ostensibly the same product (Priddy, 2007). Thus, unless the material has recently undergone testing to verify the properties, the design engineer cannot be confident that the material will meet performance expectations. To combat this problem of repackaging and reformulation, The American Association of State Highway and Transportation Officials (AASHTO) recommends that products be retested every five years through the National Transportation Product Evaluation Program (Priddy, 2011)

3.1 Repair Process

It is frequently necessary for rapid repair of pavements or bridges so that there is minimal disruption to the traveling public and improved safety on roads. The term 'rapid' is used in this setting to describe materials that gain strength at a speed that will allow a section of road open within a short period of time, usually one to three hours after the repair materials are placed. The repair process is a multistep progression and includes many factors that control the success of a repair. Removal of existing damaged concrete, adequate surface preparation of the repair patch, selection of the product, placement conditions, and procedures required by the manufacturer all influence the achievement of the project.

Some questions need to be asked when considering the repair approach for a damaged section of pavement or bridge deck. Figure 1 offers an example of these questions. Attention needs to be paid to the exposure conditions and how long the road can be closed while the repair is performed. These repair products will be installed in an unforgiving environment where freezing and thawing, chloride exposure, and drying and wetting take place. The products also are generally placed while traffic continues in neighboring lanes, making it crucial that lane closures are for the least time possible. A two to four hour window is the target to ensure minimal delays and safety for workers.

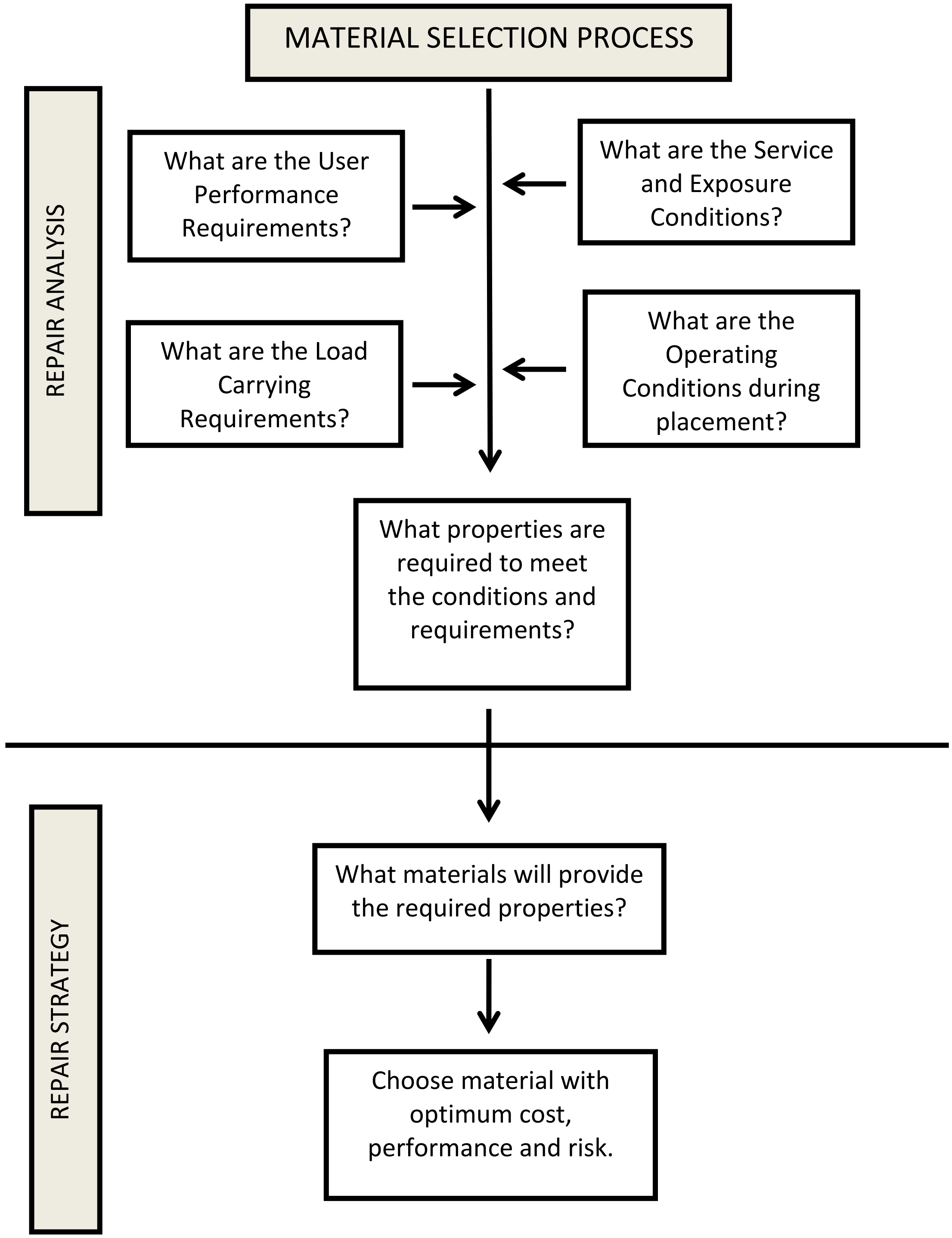

Figure 1: Questions to Consider Before Selecting a Repair Material (based on Emmons, 1993)

3.2 Choosing a Repair Material

Choosing a repair material is not easy. It involves an understanding of many factors including; constructability, exposure properties, and the structural and functional requirements. Structural requirements include load carrying and stress distribution. This requires a good bond to the existing material and a similar modulus of elasticity or strength to the existing concrete. Constructability requires speed and avoidance of special requirements to get the patch installed quickly and easily. The key is to maintain rapid setting qualities but still allow sufficient working time. Exposure conditions, namely chlorides and freezing and thawing, are important for patches. Thermal coefficient of expansion, permeability and drying shrinkage are other properties to pay attention to when dealing with these conditions. Finally, the functional requirements are rideability and a safe surface. Final selection of materials is made based on the relationship between cost, performance and risk. (Emmons 1993)

Typically, the repair material is expected to be at least as strong as the existing material and to match the properties of the substrate. This is meant to ensure that the pavement or bridge deck can carry the loads it was originally designed to carry without a failure occurring in the repair material. It is also understood that the modulus needs to be similar for both the repair and substrate material. This is due to the fact that when a load is added to the existing and new repair material combination, the deformations and stress transmitted through each of these materials should be similar.

3.3 Common Reasons for Failure in Partial Depth Repairs

There can be many reasons for failure in partial depth repairs, the main one being spalling. Spalling is a term that describes chipping or splintering at joints or cracks of the surface of concrete or other similar material. Spalling limits the lifespan of the pavement or bridge deck, if not taken care of, and can also be dangerous to road users. Spalling can be caused by repeated heavy traffic loads, freezing and thawing, corrosion of the reinforcing steel, alkali-silica reactions, or failure of doweled pavement joints to function properly. The intrusion of incompressible materials in the open cracks and inadequate construction such as poor surface finish or reinforcement that is too close to the surface can also cause spalling. (Unified Facilities Criteria, 2001) Once spalling starts, it will continue to grow. For this reason, spalling is generally treated before it extends below the top third of the slab. If the spall depth is greater than 1/3 the slab depth, full-depth patching is needed. (Concrete Repair Manual, 2004)

Studies have shown that when partial-depth patches are properly installed using good quality control practices, 80 to 100 percent of the repairs perform well after three to ten years of service (Webster et al. 1978; Snyder et al. 1989). However, in many cases, improper design and construction practices, combined with poor quality control and inspection, result in poor performance of the installed patches (Wilson et. al 1999)

Another critical factor that influences success and durability is the dimensional stability of the material. Incompatibilities that can disrupt the stability range from different elastic moduli to different expansion and contraction. Due to thermal changes, tensile stresses build within the repair, because it is unable to shrink or expand freely. This then leads to cracking or loss of bond at the interface if the stress becomes large enough. The loss of bond causes delamination.

Even though the material may be strong enough to resist cracking, high stresses can still develop due to shrinkage between the material and substrate, resulting in interfacial cracking. The most frequent causes of partial-depth patch failure are listed in Figure 2.

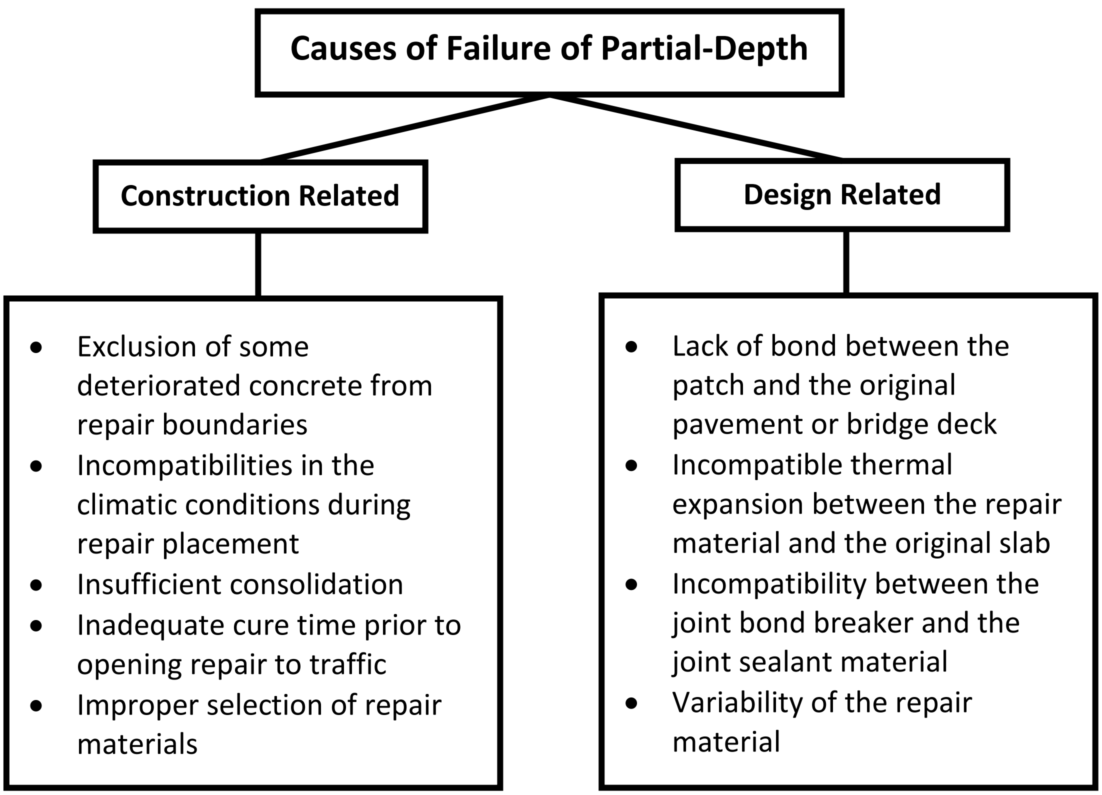

Figure 2: Factors Leading to Partial-Depth Repair Failures (based on Wilson et. al. 1999)

3.4 Classes of Repair Materials

A properly designed, placed and cured conventional portland cement concrete, remains as one of the most widely used and reliable patching materials for concrete pavements and bridge decks. It is most effective for full-depth patches or complete slab replacement. The use in partial-depth patches has given mixed results, some successful and many not. (Unified Facilities Criteria, 2001) This type of repair material, though, requires detours or lane closures for prolonged periods of time. To reduce this, there has been a significant increase in the use of “rapid-set” concrete patching materials.

Rapid-hardening cements are defined as those that can develop a minimum compressive strength of 3,000 psi (20MPa) within eight hours or less. (US Army Corps of Engineers, 1995) There are many types of these materials that include; Type III portland cement, magnesium phosphate, high alumina cement, gypsum-based, polymer concrete, polymer modified concrete, and regulated-set portland cement. ERDC focused on three families of base materials – ultrafine portland cement, magnesium phosphate and high alumina. NTPEP focused on the three categories of cementitious concrete, polymer concrete and polymer modified concrete. Emberson and Mays (1990) have chosen more general groups and fit many materials under each heading. They classified the groups to be; cementitious mortars, polymer-modified cementitious mortars and resinous mortars, shown in Table 1.

Many different products are sold under a variety of trade names and it is often difficult to identify the specific cementitious agent. All claims of performance for these proprietary products should be treated with caution, and it is always prudent to establish the performance of new products through trials prior to committing to the purchase of large quantities (Unified Facilities Criteria, 2001)

Table 1: Generic Systems for Concrete Patch Repair (after Emberson and Mays, 1990)

Cementitious Mortars	Polymer-Modified Cementitious Mortars	Resinous Mortars
Portland Cement (PC)	Styrene Butadiene Rubber	Epoxy
High Alumina Cement (HAC)	Vinyl Acetate	Polyester
PC/HAC mixtures	Magnesium Phosphate	Acrylic
Expansion Producing Grouts	Acrylic	Polyurethane

3.5 NTPEP and ERDC Testing Criteria for Cementitious Materials

The National Transportation Product Evaluation Program and the U.S. Army Engineer Research and Development Center have both conducted investigations of concrete pavement and bridge deck repair materials to determine their suitability for field repairs.

ERDC states that numerous commercial-off-the-shelf products are available for small surface repairs in portland cement concrete (PCC) pavements that provide short set times, high early strengths, and durability to withstand heavy loads. Standard laboratory tests have been set up to characterize the material properties and to provide a mechanism for assessing the material suitability for field repairs. Field testing has also been conducted and evaluated under controlled conditions.

The NTPEP Project Panel on Rapid Setting Patching Materials for portland cement concrete developed procedures for their program work plan. Under agreement with The American Traffic Safety Surfaces Association (ATSSA), this panel has two industry representatives. This ensures that industry concerns, experience and technical knowledge are considered in the testing and evaluation of products, materials and/or devices that are commonly used by the AASHTO member departments (AASHTO NTPEP report)

3.5.1 Laboratory Testing Material Criteria

Both NTPEP and ERDC tested similar repair materials in the laboratory. They were magnesium phosphate, latex modified, polymer resin and cementitious rapid setting materials designed for patching portland cement concrete bridge decks and concrete pavements. Standard laboratory tests were performed to characterize the material properties and to provide a process for assessing a material's suitability for field repairs. NTPEP specified that the product must reach a traffic loadable condition (1200 psi (8.3 MPa) compressive strength) in less than three hours. ERDC specified a compressive strength > 3000 psi (20.7 MPa) after 2 hours and 1 day. They also stated that commercial repair materials are generally categorized as cementitious or rigid, asphaltic, or polymeric. Their particular comparison is limited to cementitious products. It was also stated that in general, the products in their study can be described as belonging to one of three base materials: ultrafine portland cement, magnesium phosphate, and high-alumina. No polymeric materials were included in ERDC's study, nor were gypsum cements. Blended calcium sulfo-aluminate and calcium aluminate cements were categorized as high-alumina cements. The Repair Materials Certification Program, headed by Pete Bly, of ERDC, is an ongoing program that tests or recertifies three to six proprietary products per year. NTPEP named their base materials as cementitious concrete, polymer concrete and polymer modified concrete. Certified products are re-tested every five years. NTPEP described set time, compressive strength, freeze thaw durability, thermal expansion and shrinkage, bond strength, UV stability, soundness, gradation and absorption as key laboratory testing criteria.

The ERDC draft laboratory test criteria was developed by the Federal Highway Administration (FHWA) in 1991. They 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). Set time and shear bond were also recommended to evaluate material performance (Beer et al. 1984). Testing performed under the REMR program in 1999 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 each property. The U.S. Air Force (2006) identified 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.

Overall, the final ERDC criteria for laboratory testing was determined to be: compressive strength, flexural strength, bond strength, modulus of elasticity, coefficient of thermal expansion, volumetric expansion, shrinkage potential and time of setting.

3.5.2 Testing Performed

Standard tests and non-standard procedures were used. Although some of the tests used by both NTPEP and ERDC require different size cylinders and testing times, the final analysis results from each can be compared. Water used was the maximum allowed as designated on the manufacture's shipping container.

3.5.2.1 Summary of Tests used by both NTPEP and ERDC

Table 2: Water Based Materials

Test	Specification
Compression, Cylinders	ASTM C39
Freeze/Thaw	ASTM C666 (procedure B) and
Freeze/Thaw	ASTM C666 with salt water (procedure B)
Thermal Expansion and Shrinkage	ASTM C531 modified

Table 3: Non Water Based Materials

Test	Specification
Compression, Cylinders	ASTM C39
Freeze/Thaw	ASTM C666 (procedure B)
Bond Strength using Slant Shear	ASTM C882 (polymer systems)
Thermal Expansion and Shrinkage	ASTM C531 modified

3.5.2.2 ERDC Requirements

All tests require three replicates. The average result is then calculated from the three replicates.

- Compressive strength tests were made at either 2 hours or 1 day according to ASTM C39 using 4 x 8 inch (100 x 200 mm) cylinders. The strength requirements at each time were ≥ 3,000 psi (20.7 MPa) at age of 2 hours or ≥ 5,000 psi (34.5 MPa) at age of 1 day.
- The freeze thaw test begins at age of 3 days. ERDC has no requirement at this time. Depending on future testing, a possible freeze-thaw resistance requirement would be ≤ 50% loss in relative dynamic modulus of elasticity after 50 cycles.
- Determining the coefficient of thermal expansion, prismatic bars are required to be 1 x 1 x 10 inch (25 x 25 x 250 mm) with metal studs on the end. Measurements to be taken at 73°F (23°C) and 210°F (99°C). Testing begins at age of 3 days and needs to be ≤ 7 x 10^{-6} in./in./°F. (12.6 x 10^{-6} mm/mm/°C)

- Bond strength required cylinder specimens of 3 x 6 inch (75 mm x 150 mm) and required a ≥ 850 psi (5.9 MPa) (repair bonding to OPC mortar) at age of 1 day and a ≥ 1,000 psi (6.9 MPa) (repair material bonding to repair material) at age of 1 day.

3.5.2.3 NTPEP Requirements:

- Compressive strength tests were made at 1 hour, 3 hours, 1 day and 7 days according to ASTM C39 using 4 x 8 inch (100 mm x 200 mm) cylinders.
- Linear shrinkage and Coefficient of Thermal Expansion was measured in accordance with ASTM C531 with the following modifications: "Measure at 1, 3, 7 and 11 days. The samples are stored at 73°F (23°C) for the first 7 days, then placed in oven at 210°F (99°C) for 3 more days, then let cool a minimum of 16 hours at 73°F (23°C)".

3.5.2.4 Additional Tests done by ERDC and their requirements

ERDC also conducted some additional tests that NTPEP did not use. ERDC also specified that manufacturers shall indicate if the product is to be wet or dry cured. Dry cure was in the lab at a 50% relative humidity and 73°F (23°C). Table 4 shows those tests and their requirements.

Table 4: ERDC Additional Tests

Property	ASTM	Requirements
Flexural strength	C78	Strength should be ≥ 350 psi (2.4 MPa) (at ages of 2 hours and 1 day for a 6 x 6 x 18 inch beam (150 x 150 x 450 mm).
Modulus of elasticity	C469	Test after 2 hours and 3 days. Cylinders should be 3 x 6 inch or 6 x 12 inch at age of 2 hours. Modulus of Elasticity should be ≤ $3.0x10^6$ psi (20.7 GPa) and at 3 days should be ≤ $4.0x10^6$ psi (27.6 GPa).
Volumetric expansion (Length Change)	C157	Expansion needs to be < 0.03% or < -0.04% beginning at the age of 4 days. The prismatic bars are sized 3 x 3 x 11.25 inch (75 x 75 x 285 mm) with metal studs at each end and cured either water at 73°F (23°C) or air at 73°F (23°C) with 50% relative humidity. Readings at 4, 7, 14 and 28 days.
Shrinkage potential	C1581	Cured at 73.5°F (23°C) for 28 days. Record when crack first occurs or at 28 days if it does not occur. Should be ≤ 40 microstrain at age of 14 days and ideally no cracking at 28 days. Test begins at time of casting.
Time of setting	C191	Test begins immediately and ends when penetration resistance equals 500 psi (3.5 MPa). No requirement at this time.

3.5.2.5 Additional Tests done by NTPEP and their requirements

Below are additional tests done by NTPEP. Their requirements specified that the amount of water to be used shall be the maximum allowed as designated on the manufacturer's shipping container. Slump and air content shall be performed unless the manufacturer specifically states otherwise, and all other tests are done following ASTM standards.

Table 5: Water Based Materials

Test	ASTM
Set Time	C266
Bond Strength using Slant Shear (cementitious systems)	C882 (C928)

Table 6: Non Water Based Materials

Test	ASTM
Set Time	C266
UV Stability, Method D, (Type B bulb)	D4587

Table 7: Extender Aggregate

Test	AASHTO
Gradation	T27
Soundness	T103
Absorption	T84 or T85

- UV stability is measured in accordance with ASTM 4587 (QUV), Method D, Type B bulb. Testing was with neat material only. The specimen was 3.5 inches (90 mm) long by 2.25 inches (57 mm) wide, by 0.75 inches (19 mm) thick, with two specimens per sample. Testing is for 1000 hours or until complete failure is noted.

3.5.3 NTPEP and ERDC Field Performance Testing

Field testing by ERDC and NTPEP were on different surfaces. ERDC used a concrete pavement and NTPEP a concrete bridge deck. Both programs chose one test location for all their testing. NTPEP had requirements that needed to be met when choosing the flied testing location. The characteristics were:

- Full depth portland cement concrete bridge deck surface, no overlays or membranes.
- Wet freeze climate.
- Patches should be located away from expansion joints and end dams.

In addition, every site will generally have the following characteristics:

- Boundaries of the patch area will be original sound concrete.
- Patch areas will be similar in size (nominal 9 x 3 feet x 4 inches deep (2.7 x 0.9 m x 100 mm)).
- All patched edges will be saw cut.

ERDC determined that small volume repairs would generally have a surface area of 5 ft^2 (0.45 m^2) or less, either partial-depth or full-depth. Large volume repairs would be considered any repair from full-depth large patches (surface area greater than 5 ft^2 (0.45 m^2)) to full-slab replacement. Looking at the two different nominal patch sizes for each method, NTPEP's patch would fall into ERDC's large volume repair category for full depth large patches but not the full slab replacement.

For installation, NTPEP required that the manufacturer supplied all labor and equipment to completely install the properly sampled and marked material. This included water and extender aggregate if it was required. They certified that their patching material was installed in accordance with their written instructions and to their satisfaction. ERDC instillation did not require the manufacturer to come out and install their product. One experienced crew did all the installation and preparation for the ERDC testing.

ERDC field testing and observation was done at 1, 7, 14 and 28 days. The testing consisted of using a specially designed single wheel load cart used to simulate an F-15E aircraft. The tire was inflated to 325 psi (2.2 MPa) and loaded so it supported 35,235 pounds (15,982 kg). Initial trafficking consisted of 112 passes, starting three hours after repair completion. Once all repairs had been initially trafficked, the repairs were trafficked to failure or 5,008 passes. Data collected during trafficking was surface roughness, permanent deformation, and elastic deformation. Additionally pressure cells were installed beneath the structural cap to provide stress measurements for calculations of each repair's ability to distribute load. Freeze thaw testing was not included in the scope of work for ERDC. (ERDC/GSL TR-11-27, 2011)

NTPEP field observations cover two years to include freeze thaw cycles with photos and site characteristics including average daily traffic, percent trucks, and area weather data recorded at 12 months and 24 months. (NTPEP, 2004)

Subjective Rating of patch material performance is based on the following table:

Table 8: Rating of Patch Material Performance

Rating	Cracking or Edge Debonding		Debonding or Hollow		Spalling
1	Over 1/8 inch (3.2 mm)	and	Over 90%	and	Over 90%
2	1/16 inch (1.6 mm)	or	Over 70%	and	Over 70%
3	1/32 inch (0.8 mm)	or	Over 50%	and	Over 50%
4	Hairline	or	Over 30%	or	Over 30%
5	None	and	None	or	Slight

Field testing site for NTPEP was a bridge deck located on US route 20A over interstate 475/ US 23 in southwest Toledo, Ohio. The structure is a continuous steel beam bridge built in 1968. The deck has numerous patches and cracks, but in general, has no significant debonding or delamination and is sound dense concrete. The 2003 traffic survey data indicated the bridge carried 10,530 ADT with 9% trucks. The average weather is summarized below.

Table 9: Average Weather for NTPEP Testing Site

Average Temperature Range, °F (°C)	22.5 - 72.1 (-5.3 – 22.3)
Average Temperature, °F (°C)	48.5 (9.2)
Average Annual Rainfall, inches (mm)	33.0 (838.2)
Average Annual Snowfall, inches (mm)	37.1 (942.3)
Average # Days Below 32°F (0°C)	138
Average # Days Above 90°F (32°C)	14

ERDC does not provide their weather information. The testing site is Vicksburg, MS.

3.5.4 Shortfalls of Previous Research

ERDC states that based on review of the previous studies and requirements, few repair materials met all current Engineering Technical Letter requirements of the US Air Force. Despite not meeting minimum laboratory performance criteria, several cementitious repair materials were initially recommended for use based on good field performance. This indicated that a review of the test requirements compared to field results was needed. Additionally, because some materials were only suitable for a specific size (small or large) repair, a general approval of the material as a repair material was not appropriate. Repair materials should be approved for the different volume applications (spall repair, small patching, large patching, or full-slab replacement) or repair types (temporary vs. permanent) to which they are best suited. (ERDC/GSL TR-11-13, 2013)

3.6 Additional Literature Review

Additional review of more ERDC documents yielded extra data and supplementary information on further products. The document "Laboratory and Field Investigations of Small Crater Repair Technologies" provides useful information on their small crater patches of 5 x 5 feet (1.5 x 1.5 m). This size fits in with the previous patches studied from other resources, and the size being used in the field testing in this study. Initial laboratory testing procedures were also reviewed. Comparing the laboratory procedures to ones previously recorded found two tests that were the same (ASTM C39, ASTM C882) and one additional test (ASTM C403).

The testing requirements for ASTM C39, Unconfined Compressive Strength, were use 6 x 12 inch (150 x 300 mm) cylinders and test at 2 hours, 6 hours, 1 day and 28 days at temperatures of 73°F (23°C) and 90°F (32°C). A minimum of three replicates are necessary. ASTM C882, Slant Shear, requires 3 x 6 inch (75 x 150 mm) cylinder molds to be tested at 24 hours and 28 days at 73°F (23°C). A minimum of two replicates is essential. ASTM C403, Time of Setting, requires an initial set penetration resistance of 500 psi (3.4 MPa) and a final time set penetration of 4000 psi (27.6 MPa) with testing temperatures of 73°F (23°C) and 90°F (32°C). Again, two replicates are required.

Other requirements defined for choosing the materials are stated below and should also be considered in this study.

- Have a color similar to PCC.
- Can be mixed and placed like concrete with portable equipment.
- Do not pose significant health risks to users.
- Have accelerated hardening characteristics.
- Yield a permanent patch in concrete that can withstand traffic within short time frames for repair.

3.7 Current ODOT Specifications

The current 2013 ODOT Construction and Material Specifications book calls out item 256 for Bonded Patching of Portland Cement Concrete Pavement. Types A, B, and C patch material are specified. Type A patch material uses high early strength portland cement, but Types B and C use item 705.21 Quick Setting Concrete Mortar (page 146-148). Item 705.21 requires conditions for the mortar, stating that the materials must be capable of extending by 50% by dry mortar weight. It also provides requirements in terms of compressive strength (ASTM C39, C109), initial set time (ASTM C266), bond strength (ASTM C882), flexural strength (ASTM C79), and freeze-thaw durability (ASTM C666). (page 731-733) No requirements are placed on shrinkage or expansion. ASTM C882 is the slant shear test, which puts in the bond interface into compression and shear as opposed to the combination of tension and shear that is more likely to occur in a repair patch (Delatte et al. 2000a, 2000b, 2001, Delatte and Sehdev, 2003). Below, Table 10 outlines the requirements of the testing mentioned above and can be found on page 732 in the2013 specifications book.

Table 10: ODOT 705.21 ASTM Requirements (ODOT, 2013)

Test	Type 1	Type 2
Compressive Strength ASTM C109, psi (MPa)		
@ 1 Hour	100 (0.7)	2000 (14)
@ 3 Hour	250 (1.7)	---
@ 24 Hours	2000 (14)	5000 (34)
@ 7 Days	---	7000 (48)
Compressive Strength ASTM C39		
@ 1 Hour	100 (0.7)	(2000) (14)
@ 3 Hour	150 (1.0)	---
@ 24 Hours	1000 (10)	3500 (24)
@ 7 Days	---	6000 (41)
Initial Set Time ASTM C266 (min)	5 Minutes	10 Minutes
Bond Strength, ASTM C882 psi (MPa)		
@ 24 Hours	1000 (7)	1000 (7)
@ 7 Days	1500 (11)	1500 (11)
Flexural Strength ASTM C 78 psi (MPa)		
@ 4 Hour	---	200 (1.4)
@ 3 Day	650 (4.5)	500 (3.4)
Freeze and Thaw ASTM C 666 (use either Procedure B or A)		
Procedure B (350 Cycles) Durability Factor	80%	80%
Procedure A (300 Cycles) Durability Factor	79%	79%

Patching of concrete structures is addressed in the 2013 ODOT specifications book as item 519. The repair material is item 499 or 511 – QC 2 concrete. QC 2 concrete does not have the same performance requirements as item 705.21, in that a 28 day strength and maximum permeability are specified, but not early age strength or bond strength. (Page 284, 323, 421)

Patching is also addressed by the ODOT Supplement Specification 843, Patching Concrete Structures With Trowelable Mortar, 847 Bridge Deck Repair and Overlay with

Concrete Using Scarification and Chipping, and 848 Bridge Deck Repair and Overlay with Concrete Using Hydro-Demolition. Item 843 would seem not to be applicable for bridge decks. The materials called out in 847 and 848 are a micro-silica modified concrete (MSC) overlay; a latex modified concrete (LMC) overlay or a superplasticized dense concrete (SDC) overlay. Supplemental Specifications 847 and 848 are focused much more on overlays than on patching. (ODOT Supplement, 2003)

On the whole, the current specification and supplemental specifications are out of step with the transition in ODOT from prescriptive format, such as mixture proportions provided by ODOT, to performance based specifications. Thus, in the current format, it is difficult to make use of new materials and emerging technologies.

As stated earlier in the Introduction and Research Objectives on page 1, an important issue with concrete patching materials is that their constituents and the mechanisms by which they gain strength are generally proprietary, so they are difficult to specify on a generic basis. In addition, it is noted that products may be reformulated and repackaged, so the performance may change without warning. Priddy (2011) mentions; "To combat this problem of repackaging and reformulation, The American Association of State Highway and Transportation Officials (AASHTO) recommends that products be retested every 5 years through the National Transportation Product Evaluation Program" (Priddy, 2011, page 2).

The US Army Corps of Engineers, ERDC, undertook an extensive study of rapid setting cementitious repair materials for patching airfield pavements (Priddy, 2011). Performance goals were short set times, high early strengths, and durability to withstand heavy loads. ERDC tested 20 different potential cementitious repair materials, and only 18 were approved for either temporary or permanent repairs and only seven were approved for large patch repair.

3.8 Recap of ASTM Standards Most Suited To This Study

The different studies reviewed in the previous literature contain numerous ASTM Standards that have been used to evaluate rapid setting repair materials. Some of the most relevant and useful standards that were found are shown in Tables 11 to 15. These tables will be cut down to a smaller total number of standards that will be more appropriate for this study when lab testing commences.

Table 11: ASTM Setting Standards

ASTM STANDARD	TEST
C191	Time of Setting of Hydraulic Cement by Vicat Needle
C266	Time of Setting of Hydraulic Cement Paste by Gillmore Needles
C403	Time of Setting of Concrete Mixtures by Penetration Resistance

Table 12: ASTM Strength Standards

ASTM STANDARD	TEST
C39	Compressive Strength of Cylindrical Concrete Specimens
C78	Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
C109	Compressive Strength of Hydraulic Cement Mortars (Using 2in or 50mm Cube Specimens)
C496	Splitting Tensile Strength of Cylindrical Concrete Specimens
C579	Compressive Strength of Chemical Resistant Mortars, Grouts, Monolithic Surfacing's and Polymer Concretes
C882	Bond Strength of Epoxy-Resin Systems used with Concrete by Slant Shear
C1074	Estimating Concrete Strength by the Maturity Method
C1583	Tensile Strength of Concrete Surfaces and the Bond Strength or Tensile Strength of Concrete Repair and Overlay Materials by Direct Tension (Pull-Off Method)

Table 13: ASTM Length Change Standards

ASTM STANDARD	TEST
C157	Length Change of Hardened Hydraulic Cement Mortar and Concrete
C531	Linear Shrinkage and Coefficient of Thermal Expansion and Chemical Resistant Mortars, Grouts, Monolithic Surfacing's, and Polymer Concretes
C1012	Length Change of Hydraulic Cement Mortars Exposed to a Sulfate Solution

Table 14: ASTM Miscellaneous Standards

ASTM STANDARD	TEST
C215	Fundamental Transverse, Longitudinal, and Torsional Resonant Frequencies of Concrete Specimens (Dynamic Modulus of Elasticity And Poisson Ratio)
C469	Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression
C642	Density, Absorption and Voids in Hardened Concrete
C666	Resistance of Concrete to Rapid Freezing and Thawing
C672	Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals
C1581	Determining Age at Cracking and Induced Tensile Stress Characteristics of Mortar and Concrete under Restrained Shrinkage
D1653	Epoxy Content of Epoxy Resins

Table 15: ASTM Standard Specifications

ASTM STANDARD	TEST
C192	Making and Curing Concrete Test Specimens in the Laboratory
C881	Standard Specification for Epoxy-Resin-Based Bonding Systems for Concrete
C928	Standard Specification for Packaged, Dry, Rapid-Hardening Cementitious Materials for Concrete Repairs
D2026	Standard Specification for Cutback Asphalt (Slow-Curing Type)
D2027	Standard Specification for Cutback Asphalt (Medium-Curing Type)

ASTM C928 "Standard Specification for Packaged, Dry, Rapid-Hardening Cementitious Materials for Concrete Repairs" is a good specification to follow when determining which tests should be done in the laboratory. Table 16 contains the standards within this specification and their requirements. ODOT 705.21 specifications closely follow ASTM 928 as seen in Table 10.

Table 16: ASTM C928 Performance Requirements

Test	R1	R2	R3
Compressive Strength ASTM C39/ C109, psi (MPa)			
@ 3 Hour	500 (3.5)	1000 (7.0)	3000 (21)
@ 24 Hours	2000 (14)	3000 (21)	5000 (35)
@ 7 Days	4000 (28)	4000 (28)	5000 (35)
Bond Strength, ASTM C882 psi (MPa)			
@ 24 Hours	1000 (7)	1000 (7)	1000 (7)
@ 7 Days	1500 (10)	1500 (10)	1500 (10)
Length Change, ASTM C157, based on length at 3 hours, max (Water/Air), %			
@ 28 Days	±0.15	±0.15	±0.15
Consistency of Concrete or Mortar, ASTM C143, after addition of mixing liquid	15min	5min	5min
Concrete Slump, min, in. (mm)	3 (75)	3 (75)	3 (75)
Flow of Mortar, min, %	100	100	100
Scaling Resistance to Deicing Chemicals, ASTM C672, after freezing and thawing (25 Cycles)			
Concrete, Max Visual Rating	2.5	2.5	2.5
Mortar, Max Scaled Material, lb/ft^2 (kg/m^2)	1 (5)	1 (5)	1 (5)

3.9 Previously Researched Materials Description and Classification

The following tables list materials that have previously been evaluated by the NTPEP and ERDC testing programs. Included in the tables are the manufacturer, product name, product classification, description, and whether they passed or failed the testing process.

Under the NTPEP testing, 15 products passed and 11 products did not perform to required standards. The failures were characterized as lab or field failures. Lab failures can consist of not passing the compression strength requirements set out by NTPEP or not completing the 300 freeze thaw testing cycles. Lab failures, however, do not necessarily mean that the product is not going to perform well in the field. There were only two field failures, Strongfloor ET-1200 and Futura-15. These two products will not be considered in this study.

Table 17: NTPEP 2004 – 2007 Product Submissions (NTPEP, 2004, 2005, 2006, 2007)

Product Manufacturer	Product Name	Product Classification	Product Description	Pass/ Fail
CeraTech Inc.	Pavemend 5.0	Polymer Modified	Chemically bonded material. Magnesium Oxide, Phosphate, Crystalline Silica (quartz), Coal Ash.	Pass
CeraTech Inc.	Pavemend SLQ	Cementitious Concrete	Product withdrawn	Fail
CeraTech Inc.	Pavemend EX	Cementitious Concrete	Single component water activated, cementitious, rapid setting structural concrete.	Pass
Crafco Inc.	ElastoPatch	Polymer Concrete	100% solids, 3 components. Polyurethane and aggregate polymer concrete.	Pass
Crafco Inc.	TechCrete	Polymer Concrete	Cement, Aggregate, Polymer, Resin, Fiber.	Pass
CTS Cement Manufacturing Corp.	Rapid Set DOT Repair Mix	Cementitious Concrete	Rapid strength gain cement, high durability and low shrinkage mix for general concrete repair.	Pass
CTS Cement Manufacturing Corp.	Rapid Set Cement All	Cementitious Concrete	RapidSet cement blended with fine sand and chemical additives.	Lab Fail
Henkel Loctite	Fixmaster Magnacrete	Cementitious Concrete	Two component magnesium phosphate based.	Lab Fail
MRT Inc.	ArmorFast Rapid Hardening Hydraulic Mortar	Cementitious Concrete	Patch material for concrete derived primarily from recycled and activated coal fly ash. Silica, alumina, calcium and special clays.	Lab Fail

MRT Inc.	Armorfast 45	Cementitious Concrete	Cement (with fly ash), Sand, Minerals of Special Clays, Proprietary Compounds.	Pass
Pavement Technology Inc.	SurfCrete	Polymer Concrete	Proprietary blend of polymers, mixed with cement and sand.	Pass
Qudex	Donacrete Superpatch	Cementitious Concrete	One component. Blended Cements, Granite Aggregate, Admixtures, Nylon Fibers.	Pass
Quikrete	FastSet Concrete	Cementitious Concrete	Specially blended cement, graded course and fine aggregate.	Pass
Quikrete	FastSet DOT Mix	Cementitious Concrete	Fiber reinforced repair designed specifically to meet ASTMC 928 R3. Meets DOT Region 3 requirements. Cement, Sand, Special Additives.	Lab Fail
Quikrete	FastSet Repair Mortar	Polymer Modified	Low Slag Mortar, Blend of portland cement, fast setting hydraulic cement, sand, lime, polymers, other additives.	Lab Fail
Quikrete	FastSet DOT Mix w/ Fibers	Cementitious Concrete	Fiber reinforced. Rapid setting material specifically designed to meet ASTM C928 R3 for a high performance repair material. Fiber reinforced.	Pass
Quikrete	Fastset DOT Deck Repair Polymer w/ Fibers	Polymer Modified	Fast setting, high early strength, fiber reinforced material for concrete repair.	Pass
Roklin Systems Inc.	Flexset	Polymer Concrete	Two part polymer concrete kit with specially treated, naturally rounded, aggregate	Lab Fail
Roklin Systems Inc.	Concrete Welder	Polymer Concrete	Thin flowing rapid setting polymer concrete designed for concrete slab stabilization.	Pass
SpecChem	RepCon 928	Polymer Modified	Single component, polymer modified, fiber reinforced, rapid setting concrete repair mortar.	Pass

Strongwall Ind., Inc.	Strongfloor ET-1200	Polymer Concrete	Modified styrene based resin.	Field Fail
Transpo	T-17 Polymer Concrete	Polymer Concrete	Solvent free methyl methacrylate (MMA) polymer concrete. Two component system – Liquid – methyl Methacrylate. Powder – Sand, Inert Fillers, Polymers and Inhibitors.	Pass
Unitex	Pro-Proxy 2500	Polymer Concrete	Epoxy patching material. Three component system – Epoxy Resins, Aliphatic Amines, Select Silica Sands	Pass
US Concrete Products	HP DOT Grade Repair Mortar	Cementitious Concrete	Single component, portland cement, high early strength repair mortar.	Lab Fail
Willamette Valley Co.	FastPatch	Polymer Concrete	Two component, rapid set polymer resin for repair of holes and spalls in concrete roadways.	Lab Fail
WR Meadows	Futura-15	Cementitious Concrete	One-component cementitious, very rapid hardening structural repair mortar. Good in cold weather conditions. portland cement.	Field Fail

ERDC followed a different process in determining which products passed testing (11) and which did not comply with the lab criteria set out (21). The lab failures were the result of low compression strength, flexural strength and slant shear, but just as in NTPEP testing, this did not mean they could not be approved for use and perform well in the field. The cause of field failure was not meeting the 5,008 passes required using the load cart described on page 28. Table 19 shows if the product passed or failed field testing. If the material passed, ERDC describes what type of repair the material is suited to. It may be suited to one repair type and not another. Permanent repair types are spall repair, small patch, large patch and slab replacement. Temporary repairs include crater repair and expeditionary spall repair. Some products are in Table 18 twice as they were also tested by another agency with different results.

Table 18: ERDC 2007 - 2010 Product Submissions (ERDC, 2011)

Product Manufacturer	Product Name	Product Classification	Product Description	Pass/ Fail
ABC	ABC Cement	Portland Cement	High early strength portland cement.	Lab Fail
Tamms	Express Repair	Portland Cement	Cement-based, ready to use, rapid strength gaining repair mortar.	Lab Fail
W.R. Meadows, Inc.	Futura-15	Portland Cement	One-component, cementitious, very rapid-hardening, structural repair mortar. Good in cold weather conditions. portland cement.	Lab Fail
Dayton Superior	HD-50	Polymer Modified	Fast setting, fiber reinforced, latex-modified, heavy duty, one component concrete repair material	Lab Fail
Ceratech, Inc.	Pavemend 15	Magnesium Phosphate	Cementitious, rapid setting, self-leveling structural repair mortar. Single component powder. (3000 psi (20.7 MPa) in 2hr)	Lab Fail
Ceratech, Inc.	Pavemend SL	Magnesium Phosphate	Cementitious, rapid setting, semi-leveling structural repair concrete. (2600 psi (18 MPa) in 90min)	Pass
Ceratech, Inc.	Pavemend SLQ	Magnesium Phosphate	Cementitious, very rapid setting, semi-leveling structural repair mortar. Single component powder. (3000psi (20.7 MPa) in 60 min)	Lab Fail

Ceratech, Inc.	Pavemend TR	Magnesium Phosphate	Cementitious, rapid setting, slope grade (up to 60%) structural repair mortar. Single component powder. (3000 psi (20.7 MPa) in 3hr)	Lab Fail
Ceratech, Inc.	Pavemend VR	Cementitious Mortar	Cementitious, rapid setting, one step vertical and overhead structural repair mortar. Single component powder.	Lab Fail
Conspec Co.	PavePatch 3000	Polymer Modified	Fast setting, latex-modified, heavy duty, one component.	Lab Fail
Pre-Blend Products, Inc.	Premium Patch 200	Polymer Modified	Rapid-setting, fiber reinforced, high strength, polymer-modified cement mortar for concrete repair and overlay applications requiring high durability.	Lab Fail
CTS Cement	Rapid Set Concrete Mix	High-Alumina	Fast setting, high quality concrete repair material.	Pass
BASF	Rapid Set DOT Mix	Cementitious Concrete	High-performance, Rapid Set Hydraulic Cement.	Pass
BASF	Set 45HW	Magnesium Phosphate	One-component, magnesium phosphate-based repair mortar	Lab Fail
Sika Corporation	SikaQuick 2500	Cementitious Concrete	One-component, very rapid-hardening, early-strength gaining, cementitious.	Pass
BASF	T 10-60	High-Alumina	Very rapid-setting one-component cement based mortar.	Pass
BASF	T 10-61	High-Alumina	Rapid-setting cement-based mortar with extended working time.	Pass
Ultimax	Ultimax Concrete Mix	Cementitious Concrete	Fast setting, blended hydraulic cement.	Lab Fail
Euclid Chemical Co.	Versaspeed	Cementitious Mortar	Single-component, rapid-setting repair mortar.	Lab Fail

CTS Cement	Rapid Set Concrete Mix	High-Alumina	Fast setting, high quality concrete.	Pass
Ceratech, Inc.	Pavemend SLQ	Magnesium Phosphate	Cementitious, very rapid setting, semi-leveling structural repair mortar. Single component powder. (3000psi (20.7 MPa) in 60 min)	Lab Fail
Ceratech, Inc.	Pavemend SL	Magnesium Phosphate	Cementitious, rapid setting, semi-leveling structural repair concrete. (2600 psi (18 MPa) in 90min)	Lab Fail
ABC	ABC Cement	Portland Cement	High early strength portland cement.	Pass
Ceratech, Inc.	DOTLine	Cementitious Concrete	Cementitious, rapid setting, semi-leveling structural repair concrete.	Lab Fail
Ceratech, Inc.	Mainline	Cementitious Concrete	High performance, rapid setting, new construction and repair. Highly green-sustainable, non-portland, non-epoxy.	Lab Fail
Ceratech, Inc.	Great White	Cementitious Cement	Rapid setting, single component powder.	Lab Fail
Ceratech, Inc.	Pavemend TR	Magnesium Phosphate	Cementitious, rapid setting, slope grade (up to 60%) structural repair mortar. Single component powder. (3000 psi (20.7 MPa) in 3hr)	Lab Fail
Euclid Chemical	Speedcrete 2028	Cementitious Mortar	Cement based repair mortar. Proprietary formulation of blended cements, selected aggregates and corrosion inhibitor.	Lab Fail
Quikrete	FastSet DOT Mix	Portland Cement	Fiber reinforced repair meets ASTMC 928 R3 & DOT Region 3 requirements. Cement, Sand, Special Additives.	Pass
Dayton Superior	HD-50	Polymer Modified	Fast setting, fiber reinforced, latex-modified, one component concrete repair material.	Pass

Pre-Blend Products, Inc.	Premium Patch 200	Polymer Modified	Rapid-setting, fiber reinforced, high strength, polymer-modified cement mortar for concrete repair and overlay applications requiring high durability.	Pass
Western Material & Design, LLC	Fastrac 246 Concrete Mix	Cementitious Concrete	One component, shrinkage compensated concrete. Non gypsum based.	Lab Fail

Table 19: ERDC Type of Patch Approval

Product Name	Recommendation
ABC Cement	Not approved
Express Repair	Not approved
Futura-15	Not approved
HD-50	Expeditionary spall repairs
Pavemend 15	Expeditionary spall repairs
Pavemend SL	Expeditionary spall repairs
Pavemend SLQ	Spall repair, small patches
Pavemend TR	Expeditionary spall repairs
Pavemend VR	Not approved
PavePatch 3000	Not approved
Premium Patch 200	Expeditionary spall repairs
Rapid Set Concrete Mix	Spall repairs, small & large patches, slab replacement, small & large crater repair
Rapid Set DOT Mix	Expeditionary spall repairs
Set 45HW	Spall repair, small & large patches, small crater repair
SikaQuick 2500	Expeditionary spall repairs
Thoroc 10-60	Spall repair, small & large patches, slab replacement
Thoroc 10-61	Spall repair, small & large patches, slab replacement, small & large crater repair
Ultimax Concrete Mix	Spall repair, small & large patches, slab replacement, small & large crater repair
Versaspeed	Expeditionary spall repairs
Rapid Set Concrete Mix	Spall repair, small & large patches, full-slab replacement, small & large crater repair
Pavemend SLQ	Spall repair, Small patches
Pavemend SL	Not recommended
ABC Cement	Spall repair, small & large patches, full-slab replacement, small crater repair
DOTLine	Not approved
Mainline	Not approved
Great White	Slab replacement
Pavemend TR.	Approved with 4 hour cure. Spall repair, small patches, and large patches
Speedcrete 2028	Not recommended
FastSet DOT Mix	Expeditionary spall repairs, small patches, spall repair
HD-50	Expeditionary spall repairs, small patches, spall repair
Premium Patch 200	Expeditionary spall repairs, small patches, spall repair
Fastrac 246 Concrete Mix	Not Recommended

Research by ERDC on airfield damage repair produced the report; Laboratory and Field Investigations of Small Crater Repair Technologies (ERDC/GSL TR-07-27, 2007). The materials tested are found in Table 20.

Table 20: Additional Research Products (ERDC, 2007)

Product Manufacturer	Product Name	Product Category	Product Description	Pass/ Fail
D.S. Brown Co.	Pavesaver	Polymeric	Two part polymeric spalls/cracks.	Lab/ Field Fail
CTS Cement	Rapid Set Concrete Mix	High-Alumina	Cementitious, dry blend.	Pass
CeraTech, Inc.	Pavemend SLQ	Magnesium Phosphate	Magnesium phosphate based, cementitious, very rapid setting, semi-leveling. Can be used for full depth repairs.	Pass
CeraTech, Inc.	Pavemend SL	Magnesium Phosphate	Magnesium phosphate based, cementitious, rapid setting, semi-leveling.	Lab/ Field Fail
BASF	T 10-60	High-Alumina	Rapid-setting one-component cement based. Proprietary blend of high-alumina, portland cement, fly ash.	Pass
BASF	T 10-61	High-Alumina	Rapid-setting cement-based, extended working time. Warmer environments.	Pass
BASF	Set 45 HW	Magnesium Phosphate	One-component, magnesium phosphate-based, rapid setting, warm environments (85 to 100°F) (39 to 38°C)	Pass
Euclid Chemical	Express Repair	Portland Cement	Portland cement-based, rapid strength gaining repair mortar.	Lab Fail

Ultimax Corp.	Ultimax Concrete	Alumina Phosphate	Fast setting, alumina phosphate based, blended hydraulic cement. No extension needed.	Pass
ABC Cement	Express Repair Mortar	Portland Cement	High early strength, proprietary blend of portland cement, other hydrating cements, aggregates.	Lab Fail

Based on laboratory results and criteria from the United States Air Force, four products did not pass laboratory testing. From this, ABC cement was excluded from field testing. Two products did not pass field testing. These were Pavesaver and Pavemend SL. Pavesaver failed due to low unconfined compressive strength at 2 hours at elevated conditions and had low bond strength for rapid setting material to rapid setting material bond requirements enough to support the aircraft tire. Both these products and ABC Cement will not be used in this study.

3.10 Summary of Results

In summary, the literature reviewed in this chapter described the properties to consider and factors that determine a good repair material such as high early compressive strengths and freeze thaw resistance, along with areas to avoid or watch. The repair material should generally have a similar or slightly higher strength than the substrate, a similar elastic modulus, bond well to the existing material, and show volume stability when exposed to temperature or moisture change.

Lab testing standards were narrowed down and a number of materials were identified that should not be included in this study due to previous results from other testing agencies. These products excluded are; Tamms Express Repair, Pavemend VR, PavePatch 3000, CeraTech DOT Line, CeraTech Mainline, Speedcrete 2020, Fastrac 246 Concrete Mix, Strongfloor ET-1200 , Futura-15, Pavesaver, Pavemend SL and ABC Express Repair Mortar.

CHAPTER IV

BACKGROUND AND LITERATURE REVIEW OF ASPHALT PAVEMENT REPAIR

Asphalt pavements may be repaired with either hot mix or cold patch materials. The current 2013 ODOT Construction and Material Specifications book calls out item 251 for Partial Depth Pavement Repair, using item 448 Asphalt Concrete, defined as “surface course or an intermediate course of aggregate and asphalt binder mixed in a central plant.” Item 253, Pavement Repair, mentions asphalt concrete but does not call out 448 and refers to “replacement material.” (136, 138) The ODOT RFP for this project referred specifically to a need to consider and address cold patch materials.

Three research reports were evaluated in the literature review. The first was, “Evaluating Winter Pothole Patching Methods” (Nazzal et. al., 2014) prepared for The Ohio Department of Transportation, Office of Statewide Planning & Research. The main object of the study was to evaluate the performance and cost-effectiveness of different methods of asphalt repair. The second was an ERDC report titled “Certification Tests on Cold Patch Asphalt Repair Materials for Use in Airfield Pavements”. (Mejias-Santiago et.al, 2013) The report was conducted to determine cold asphalt repair products suitable for airfield pavement repair. Laboratory tests were followed up with a field evaluation. Seven different materials were tested, all of which were commercially available. Six used a cutback as a binder, and one used an emulsion. The third report was “Expedient Repair Materials for Roadway Pavement” also by ERDC (Shoenberger et. al, 2005). The goal of this study was to find suitable materials for rapid repair of asphalt and concrete pavement in theater roadways.

All three reports were reviewed to determine causes of asphalt potholes, types of repair methods, laboratory and field testing procedures, products available, and results of previous testing.

4.1 Causes of Asphalt Potholes

Potholes are one of the most aggravating forms of pavement deterioration because of the danger they pose to the travelling public and the potential damage they can cause to vehicles. Potholes form due to two main factors: traffic loads and water. The mechanism of pothole formation varies depending on the type of pavement.

For flexible pavements, potholes generally develop in weak areas of the pavement where heavy traffic loads result in excessive bending (flexing) and cracking. Water can then easily enter the pavement structure through these cracks and weaken the various layers. Freezing and thawing further leads to the expansion and contraction of the pavement structure, which accelerate the formation of potholes under subsequent traffic loads.

For composite pavements, potholes typically develop in the top layer due to reflective cracking, which occurs at the location of the joints or cracks in the underlying concrete slab. The reflective cracks in the asphalt overlay will gradually widen with time, and if not sealed, water can enter and weaken the asphalt layer due to freezing and thawing, and eventually lead to the formation of potholes. (FHWA/OH-2014/2)

4.2 Types of Repair Methods

Nazzal, Kim and Abbas (2014) outline five main methods used to patch asphalt potholes in the report, “Evaluation of Winter Pothole Patching Methods.” They are the throw and roll method, semi-permanent method, edge seal method, spray injection method and the tow-behind combination infrared asphalt heater/reclaimer method. The most widely used pothole patching method in Ohio is the throw and roll method. This method is effective if done correctly and performed when the temperatures are warmer. Since potholes generally form during the winter months and most asphalt plants are closed in wintertime, cold asphalt mixtures are typically used instead of hot mix asphalt. The use of cold mixtures may result in reduced adhesion to the existing pavement material, leading to premature patch failure.

4.2.1 Throw and Roll

This method is one of the oldest methods used for pothole patching. It is the most widely used since it is easy, fast, and does not require specialized equipment. There are two slightly different methods within this technique.

The first and simplest procedure for the throw and roll method, also known as the throw and go, consists of throwing the hot or cold mix into the pothole regardless of the amount of debris or water that is in the hole. It is then compacted with a shovel or by truck tire. The main advantage of this method is that it can be performed in a relatively short time, using few workers.

In the second method, water and debris is removed from the pothole and the hot/cold asphalt mixture is compacted in lifts with a maximum thickness of two inches until a 0.15 – 0.25 inch (3.8 – 6.4 mm) crown is formed. The slipping and compressing of the asphalt allows for the extra crown to be squeezed into the cracks as much as possible, which will result in a tight patch. Although this method required more time to complete, it is preferred over the first method as it significantly extends the life of the patch, which leads to reduced overall repair costs and improved safety. (Nazzal et. al, 2014)

4.2.2 The Semi-Permanent Method

This method is more involved than the "throw and roll" procedure and can be considered as a partial-depth repair. The time and effort needed to perform this procedure are thought to improve the success rates for pothole patches. The steps include removing all water and debris from the pothole, squaring the sides and installing the asphalt so it mounds in the center and tapers at the edge to meet the existing pavement. This method results in the longest life for the pothole patch due to the solid compaction against the sides, but requires more workers and equipment and is less effective in winter conditions. However, some studies showed that with high quality the throw and roll method can be as effective as the semi-permanent method while being comparatively less labor intensive. (Nazzal et. al, 2014)

4.2.3 The Edge Seal Method

This method is also similar to the throw and roll method. However, in this method the patch is left to dry for one day after installation and a ribbon of asphaltic tack material is placed on the patch edge with a layer of sand placed on that. This procedure is intended to limit the amount of water that penetrates through the edges of the patch. The steps are as follows; place material into pothole (no preparation or removal of water and debris is needed prior to material placement), compact the patching material leaving a slight crown, allow patch surfaces to dry for one day after the installation, place a band of bituminous tack coat material along the perimeter of the patch, then place a layer of cover aggregate over the tack material to prevent tracking. The main disadvantage of the edge seal method is that it requires a long recovery time between patching and opening the roadway to traffic. (Nazzal et. al, 2014)

4.2.4 Spray Injection Method

The spray injection is another method that has been used for patching potholes. This method is also referred to as blow patching. It requires the least expensive materials and utilizes air pressure as the main source of compaction. The air pressure also works to dry the hole and remove water. The equipment required is the spray injection system, hose and boom. While three different units (trailer, modified truck, self-contained) can be used for placing spray-injection patches, the same basic procedure can be used in all cases. It entails; blowing water and debris from the pothole, spraying the bottom and sides of pothole with binder material to act as tack coat, spraying aggregate and binder into the pothole simultaneously so that the aggregate is coated as it impacts the repair, continuing until the pothole is filled just above the level of the surrounding pavement and finally cover the top of the patch with a layer of aggregate to prevent tracking by passing vehicles.

Compared to the throw and roll, this method requires the least expensive materials. It is very versatile and can be used for potholes, transverse crack repair, alligator cracks, utility cuts, corrugations, depressions, slipping cracks, ruts, and spalls in portland cement concrete. Another important advantage of the spray injection method is that it can be used in most weather conditions, including mild rain and slightly cold weather. In terms of disadvantages, cold joints could form due to the drastic temperature difference between patching and existing asphalt materials during installation. (Nazzal et. al, 2014)

4.2.5 Tow-Behind Combination Method

The tow-behind combination infrared asphalt heater/reclaimer can help in addressing the temperature difference problem encountered during winter pothole patching. This system consists of a reclaimer and a pavement heater. The reclaimer, a hopper that is heated by two infrared heaters, is designed to recycle asphalt material by reheating it to a workable temperature without burning it. This system enables hot patching mixtures to be created in cold weather conditions. The heating process can take between 8 to 16 hours, depending on the ambient temperatures and the amount of asphalt that is being heated. This combination system also has an infrared pavement heater that is placed over the area to be repaired for 5 to 10 minutes to heat both the pothole and the surrounding area. A steel rake is typically used to square the area around the pothole and scarify the existing asphalt material. Recycled hot mix asphalt obtained from the reclaimer is then added and compacted with the existing asphalt material, creating a watertight, seamless patch. The use of infrared asphalt heaters/reclaimer can also be considered an environmentally friendly patching method as it helps in reusing waste asphalt mixes and eliminates the need for new asphalt mixes. Despite the potential benefits from using the infrared heater/reclaimer system, no study has been conducted to evaluate its use in pothole patching and verify its benefits. (Nazzal et. al, 2014)

4.3 Asphalt Binder Materials

ERDC report, “Expedient Repair Materials for Roadway”, (ERSC/GSL TR-07-7, 2005) states three types of asphalt binder materials; cutback, emulsion and proprietary products. Cut back asphalts have historically been used as the binder for cold-mix asphalt patches. They can be combined with well-graded blends of aggregates to produce dense asphalt pavement patches. The cutbacks used can be classified by type as either medium curing (MC) or slow curing (SC), as defined in ASTM D2027(2013) and D2026(2010), respectively. The particular grades of each type recommended for applications of immediate use in repairs include MC-250, MC-800, and SC-800.

In an emulsion, the asphalt binder is suspended in an aqueous solution. This is an economical and environmentally acceptable method of obtaining asphalt cement in a workable consistency at ambient temperatures. A limitation of emulsions is the relatively short time they take to break and cure. Therefore, only slow-setting emulsions should be used for cold mixes, and they should be used immediately and not stockpiled. This includes grades SS-1, SS-1h, CSS-1h. “C” is cationic and “h” indicates an emulsion made from harder (higher viscosity) asphalt cement.

Proprietary product manufacturers generally start with a cutback or an emulsion and then add some type of anti-stripping agent, polymer, or fiber. These materials are added to improve the strength, bonding, and durability of the repair material. Proprietary materials are usually available in ready-to-apply containers, sometimes varying from small bags or buckets to large containers. Some proprietary material manufacturers also sell the binder itself, which can be combined with suitable aggregates in the area it is to be applied. (ERDC/GSL TR-05-7, 2005)

4.4 Asphalt Patching Products

Following the ERDC report, “Certification Tests on Cold Patch Asphalt Repair Materials for Use in Airfield Pavements”, (ERDC/GSL TR-10-14, 2010) caution was used as asphalt materials had only been used for small repairs, such as core hole repairs during airfield evaluations and quality control efforts. Although the materials have been used extensively for road and parking lot repairs, the use of the materials on a larger scale for airfield use and on highway pavements is unknown. The materials that were investigated are listed in Table 21 and are described in Table 23.

Table 21: ERDC/GSL TR-10-14 – Cold Patch Products Selected for Testing

Manufacturer	Product	Container	Binder Type
Roadway Research International	Instant Road Repair	5-gal (20 L) buckets	Cutback
Unique Paving Materials Corp.	UPM Summer Grade	50-lb (23 kg) bags	Cutback
Unique Paving Materials Corp.	UPM Warm Summer Grade	50-lb (23 kg) bags	Cutback
Quality Pavement Repair	QPR	50-lb(23 kg) bags	Cutback
EZ-Street Co.	EZ-Street	50-lb (23 kg) bags	Cutback
EZ-Street Co.	EZ-Street Hybrid	50-lb (23 kg) bags	Cutback
Wespro	Wespro	5-gal (20 L) buckets	Emulsion

ERDC report on expedient repair materials tested the following products in Table 22.

Table 22: ERDC/GSL TR-05-7 – Repair Materials

Manufacturer	Product	Container	Binder Type
Matrex Co.	Cold Patch (Winter/ Summer Grades)	5-gal (20 L) buckets	Emulsion
DuraPave Inc.	DuraPave	5-gal (20 L) buckets	Emulsion
Vulcan Matl. Co.	ENVIROPATCH	5-gal (20 L) buckets	Inverted Emulsion
Matrex Co.	EZ Pave	5-gal (20 L) buckets	Emulsion
EZ-Street Co.	EZ Street	35-lb (16 kg) bags	Cutback
Roadway Research Inter.	Instant Road Repair	50-lb (23 kg) pails	Proprietary Cutback
Optimix Inc.	Optimix	5-gal (20 L) buckets	Cutback
National Paving and Contracting	Perma-Patch	60-lb (27 kg) bags	Cutback
Quality Pavement Repair	QPR-2000	50-lb (23 kg) bags	Cutback
Sylcrete Corp.	Sylcrete-EV	4-gal (15L) buckets	Proprietary Liquid Asphalt
Unique Paving Materials Corp.	UPM Spring & Fall Grade	50-lb (23 kg) bag	Cutback + Additives

Table 23: Asphalt Product Descriptions

Product	Description
Instant Road Repair	Cold-mix patch material for asphalt and concrete pavements. Binder is a rapid-curing proprietary blend of cutback asphalt cements with polymer and anti-strip agents. Aggregate is a relatively dense-graded crushed limestone. Used throughout the US, marketed as permanent repair.
QPR	Ready-to-use formula for patching potholes, filling utility cuts, and repairing damaged asphalt. Material is workable from -5°F to 105°F (-20°C to 41°C), approved for use by the DOTs in all 50 states.
EZ-Street	Cold-mix patch material. Binder is a proprietary blend of cutback asphalt cement, RAIP (Reactive Aggregate Insertion Polymer). Aggregate is a well-graded crushed limestone or other locally available aggregate. Used throughout the US, marketed as permanent repair.
EZ-Street Hybrid	Cold asphalt, original portions replaced with naturally occurring fuels, reuses crushed asphalt particles.
Wespro	Cold mix asphalt for patching pot-holes and damaged areas. The binder is a proprietary special liquid blend.
DuraPave	Cold-mix patch material. Binder is a proprietary blend of recycled asphalt and other petroleum ingredients in a water emulsion. Aggregate is a well-graded blend. Used in NC and several other states, marketed as permanent repair.
Cold Patch (Winter/ Summer Grades)	Aggregate-specific cold-mix patch material for asphalt and concrete pavements. Binder is a proprietary blend of cutback asphalt cement, high-grade co-polymers, and diluents. Open-graded mixture made with limestone, sandstone, or granite aggregates. Used throughout the US, marketed as permanent repair.
Enviropatch	Cold-mix patch material. Binder is a proprietary inverted asphalt emulsion. Aggregate can be either an open- or dense-graded. Used in Southern states, not a permanent repair.
EZ Pave	Emulsified cold-mix, cold-laid paving mixture for pavement overlays. Binder is an emulsified proprietary blend of asphalt cement, emulsifying agents and water. Variety of gradations can be used, open or dense-graded, can include most types of acceptable aggregates. Used throughout the US.
Optimix	Cold-mix binder of patch material for asphalt and concrete pavements. The liquid asphalt blend is a proprietary blend of cutback asphalt cement with various anti-strip and high-adhesion additives. Open-graded, high-quality, locally available aggregate required for blending. Used throughout the US, including Alaska. Marketed as permanent repair.

Perma-Patch	Cold-mix patch material for asphalt and concrete pavements. Binder is a medium-curing proprietary blend of cutback asphalt cements. Binder is combined with an open-graded aggregate. Used throughout the US, marketed as permanent repair.
QPR-2000	Cold-mix patch material for asphalt and concrete pavements. Binder is proprietary modified bitumen. Aggregate is an open-graded blend of 100% crushed limestone or a locally available acceptable aggregate. Used throughout the US, marketed as permanent repair.
Sylcrete-EV	Cold-mix patch material for asphalt and concrete pavements. Binder is a proprietary blend of cutback asphalt cement. Open-graded aggregate mixture for cold weather or dense-graded aggregate for warm weather. Binder can be obtained and combined with a locally available, high-quality crushed aggregate. Used throughout the US, marketed as permanent repair.
UPM Spring, Fall, Summer Grade 4 and Warm Summer Grade 5	Cold-mix patch material for asphalt and concrete pavements. Binder is a proprietary blend of cutback asphalt cement and other additives. Open-graded aggregate mixture for cold weather or with dense-graded aggregate for warm weather. Binder can be obtained and combined with a locally available, high-quality crushed aggregate. Used throughout the world, marketed as permanent repair.

4.5 Asphalt Laboratory Testing

The laboratory tests listed in Table 24 are comprised of the products used in both ERDC/GSL TR-10-14, 2010 and ERDC/GSL TR-05-7, 2005 testing programs. They include; compaction (Superpave gyratory), Rice gravity, flow time (static creep), flow number (dynamic creep), durability, workability, tri-axial strength, penetration and viscosity, following ASTM, AASHTO, and NCHRP protocols.

Table 24: Outline of Laboratory Tests for Cold Patch Asphalt Repair Materials (ERDC, 2005, 2010)

Material Property	Test Method	Test Standard/ Reference
Compaction	Superpave Gyratory Compactor Method	ASTM D7229-08
Rice Gravity	Theoretical Max. Specific Gravity & Density	ASTM D2041-03a
Bulk Specific Gravity	Marshall Sample	ASTM D2726
Flow time	Static Creep	NCHRP 465
Flow number	Dynamic Creep	NCHRP 465
Durability	Retained Tensile Strength	AASHTO T 283-07
Workability	Workability Test	ASTM D6704
Strength	Marshall	ASTM D1559
Strength	Triaxial	-
Binder Content	Extraction	ASTM D2172
Recovered Binder	Penetration	ASTM D5
Recovered Binder	Viscosity	ASTM D2171

ERDC/GSL TR-10-14, 2010 found that gradations, air voids, and specific gravity were highly variable among the products, which made it difficult to establish threshold acceptance criteria. Static creep for the cold patch materials was significantly higher than for the hot mix asphalt control. The cold patch materials were also susceptible to moisture durability problems. It was suggested that hydrated lime be used as an anti-stripping agent. The four materials that performed best in the laboratory were then evaluated in the field. They were Instant Road Repair, Wespro, EZ-Street and EZ-Street Hybrid.

The results in the ERDC/GSL TR-05-7 testing showed that the mixtures with denser or well graded aggregates and with the harder binders tended to have higher Marshall stability values. Most materials were very cohesive and had similar axial strains. Five materials were placed in the test section: DuraPave, Instant Road Repair, Optimix, QPR and UMP.

4.6 Asphalt Field Testing

ERDC report TR-10-14, 2010 field testing consisted of using a load cart, the same as used in the concrete pavement testing described on page 28, weighing 35,235 pounds (15,982 kg). The products were first allowed to cure for approximately 24 hours before trafficking. Each repair showed severe rutting after three passes. After 16 passes, rut depths ranged from 1 ¾ to 3 ¾ inches (45 to 95 mm).

The test pavement was 5 inches (125 mm) thick, over 8 inches (200 mm) of limestone base, 6 inches (150 mm) of stabilized clay gravel sub-base and 16 inches (405 mm) of clay gravel. Each test patch was 5 by 3 feet (1.5 by 1 m), and 5 inches (125 mm) thick. The material was placed straight from the manufacturer's packaging into the holes and then was compacted in two, 2 inch (50 mm) lifts, using a plate compactor and a pneumatic tamping compactor. Density was measured with a nuclear gauge. The researchers attempted to obtain cores, but the core samples fell apart during extraction.

In the ERDC Report TR-05-7, 2005, field testing was located on pavement that contained 4 inches (100 mm) of HMA over a 6 inch (150 mm) crushed stone base. The center section of this area of the road was selected as the location for placing the test items. The items were all placed in a line down the center of the roadway section. The individual test items were about 20 inch (510 mm) wide and 36 inch (915 mm) long. The holes for these items were cut with a dry-cut saw through the HMA and then pried out; the removed material was wasted.

The five cold patch materials chosen for testing were placed in two lifts. The first lift was compacted with a 5 inch (130 mm) diameter tamping compactor and a vibratory plate compactor. The second lift was compacted the same, except only the plate compactor was used. Each of the mixtures was placed in both dry and wetted holes. To wet the holes, enough water was added to saturate the hole and leave somewhere between 0.5 to 1 inch (15 to 25 mm) of water in the hole prior to the introduction of the cold-mix material. Materials that the manufacturers said could be placed in wetted holes and/or displace free water worked very well in the wetted holes.

The vehicle used to traffic the repaired areas was an Oshkosh, PQT dual-axle truck, loaded with 5 tons (4535 kg) of payload. The specifications on the truck were a front axle weight of 12,789 pounds (5800 kg), middle axle weight of 13,165 pounds (5970 kg) and real axle weight of 13,133 pounds (5960 kg). The maximum tire pressure was 57psi (393 kPa). The holes were given a total of 70 passes with all three tires on the driver's side of the truck. The last ten passes were applied after the asphalt patch material had been reworked or leveled because, after trafficking, the material heaved up above the level of the surrounding pavement.

The performance of each of the asphalt materials was similar. Each material experienced some additional compaction under traffic, as evidenced by the slight rutting that occurred. The amount of rutting was greater when the hole was overfilled. After compaction and numerous passes of traffic, any of the patch materials could easily be scarified, leveled, and re-compacted without pickup on the wheels.

4.7 Summary and Conclusions

When reviewing the patching methods described in this chapter, despite the advantages that the throw and roll and spray injector methods have, they are limited in use for the winter months. The use of the infrared asphalt heater/reclaimer system has the potential to solve problems associated with cold joints, improve the performance of winter pothole patching and reduce its cost. In the summer months, the throw and roll method along with the spray and injector method will work well as cold joints are not as much of a factor.

ERDC research report TR-10-14, 2010, determined that the cold mix repair materials evaluated were not suitable for repairing asphalt airfield pavements. However, the load cart represents a much higher tire pressure than a typical highway truck, and thus very high potential for rutting. It is possible that some of these materials would prove usable for ODOT highway repairs. It is also possible that ODOT procedures would provide much greater compaction, improving stability and durability. Other recommended areas of improvements include anti-stripping agents, aggregate type (quality), aggregate gradations and stiffer binder. One concern raised by the research was the high variability of test results.

Under ERDC report TR-05-7, 2005, the asphalt cold-mix repair products that were investigated in the laboratory and in the field all performed well. The materials tested showed good cohesive and adhesive properties. The materials were also all easy to apply in field and were able to carry the applied load without excessive displacement. When material was displaced, it could easily be re-leveled and trafficking continued without any loss of material. The four cold-mix products that advertised application to a wet pavement performed very well and did not show any difference in performance between the dry and watered holes.

Two asphalt products were also chosen to be reviewed closer; they are Instant Road Repair and Optimix. They are explained in more detail in Chapter 5.

CHAPTER V

MATERIALS SELECTED FOR FURTHER INVESTIGATION

Twelve materials have been selected for further investigation. Table 25 contains laboratory testing information on the chosen concrete repair products. It is coded to represent whether the product has passed current ODOT standards. The table is based on an initial list of six materials received from District 8 consisting of Delpatch, Pavesaver, Wabo Elastopatch, FlexSet, MG Krete and SR 2000. Four additional products were added to the comparison table based on the literature review results from ERDC and NTPEP. The additional products are T 1060, FastSet DOT Mix, RepCon 928, HD-50. Two asphalt products were also chosen to be reviewed closer; they are Instant Road Repair and Optimix but are not included in the table.

When evaluating these products, this chapter provides a brief outline about the product and its composition, a general summary of its properties and different ASTM values will then be presented. A list of States was put together that represent similar climates to Ohio, to see if any of the concrete repair materials were already approved in these States. The list consists of New York, Minnesota, Wisconsin, Michigan, Colorado and Pennsylvania. This is included in the review. The literature review testing results for particular products were evaluated to determine the suitability for the field. The list will be narrowed down to six products based on this in-depth analysis.

The first two products evaluated are FlexSet and MG Krete as they were chosen to be the winter testing materials due to their temperature range and excellent research results.

Table 25: Analysis Table of the 10 Selected Cementitious Products

Product Name	Material Type	Cost Per ft³	Working Time (min)	Traffic Acceptance	Wet/ Dry Install	Special Equipment	Repair Preparation	Min/ Max Thickness	Concrete /Asphalt Repair	Temperature Range
Delpatch (Delcrete)	Polymer	$232.43	5-10	1hr	Dry	Hobart or Drill Mixer	Sandblast, Cut, Blow, Clean, Tape	1" Min	Concrete	> 45°F
Pavesaver	Polymer	$230.00	-	3hr	Dry	Jiffy Style Mixer	Sandblast, Cut, Clean	-	Concrete	> 40°F
Wabo Elastopatch	Polymer	$170.00	23	1hr	Dry	High Torque Paddle Mixer w/ Mud Beater	Cut, Clean, Primer	-	Concrete	> 40°F
FlexSet	Polymer	$235.00	9-12 @75°F	30min	Dry	No	No Cleaning	½" Min	Both	-10°F - 140°F
MG Krete	Magnesium Phosphate	$122.22	-	30min	Dry	No	No Cut, Clean	Feathering to Deep Pours	Concrete	> 14°F
SR-2000	Polymer	$175.00	-	2hr	Dry	No	Total Clean	-	Both	35°F - 120°F
T 1060	High Alumina	$56.53	8 -15 @72°F	1hr	SSD*	No	Cut, Roughen, Clean	½" Min	Concrete	> 40°F
FastSet DOT Mix	Portland Cement	$11.32	20-30	1.5hr	Dampen	No	Cut, Clean, Roughen, Water blast	½" Min	Concrete	> 40°F
RepCon 928	Polymer Modified	$57.36	-	1hr (Foot Traffic)	SSD*	No	Clean, Cut, Sandblast,	1" Min	Concrete	> 45°F Optimum: 65°F - 85°F
HD-50	Polymer Modified	$97.90	15	1hr	SSD*	Mud Paddle or Mortar Mixer	Clean, Cut, Sandblast	½" Min	Concrete	> 10°F

*Saturated Surface Dry - surfaces of the particles are "dry" (*i.e.*, surface adsorption would no longer take place), but the inter-particle voids are saturated with water.

Product Name	Primer	State DOT Approval (NY, OH, MN, WI, MI, CO, PA)	General Properties	Set Time (C191)	Compressive Strength (C109)	Compressive Yield (D695)
Delpatch (Delcrete)	Yes	-	Flexible	-	-	800psi-1400psi (Stress) >95% (Resilience)
Pavesaver	No	-	Flexible	-	(C579-B) 1 day >3500psi	
Wabo Elastopatch	Yes	-	Flexible	-	-	1100psi (Stress) @5% Deflection, 500psi (Stress)
FlexSet	No	-	Flexible	-	(C579-B) 1 day 1710psi 7 days 1820psi (Required >200psi)	-
MG Krete	No	PA (Also Alberta)	Rigid	15 @68°F	45min 2610psi 2hr 3481psi 1 day 5148psi 7 days 5815psi	-
SR-2000	Yes	-	Flexible		(C39) >6800psi @10 days	
T 1060	No	OH, MN, MI, PA	Rigid	16-28 @72°F	1hr 2000psi 1 day 4000psi 28 days 8000psi	-
FastSet DOT Mix	No	OH, WI, CO, PA	Rigid	20-45 @73°F	1.5hr 3000psi 3hr 4500psi 1 day 6500psi 7 days 8000psi	-
RepCon 928	No	NY, MN, WI, CO,	Flexible	40-45 @70°F	3hr 3000psi 1 day 6100psi 7 days 8750psi	-
HD-50	No	NY, MN, WI, MI,PA	Rigid	15-20 @70°F	1hr 2000psi 3hr 3500psi 1 day 6145psi 7 days 7000psi	-

Product Name	Coefficient of Thermal Expansion (CRD C39)	Flexural Strength (C78)	Elongation at Break (D412)	Length Change @ 28 Days (C157)	Tensile Strength (D412)	Splitting Tensile Strength (C496)	Tensile Modulus (D638)	Modulus of Elasticity (C469)
Delpatch (Delcrete)	-	-	25%	-	600psi	-	-	7.4E4psi
Pavesaver	-	-	-	-	-	-	-	-
Wabo Elastopatch	-	-	31%	-	1000psi		-	7.9E4psi
FlexSet	-	1 day 740psi 28 days 1008psi	-	-	-	-	-	1 day 1.23E4psi 28 days 2.36E4psi (Chord Modulus)
MG Krete	-	(C293) 1 day 670psi 7 days 845psi 28 days 1405psi	-	Dry -0.027%	-	-	-	3.75E6psi
SR-2000	-	(D790) 1500psi (Strength) 3.73E5psi (Modulus)	>40% (D638)	-	-	-	1.38E5	-
T 1060	7.0E-6in/°F	-	-	Dry -0.05% Wet +0.03%	-	1 day 400psi 28 days 450psi	-	4.4E6psi
FastSet DOT Mix	-	2hr 404psi	-	Dry -0.052% Wet +0.024%	-	-	-	2hr 2.70E6psi
RepCon 928	6.0E-6in/°F	(C348) 7 days 650psi 28 days 1150psi	-	-	-	-	-	4.7E6psi
HD-50	-	2hr 379psi	-	Dry -0.082% Wet +0.051%	-	-	-	-

Product Name	Bond Strength (C190)	Slant Shear Bond Strength (C882 Mod.)	Impact Resistance (D3029)	Specific Gravity (C127)	Gel Time (Tex-614-J)	Resilience (Tex-618-J)	7 Day Compressive Stress @ 0.1in. (Tex-618-J)	7 Day Wet Bond (Tex-618-J)
Delpatch (Delcrete)	-	-	>10ft	-	-	-	-	-
Pavesaver	-	-		-	1-60min	>75%	>3000psi	>350psi
Wabo Elastopatch	> 250psi	-	>10ft No Cracks	-	-	-	-	-
FlexSet	1 day 203psi 28 days 355psi (CT 551)	-	-	1.84	5-60min (Result 9min)	>90% (Result 97.2%)	>200psi (Result 733psi)	>100psi (Result 176psi)
MG Krete	3hr 223psi 28 days 3046psi (C1245)	-	1 day 15.2ft-lb 28 day 15.2ft-lb (C2794)	-	-	-	-	-
SR-2000	Exceed Type II (C1059)	-	-	-	-	-	-	>100psi (Result 176psi)
T 1060	-	1 day 2300psi 28 days 2600psi	-	-	-	-	-	-
FastSet DOT Mix	-	1 day 1200psi 7 days 1620psi	-	-	-	-	-	-
RepCon 928	-	14 days 1500psi	-	2.6-3.2	-	-	-	-
HD-50	-	1 day 2000psi 7 days 2750psi	-	-	-	-	-	-

Product Name	Rapid Chloride Perm. (C1202)	Heat Distortion (D648)	Hardness (D2240)	Water Absorption (C642)	Hydraulic Conductivity (D5084)	Thermal Compatibility (C884)	Freeze Thaw Resistance @ 300 Cycles (C666)	Scaling Resistance at 25 Cycles (C672)
Delpatch (Delcrete)	-	-	50 points min	-	-	-	-	-
Pavesaver	-	-	-	-	-	-	-	-
Wabo Elastopatch	-	-	-	-	-	-	-	-
FlexSet	-	-	-	0.33% (CT 551)	-	No delam. or cracking after 9 cycles (Result: Pass)	-	-
MG Krete	-	-	-	7 days 2.3% 28 days 3.5%	2.3E-11ft/s	-	100%	0 Rating (No Scaling)
SR-2000	-	110°F	-	-	-	-	-	-
T 1060	<300C	-	-	-	-	-	100%	0 Rating (No Scaling)
FastSet DOT Mix	-	-	-	-	-	-	78%	0 (Mass Loss +0.38% @ 50 Cycles)
RepCon 928	-	-	-	-	-	-	-	-
HD-50	Very Low	-	-	-	-	-	100%	0 Rating (No Scaling)

Product Name	Cylindrical Height Change (C1090)	ERDC/ NTPEP Tested	Other
Delpatch (Delcrete)	-	N/A	Primer cure 30min before placement, reapply after 6hr.
Pavesaver	-	ERDC '07	-
Wabo Elastopatch	-	N/A	-
FlexSet	-	NTPEP '06	-
MG Krete	-	N/A	<50°F use accelerator, >68°F use retarder. Great Resistance to Water, Gas, Oil
SR-2000	-	N/A	-
T 1060	-	ERDC '07	Extended 100% by weight
FastSet DOT Mix	+0.02%	NTPEP '04 ERDC '09, '10	Fiber Reinforced, Repairs > 2in extend
RepCon 928	-	NTPEP '09	Fiber Reinforced, Heat repair area for temp <45°F, Light spray of SpecFilm as finishing aid
HD-50	-	ERDC '07, '09, '10	Latex Modified, Fiber Reinforced, Portland Cement Compatible, Repairs > 2in extend, Hot & Windy Days – Moist Cure 1hr

5.1 Roklin Systems Inc. – FlexSet

Roklin Systems produces a product called FlexSet which was a part of the initial list received. Flexset is a two part, A and B polymer concrete. It was originally developed as a rapid runway concrete repair system for the military. It is now used as a cost-effective alternative to traditional spall repair, driveway concrete repair, floor repair and other concrete restoration. (Roklin, 2013)

FlexSet is packaged in 5 gallon (20 L) sealed, plastic pails. Each kit contains ½ gallon (2 L) each of specially formulated A and B polymers, 30 pounds (14 kg) of polymer coated sand, and 12 pounds (6 kg) of uniformly graded polymer coated topping sand which will deliver 0.4 ft^3 (0.01 m^3) and cover approximately 50 ft^2 at a thickness of 1/8 inch (3 mm). A 25 pound (11 kg) bag of 3/8 inch (10 mm) polymer coated basalt aggregate can be used to extend the material which is brought separately. This product costs $235 per cubic foot (0.028 m^3). (Roklin, 2013)

To prepare the hole, saw cutting is optional, but the hole needs to be completely clean with no dust or loose material. Loose pieces should be jack hammered. While mixing the materials together, it is important to make sure there are equal parts of both A and B polymer. The amount of sand added is up to the user, depending on whether a thicker or more flowable material is required. This is the same with the extender aggregate. Polymer A should be added first and fully mixed with the sand before B is added. If an accelerant is needed for cold weather this should be included to the B polymer before it goes in the main mixture. FlexSet components can be mixed in the bucket it comes in with a hand drill or with their low cost Motor Mix Machine ($1600) and will self-level and compact. The topping sand is for skid resistance and to make it look aesthetically pleasing.

What sets FlexSet apart from other products is that it utilizes naturally rounded polymer coated sand. This type of aggregate greatly enhances flowability and increases the overall strength of the crack repair. A welder (thin, high viscosity, high strength urethane resin) can be used before laying the repair material. It is placed in the cracks and adjacent slab joints to fill voids beneath the slab and bond cracks. By filling the voids and water channels below the slab, the welder eliminates lateral water movement and pumping. It is much more effective than normal crack sealing on the top surface.

The material has a 9-12 minute working time at 75°F (24°C). The resulting repair can be put back into service in as little as 30 minutes. It can be laid at a minimum thickness of ½ inch (13 mm) and can be used for both concrete and asphalt repair. It has a great temperature range of -10°F - 140°F (-23°C - 60°C), making it one of only a few materials that can be placed at the extreme hot and cold temperatures. (Roklin, 2013)

FlexSet is a safe product because repairs are quick, decreasing worker's time on the highway and exposure to traffic. Furthermore it is odorless and vaporless. Flexset passes the flexural strength criteria set by ODOT and ASTM 928. It has a compressive strength at one day of 1710psi (11.8 MPa) using ASTM standard C579-B. The requirement is only 200psi (1.3 MPa) to pass although ODOT requires 2000psi (13.8 MPa). Not meeting this standard is why the product is not currently approved by ODOT for rapid pavement repair. A lower compressive strength, however, is good when flexibility is needed, i.e. joining slabs that require enough flexibility to minimize bond stresses and thermal stresses that cause failure in conventional repair materials while supporting highway loads. Too much strength can lead to cracking and damage. It has not been previously approved in any of the state DOT's chosen to represent similar climates to Ohio, but is an example of why ODOT is looking at changing its way of approving materials.

FlexSet was tested by NTPEP in 2006. According to the submission from NTPEP, Flexset had no mid panel debonding, delamination or spall after 1 year but 1/16" (1.6 mm) over 12ft edge cracking. After two years it still has no mid panel cracking or spalling but has 22% delamination and 1/8" (3.2 mm) over 10ft (3 m) and 1/16" (1.6 mm) over 14ft (4 m) of edge cracking. It was given a subjective rating of two after both year one and two which indicated 1/16" (1.6 mm) cracking or edge debonding or over 70% delamination and over 70% spalling. According to Table 8, on page 40, a rating of one is the worst and five the best.

The paper, "Rapid Curing Polymers Reduce Repair Time and Improve Pavement Performance" (Krauss, 2010), observes that the main advantages of urethane resins like FlexSet are that, "the resins are very rapid setting and usually no surface preparation is needed. Damaged concrete often remains in place, speeding the repairs and reducing pavement debris and disposal. Repairs can be performed in cold weather, and repairs have proven to be durable and effective for both portland cement concrete and asphalt concrete pavements."

5.2 IMCO Technologies Inc. – MG Krete

IMCO produces MG Krete, an inexpensive, two component, magnesium phosphate based, high early strength repair material that is suitable to cure in all weather and temperatures greater than 14°F (-10°C). It comes in four forms; fine, regular, flex, stamp. The 'fine' type is used for feathering and shallow patches, the regular is for normal pavement repair and deep pours and flex has added fibers to add flexural strength for use on bridge decks. Stamp can accept colors at the jobsite and decorates and repairs existing concrete. (IMCO, 2012)

MG Krete is packaged as a 50 pound (23 kg) bag of dry compound and 1 gallon (3.8 L) of liquid activator. By maintaining the mix ratio supplied of one container of liquid to one bag of compound, it will give a trowellable consistency, however the ratio may be adjusted to suit the needed application by increasing either of the two components. There is no critical mix formula. If adding accelerant, it goes into the mixture last. Up to two scoops can be used per kit. It is not needed when the temperatures exceed 40°F (5°C). This product costs $122.22 per cubic foot (0.028 m^3).

The material requires no special equipment and no primer. Its rapid curing means it can return to service in 30 minutes and is stronger than concrete in 45 minutes. Its ideal use is concrete repair but it can also be used in asphalt repair if the surface is rigid.

When mixing, to ensure a good blend, only use half the sand and liquid at once. Pea gravel is used to extend the product, but needs to be clean and dry, otherwise the product will most likely fail due to poor bond. The hole must be clean, dry and free of loose material. Water will ruin the integrity of the mix, so the patch location must be completely dry also. The more aggregate used, the more heat absorbed, therefore slowing down the setting process. Also the deeper the patch the hotter the repair will become when setting due to the hydration reaction taking place. A green ammonia smelling slime and gas will be produced on the surface from this reaction.

MG Krete is a rigid material with a set time of 15 minutes at 68°F (20°C) and a 2 hour compressive strength greater than 3000psi (20.7 MPa). It has a modulus of elasticity of $3.75x10^6$psi (25.8GPa) and a 0 rating for scaling resistance. (IMCO, 2012) The compressive strength, flexural strength, length change, freeze thaw resistance and scaling resistance all satisfy ODOT and ASTM 928 requirements. Under the state approval list, using states similar to Ohio, Pennsylvania was the only one to have approved this product for rapid pavement repair, but it is approved in Alberta. It was not tested by ERDC or NTPEP in their studies.

5.3 D.S Brown – Delpatch (formally Delcrete)

In 1983 the D.S Brown Company introduced Delcrete in a bridge expansion joint assembly in Louisiana. It soon became a premier solution for bridge and highway spall repair but a need for more permanent repair solutions was still needed. This is when the reformulated Delcrete became Delpatch. (Delpatch Elastomeric Concrete, 2013)

Delpatch is a two-part polyurethane elastomeric concrete that can accept traffic within one hour after final pour, two hours maximum. It develops an excellent bond to a variety of surfaces, including concrete and steel. Delcrete has wide applications in concrete pavements due to its flexibility, outstanding anti-spalling property and high load bearing capacity. The typical Delcrete application is in concrete spall repair patching or bridge expansion joint work. It is not to be used in asphalt repair.

Delpatch comes as a bag of sand and fiberglass, part A and B polyurethane liquid and primer. The primer can be sprayed or brushed into the hole. Mixing of the material asks for 100 ounces (3000ml) of Part A and 50 ounces (1500ml) of Part B measured out using beakers. These liquids are added to the mixing bowl and the mixer is started at a slow speed. Immediately the sand/fiberglass mixture is added at a gradual rate. The mixer is then increased to a medium speed until an even grey color indicates an even mix. It is specified that a Hobart, drill or pail mixer be used when mixing the material. A 1 inch (25 mm) minimum application depth is required and it must be installed at 45°F (7°C) or higher. There cannot be even slight rain when it is poured and on hot, sunny days, the kit must be kept under cover or in the shade. This product costs $232.43 per cubic foot (0.028 m^3).

Since it is a polymer concrete, it is a flexible material with a modulus of elasticity of 7.4E4psi (510 MPa) and has an elongation at break of 25%. Delpatch was not in any of the NTPEP or ERDC studies, and had not been approved in any of the state DOT's chosen to represent similar climates to Ohio. Additional research was found and is explained below.

A study by the Kansas Department of Transportation titled; Evaluation of Elastomeric Concrete in Bridge Expansion Joint Header Repair Applications (Distlehorst et. al, 2005) uses D.S.Browns' Delcrete in its study. The spalling resistance, rutting performance and overall integrity was evaluated. The study started in 1990 and continued until 2000. A 40ft (12 m) long joint was installed in just over five hours, at air temperatures that ranged from 48° F to 60° F (9°C to 16°C). The cold-applied Delcrete-brand elastomeric concrete gave outstanding performance over the course of the study. No distress was recorded in the joint header material; in 2000, nine years after installation the surveyor commented that it "looks like new material." No spalling was recorded and the rutting performance was also quite good with the materials deepest rut being 0.18 inches (4.5mm) and the average rut was less than 0.12 inches (3mm) in depth. If rutting continued at that rate, the Delcrete will have rutted 0.26 inches (6.6 mm) after 20 years. This behavior is consistent with the laboratory test results that showed Delcrete to be soft and more like to deform plastically. In the lab the Delcrete specimens were compressed to 75% of their height at 1100 psi (7.6 MPa).

5.4 D.S Brown - Pavesaver

Pavesaver is a non-shrink epoxy-based, 2-part polymeric, elastomeric concrete used to fix spalls and cracks on airfield, bridge decks, bridge expansion joint headers, and highway pavements. It has great flexibility and strength to provide excellent long-term patching solutions. (D.S.Brown, 2005)

Pavesaver is packaged as Part A (grey liquid), Part B (clear liquid) and a 50 pounds (23 kg) bag of aggregate. It does not require a primer which cuts down on the time it takes to install the patch. There is a critical mix formula; 2000 ml (68 ounces) of Part A and 2300ml (78 ounces) of Part B and 53.5lb (24 kg) (2 bags) of sand and aggregate. Parts A and B should be mixed first for 30-60 seconds. Before placing this mixture the repair area needs to be cut, free of loose material, sandblasted and dry. The temperature should be greater than 40°F (4°C) when placing the material. The repair can accept traffic three hours after it is laid. It bonds well to concrete and has a one day compressive strength greater than 3500psi (24 MPa) using ASTM 579-B (D.S.Brown, 2005). This product costs $230 per cubic foot (0.028 m^3).

Pavesaver was tested by ERDC in 2007 in the report, ERDC/GSL TR-07-27, "Laboratory and Field Investigations of Small Crater Repair Technologies". In the report, the Pavesaver crater repair sustained only 62 passes from the load cart device used to simulate an F-15E aircraft. The traffic weight the road will be expected to hold will be up to a class 8b combination truck which has an empty weight of 23,500 pounds (10,660 kg) to 34,000 pounds (15,400 kg) and a typical payload capacity of 40,000 pounds (18,150 kg) to 54,000 pounds (24,,500 kg) (Davis, pg. 68). The patch exceeded the maximum deformation on the repair edges, reaching 1.56 inches (40 mm) after three hours of setting. At ambient temperatures the unconfined compressive strength increased with age as expected. However, there was high outside temperatures during placement (90 °F, 32°C), and the compressive strength (457psi, 3.15 MPa) showed significant reductions in strength. It was far less than the 3000psi (20.7 MPa) criteria set forth at two hours. This contributed to the early failure of the repair along with reduced strength in the elevated slant shear strength. The bond strength was only 290psi (2 MPa) which doesn't meet the minimum 500psi (3.5 MPa). The loss of bond to the surrounding pavement after 30 passes implies that the bond did not improve in field placement. Based on the results of the field and laboratory testing, Pavesaver was not recommended for small crater repairs. It has not been approved by any states on the list chosen to represent similar climates to Ohio.

5.5 BASF - Wabo Elastopatch

Wabo Elastopatch is an ambient cured, unique modified elastomeric, two-part polymer concrete repair material used for spalls and cracks in existing portland cement concrete pavement. It is resistant to harsh chemical attacks and wears well under repetitive loadings. (Wabo Elastopatch, 2013)

Wabo Elastopatch comes with; ½gal (1.9 L) Part A, 1gal (3.8 L) part B, 40lb (18 kg) of aggregate and a 50lb (23 kg) bag of WaboCast silica sand. The repair must be saw cut and brushed with the primer before the material is placed but it should not have time to cure. It should also be clean, dry and above 40°F (4°C). Part B must be thoroughly stirred before being mixed with Part A for at least 30 seconds. Add the aggregate fiber combination until it is all coated. Place in the repair hole and spread the WaboCast Silica Sand on top for skid resistance. It can be opened to the traffic typically in one hour. Testing results show a modulus of elasticity of 7.9E4psi (545 MPa) elongation at break of 31% and a bond strength greater than 250psi (1.7 MPa). (Wabo Elastopatch, 2013) This product costs $170 per cubic foot (0.028 m^3).

This material has not been approved by any states on the list chosen to represent similar climates to Ohio and has not been included in any tests by ERDC or NTPEP so its past performance is unknown.

5.6 Southeast Resins – SR-2000

SR-2000 is a polymer concrete composed of a two part polyester resin used to restore damaged concrete and asphalt. It is a flexible product, using the same compound for both applications. (Southeast Resins Inc., 2012)

To lay the repair patch the hole needs to be clean of loose materials, have no dust or oil and primed with the resin part of SR-2000. The kit comes as liquid resin and a bag of #30 grit aggregate, which is clean and dry. Pea gravel can be added to extend the product. A non-slip top coat can be added if required. It can be re-opened to traffic within two hours after the repair is complete and requires no expensive equipment. This product costs $175 per cubic foot (0.028 m^3). (Southeast Resins Inc., 2012)

SR-2000 can be used in temperatures ranging from 35°F to 120°F (2°C to 50°C) and exceeds a compressive strength of 6800psi (47 MPa) in 10 days using ASTM C39. The requirement from ODOT is 6000psi (41 MPa) after seven days so it is hard to tell if SR-2000 would have reached that level of strength in the required time. It has an elongation at break greater than 40%. (Southeast Resins Inc., 2012)

It has not been approved by any states on the list chosen to represent similar climates to Ohio. It was not tested by ERDC or NTPEP in their studies.

5.7 BASF – MasterEmaco T 1060 (previously Thoroc 10-60)

MasterEmaco T 1060, previously Thoroc 10-60, is manufactured by BASF Building Solutions (formerly Degussa) and is used to repair horizontal concrete structures. It is a very rapid-setting cementitious material consisting of a proprietary blend of high-alumina cement, portland cement, and fly ash. (BASF, 2013)

T 1060 comes as a 50lb (23 kg) bag of repair mortar and can be extended 100% with aggregate. It is added to 5.5 pints (2.6L) of water while using a slow speed drill and paddle and mixed for three minutes. The damaged pavement must be cut, roughened and water-blasted before the repair mixture is added. The surface should be damp and have no standing water. No primer is needed. This product has extra low permeability and is rapid setting to allow structures to re-open within one hour to traffic. It must be placed in temperatures above 40°F (4°C) and have a minimum thickness of ½ inch (13 mm). It has a working time of 8-15 minutes at 72°F (22°C) and involves no special equipment. (BASF, 2013) This product costs $56.53 per cubic foot (0.028 m^3).

This rigid material has a set time of 16-28 minutes, one hour compressive strength of 2000psi (13.7 MPa) (ASTM C109) and a wet/dry 28 day length change of +0.03% and -0.05% respectively. According to Emmons (1993), any length change less than 0.05% is considered low shrinkage. The compressive strength, bond strength and length change values all satisfy ODOT and ASTM 928 requirements. It has been approved by Minnesota, Michigan and Pennsylvania on the list chosen to represent similar climates to Ohio. It has also been approved in Ohio already.

T 1060 was approved in ERDC's Development of Laboratory Testing Criteria for Evaluating Cementitious, Rapid-Setting Pavement Repair Materials (2011) report for temporary repairs including small and large crater repairs and expeditionary spall repairs. It was also approved for airport repairs from spalls to full slabs. In another ERDC report, Laboratory and Field Investigations of Small Crater Repair Technologies (2007), T 1060 was again approved for repairs and passed the unconfined compressive strength, slant shear, time of setting and load cart test.

5.8 Quikrete – FastSet DOT Mix

FastSet DOT Mix is a fiber reinforced, portland cement, rapid setting repair material specifically designed to meet ASTM C928 Category R3 specifications. It can be used at a thickness of ½" (13 mm) to 2" (51 mm) and can be extended by up to 25lb (11 kg) to repair roads and bridges at a minimum thickness of 2 inches (51 mm). (Quikrete, 2012)

All surfaces should be clean of foreign substances and cut to remove spalling areas before laying the patching material. Water blasting is also required to clean the remaining matter and to leave the surface damp for the new patch. No primer is required. The DOT Mix comes in 55lb (25 kg) bags and the extended version in 80lb (36 kg) bags. The bag is added to 1 gallon (3.8 L) of water and mixed for three minutes. The water can be adjusted as necessary to achieve the required consistency but without exceeding the recommended slump range. The 55lb (25 kg) bag can be extended with 25lb (11 kg) of high quality ASTM C33 size number 8 aggregate. The cost of this product is $11.32 per cubic foot (0.028 m^3). (Quikrete, 2012)

FastSet DOT Mix has a 20-30 minute working time and can accept traffic 1.5 hours after the patch has been poured. It has a compressive strength of 4500 psi (31 MPa) after 3 hours, a flexural strength of 404 psi (2.8 MPa) after 2 hours, a 28 day wet/dry length change of +0.024% and -0.052% respectively, bond slant shear at 1 day of 1200 psi (8 MPa) and no scaling. All of these values pass the ODOT and ASTM C928 requirements. The one section it doesn't quite pass is the freeze thaw resistance value of 78% after 300 cycles. The standard calls for 79%. (Quikrete, 2012)

FastSet DOT Mix has been approved by Wisconsin, Colorado and Pennsylvania on the list of states chosen to represent similar climates to Ohio. It has also been approved in Ohio already. This testing will be a good indication whether it should stay as a selected product and also serves as a baseline for the other materials.

ERDC tested this Quikrete product in 2009 and 2010 with good results. It met all laboratory testing criteria and was approved for expeditionary spall repairs, small patches and spall repair. It was not field tested so was not recommended for large patches or crater repair. (ERDC/GSL TR-11-13, 2011)

NTPEP tested the product in 2004 and it failed in the Laboratory. This was due to freeze thaw testing. The neat version had flaking at the edges and ends after 128 cycles but lasted all 318 cycles. The extended version deteriorated to the point it was removed from the test after 160 cycles. The smaller cube and cylinder samples experienced much worse freeze thaw effects, losing as much as 57.3% after 50 cycles. Field testing indicated hairline cracks after one year and 1/16 inch (1.6 mm) cracks after two years but otherwise remained in good condition. (NTPEP, 2004)

5.9 SpecChem – RepCon 928

RepCon 928 is a single component, polymer modified, fiber reinforced, rapid setting concrete repair mortar with corrosion inhibitor for use on concrete floors, highway pavements, bridge decks and other applications requiring early resumption of traffic or use. It needs no primer and is formulated to meet the requirements of ASTM C928 and AASHTO T260. (SpecChem, 2010)

Surface preparation for the patch involves removing all foreign objects including oil, grease and dust. The edges should be saw cut and 1/8 inch (3.2 mm) deeper than the depth of the repair. Best results will be obtained by abrasive blasting the area to be repaired. All surfaces to be repaired should be in a saturated-surface-dry (SSD) condition with no standing water on the surface. Mixing the materials calls for 4.75 to 5.0 pints (2.2 to 2.4 L) of water per 50lb (23 kg) bag and a mortar mixer or drill. RepCon can be extended with clean, SSD, 3/8 inch (9.5 mm) aggregate up to 60% by weight. It requires a minimum depth of 1 inch (25 mm) and can be opened to traffic after one hour. The optimum temperature range for installing the patch is 65°F to 85°F (18 to 29°C) but can be installed in temperatures as low as 45°F (7°C). (SpecChem, 2010) This product costs $57.36 per cubic foot (0.028 m^3).

Testing data showed a 3 hour compressive strength of 3000 psi (20.7 MPa), which is more than required by ODOT and ASTM 928. It also has a coefficient of thermal expansion of 6.0×10^{-6} in/in/°F (1.08×10^{-5} mm/mm/°C), modulus of elasticity of 4.7×10^{6} psi (32.4 GPa) and is very freeze thaw resistant. (NTPEP, 2007) RepCon 928 has been approved by New York, Minnesota, Wisconsin and Colorado on the list of states chosen to represent similar climates to Ohio.

RepCon 928 was tested by NTPEP in 2007. It passed all the laboratory testing requirements including the compressive strength, length change and bond strength. Results also indicated exceptional freeze thaw resistance with 0% loss for cubes, cylinders and rectangular beams. After two years of observation in the field, no delamination or spalling was recorded. Both years recorded a 1/32 inch (0.8 mm) crack width.

5.10 Dayton Superior – HD-50

HD – 50 is a fast setting, fiber reinforced, latex modified, heavy duty, polymer modified concrete repair mortar designed for concrete highways, bridge decks, parking structures and loading docks etc. It has one component, a 15 minute working time and can open to traffic in as little as one hour. (Dayton Superior, 2009)

The material comes in a 50 pound (23 kg) bag and requires 3.25 quarts (3 L) of water. A mud beater is used to mix the two together for approximately three to five minutes. A mud beater is an egg beater design which minimizes air entrapment for greater compressive strengths of mortar. It can be extended by up to 60% by weight with clean SSD 3/8 inch (9.5 mm) pea gravel. HD-50 can be used in temperatures as low as 10°F (-12°C), but additional steps need to be taken. The surrounding concrete should be heated until warm to the touch, the repair material should also be warmed and mixing water used at 90°F (32°C). For hot weather, cold water should be used as a mixing agent. The repair area should also be covered with wet burlap. (Dayton Superior, 2009) This product costs $97.90 per cubic foot (0.028 m^3).

Surface preparation consists of removing all residue, grease, dirt, oil, etc. All loose concrete must be removed; the perimeter saw cut and all surfaces should be in a saturated surface dry (SSD) condition with no standing water on the surface. The minimum repair depth is ½ inch (13 mm). (Dayton Superior, 2009)

HD – 50 was designed to meet ASTM 928 R3 specifications. The testing results showed a compressive strength of 3500 psi at three hours, a two hour flexural strength of 379 psi (2.6 MPa), 28 day wet/dry length change of +0.051% and -0.082% respectively, a slant shear bond at 1 day of 2000 psi (13.8 MPa), 100% freeze thaw resistance and no scaling. (Dayton Superior, 2009) All of these pass the requirements set out by ODOT and ASTM 928. HD – 50 has been approved by New York, Minnesota, Wisconsin, Michigan and Pennsylvania on the list of states chosen to represent similar climates to Ohio.

HD – 50 has been tested by ERDC in 2007, 2009 and 2010. It failed lab tests but was approved for expeditionary spall repairs, small patches and spall repair because of good field testing results. The failure in the laboratory was due to not meeting the modulus of elasticity or compressive strength requirement. Modulus of elasticity required less than $3x10^6$ psi at two hours and $4x10^6$ psi at three days, the results were $3.55x10^6$ psi at two hours and $4.10x10^6$ psi at three days. Compressive strength required 3000 psi, it achieved 2850 psi. It passed flexural strength, bond strength and volumetric expansion requirements. (ERDC/GSL TR-11-13)

5.11 International Roadway Research – Instant Road Repair

Instant Road Repair (IRR) is a rapid-curing, cold-mix patch material for asphalt and concrete pavements. The binder is a rapid-curing proprietary blend of cutback asphalt cements with polymer and anti-strip agents. The aggregate is a relatively dense-graded crushed limestone. (ERDC/GSL TR-05-7, 2005)

When preparing the mixture, to better facilitate the placement, the material should be allowed to warm as high above freezing as possible, without directly heating the material (i.e., to normal room temperature). The shelf life in sealed containers is 1 year, with longer periods possible when they are stored at moderate levels of temperature and humidity. (ERDC/GSL TR-05-7, 2005)

Application conditions state the area to be patched can be wet, but it should be free of loose debris and standing water. A prime or tack coat should not be used. The minimum depth of patch should be about 1 inch (25 mm) with a maximum compacted layer thickness of 3 inches (76 mm). Thicker layers should be placed in approximately 2 inch (51 mm) thick lifts. No curing time is required-just mound material and compact with traffic. In areas with heavier loads or high tire pressures (i.e., airfield pavements), a vibratory plate compactor is recommended. (ERDC/GSL TR-05-7, 2005)

The standard packaging of the patch material is in 50-lb (23 kg) pails (36 pails per pallet and 23 pallets per truck load). Containers may be stored outdoors in extreme temperatures, but should be covered for long-term storage. The cost of a 50-lb (23 kg) pail of Instant Road Repair is $15.50, which is $32.98 per cubic foot (0.028 m^3). The binder material can also be purchased for use with suitable local aggregates.

Instant Road Repair is widely used throughout the United States and in several other countries. The material is manufactured in Texas, and the proprietary binder properties allow for this product to be used successfully in any geographical region. Instant Road Repair is marketed as a permanent pothole repair material for any asphalt or concrete pavement. (ERDC/GSL TR-05-7, 2005)

The ERDC studies found that IRR performed well in the laboratory testing. It displayed good cohesive and adhesive properties. The field testing results were mixed as it was determined that IRR was not suitable for repairing asphalt airfield pavements because of the load requirements of an F-15E aircraft. However, the load cart represents a much higher tire pressure than a typical highway truck, and thus very high potential for rutting. It is likely that IRR could be usable for ODOT highway repairs. It is also possible that ODOT procedures would provide much greater compaction, improving stability and durability. (ERDC/GSL TR-05-7, 2005) (ERDC/GSL TR-20-14, 2010)

In the regular highway testing, IRR was easy to apply in the field and was able to carry the load without excess displacement. Testing also indicated that IRR, as a dense material had a lower workability (higher workability number) than the well graded mixtures. The axial strain exhibited the material would easily densify when trafficked. It performed well on both wet and dry pavement. (ERDC/GSL TR-05-7, 2005)

5.12 Optimix Inc. – Optimix

Optimix is a cold-mix binder of patch material for asphalt and concrete pavements. The Optimix liquid asphalt is a proprietary blend of cutback asphalt cement with various anti-strip and high-adhesion additives. An open-graded, high-quality, locally available aggregate is required for blending with the binder. (ERDC/GSL TR-05-7, 2005)

In the mixture preparation, the maximum mixing temperature of the liquid binder and the local aggregates should be between 140 °F (60°C) and 170 °F (77°C). The combined mixture should be stockpiled in up to 6 feet (1.8 m) depths until it has reached ambient temperature for at least 48 hours; then, it can be effectively maintained in uncovered stockpiles of 100 tons (91 metric ton) or more. (ERDC/GSL TR-05-7, 2005) This product costs only $4.71 per cubic foot (0.028 m^3).

The area to be patched can be wet but should be free of loose debris and standing water. A prime or tack coat should not be used. The minimum depth of patch should be about 1 inch (25 mm), with a maximum compacted layer thickness of 3 inches (76 mm). Thicker layers should be placed in approximately 2 inches (51 mm) thick lifts. No curing time is required, just mound material and compact with traffic. In areas with heavier loads or high tire pressures, (i.e., airfield pavements), a vibratory plate compactor is recommended. (ERDC/GSL TR-05-7, 2005)

The material is widely used throughout the United States, including Alaska. The properties of the Optimix liquid asphalt blend are varied to meet requirements in that geographical region. Optimix is marketed as a permanent pothole repair material for any asphalt or concrete pavement. (ERDC/GSL TR-05-7, 2005)

Results of the ERDC study showed that Optimix performed well in the laboratory and field testing. It showed good cohesive and adhesive properties, was easy to apply in the field and was able to carry the load without excess displacement. It presented the smallest depth change with number of passes, with an initial change of 1/8 inch (3.2 mm) and final change of 3/8 inch (9.5 mm). It performed well on both wet and dry pavement. (ERDC/GSL TR-05-7, 2005)

CHAPTER VI

CONCLUSIONS AND MATERIAL RECOMMENDATIONS

6.1 Final Product Recommendations

As stated in the last chapter, FlexSet and MG Krete have already been chosen and placed in the field as the winter patching test materials. Their excellent temperature range, compliance of most ODOT and ASTM 928 laboratory standards and great previous field testing results from ERDC and NTPEP made them an obvious choice. The additional four products for field testing recommended are Delpatch, RepCon 928, SR-2000 and Optimix. This includes three polymer materials, two polymer modified materials and one asphalt material. No cementitious materials were chosen. It will be explained in the next section.

6.2 Final Winter Product Recommendations

FlexSet's ability to patch asphalt and concrete pavements gave it an advantage over other traditional repair materials when it came to narrowing down which materials should be chosen. Although it is the most expensive product on the list, its ability to be back into service in as little as 30 minutes, be used at a thickness of ½ inch (13 mm) or greater, utilize no surface preparation and the ease of use, such as self-leveling, mixing in the bucket it came in and no critical mix ratio outweigh this cost and add to the list of benefits.

Its interesting proprietary design utilizing polymer coated sand and slightly lower compressive strength is a new concept for ODOT. The chance to introduce it into the testing program will allow it to prove its durability and usefulness for future patching jobs and influence change in the standards to fit with the new direction of performance based specifications. The benefits to the lower compressive strength is shown when flexibility in the repair is needed, i.e. joining slabs require enough flexibility to minimize bond stresses and thermal stresses that cause failure in conventional repair materials while supporting highway loads. Too much strength and stiffness can cause stress concentrations and worse cracking and damage. The testing results from NTPEP bode well for beneficial outcomes because of no delamination or spalling reported and only minimal cracking seen after two years.

MG Krete's ability to come in different forms allows for a wide range of uses, from the "flex" type for bridge decks to the "fine" type for feathering cracks. This advantage combined with no critical mix formula, no primer, satisfying all ODOT requirements and a return to service in 30 minutes demonstrates it will be beneficial to test further. Although it was not tested by ERDC or NTPEP in their studies, the advantages stated above and the fact it has no shrinkage and been approved for use in Pennsylvania, a

State similar in climate to Ohio and Alberta, a more extreme region of climate, indicates worthwhile results. Its pricing is also reasonable as it in the mid-range of all the products.

6.3 Final Summer Product Recommendations

Delpatch was chosen due to its ability to develop an excellent bond to a variety of surfaces, including concrete and steel and previous research results. It gave outstanding performance over the course of Kansas DOT's nine year study. No distress was recorded in the joint header material; it "looked like new material." There was no spalling and the rutting performance was also good, which was consistent with the laboratory test results that showed Delcrete to be soft and more like to deform plastically. The mixing method of Delpatch is more complex than the previous two products but is still easy to complete in the field. It is again one for the more expensive products on the list, but the benefits stated above, its traffic acceptance within one hour and suggestion by District 8, conclude that is it appropriate to do further testing.

RepCon 928 needs no primer and meets all the requirements of ASTM C928 and AASHTO T260. It has exceptional freeze thaw resistant and has been approved by New York, Minnesota, Wisconsin and Colorado on the list of states chosen, showing that it is widely accepted and would work well in Ohio. It is one of the cheaper products on the list costing only $57.36 per cubic foot.

Previous testing by NTPEP passed all the laboratory testing requirements and displayed no delamination or spalling in the field testing. Both years of testing recorded only a 1/32 inches (0.8 mm) crack width. It can be opened to traffic after one hour. These qualities warrant further testing in this study. The surface does require thorough preparation by removing all foreign objects including oil, grease and dust but by doing this the repair should last a lot longer.

SR-2000 was chosen because of its versatility to be used on asphalt and concrete pavement. Other advantages are; any type of clean, dry pea gravel can be used to extend the product, it requires no expensive equipment and can be re-opened to traffic within two hours after the repair is complete. It has an elongation at break greater than 40% and can be used in a large range of temperatures from 35°F to 120°F (2°C to 49°C). Although it has not been tested by ERDC or NTPEP, or been approved by any states on the list chosen to represent similar climates to Ohio, it has many features that make it appropriate to do further testing. It is in the medium range of pricing at $175 per cubic foot (0.028 m^3).

Based on good laboratory and field results from the ERDC study, and knowing the material is widely used throughout the United States, including Alaska, suggests the use of Optimix in Ohio will present adequate results. It exhibited the smallest depth change with number of passes, doesn't require a primer or tack coat, has no curing time and a vibratory plate compactor is not needed. The properties of the liquid asphalt blend are varied to meet requirements in each geographical region which imply testing will bring worthwhile results. Optimix was easy to apply in the field and was able to carry load without excess displacement. It performed well on both wet and dry pavement making it a versatile material and is marketed as a permanent pothole repair material suitable for any asphalt or concrete pavement. These features and the cost of only $4.71 per cubic foot exhibit why Optimix was chosen for testing.

6.4 Products Not Chosen For Testing

This section describes why the remaining shortlisted products were not chosen for further testing in this study.

First, the reason for having no cementitious materials such as FastSet DOT Mix (portland cement) and T 1060 (high alumina cement) presently in the short listed products is because the current approved list by ODOT contains 78% cementitious materials. The other 22% are magnesium phosphate (polymer modified) based materials. This study is a chance to break from that pattern and learn about the other types of repair materials that might perform as-well or better than the current recommended products. FastSet DOT Mix and T 1060 are already approved in Ohio which makes the other products more useful to test, but were chosen in the shortlist to provide a good comparison in the table for the new products. These cementitious products can be added into the study later if desired to re-confirm they pass all standards required by ODOT. Table 26 lists the current ODOT approved products.

Table 26: ODOT Product Approved List

ODOT Approved List		
PRODUCT	**MANUFACTURER**	**Material Category**
EMACO T415	BASF	Cementitious Concrete
10-60 RAPID MORTAR	BASF	Portland Cement
SET 45 HW	BASF	Magnesium Phosphate
SET 45	BASF	Magnesium Phosphate
PAVEMEND SL	CERATECH	Magnesium Phosphate
CHEMSPEED 55	CHEMMASTERS	Cementitious Concrete
CHEMSPEED 65	CHEMMASTERS	Portland Cement
RAPID SET DOT REPAIR MIX	CTS	Cementitious Concrete
EUCO-SPEED MP	EUCLID CHEM.	Magnesium Phosphate
SPEEDCRETE RED	EUCLID CHEM.	Portland Cement
SPEEDCRETE GREEN	EUCLID CHEM.	Portland Cement
SPEEDCRETE 2028	EUCLID CHEM.	Cementitious Concrete
FAST SET DOT MIX	QUIKRETE	Cementitious Concrete
RAPID HARDENING SAND	QUIKRETE	Portland Cement
RAPID ROAD-UNFIBERED	QUIKRETE	Portland Cement
FAST SET DOT MIX	QUIKRETE	Cementitious Concrete
RAPID ROAD REPAIR	QUIKRETE	Portland Cement
SIKAQUICK 2500	SIKA CORP.	Cementitious Concrete

Cementitious Total =	**14**	**78%**
Polymer Modified Total =	**4**	**22%**
Total =	**18**	

Pavesaver was not chosen due to the results in laboratory and field testing from ERDC. The low unconfined compressive strength at 2 hours in elevated conditions and low bond at 1 day of cure indicates it will not be suitable to include in the testing. It only sustained 62 passes of traffic before failure. The loss of bond to the surrounding pavement after 30 passes implies that the bond did not improve in field placement.

Wabo Elastopatch has not been approved by any states on the list chosen to represent similar climates to Ohio and has not been included in any tests by ERDC or NTPEP. None of the testing data that ODOT requires was found, therefore performance is unknown.

HD-50 was not chosen mainly because only six products were required by ODOT for further testing out of the list of 12. A range of material types were put forward to ODOT for further testing and a polymer modified product had already been chosen. Even though testing results were unknown for the chosen polymer modified product, SR-2000, its ability to be used on concrete and asphalt put it above HD-50. It is a viable alternate for testing.

There was not much difference in IRR and Optimix but IRR was not chosen as Optimix had better viscosity and durability values. IRR is also another alternate product that is viable for testing.

The final six materials have three products that can be used on asphalt pavement and five on concrete pavement.

6.5 Recommendations for Laboratory Testing

The chosen laboratory testing standards are based off current ODOT requirements, past ERDC and NTPEP testing and tests that are able to be done in the Cleveland State University concrete laboratory.

Table 27: Recommended Testing Standards

STANDARD	TEST
ASTM C192	Making and Curing Concrete Test Specimens in the Laboratory
ASTM C39	Compressive Strength of Cylindrical Concrete Specimens
ASTM C109	Compressive Strength of Hydraulic Cement Mortars (Using 2in or 50mm Cube Specimens)
ASTM C579	Compressive Strength of Chemical Resistant Mortars, Grouts, Monolithic Surfacing's and Polymer Concretes
ASTM C78	Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
ASTM C882	Bond Strength of Epoxy-Resin Systems used with Concrete by Slant Shear
ASTM C496	Splitting Tensile Strength of Cylindrical Concrete Specimens
ASTM C1074	Estimating Concrete Strength by the Maturity Method
ASTM C469	Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression
ASTM C666	Resistance of Concrete to Rapid Freezing and Thawing
ASTM C157	Length Change of Hardened Hydraulic Cement Mortar and Concrete
ASTM C531	Linear Shrinkage and Coefficient of Thermal Expansion and Chemical Resistant Mortars, Grouts, Monolithic Surfacing's, and Polymer Concretes
ASTM C1581	Determining Age at Cracking and Induced Tensile Stress Characteristics of Mortar and Concrete under Restrained Shrinkage
AASHTO T27	Sieve Analysis of Fine and Coarse Aggregates
AASHTO T84	Specific Gravity and Absorption of Fine Aggregate
AASHTO T85	Specific Gravity and Absorption of Coarse Aggregate
AASHTO T103	Soundness of Aggregates by Freezing and Thawing
AASHTO T283	Resistance of Compacted Bituminous Mixture to Moisture Induced Damage for Superpave

6.6 Recommendations for Field Testing

For field testing, it would be useful to invite the product representative to be present on site when their product is being installed for the first time. This will ensure that proper methods are being followed, and any questions that may arise are answered by someone knowledgeable about the material. Another recommendation is to document all conditions of the patch hole, surrounding pavement and weather conditions. By doing this a more thorough evaluation and analysis can be completed later in the study to give validated recommendations to ODOT on what materials should be approved for use in the state of Ohio.

6.7 Follow on Research

A full field study of all six products will take place over the next two years to allow for freeze thaw cycles to take place and adequate time for surface wearing of the repairs. Concurrently, laboratory testing will take place on all the chosen materials. Additional products may also be brought in and tested to extend the scope of the research and also may be tested in the field if desired by ODOT.

HD-50 would be the next product recommended to be tested as it is easy to use and was designed to meet ASTM 928 R3 specifications, indicating it passed all the requirements set out by ODOT. It has also been approved by New York, Minnesota, Wisconsin, Michigan and Pennsylvania on the list of states chosen to represent similar climates to Ohio. ERDC testing showed good field results and approval for expeditionary spall repairs, small patches and spall repair. It failed some laboratory tests, but the failure in the laboratory was due to not meeting current ODOT requirements. These requirements could be changed based on field results.

The results from this research will be analyzed and comprehensive standard material and performance based generic specifications in Standard ODOT Construction Material Specifications or Supplemental Specifications format will be produced based on desired ASTM or equivalent material properties and field performance analysis.

6.8 Final Conclusions

Background research from ERDC and NTPEP, provided invaluable insight into both laboratory and field testing criteria that was used to identify durable and permanent high performing pavement and bridge deck patching products that allow for expediting pavement and bridge deck wearing surface repair. The study of literature on similar topics also showed what type of research has been completed and methods that were taken to get to the end result. The information found was adapted to meet the requirements of this research.

This research accomplished all the objectives set out from the beginning. They consisted of:

- Reviewing literature to obtain history on causes of pavement patching failures.

- Identifying and comparing previous laboratory and field testing criteria being used by other organizations.
- Identifying and determining product laboratory and field testing criteria for comparative analysis of selected products.
- Comparing and investigating previous products tested and their results.
- Determining product classifications based on material make-up.
- Identifying products to be tested based on previous research

At the conclusion of this research, by accomplishing these objectives, the new products tested can then be specified and based on results, incorporated into the ODOT Approved list and into use. Current specifications can then be changed to allow for newer products and products with features previously didn't meet requirements, but are known to perform well in the field.

The products chosen for the winter patching project were FlexSet and MG Krete. They have been placed in the field already and were chosen due to their excellent temperature range, compliance of most ODOT and ASTM 928 laboratory standards and great previous field testing results from ERDC and NTPEP. The other four products recommended for summer placement are Delpatch, RepCon 928, SR-2000 and Optimix. They displayed characteristics desirable for further testing and represent a range of material classifications.

Recommended laboratory standards were specified based on current ODOT requirements and past research and are listed in this chapter. Field recommendations consisted of having the product representative present on site during placement and to document all conditions of the patch hole, surrounding pavement and weather conditions.

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ACRONYMS

AASHTO	American Association of State and Highway Transportation Officials
ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
ERDC	Engineer Research Development Center
NTPEP	National Transportation Product Evaluation Program
ODOT	Ohio Department of Transportation

APPENDICES

Appendix A: Winter Field Locations of Pavement Patches

Patch #	Date	Road type	Material	Mile Marker	Dimensions	Depth		Direction	Location Descriptions
						Range	Average		
1	3/6/2014	Bridge deck	MG Krete (flex)		8'4" x 6'3"	3-6"	4"	SR35 Westbound	Bridge 1/4 mile Before Bellbrook Road Exit
2	3/6/2014	Bridge deck	FlexSet		9'1" x 6'3"	3-8"	4"	SR35 Westbound	Bridge 1/4 mile Before Bellbrook Road Exit
3	3/6/2014	Asphalt Pavement	FlexSet		3'6" x 2'	2-3"		SR35 Westbound	A Few ft Infront of Patches 1 and 2
4	3/6/2014	Asphalt Pavement	FlexSet		3' x 2'	2-4"	3"	SR35 Westbound	Under Bridge Directly Before Bellbrook Rd Exit
5	3/7/2014	Concrete Pavement	FlexSet	15.9	4'3" x 2'7"	2-5.5"		SR35 Eastbound	Right Before Patch 6
6	3/7/2014	Concrete Pavement	MG Krete (flex)	15.9	2'2" x 1'6"		2"	SR35 Eastbound	Right After patch 5
7	3/7/2014	Concrete Pavement	MG Krete (flex)	16.1	2'5" x 2'2"	2-3"		SR35 Eastbound	Around 75 feet Before Patch 8
8	3/7/2014	Concrete Pavement	FlexSet	16.1	2'10" x 2'2"		3"	SR35 Eastbound	75ft After Patch 7, Edge of Lake
9	3/7/2014	Concrete Pavement	FlexSet	16.2	3'7" x 2'10"	2.5-3.5"		SR35 Eastbound	Directly Infront of Patch 10
10	3/7/2014	Concrete Pavement	MG Krete (flex)	16.2	3'7" x 3'1"	2.5-3.5"		SR35 Eastbound	Directly After Patch 9
11	3/7/2014	Concrete Pavement	FlexSet	16.7	3'4" x 2'6"	2.5-4"		SR35 Eastbound	Before And Next to Patch 12
12	3/7/2014	Concrete Pavement	MG Krete (flex)	16.7	2'6" x 2'6"		2.5"	SR35 Eastbound	After And Next to Patch 11
13	3/7/2014	Concrete Pavement	MG Krete (flex)	18.3	2'4" x 2'3"	2-4"		SR35 Eastbound	15-20ft before Patch 14
14	3/7/2014	Concrete Pavement	FlexSet	18.3	2'7" x 2'2"		3"	SR35 Eastbound	15-20ft After Patch 13

Appendix B: Potential Future Field Locations of Pavement Patches

County	Route	Begin Section	Length	Surface Pavement Type	Location Description
Greene	35	14.0	-	Reinforced Concrete	All the way along Route 35
Hamilton	71	1.97	Br. Deck	Concrete Overlay	I-71 over US 22
Hamilton	74	9.11	Br. Deck Left	Monolithic Concrete	Already Repaired using Fibrecrete. To be overlayed.
Warren	73	14.62	Br. Deck	Concrete Overlay	SR73 over LMR Bike Path and Corwin Rd.
Warren	73	14.58	Br. Deck	Concrete Overlay	SR73 over the Little Miami River (LMR)
Clinton	71	3.99	Br. Deck L&R	Concrete Overlay	????