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16. Abstract

This project investigated the properties and performance of the products used for spall repair of concrete pavement. A survey of TxDOT maintenance engineers produced a roster of 10 repair materials currently in use in the state. After identifying the key characteristics of a successful repair material, a laboratory testing program was developed to evaluate the properties of the repair materials. These materials were tested for strength, compatibility, and bond to quantify their characteristics relative to those products known to work well. To correlate laboratory data to field data, researchers conducted performance surveys including field core tests, and the field placement of products was performed on a test section.

Researchers made recommendations regarding properties, which best predict the success of material and testing procedures to determine these properties. The results of this project will then be used to develop a set of guidelines for the selection of repair materials and the repair procedures to be used by TxDOT engineers to yield the best performance of repaired pavement.

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INVESTIGATION OF SPALL REPAIR MATERIALS FOR CONCRETE PAVEMENT

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DISCLAIMER

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TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

CHAPTER 1. INTRODUCTION

RESEARCH BACKGROUND

Spalling is a surface distress in portland cement concrete pavement that occurs most frequently at transverse cracks or joints where delaminated concrete dislodges from the vicinity of the joint roughening the surface of the pavement. Spalling results in a rough ride and also gives the traveling public a negative perception of integrity of the pavement. From a structural standpoint, loss of concrete due to spalling may lower the load transfer efficiency (LTE) across the transverse random cracks in continuously reinforced concrete pavement (CRCP) and/or joints in jointed concrete pavement (JCP). The reduction in LTE will increase the stress level due to traffic loading in the pavement and will eventually lead to more severe forms of distress such as punchouts in CRCP and joint faulting in JCP.

For many years the Texas Department of Transportation (TxDOT) has been confronted with the problem of spalling concrete pavement. Large urban districts such as the Houston District find this condition especially prevalent and have tried a number of different products to patch spalls with varying degrees of success. The cause of the spalling condition has been attributed to several factors, including the manner in which the concrete is cured and the use of certain types of siliceous river gravel in concrete pavement. The need still exists to understand which repair products work best and to develop guidelines to assist engineers in selecting cost-effective patching materials with procedures that work well.

RESEARCH OBJECTIVES

The main objective of this research project is to address the determination of the best practices and materials to make repairs to spall damage in portland cement concrete pavement. In order to accomplish the main objective, the project has the following sub-objectives:

1. Evaluate the effectiveness of existing patching materials and procedures currently used for spall repair throughout the state of Texas.
2. Conduct performance surveys to evaluate the performance of the repair material through visual inspection and taking cores.
3. Perform the laboratory tests that measure existing materials for spall repair.

4. Organize the guidelines for a selection process of spall repair materials that can be used by TxDOT engineers.
5. Conduct training seminars for TxDOT personnel.

SCOPE OF RESEARCH

This research was a joint project between the Texas Transportation Institute (TTI) at Texas A&M University and the Center for Transportation Research (CTR) at the University of Texas at Austin. The research by these two agencies was conducted within the context of CRC pavement behavior and performance but many of the recommendations made relative to best practices and materials for spall repairs may be applied to jointed concrete with a certain amount of discretion on the part of the reader. Given the research objectives above, the research team collected information on spall repair materials and procedures, evaluated the performance of materials in fields and laboratory, and developed guidelines for spall repair and material selection.

This project was divided into a number of parts, which are explained in the following chapters. Chapter 2 describes the background information for this project including a literature search, survey of different TxDOT districts, and collection of product information. Chapter 3 gives an overview of materials currently being used for spall repair along with their various properties. In addition, a description of each material selected for testing is given.

The fourth chapter describes the experimental portion of this project including the laboratory tests performed on selected repair materials and the results of these tests. Chapter 5 explains the field evaluation of spall repair materials carried out in TxDOT districts and also the observations and data from field placement of selected repair materials at a test site in Ft. Worth, Texas.

In Chapter 6, the selection guideline is proposed to select a best spall repair material to be applied in the pavement. Finally, conclusions and recommendations from this project are developed in Chapter 7.

CHAPTER 2. BACKGROUND

INTRODUCTION

The background of this research consists of a literature review to collect general information about spall repair, including the mechanics behind spalling, behavior of spall repair, characteristics of different repair products, test methods to determine physical properties, preparation techniques, and selection guidelines.

Several textbooks including Noel Mailvaganam's "Repair and Protection of Concrete Structures" give a general overview of the problems and solutions associated with spalled concrete (*1*). They also provide an introduction to the different types of repair materials commonly used and their general chemical and physical properties. General selection guidelines from a number of sources were reviewed to establish the important properties to consider for a successful spall repair material. The American Concrete Pavement Association recommends considering the material strength gain, modulus of elasticity, bond strength, freezing and thawing resistance, coefficient of thermal expansion (CoTE), and shrinkage when choosing a repair material (*2*). Keeping this in mind an effort was made to find other studies which had tested repair materials in an attempt to identify appropriate laboratory tests for the given properties. The research found test results on some materials tested by others to be out-of-date because the materials had either been replace by newer repair materials or updated, but several of the procedures and standardized test methods found in these studies were used as a guide for the project testing program.

One reoccurring theme in the publications reviewed was the need for adequate surface preparation to ensure a successful repair. Recommendations were also made regarding installation procedures and preventative maintenance, all of which were considered when developing the laboratory study and incorporated in the recommendations of this project.

MECHANISM OF SPALLING

Spalling, taking place at the transverse cracks or joints in portland cement concrete pavement, is a distress where a visible surface distress is caused by pieces of concrete being dislodged from the surface of the pavement.

Previous TxDOT-funded field studies (*3*, *4*) have confirmed that spalling is a consequence of the early age cracks, delamination, that form at essentially the same time that early age transverse cracks develop in the construction of CRCP. The crack is parallel to and at a shallow depth below the surface of the pavement. The delamination occurs at an early concrete age due to large evaporation induced stress gradients that result in a shearing action in the concrete near the pavement surface by the gradient effect. The moisture or evaporation induced gradient is affected by the amount of wind and type of curing during and after placement of the concrete as shown in Figure 2.1. That is, the evaporation results in differential drying shrinkage near the pavement surface and the shrinkage produces shearing action within the concrete near the pavement surface that can cause the delamination. Once delamination has formed, it may develop later into spalls as a result of incompressibles moisture wetting and drying cycles, traffic loading, and other effects.

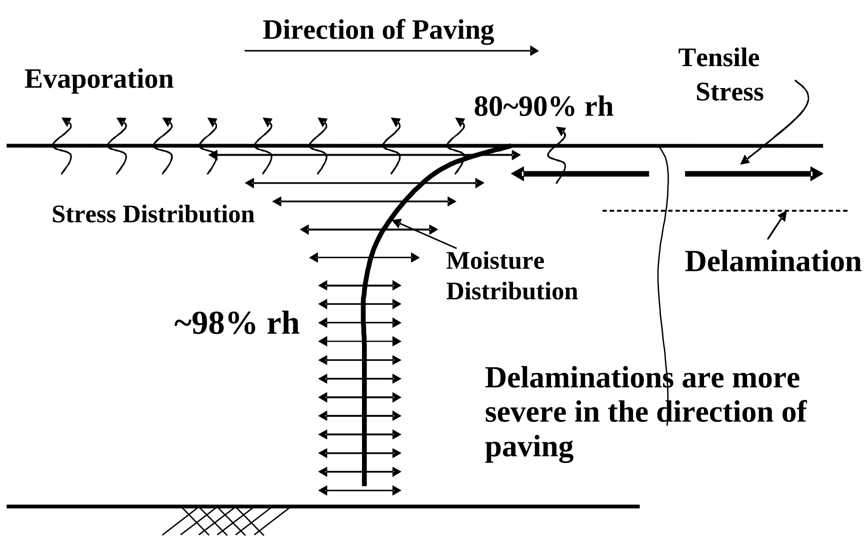

Figure 2.1 Evaporation Induced Stress Gradient at an Early Concrete Age (*4*)

Spalling occurs in both CRCP and JCP. This distress results in a rough riding quality to the pubic as well as reduction of LTE across the transverse cracks or joints. The reduction of the LTE will increase the stress level due to traffic loading and finally cause more severe distresses such as punchouts and joint faulting. Therefore, when spalling occurs on the pavement, it is important to repair the distress areas with an appropriate spall repair material and technique.

BEHAVIOR OF SPALL REPAIR

The behaviors of spall repair materials in patching areas are different depending on the properties of materials. Apparently, in order to be a successful spall repair material, a material manifesting high crack resistance must have good bond strength. If the material manifests low crack resistance, then the requirements for bond strength are not as stringent. Figure 2.2 shows consideration of the role of thermal effects on spall repair materials and illustrates a profile of the spall repair.

Differences in CoTE between repair material and concrete will create shear stress and normal tensile stress along the interface. The CoTE of concrete is typically significantly much smaller than the CoTE of many of the materials used in spall repair. This difference can create significant shear and normal stresses on the interface; however, this level of stress is minimized when the existing transverse crack is reflected through the repair material. It, therefore, appears reasonable that the threshold bond strength values should be considered based on the CoTE of the spall repair material and its capability to resist crack propagation for specification purposes. The driving force for the crack reflection is directly related to the CoTE and the change in temperature in the existing concrete which may open or close the existing transverse crack. The opening of the crack is most critical since it causes the crack to propagate into the repair material and eventually reflect through to the pavement surface.

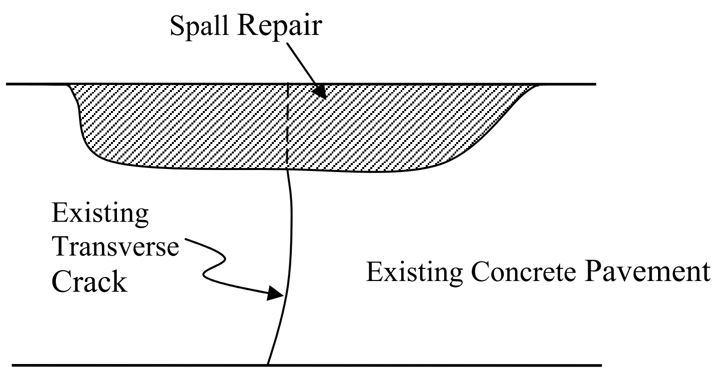

Figure 2.2 Spall Repair in Profile

SURVEY OF DISTRICTS

Some of the best information about spall repair comes from the engineers and maintenance supervisors who work with the repair materials on a regular basis. For this reason, researchers contacted several districts across the state in an effort to determine what products and procedures are currently being used. Selected districts were contacted and interviewed over the phone, emailed, and/or faxed a survey sheet for additional information. Each district was asked questions relating to (1) surface preparation, (2) materials they presently use for spall repair, (3) mixing procedures, and (4) performance of repairs. Tables 2.1 to 2.3 give an overview of this survey.

Part of the survey asked each district to describe the patching materials they are currently using with success as well as any materials for which they experience failures. It was found that a wide variety of products has been used across the state with varying degrees of success. Table 2.1 identifies products used by the various districts contacted.

Table 2.1 Repair Materials Used by District

District	Patching Product Used
Atlanta	RSP, UPM (Found UPM does not work for them)
El Paso	Road Patch, Class K concrete
Ft. Worth	RSP, MgKrete, FlexKrete, Deery Mastie
Houston	Delpatch, FlexPatch, Wabo ElastoPatch, Fibrescreed
Lubbock	RSP, Durcal (Durcal does not work for them)
San Antonio	UPM, UPR
Waco	USP, Rapid Set, Fibrescreed

Some products such as Fibrescreed and RSP were mentioned by multiple districts, and in many cases maintenance districts would try products after hearing about their use in other districts. All districts expressed an interest in learning about spall repair materials that work well.

Numerous sources in the literature search indicated that surface preparation is a vital element in the patching process. Proper surface preparation is key in developing a good bond to the concrete. For this reason, each district was also surveyed for information on its standard procedures for surface preparation. Table 2.2 summarizes the information collected.

For the most part, districts either follow the manufacturer's recommendations for surface preparation, or they do a minimal amount of surface preparation because they need a quick repair that is considered a temporary solution. At a minimum, districts clean and blow out the spall, but most would like to avoid chipping and saw cutting of the area unless required due to the added time and expense. Many districts surveyed stated that the reason repairs frequently fail is inadequate preparation of the substrate concrete.

Table 2.2 Surface Preparation Procedures by District

District	Surface Preparation:
Atlanta	Blow or sweep to clean the hole. No saw cutting or priming of the hole.
El Paso	Cleans out hole by sweeping or blowing. They do not do a lot of preparation work because the repair is temporary.
Ft. Worth	Air blast hole, clean or sweep out; ideally they jackhammer out the material, but usually they do not do a lot of saw cutting or chipping of the spalls because spalling is so minor in their district.
Lubbock	Saw cut the spall and chip out the deteriorated concrete down to rebar. Clean out the hole with air, and dry the hole as much as possible.
Waco	Sandblast and clean out hole when using RRS or USP. Mill the hole, then clean thoroughly when using Fibrescreed.

Another element, which was given high importance, was the speed of the repair process. Minimizing lane downtime helps to reduce the hazards to work crews and the driving public by minimizing the amount of disruption. A short downtime can be especially important in larger cities with high levels of traffic making a repair material, which can be opened to traffic quickly after placement very valuable. Each district was queried about how long it waits before turning the roadway over to traffic, and Table 2.3 gives this information for repair materials. Time to traffic after spall repair varied between 30 minutes to 2 hours for most districts, with most districts following the manufacturer's recommendations.

General findings in the survey were that in all the districts (with the exception of Houston) spalling of concrete pavement is not currently a huge problem because most districts do not have large amounts of concrete pavement to maintain. The Lubbock District did, however, indicate that spalling was becoming more of a problem because its pavements were 30 years old and starting to deteriorate.

Standard procedures for dealing with a spall in most districts are to ignore them as long as possible, then use cold patch or a more durable patching material as a temporary fix until eventually an asphalt overlay is applied. Procedures for the preparation of a spall area before the installation of repairs varied by district, but a theme common among many districts was that repairs frequently failed due to poor surface preparation.

Table 2.3 Time to Traffic by District

District	Time to Traffic
Atlanta	RSP - about 30 minutes
El Paso	Road Patch - 10 minutes, Class K concrete ready in about 30 minutes
Ft. Worth	Follow manufacturers recommendations, usually 30 to 60 minutes
Lubbock	RSP - 2 hours, but could probably get traffic on it in an hour
Waco	Rapid Road Set - 2 hours.

SURVEY OF SELECTED MANUFACTURERS

From both the literature search and the performance surveys 10 different products were selected for testing and further research. In selecting these products an effort was made to consider materials that had been used by the various districts so comparisons could be made between test data and field performance. It was desired to test a range of different types of materials. They were grouped according to type as shown in Table 2.4.

Each product manufacturer was contacted to obtain additional product information, as well as to order material for testing. Table A.1 in Appendix A contains a list of all the product manufacturers that were used for this project, along with their contact information.

Table 2.4 Types of Repair Materials Selected

Products to Be Tested	Type of Material	Product Used By
RSP	Polyurethane Polymer Concrete	FTW/ Lubbock/Atlanta
Delpatch	Polyurethane Polymer Concrete	Houston
Wabo ElastoPatch	Polyurethane Polymer Concrete	Houston
FlexPatch (SSI)	Epoxy Polymer Concrete	Houston
FlexKrete	Thermosetting Vinyl Polymer Concrete	FTW
EucoSpeed MP	Magnesium Polyphosphate	FTW
MgKrete	Magnesium Polyphosphate	FTW
Pavemend 15	Magnesium Polyphosphate	FTW
Rapid Set	Hydraulic Cement	Houston/ FTW/ Waco
Fibrescreed	Polymer Modified Bitumen	Houston/ Waco/ Dallas

SELECTED PRODUCT INFORMATION

After contacting product manufacturers, information on each of the products was collected to identify mixing procedures, surface preparation, product usage, and materials costs. This information was then synthesized to prepare for testing, as well as to incorporate into the product selection guideline procedures.

Table 2.5 summarizes this information for each product selected for testing in this project. The materials were found to vary significantly. Some materials, like Fibrescreed, require special proprietary equipment and training while other materials, like Pavemend, EucoSpeed, and Ready Set, consist of self-contained units requiring only the addition of water. Time to traffic also varied, but all could be released to traffic in under two hours. Material costs also varied greatly ranging from $26 per cubic foot to $152 per cubic foot, with the costs for polymer concrete greatly exceeding the costs for other rapid setting repair systems. It should be emphasized that when choosing a repair material, the total lifetime cost of the patch should be considered. This lifetime cost includes material and equipment costs, cost of time delays to motorists, and labor costs over the life cycle of the repair.

Table 2.5 Product Information Summary[1]

Product	Product Preparation	Surface Preparation	Usage/ Time to Traffic	Material Cost ($/cft)
Delpatch	Mix Part A and Part B components with the provided pre-weighed bag of sand and fiberglass.	Chip or saw out loose concrete, then sandblast the repair area and apply primer.	1 hour	$145.00
EucoSpeed MP	Mix product with specified amount of water. Product may be extended with pea gravel.	Prepare surface mechanically. Make sure it is clean and free of dirt or residue.	1-2 hours	$43.00
Fibrescreed	Requires proprietary equipment to heat and melt product for placement.	Sandblast spall to remove all road film and any unsound concrete. Heat and prime surface.	15-60 min	$101.00
FlexKrete	Mix FlexKrete with indicated amount of catalyst. Then add appropriate ratio of blast sand to the mix.	Clean and roughen surface making sure it is free of dirt, oil, moisture, and debris. Prime surface.	45-90 minutes	$110.00
FlexPatch (SSI)	Mix components A and B, then add component C (aggregate) to mixture.	Remove deteriorated concrete. Sandblast area and remove loose dirt or dust.	1-2 hours	$115.00
MgKrete	Mix one container liquid activator to one bag of dry component. Material may be extended with pea gravel	Surface should be rough, with care taken to insure area is clean, dry, and free of dirt and loose material.	1-2 hours	$62.00
Pavemend 15	Mix product with water until critical temperature is reached.	Prepare exposed aggregate surface by mechanical methods making sure it is clean.	1.5 hours	$90.00
Rapid Set	Mix product with specified quantity of water.	Roughen surfaces and remove unsound concrete. Make sure surfaces are clean and free from oil or dirt.	1 hour	$26.00
RSP	Two-part kit liquid polyurethane. Combine components and pour over clean dry aggregate.	Sweep out repair area and make sure it is free of moisture.	8-10 minute set time	$52.00
Wabo ElastoPatch	Mix part A and part B components. Add part C the pre-weighed aggregate.	Clean concrete by methods including sandblasting, chipping, and saw cutting. Apply primer to surface.	1 hour	$152.00

[1] Information provided by material manufacturer.

CHAPTER 3. REPAIR MATERIALS

The spall repair products selected for this project cover a wide variety of types with different chemistries and physical properties. Some of the materials have a higher modulus and are brittle, behaving much in the same way as normal concrete, while others are much lower in modulus with a much higher ductility. An understanding of material properties and behavior is important in order to select the proper material. This study tested polymer concretes, magnesium phosphates, a hydraulic cement, and a bituminous repair material.

POLYMER CONCRETES

This project tested three types of polymer concretes: urethane polymer concretes, epoxy polymer concretes, and thermosetting vinyl polymer concretes. Urethane polymer concretes are two-component systems in which a liquid resin is mixed with a curing agent. This liquid mixture acts as the binder for the aggregate. Because of the many curing agents available, polyurethanes can have a wide variety of properties; they are characterized by fast curing, good resistance to abrasion, good bond strength, and flexibility. They often have high CoTE, large amounts of initial shrinkage, and a limited ability to accept an asphalt pavement overlay without special surface preparation. Many types of polyurethanes are intolerant to water (*1*).

Epoxy polymer concretes are also two-component systems consisting of a liquid epoxy resin that is mixed with a curing agent. The epoxy is the binder for a given aggregate. Again, because of the different curing agents available, epoxy concretes can have a wide variety of properties. Epoxy amines provide good chemical resistance, but are not very moisture tolerant, while epoxy polyamides are tough, flexible, more moisture tolerant, and have better bonding abilities (*1*). Epoxies can offer high compressive and flexural strengths, good bond strengths as well as a low amount of shrinkage and permeability, but like the polyurethanes they tend to have a high CoTE (*2*, *5*).

The last type of polymer concrete used in this study is the thermosetting vinyl polymer. Created in a similar manner to the other polymer concretes, a thermosetting vinyl polymer is a polymer made up of long chains of vinyl monomer molecules that cross-link with each other creating a rigid structure. It has similar properties to other polymer concretes, and like some epoxies its thermosetting characteristic means the product can soften with the application of heat but cannot be reshaped.

RSP

RSP is a two-part urethane repair product manufactured by the BMK Corporation. The product consists of a liquid component A and a liquid component B, which are mixed together at a one-to-one ratio and then poured over clean, dry aggregate pre-packed into the spall repair hole. The material has two application methods: (1) the mixed A and B components can be poured over the aggregate or (2) a pressurized kit which mixes the liquids in a gun and sprays out over the aggregate can be used. The material binds to the aggregate and hardens in approximately 8 to 10 minutes. For testing purposes a 0.75 inch limestone aggregate was used.

Delpatch

Delpatch is a urethane-based repair product manufactured by the D. S. Brown Company that comes in a three-part kit. Part A and part B are the two liquid components, and part C is a pre-weighed aggregate which contains a mix of fiberglass and sand. To mix the material, part A and part B components are blended together at a two-to-one ratio for approximately 10 seconds, immediately after which component C is added and mixed for an additional two minutes. This product also requires that a primer be added to the repair surface and allowed to cure before placement of the repair material. A catalyst can be added to speed up set time for cold weather applications in low temperature tests.

Wabo ElastoPatch

Wabo ElastoPatch is a urethane-based repair product manufactured by Watson Bowman Acme that also comes as a three-part kit. Parts A and B are the pre-measured liquid components which are blended together at a one-to-one ratio in the provided bucket with a jiffy type paddle for two minutes. Part C, the pre-weighed aggregate mixture of graded sand, is added and mixed for approximately two minutes until the aggregate is completely coated. This product comes with a two-part primer, which must be mixed and applied to the repair surface but not allowed to cure before the application of the repair material.

FlexPatch

FlexPatch is a two-component epoxy repair material marketed by Silicone Specialties Inc. (SSI). The product consists of two pre-measured liquid components, part A and part B, which are mixed together at a one-to-one ratio for three minutes. A third component, C, which consists of pre-weighed coarse sand is then slowly added to the liquid and mixed thoroughly. The product is then placed in the repair area. No primer is needed. The company produces a different formulation for cold weather applications, but the product was not tested in the current project.

FlexKrete

FlexKrete is a thermosetting vinyl polymer marketed by FlexKrete Technologies. The product comes in a five-gallon bucket from which the amount required for the size of the repair is measured. To the FlexKrete a liquid catalyst is added at a ratio of 1.2 oz per gallon and mixed for 30 to 60 seconds. After being mixed, a small amount of this liquid is used to prime the repair surface. Next, blast sand is added to the catalyzed liquid, at a volume ratio of approximately 3 to 4 parts sand per liquid base. For the purpose of testing a ratio of approximately 3.5 parts sand to liquid was used. The company produces an accelerator which can speed up set times for cold weather applications; this accelerator was used in low-temperature tests for this project.

MAGNESIUM PHOSPHATES

Magnesium phosphate cement is a rapid repair material, which stems from the reaction of a phosphate solution with magnesium. The resulting product is a magnesium ammonium phosphate hydrate. Magnesium phosphate systems can be packaged as a one-component or two-component system. The two-component system consists of powdered magnesium and aggregate, to be mixed with a liquid solution of phosphate. The other system consists of the magnesium and phosphate together in powdered form along with any additional aggregate, to which a specified amount of water is added. Magnesium phosphates are very rapid setting, and the reaction is exothermic, meaning it gives off heat. The product usually has a high compressive strength and good bond strength, and is relatively sensitive to the amount of water added; excess water can reduce strength (*1*).

Pavemend 15

Pavemend 15 is a magnesium phosphate repair material manufactured by CeraTech Incorporated. It comes in a bucket with 45 pounds of pre-weighed aggregate and powder mix. For each bucket of material, one gallon of water is added and mixed until a critical temperature of 95 degrees F is reached at which time the material is placed. Besides Pavemend 15 with a 15 minute set time, the company makes two other formulations with set times of 5 and 30 minutes.

MgKrete

MgKrete is a two-part magnesium phosphate repair material manufactured by IMCO Technologies Inc. that consists of a 50 lb bag containing dry mix and aggregate, and a one-gallon container of liquid activator. The two components are mixed together by mechanical means to get the final product, which is quickly placed in the spall repair area. Pea gravel may be added to extend the mix for deeper repairs. The company also produces a low temperature accelerator and a high temperature retarder, which can adjust the cure time of the material.

EucoSpeed MP

EucoSpeed MP is a magnesium phosphate repair material produced by the Euclid Chemical Company. It comes as a 50 lb bag of aggregate and powder mix. For each bag of aggregate, 0.45 gallons of water are added and mixed thoroughly for 2 minutes, after which the material is quickly placed. The mix can be extended with up to 30 lb of pea gravel for deeper repairs. For testing purposes 15 lb of 3/8-inch aggregate were added per manufacturer’s recommendations to extend the mix. The company makes a hot weather formulation that can extend set time for temperatures above 85 degrees F, but this formulation was not used in high-temperature tests.

MODIFIED CEMENT

Rapid Set

Another type of repair material is high alumina cement. These cements are similar to portland cement except that they gain strength much quicker with high ultimate strengths. The rapid strength gain is due to the rapid rate of hydration that can be accelerated at high temperatures and humidity.

Rapid Set is a hydraulic cement repair material manufactured by CTS. It is made of approximately 1/3 calcium sulfoaluminate (C_4A_3S) and 2/3 dicalcium silicate (C_2S). Rapid Set comes in a 60 lb bag, which is mixed with approximately 3 to 5 quarts of water for 1 to 3 minutes until a uniform consistency is reached. For the purpose of testing, 5 quarts of water were mixed with each bag. The company produces a variety of additives that can accelerate set time in cold weather applications, retard set time in hot weather application, increase strength and increase adhesion properties of the mix, but none of these additives was utilized in the testing program.

BITUMINOUS MATERIAL

Fibrescreed

Bituminous materials are made up of a mixture of hydrocarbons and aggregate. Hot mix asphalt pavement and cold patch are common types of bituminous materials, but this group includes materials such as tars and pitches, which often have a soft viscous nature.

Fibrescreed is a unique type of bitumen-based repair material distributed by Marketing Associates, Inc. It is made up of synthetic polymers, mineral fillers, various fibers, sand, and granite aggregate. The company makes two types of materials; Fibrecrete, a black material that comes boxed, and Fibrescreed, a gray material that comes bagged in small pieces. For this project, only Fibrescreed was tested. In both cases, the material must be heated to a molten state with special propriety equipment by trained personnel. The material is then applied to the repair area in lifts with granite aggregate included in each layer prior cooling and stiffening. Substrate concrete should be heated before application of repair material, and normally the repair area is primed before the application; no primer was available for these tests.

SUMMARY OF MATERIALS USED IN PROJECT

Table 3.1 summarizes all the materials used in this project as well as their classification as to type and some of their properties. The products classified as magnesium phosphates and hydraulic cements produce concretes that behave much in the way portland cement concrete behaves, having similar properties, except an accelerated curing time. The polymer concretes all have a polymer binder, which is mixed in a similar manner. Due to the wide variety of formulations each can behave very differently, especially since the formulation for each can vary as well as the type of aggregate each product specifies. Polymer concretes in general have very specific mixing instructions, and any deviations have the potential for creating a substandard product The bitumen product can be expected to be much softer than concrete, becoming much more fluid and viscous at higher temperatures.

Table 3.1 Products and Properties

Product	Type of Material	Usage/ Time to Traffic	Storage Life (yrs)	Material Cost ($/cft)
Delpatch	Polyurethane Polymer Concrete	1 hour	2	$145.00
RSP	Polyurethane Polymer Concrete	8-10 minute set time	0.5	$52.00
Wabo ElastoPatch	Polyurethane Polymer Concrete	1 hour	1	$152.00
FlexPatch (SSI)	Epoxy Polymer Concrete	1-2 hours	1	$115.00
FlexKrete	Thermosetting Vinyl Polymer Concrete	45-90 minutes	0.5	$110.00
EucoSpeed MP	Magnesium Polyphosphate	1 hour	1	$43.00
MgKrete	Magnesium Polyphosphate	30 minutes	0.5	$62 .00
Pavemend 15	Magnesium Polyphosphate	1.5 hours	1-3	$90.00
Rapid Set	Hydraulic Cement	1 hour	1	$26.00
Fibrescreed	Polymer Modified Bitumen	15-60 min	2	$101.00

CHAPTER 4. LABORATORY TEST PROGRAM

INTRODUCTION

In an effort to evaluate the various repair materials, laboratory testing was necessary to determine the basic physical properties of each and provide for some basis of comparison. Through the literature search an effort was made to find other studies that reported on the spalling problem, including tests performed on other patching materials. Results of these studies were used to determine which tests would be most beneficial in identifying properties important for material selection.

The Federal Highway Administration (FHWA) completed one such study in 1991. The project included laboratory tests and field performance surveys for rapid setting repair materials in concrete pavements. The study analyzed several different types of materials, their placement in different climatic regions, and use of different repair procedures. The sites were monitored over a period of several years with most of the sites experiencing a high rate of success (*6*). Tests used in this project included the determination of compressive and flexural strength, modulus of elasticity, Poisson ratio, bond strength of epoxy resin to concrete (ASTM C 882), thermal compatibility, length change, resistance to freezing and thawing, and resistance to abrasion and scaling (*6*).

Another study done at the University of Texas in 1984 on four rapid setting repair materials recommended testing for compressive and flexural strength, Gilmore needle set time, and shear bond to distinguish the best performing repair material (*7*). A follow up study recommended testing for freezing and thawing resistance and shrinkage of each material in addition to the aforementioned tests (*8*).

Due to the limited nature of this project, the decision was made to test flexural strength, compressive strength, modulus of elasticity, shrinkage, and set time to determine the material properties of each product. In addition, simulated spalls were created in small concrete slabs in which repair material was placed. The slabs were then thermal cycled repeatedly to mimic field environmental conditions of the repair materials.

With the exception of MgKrete, which was a late addition to the project line up, manufacturers' representatives were invited to assist in the mixing and placing of their respective products to ensure proper procedures were followed. All materials were mixed explicitly according to provided instructions in a five-gallon bucket with a paddle mixer attached to a drill as illustrated by Figure 4.1. The exception to this was RSP and Fibrescreed. Fibrescreed required special proprietary equipment for melting, and RSP consisted of a liquid that was poured over aggregate as opposed to being mixed with aggregate.

Figure 4.1 Standard Mixing Setup

Since temperature can be a factor in the strength, workability, and set time of a repair material, tests were performed not only at 70 degrees F, but also at a low temperature of 40 degrees F, and a high temperature of 100 degrees F to simulate the use of different repair materials at different temperature extremes.

Through discussions with TxDOT engineers, it was determined that the time-to-traffic reopening was an important factor, so the decision was made to measure compressive strengths at 1 hour and 24 hours after cure. The one-hour-after-cure timeline was assumed to predict the strength against initial traffic loadings, and the 24-hours-after-cure was assumed to predict final strengths (since these are quick setting materials, 24 hours was assumed adequate time to reach ultimate strengths).

For each temperature, i.e., 40, 70, and 100 degrees F, each repair material was batched (weighed and measured) and placed with mold forms in temperature-controlled rooms for at least 24 hours. All materials were brought to the mixing room, where they were mixed at 70 degrees

F. Materials were allowed to quickly cure at 70 degrees F. They were then either immediately tested or put back in the temperature-controlled room for testing at 24-hours. This procedure was repeated for each of the three temperatures. A couple of materials could not be tested at all three temperatures. The manufacturer's representative for FlexPatch recommended against testing the material at 40 degrees F as it would take too long to cure. The company does make a repair product for cold weather applications, but the additional material was not tested in the current testing program. Fibrescreed was tested only at one temperature since the material itself can be applied only after it is heated to 350 degrees F. Additionally, because of its late addition to the project, researchers tested MgKrete at only 70 degrees F.

As mentioned, the materials that were selected for this program were found to have vastly different stiffnesses. Ideally the same tests would be performed on each material under identical conditions allowing for the direct comparison of the properties measured. It was found that test methods that worked well for rigid materials, such as the magnesium phosphates and hydraulic cements, were very difficult to apply to more flexible materials like the polymer and elastomeric concretes. This, in turn, made testing of the different materials for a direct comparison of properties difficult.

TEST METHODS DESCRIPTIONS

The objective of the testing program was to provide some basis by which each material could be compared and to use the results of these tests in the further development of a repair material selection process. Through the literature search several studies were found which had previously tested repair materials using standard ASTM testing procedures. Using these studies as a guide, tests were chosen and conducted to attempt to capture the basic material properties of the finished materials.

SET TIME

The set time is an important property of a repair material. Materials are chosen because they can achieve adequate strength relatively quickly allowing for a quick repair and the least amount of traffic disruption. Set time for each sample was measured using ASTM C 403 "Standard Method for Time of Setting of Concrete Mixtures by Penetration Resistance" (9). Two containers were filled with repair material for each of the three different temperatures.

Measurements were taken with corresponding times recorded, and the data were then graphed with values for initial set (500 psi) and final set (4000 psi) interpolated.

Table 4.1 shows a summary of the relative set times for each material at the various tested temperatures. The complete set of results for each material is located in Appendix E. Materials like the magnesium phosphates cured very quickly, staying liquid for approximately 80 percent of their set time, but then passed from a liquid state to a solid state in just minutes, making multiple readings with the penetrometer difficult. Other materials like Delpatch, an elastomeric, took much longer to cure and continued to stay "soft" but solid hours after placement. It should be noted that while these were the set times experienced in the lab, almost all materials have chemical additives that can accelerate or retard the repair material set time. Additionally, the rate and length of time for which a material was mixed, the quantity of material mixed, and the temperature all have significant influence over the set time. The key is having enough familiarity with the materials and their additives to use them correctly to get a working time which is long enough to place the material but a set time which is quick enough to limit the amount of traffic disruption.

Table 4.1 Material Set Time

Product	40°		70°		100°	
	Initial Set (min)	Final Set (min)	Initial Set (min)	Final Set (min)	Initial Set (min)	Final Set (min)
Delpatch	91	524	80	444	87	345
EucoSpeed	30	34	15.0	20	8.5	10
Fiberscreed	--	--	--	--	290	*
FlexKrete	19	26	11	18	18	24
FlexPatch	--	--	55	78	29	43
MgKrete	--	--	9	10	--	--
Pavemend	**	52	13	15	**	10
Rapid Set	59	65	23	28	10	13
RSP	**	6	**	6	**	6
Wabo ElastoPatch	38	66	23	47	13	27

* Material does not reach Final Strength
** Material changed viscosity too quickly to get adequate readings

MECHANICAL PROPERTIES

The mechanical properties of the repair materials include the tests for compressive and flexural strength. For a repair material, the mechanical properties become important when the transfer of load or redistribution of stresses is required because of an external applied load, such as traffic, or internal stress such as volume changes in the material due to temperature fluctuations. Additionally a study by Texas A & M University concluded that strength of a repair at the time when it was reopened to traffic was an indicator of whether it would be a successful repair, and testing for mechanical properties such as compression and flexure provide a quick and economical test to complete (*10*).

As indicated by the data, results were mixed, as complications arose due to the different nature of each material. The materials were classified in three stiffness categories: rigid materials, defined as having behaviors similar to concrete; flexible materials, defined as having ductile properties; and semi-rigid materials, defined as having intermediate stiffnesses. Rigid materials consisted of the magnesium phosphates (EucoSpeed, MgKrete, and Pavemend) and the hydraulic cement (Rapid Set). The semi-rigid materials consisted of RSP, a polyurethane polymer poured over limestone aggregate, FlexKrete, a thermosetting vinyl polymer mixed with coarse blast sand, and FlexPatch, an epoxy polymer mixed with coarse blast sand. Semi-rigid materials had a fair amount of compressive strength but failed abnormally when compared to concrete. They also had a fair amount of tensile strength translating into higher flexural strength when compared to concrete. Flexible materials consisted of Delpatch and Wabo ElastoPatch, both polyurethane polymer bases, which were mixed with aggregates of sand and micro-fines, as well as Fibrescreed the polymer-based bitumen. Each was too ductile to get a compressive strength reading and too flexible to get a flexural strength reading. Delpatch and Wabo ElastoPatch were stiff enough for specimens to keep their shape under minimal load, but Fibrescreed was so soft and ductile that it experienced plastic deformation under small loads, and finger imprints could be left in the material at room temperature. Table 4.2 shows how the various materials were categorized.

Table 4.2 Products and Properties

Products to Be Tested	Type of Material	General Properties
RSP	Polyurethane Polymer Concrete	Semi-Rigid
Delpatch	Polyurethane Polymer Concrete	Flexible
Wabo ElastoPatch	Polyurethane Polymer Concrete	Flexible
FlexPatch (SSI)	Epoxy Polymer Concrete	Semi-Rigid
FlexKrete	Thermosetting Vinyl Polymer Concrete	Semi-Rigid
EucoSpeed MP	Magnesium Polyphosphate	Rigid
MgKrete	Magnesium Polyphosphate	Rigid
Pavemend 15	Magnesium Polyphosphate	Rigid
Rapid Set	Hydraulic Cement	Rigid
Fibrescreed	Polymer Modified Bitumen	Flexible

Compressive Strength

Compressive strength for each sample was measured using ASTM C 39 "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens" (*11*). A total of six 4-inch x 8-inch cylinders were created from each product at each of the three different temperatures. Three cylinders were tested at one hour after cure, and three more cylinders were tested at 24 hours after cure. All specimens were sulfur capped except RSP (which utilized neoprene pads). Figure 4.2 shows the results for tests completed at 24 hours. A complete set of data for all materials is located in Appendix B.

It was discovered that some of the repair materials had such a low modulus of elasticity that failure normally associated with concrete specimens could not be reached. Rigid materials failed as expected, and ultimate strengths were recorded, but the ultimate load of the soft flexible materials could not be defined as the material continued to compress, in some cases up to an inch or more before the capacity of the testing equipment was reached. FlexPatch, Fibrescreed, Wabo ElastoPatch, and Delpatch were all considered too ductile to test as Figure 4.3 illustrates.

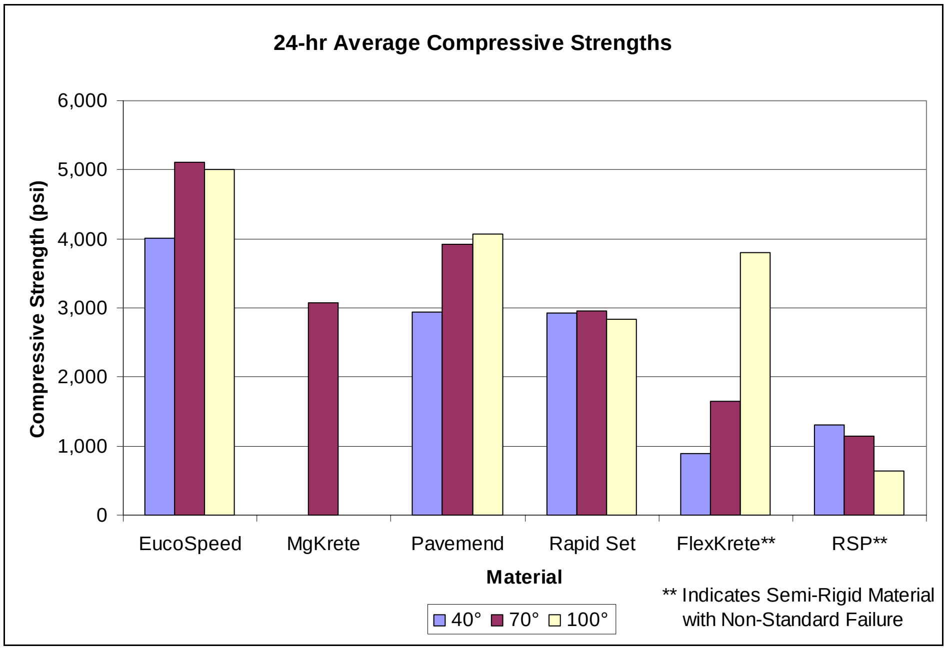

Figure 4.2 24-hr Average Compressive Strengths

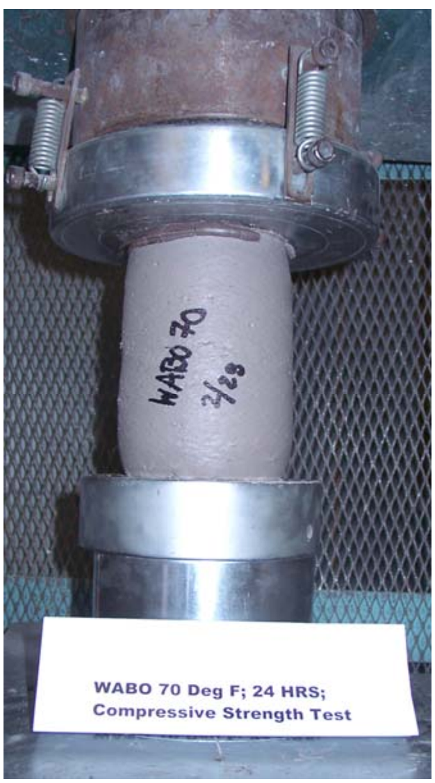

Figure 4.3 Compressive Strength Testing of Wabo ElastoPatch During and After Test

Results for FlexKrete and for RSP (both semi-rigid materials) are slightly misleading in that they did not fail in the normal manner for concrete specimens. When compressed, they visibly bulged outward until finally the hoop stress in the perimeter of the cylinder was too great, and the material split. Only the magnesium phosphates and the hydraulic cement failed in the normal manner. In comparing the results for both the 1-hour tests and the 24-hour tests, EucoSpeed had the highest strengths of the rigid materials in each of the three temperature categories. This may be because the mix was extended with 3/8-inch pea gravel as recommended by the sales representative on hand at the time of mixing. Both EucoSpeed and MgKrete allow extending the mix with pea gravel, and it should be noted that the strength will be affected by the type and the amount of aggregate added. Another point is that Rapid Set, which experienced some of the lowest strengths, was batched using 5 quarts of water per mix (the maximum quantity allowed) because the sales representative was worried about the workability of the product at the lower temperatures. Product literature indicates that using less water in the mix will give higher strengths.

Flexural Strength

Flexural strengths for each material were determined using ASTM C 78 "Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)" (*12*). Six 3-inch x 3-inch x 12-inch beams specimens were made at each temperature. Three specimens were tested at 1 hour after cure and three more tested at 24 hours after cure. Specimens were centered on supports 9-inch apart and loaded at the third points.

In this project, testing of rigid and semi-rigid materials was possible, but it was not possible to obtain flexural strengths on the soft flexible materials due to the fact that they did not fail under load. Figure 4.4 illustrates the very flexible nature of some of the more ductile materials tested, and illustrates very large deflections.

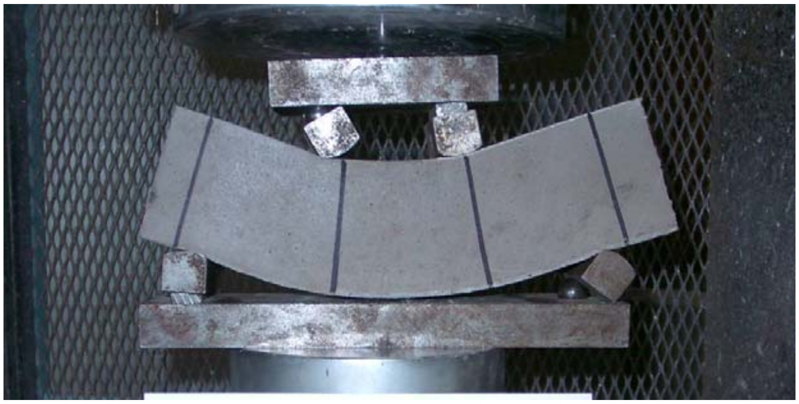

Figure 4.4 Flexural Testing of Wabo ElastoPatch at 70°F

Figure 4.5 gives graphical results for flexural strength tests on rigid and semi-rigid materials at 24 hours. A complete set of data for all materials is located in Appendix B. The data show that the magnesium phosphates all had comparable flexural strengths between 450 psi and 600 psi after 24 hours, but polymer concretes including FlexKrete, RSP, and FlexPatch experienced flexural strengths that were two to three times higher. This was likely due to the greater tensile strengths of the polymer concretes allowing them to achieve higher ultimate loads.

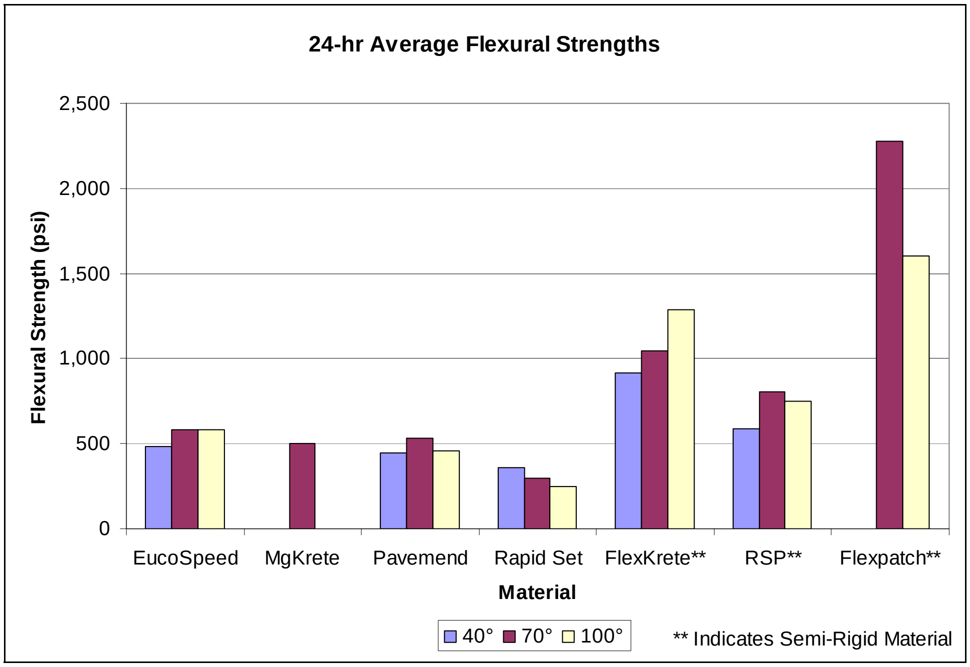

Figure 4.5 24-hr Average Flexural Strengths

For each material, three specimens were tested, and it was noted that there was a considerable amount of variability in the flexural strength values for RSP. For example, at a mix temperature of 100 degrees F the 24-hr flexure specimens broke at strengths of 490 psi, 680 psi, and 1085 psi. There are reasons for this variation. The liquid resin of RSP reacts with water and tends to foam, so moisture on the aggregate caused a reaction creating small air voids in the final product. Inspections of the failed beams showed that beams failing at higher strengths had a more densely packed aggregate with less air voids due to reactions with water. Another factor in the strength of RSP specimens was the size of the aggregate used. Failures at higher loads showed fracture of larger limestone aggregate, while failure at lower loads occurred as the material debonded from around smaller aggregates. It can be concluded that when using RSP, having a well-graded aggregate, which is dry and densely packed, helps produce a stronger product. Rapid Set again experienced the lowest flexural strengths of the test program, but this may be attributed to the higher amount of water used in the test mixes.

COMPATIBILITY

Compatibility is one of the most important yet often overlooked properties when considering the selection of repair materials. It requires investigating the material properties of both the repair material and the substrate to ensure the durability of both. It is defined by Peter Emmons as "the balance of physical chemical and electrochemical properties and dimensions between repair materials and existing substrate that ensures the repair withstands all anticipated stresses induced by physical changes, chemical and electrochemical effects without distress, and deterioration over a designed period of time" (*13*). Compatibility includes a number of different components including chemical, electrochemical, permeability, and dimensional compatibility. While all play an important role, this project focused on dimensional compatibility. Dimensional compatibility occurs when materials change volume and induce stresses in the repair material and the substrate. These volume changes can be due to a number of causes such as drying shrinkage, thermal expansion, and creep. Stresses are the product of the modulus of elasticity and the shrinkage strain and/or the thermal expansion/contraction strain. So, modulus, shrinkage, and CoTE were all tests performed to determine the compatibility properties of the various repair materials. For the most part, the rigid materials had higher modulus of elasticity values, with lower CoTE and shrinkage values, while the reverse was true for the flexible materials.

Modulus of Elasticity

Modulus of elasticity is the key in dimensional compatibility because it determines how a material will distribute loads due to volumetric changes. If a material has a high modulus, small changes in volume (strain) produce large amounts of stress in the material and, in turn, on the surrounding concrete. Conversely, materials with a lower modulus are able to endure volume changes without high levels of stress. Poisson ratio is another property that can play a key role. It is defined as the ratio of displacement in the perpendicular direction to the displacement in the parallel direction of an applied load. When included with the modulus of elasticity it can relate how loads from traffic are distributed to the perpendicular sides of the spall, or how the material deforms laterally due to the vertical applied load. Modulus of elasticity for each product was determined using ASTM C 469 "Standard Test Method for Static Modulus of Elasticity and Poisson Ratio of Concrete in Compression" (*14*). Two 4-inch x 8-inch cylinders were tested at 24 hours for rigid materials.

For materials that were not rigid, with a much lower modulus, the modulus was calculated using a slightly modified approach. Using the compressometer from ASTM C 469 tests, readings for vertical deflection were taken with loads recorded at varying intervals and graphically plotted to determine the modulus using a line of best fit.

While the test was conducted for rigid materials 24 hours after curing, flexible materials were tested approximately one month after test specimens were created. Figure 4.6 shows a comparison of the modulus for different materials created and tested at 70 degrees F. The complete set of data for elastic modulus is located in Appendix B.

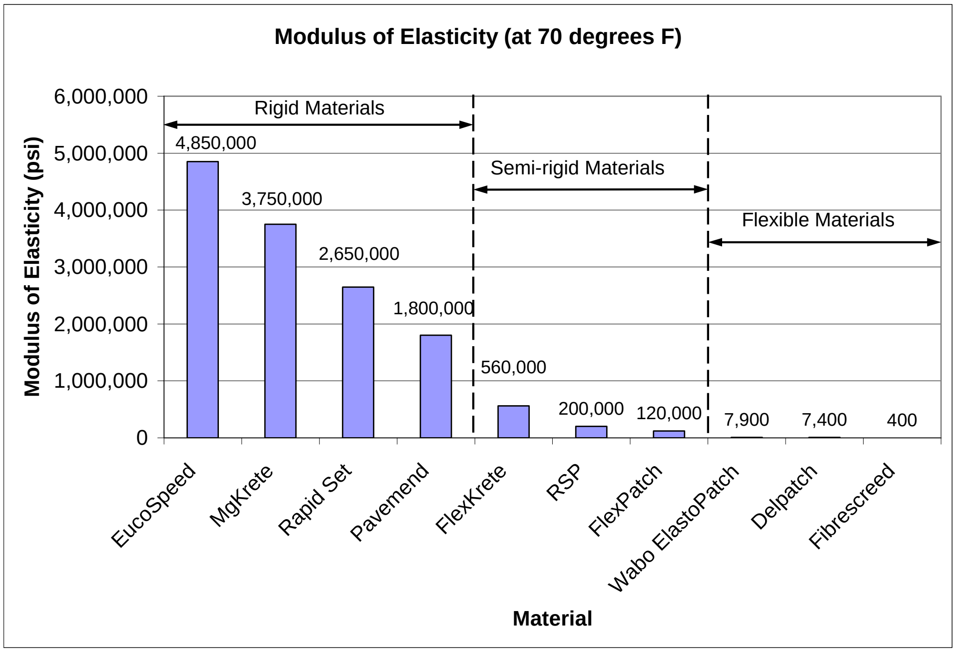

Figure 4.6 Elastic Modulus

In general, the rigid materials, the magnesium phosphates, and hydraulic cements, had elastic moduli that were 3 to 10 times greater than the polymer concretes. Rigid materials had elastic moduli between 1,800,000 and 4,850,000 psi. Semi-rigid materials had elastic moduli between 120,000 and 560,000 psi. Flexible materials had moduli between 400 and 7,900 psi.

One thing that must be stressed is that the test method used was not meant for such flexible materials, and at times it was difficult to determine how much deflection was due to the applied load, and how much was due to creep. When the test was performed, an attempt was made to keep the loading rate the same for all samples, but at times due to the flexible nature of the material the deflection would lag behind the application of the load. The dynamic properties of these more ductile materials were very hard to predict without testing, but in future tests it is recommended that the modulus be tested with ASTM D 638 "Standard Test Method for Tensile Properties of Plastics" (*15*).

Shrinkage

As a repair material initially sets, a volume change due to moisture, chemical, and temperature changes can occur, called initial shrinkage. Many times when the material is first placed it will expand in the spall area due to moisture or temperature. This expansion initially puts compressive stresses on the sides of the substrate, but eventually the material will shrink. Once the material has bonded to the substrate, tensile stresses will be induced in the repair material. Care must be taken to ensure that both the substrate and the repair material can accommodate the stresses induced by this initial shrinkage.

The DuPont shrinkage device was used to determine initial shrinkage of the materials in the first 18 hours after placement. Beam molds, 3-inch x 3-inch x 12-inch in size, were lined with plastic sheets to reduce friction on the surfaces of the molds. The material was then poured into the mold, and instrumentation consisting of an LVDT attached to a rod with two removable angles was inserted into the material. The change in length of the material was recorded while it was curing in a 70-degree temperature-controlled room over a period of about 18 hours. Results were then graphed and maximum shrinkage calculated as the maximum percentage of length change across the length of the specimen while curing.

The results for the initial shrinkage of each material after the first 18 hours are shown in Figure 4.7 with the complete set of shrinkage plots for each material and temperature given in Appendix C.

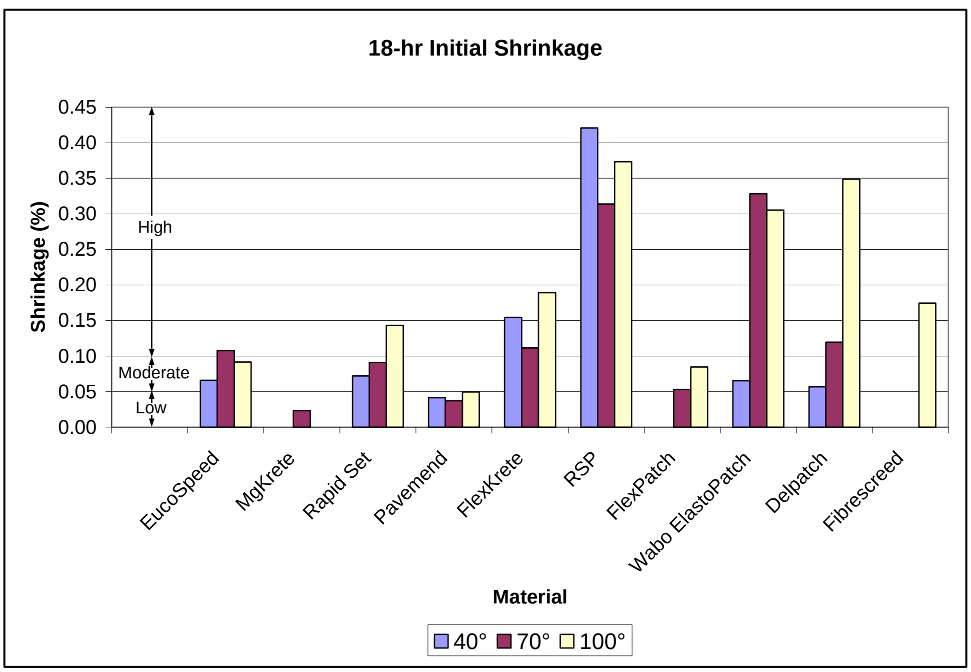

Figure 4.7 Shrinkage Comparison at 18 hours

Initial shrinkage is mainly due to moisture, chemical, and temperature changes. Many of the materials tested are exothermic, giving off heat as they cure. The maximum temperature they attain and the CoTE of a material will greatly affect the initial shrinkage value as well as any additional shrinkage that occurs due to the moisture losses and chemical changes.

Emmons defines low shrinkage as being between 0.0 and 0.05 percent, moderate shrinkage as being between 0.05 and 0.10 percent and high shrinkage as being greater than 0.10 percent (*16*). Rigid materials in general had low to moderate shrinkage with Pavemend and MgKrete having a low amount of shrinkage, and EucoSpeed and Rapid Set having moderate amounts of shrinkage. Rapid Set had shrinkage values higher than other rigid materials, but again, test mixes with Rapid Set used a larger quantity of water, and higher water cement ratios tend to increase shrinkage. Semi-rigid and flexible materials experienced a high amount of shrinkage, with the exception of FlexPatch, the epoxy polymer concrete. There are two reasons for this lack of shrinkage, the first being that epoxy polymers usually experience low amounts of shrinkage, and the second being that temperature data showed the product was not exothermic so CoTE did not play a role. RSP experienced some of the highest shrinkage rates of all the materials tested and much can be attributed to the fact that the material bubbled and expanded when the polyurethane binder reacted with the moisture on the aggregate then later contracted. It should be noted that all materials were allowed to cure unattended under the same conditions in a 70-degree temperature-controlled room with no additional curing considerations or precautions.

Materials like magnesium phosphates and more rigid materials had lower shrinkage values probably due to both their chemistry and their low CoTE values. Materials with low CoTE values exhibit only small amounts of expansions due to thermal changes as the material heats up because of its exothermic nature. Polyurethane polymer concretes on the other hand experienced high initial shrinkage values due to both their chemistry and their high CoTE values combined with their exothermic nature.

Coefficient of Thermal Expansion

Thermal expansion is another property affecting compatibility that should be considered. Usually the CoTE of the repair material will be larger than the CoTE of the surrounding concrete, meaning when the temperature rises, the repair material will expand, pushing outward on the concrete. If the repair material is stiffer and stronger than the surrounding concrete it will force the surrounding concrete to deform, possibly causing the repair to fail. On the other hand, if the temperature falls, the repair material will contract. The bond between the repair and the surrounding concrete can cause tensile stresses as the repair contracts leading to failure. If the temperature drops and the repair material is poorly bonded to the concrete, the possibility arises that it will pop out of the spall area as it contracts.

CoTE was determined using Tex-428-A "Determining the Coefficient of Thermal Expansion of Concrete" (*17*). The 4-inch x 8-inch cylinders of each material that were made at 70 degrees F were cut to a length of 7-inch and cycled between the temperatures of 10 and 50 degrees F. The change in length was measured with an LVDT device located above the support stand and the corresponding CoTE calculated.

The results of CoTE tests for the different repair materials are shown in Figure 4.8 with a complete set of results given in Appendix C. It was observed that the more rigid materials like the magnesium phosphates and hydraulic cements had relatively low CoTE values between 5.7×10^{-6} and 7.5×10^{-6} /°F. For comparison, these values are similar to the CoTE for normal weight concrete, between 4.1×10^{-6} and 7.3×10^{-6} /°F (*18*).

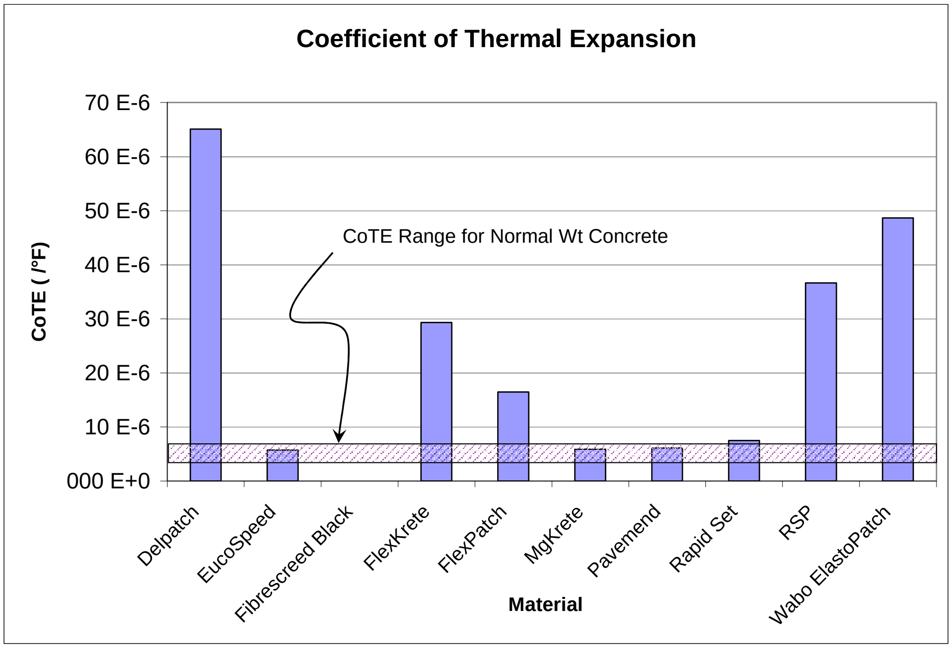

Figure 4.8 CoTE of Materials

The semi-rigid and flexible materials (all representing polymer concretes) had CoTE values that were much higher, in the range of 16.4×10^{-6} to 65.1×10^{-6} /°F. Attempts were made to measure the CoTE values of Fibrescreed, but the material was so soft it crept under the LVDT needle and made determination of CoTE via this method impossible.

For CoTE testing purposes, all samples were run with aggregate included in the specimen. The CoTE of a material will depend in large part on the type of aggregate contained in the repair. Some of the repair materials can be extended with user-supplied aggregate (including MgKrete and EucoSpeed) but the CoTE will change depending on the type and the amount of aggregate used. (For testing purposes only EucoSpeed was extended.) The same holds true for the polymer materials. The type and amount of aggregate used with RSP or the type of sand used with FlexKrete will affect the CoTE value. Manufacturers who supply the aggregate with their kits will experience a lower amount of variability in the CoTE for their product than those who allow the user to supply the aggregate.

It should be noted that some of the repair materials had unexpectedly high CoTE values. The test equipment is designed to take very accurate readings but when the material expands beyond normal limits, the accuracy of the CoTE value is limited. The CoTE results from this project give a general idea of the range of CoTE values, which can be used for classification purposes, but if a more accurate CoTE value is needed, different testing equipment and procedures would need to be used.

CYCLIC ENVIRONMENTAL CHAMBER TESTS

Simulated spalls were constructed in an effort to observe the real life application of the various repair materials and in an attempt to correlate laboratory data to later specimens collected in the field. The simulated spalls, as shown in Figure 4.9, were created in concrete specimens which were 6-inch deep by 18-inch wide, and 9-inch long made from a 4,000 psi concrete paving mix utilizing siliceous river gravel. Field evaluations in Houston indicated that the majority of spalls are caused by delaminations within the top 3-inch of concrete pavement, meaning most spalls are no greater than 2-inch deep. For this reason simulated spalls were created 2-inch deep in the test slabs. Evaluations also showed the surface of spalled concrete is prone not only to heavy delaminations, but also to micro-cracking at edge surfaces, and large transverse cracks running the width of the pavement. A crack was placed down the center of the concrete slab to observe how well a material can bridge over damaged concrete and to see if the crack would reflect through the repair. Additionally, failure was found to be common at the edge of many repairs. In an effort to observe how edge preparation affects the performance of a repair, a saw cut was created on one edge of the spall, and a chiseled edge was created on the other. After slabs were cast and cured for 28 days, spalls were created, and the surface of each was cleaned, sandblasted, and blown out to prepare for the repair.

Figure 4.9 Photo of Simulated Spall

When each material was batched and mixed at the various temperatures, the slab was also brought to the same temperature in an attempt to simulate both cold weather and hot weather applications. After simulated spalls were created and then repaired with the various repair products, they were placed in an environmental chamber and cycled between 20 and 120 degrees F at a rate of one cycle per day for 75 days in an effort to simulate weathering of the slobs. It was hoped that this cycling would mimic accelerated weather on the spalls, inducing stresses due to thermal loads on both the material and the bond. This was done both to determine if the repair material would remain bonded to the substrate at the base and edges of the spall, and to see if cracks in the underlying concrete would be reflected through the repair. In addition, the bond strength between the repair material and the substrate was tested after the inspection.

General Observations

After cycling the test slabs, the spalls were inspected visually to determine how the repair materials performed and if any deterioration could be seen. Additionally, observations were made to determine if cracks placed in the artificial spall were able to propagate through the repair material and if the edge preparation (using a cut edge versus a feather edge) played any role in the performance of the material. Thermal cycling of the miniature repaired spalls was discontinued after 75 days, and each slab was inspected for signs of distress. No distress was observed in any of the materials. None of the cracks from the underlying concrete propagated through any of the repair materials, and upon careful visual inspection as the photo of Figure 4.10 illustrates, no material was observed to have pulled away from the saw cut edge, or to have become raveled at the feathered edge.

There are a couple of reasons why failure did not happen. One is that many of the repair materials came with good recommendations from the districts that used them so this test merely proves that the materials work well. Another reason is that there was no moisture introduced into the test, which would simulate freezing and thawing conditions during extreme temperature changes that could play a role in the survival of the repair materials. Also, the mini spalls were too small to simulate the real magnitude of expansion and contraction that occurs under field conditions.

Figure 4.10 Spall after Thermo Cycling

Temperature changes induce the repair material to expand and contract placing stress on both the repair and the surrounding concrete. These temperature changes also cause the surrounding concrete to expand and contract, forcing cracks to repeatedly open and close. The small size of the simulated spall produced only small changes in volume and crack displacement meaning the associated stresses were also small. Another consideration was that these mini spalls were not subject to any traffic loadings as a spall normally would be under field conditions.

Bond Strength

The ability of a repair material to bond to concrete is another factor in the success of the repair. Studies by Texas A & M University concluded that the bonding of a patching material to its concrete base plays a very important role in the performance of a repair (*10*). The bond strength allows the material to stay adhered to the concrete below even when the material undergoes dimensional changes due to shrinkage and CoTE that cause stresses at the interface of the repair material and substrate. It was discovered from the field cores that often the spalled concrete is heavily delaminated, and the bond of the repair material to the substrate helps to hold the concrete together.

After careful inspection of the repaired spalls, the bond of the material to the substrate was tested using an adaptation of ACI 503R. Each spall material was cored using a 2-inch diameter core drill to a depth of 0.5-inch below the spall interface in a minimum of three different locations. Next, aluminum plates were glued to the surface of the repair material, and a Dyna pull off tester was used to measure the tensile force required for failure to occur.

Three types of failure are possible with this test. The concrete material below the spall can fail indicating that the repair material and its bond to the existing concrete is stronger that the substrate concrete. The repair can fail at the bond location between the repair material and the underlying concrete, which indicates that the bond is weaker than the underlying concrete and the repair material. Failure can also occur within the repair material indicating that the material is weaker than either the bond to concrete, or the underlying concrete. For this test the tensile load at failure and the method of failure were recorded.

Results of the tension bond pull-off test shown in Figure 4.11 reveal significant variability in the results and were only slightly conclusive. The complete set of data for tension bond strength is located in Appendix D. It is believed that much of the variability comes from the nature of the test. Artificial spalls were created in the small test slabs, and it is impossible to reproduce the same surface on each one. The size and angularity of the spall surface affect how well a material bonds to the substrate. Having a large amount of exposed aggregate would provide a better bond surface than a smooth surface of fine cementations material.

The highest pull-off strengths came from materials that were able to force the failure in the concrete substrate by pulling a small piece of the underlying concrete with them. Solid conclusions are hard to be drawn though, due to the variability in the test results. In some situations rigid, semi-rigid, and flexible materials all performed well. Additionally, there were some situations where materials without primed surfaces performed just as well as materials with primed surfaces, but encouragingly Wabo ElastoPatch and FlexKrete had had consistently high bond strengths above 100 psi. It should be noted that both of these materials use a wet primer, which may have improved their bonding ability.

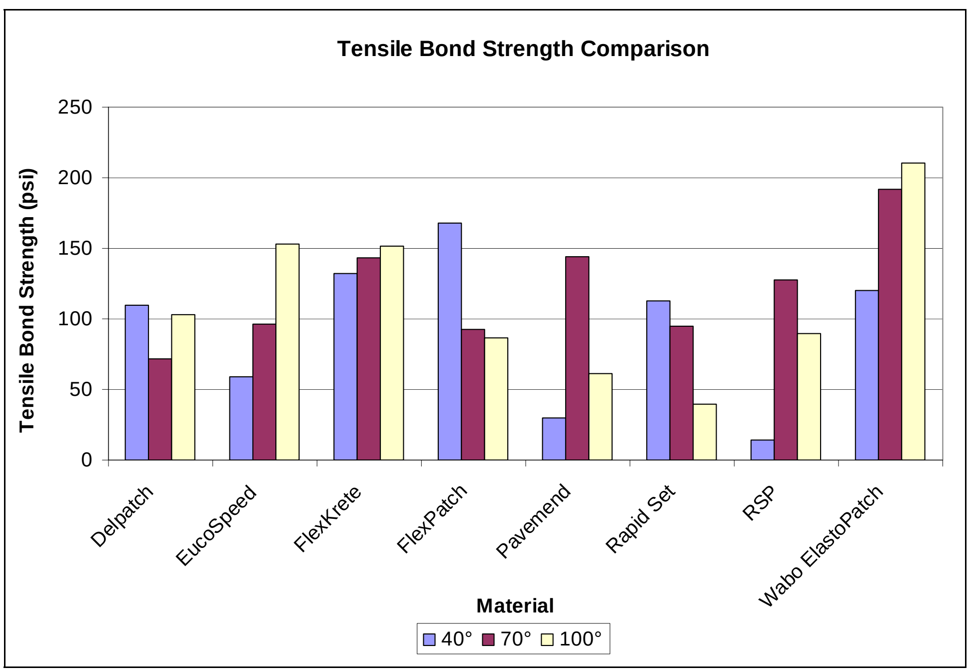

Figure 4.11 Tensile Bond Strength

This test is difficult to complete on very ductile materials like Delpatch and Wabo ElastoPatch since they have a moderate tensile capacity. Occasionally, when testing the more ductile materials, the tensile load would cause elongation of the material to the limit of the testing device without failing the material or the bond. When this occurred, no ultimate peak load could be recorded. Fibrescreed, the most ductile material tested in this program, was not able to be tested for bond strength since it was impossible to core the material without it gumming up the coring rig and deforming the core area.

Another observation made from this test was that the more brittle materials tended to have low shear bond strengths because when attempts were made to core some of the rigid materials, the 2-inch diameter specimens would break at the bond line from vibrations during the coring process.

DURABILITY PROPERTIES - ABRASION

Another consideration when evaluating a repair material is its durability in the presence of daily traffic. Vehicular loads can create high shearing forces that are abrasive to the road surface. The ability of a repair material to resist abrasion was measured using ASTM C 418 "Standard Test Method for Abrasion Resistance of Concrete by Sandblasting" (*19*). 4-inch diameter discs were cut from 4-inch x 8-inch cylinders cast at 70 degrees F. Samples were cleaned and weighed with the mass recorded. Researchers tested specimens at eight different locations, after which the samples were again cleaned and weighed to determine the amount of material lost. All abrasion testing was performed at 70 degrees F.

Figure 4.12 shows results from abrasion testing. Pavemend and Rapid Set experienced the largest abrasion of material while the polymer concretes experienced much lower losses probably due to the materials containing only fine aggregates, which were easily sandblasted away. The polymer repair materials, on the other hand, used sand and larger aggregates with their resin binders that were able to provide much higher tensile strengths with more ductility resulting in greater abrasion resistance.

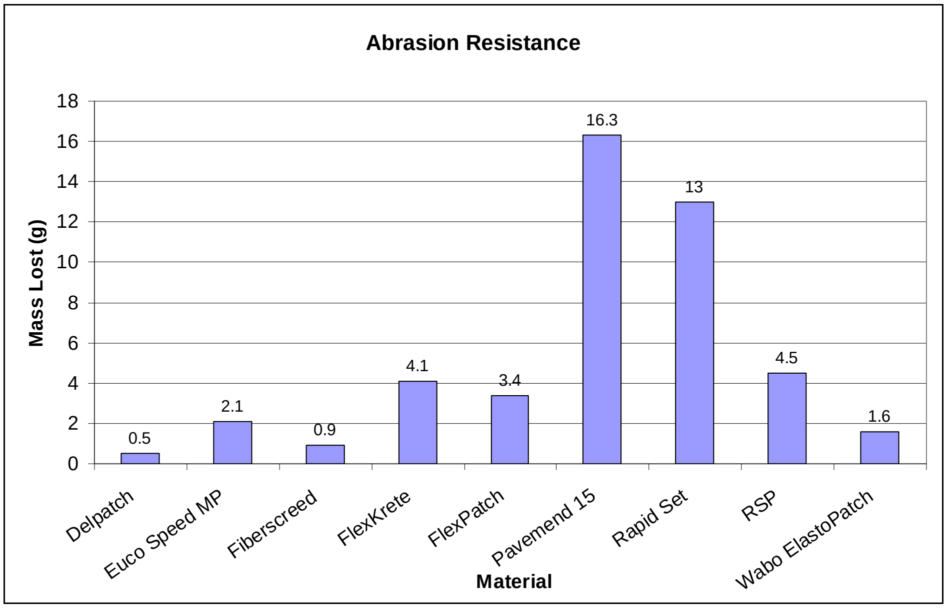

Figure 4.12 Abrasion Resistance

Some sources have recommended additionally testing polymers for abrasion at higher temperatures since some polymers soften when heated and tend to lose their abrasion resistance especially since many road surfaces in Texas experience temperatures above 70 degrees F on a regular basis (*20*).

DISCUSSION OF TEST RESULTS

Results of the test program showed that many of the repair materials were surprisingly different. Since districts have found products of each type successful it requires a re-analysis of some of the properties required for a successful repair.

Mechanical Properties

Many times the high compressive strength of a material is its most advertised asset, but in reality a high compressive strength is only required of a repair material if it is subjected to a high compressive load. It may be that for smaller spall repairs where repair materials only need to transmit vehicle loads to the underlying substrate, a higher compressive strength is not necessary. If a material is thermally incompatible, meaning it has a relatively high CoTE value along with a high modulus compared to the substrate, the repair is vulnerable to failure during large thermal cycles. In fact, more focus should be placed on properties like compatibility and the ability to bond when choosing a repair material rather than just its strength.

When compressive strength cannot be obtained for polymeric materials, a better mechanical comparison property would be tensile strength and elongation. It was found that many of the polymeric materials have a substantial amount of tensile strength and are more flexible than their rigid counterparts. This high level of tensile strength works to hold the aggregate of the material together when it is subjected to traffic loads, and resist the tensile stresses caused by thermal and shrinkage contraction. Additionally, the ability of a material to elongate can provide it with the flexibility to expand and contract under thermal cycles while avoiding tensile failures (*5*).

Compatibility Properties

Originally it was thought that for a repair material to be effective it was critical for the CoTE to be as similar as possible to the concrete to which it was adhering. This line of thought developed because most repair materials have compressive strengths higher than concrete and a modulus of elasticity that was relatively similar to concrete. With this being the case, to comply with compatibility concerns the CoTE also needed to be similar to concrete to avoid cracking the concrete surrounding the repair during temperature changes.

As Figure 4.13 illustrates, for many of the polymer concrete repair materials tested, the CoTE was very high in comparison to concrete, but the modulus of elasticity was very low, making the material very flexible. Since stress is the product of modulus and the strain due to thermal changes in the product, or CoTE and temperature changes, the stresses will be lower when CoTE is lower. This indicates that the high CoTE value associated with many of the polymeric concretes is acceptable as long as the elastic modulus is low. Figure 4.14 shows the product of CoTE and elastic modulus (strain) for each material alongside the elastic modulus for the material. This shows that for the materials tested, modulus is the bigger influence on strain due to temperature change. As a point of reference, values for normal weight portland cement concrete with an elastic modulus between 3,000 and 6,000 ksi and a CoTE of between $7x10^{-6}$ and $13x10^{-6}$ per degree Celsius are included.

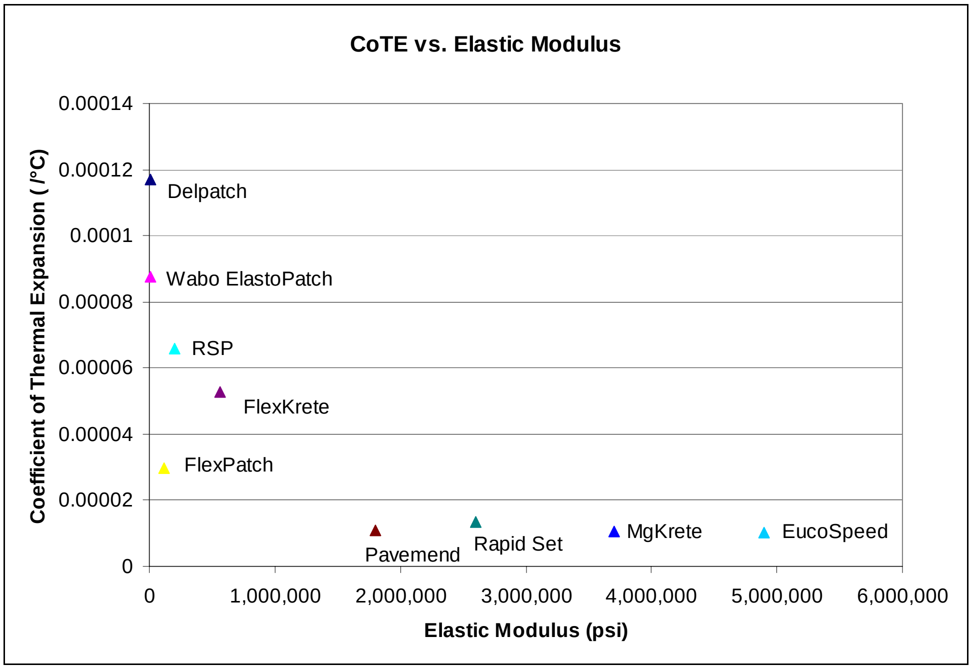

Figure 4.13 CoTE vs. Modulus Comparison

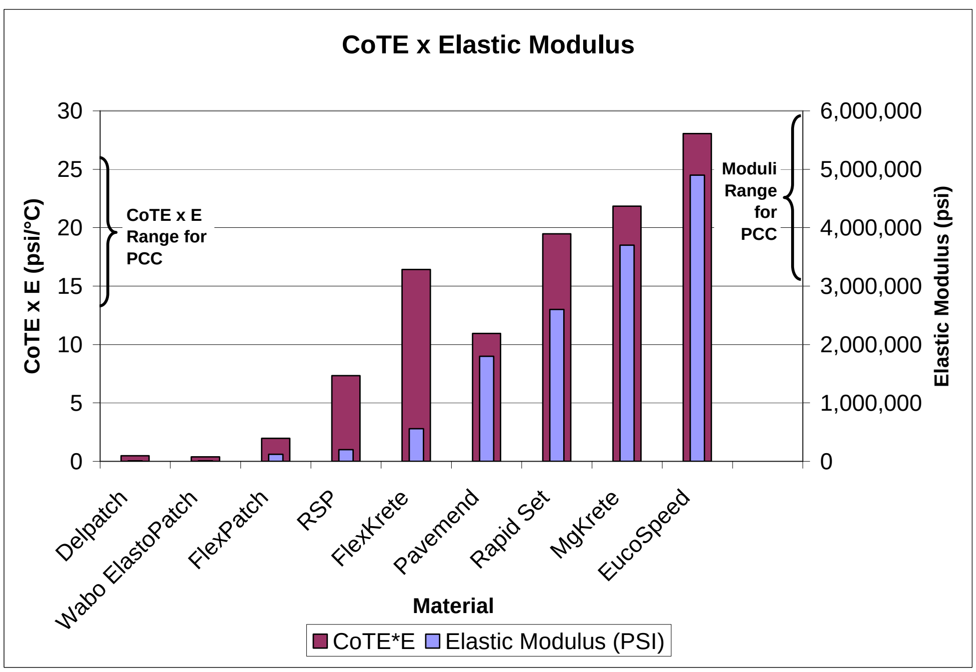

Figure 4.14 CoTE Times Elastic Modulus

Bond Properties

Small artificial slabs were created in the laboratory and then repaired with the various repair materials in an effort to test surface preparation. One side of the spall was chipped out to represent a feather edge, and the other side was saw cut to determine if a repair needed to be saw cut on all edges, or if a feathered edge could be created thereby saving time during surface preparation, and material when filling the spall. Since no deterioration of any kind was observed, no definite conclusions can be drawn.

The literature review did find some discussion in a previous study for the Pennsylvania DOT that recommended for polymer or epoxy repairs, where saw cutting is not required, a vertical edge be provided by means of chipping or jack hammering. The report also discourages feather edges if any large aggregate is contained in the polymer concrete (*21*).

The FHWA recommended using a chip-and-patch procedure over a saw-and-patch procedure since its studies showed the repairs perform equally. The saw-and-patch procedure consists of sawing the edges of a repair area and then jack hammering out the center of the repair area. The chip-and-patch procedure chips out only the damaged concrete. The advantage of the chip-and-patch procedure is that it requires less time and equipment and also gives a rougher surface at the edges to promote bonding. Care needs to be exercised to ensure that only light jackhammers are used since heavier jackhammers can damage the concrete below (*22*).

A saw cut edge is recommended for rigid repair materials because they need a solid boundary to avoid applying the products in thin layers at a feathered edge. This is because the materials are more brittle in nature with a low amount of flexibility, and in thin layers they are apt to break at the edge of the spall. Flexible materials with good bond strengths would most likely be able to sustain a feathered edge, and depending on the depth of the spall and the modulus of a material, a saw cut edge might even be detrimental to the repair area. This is because if the material has a very low modulus it gives very little resistance to support the saw cut edge, and the edge of the concrete being left unreinforced and subjected to traffic loadings could break or crack off causing edge failure.

Surface Preparation

A study of bond strength highlights a common theme to many of the conclusions drawn from reports during the literature survey and interviews with various TxDOT personnel. All agreed that surface preparation is a key to a successful repair, and no matter how good a repair material is the repair will not succeed if the surrounding concrete fails. If the surface is adequately prepared as required by the manufacturer a good bond to the existing concrete is much more likely. Surface preparation is critical to the success of all repairs; however, in a summation of tests done by the Michigan DOT, polymer concretes tolerated poor surface preparation better than portland cement based repairs (*23*). This was also observed by researchers at sites where field cores of polymeric materials (Delpatch, WaboCrete, FlexPatch, and Fibrescreed) were taken in Houston. Materials were performing well despite delamination present in the concrete directly under the spall repair. It is stressed, though, that even with the use of a well-performing material, good surface preparation is important to achieving a quality repair.

Relevant Properties Tests

One of the goals of this project was to determine some of the physical properties of the various repair materials to be used for comparison as well as to recommend the tests for obtaining these physical properties. Because the types and properties of the various materials differ so greatly, it is very hard to develop a test program that utilizes the same tests for each material. Additionally, some tests were found effective at obtaining material physical properties while other tests were less so.

Set time was tested using ASTM C 403 with a penetrometer, but this test becomes difficult when taking multiple readings on a fast setting repair material, especially with magnesium phosphates that change from liquid to solid states in just minutes. Instead a test for pot life could be utilized which keeps a small amount of material in a plastic bag that is continually worked in the hand until it is deemed too stiff to be trowlable. While this test is more subjective, it is a simple method that can be performed in the field.

For more rigid materials, standard tests for the compressive and flexural strength used in this program work well for comparing the various products. For the more flexible materials it is recommend that tests for tensile strength and elongation be run according to ASTM D 638 “Standard Test Method of Tensile Properties of Plastics.” For compatibility considerations elastic modulus should be determined, and the methods used in this test program work well for rigid materials, but for more flexible materials, elastic modulus can be determined from ASTM D 638.

Tests for shrinkage, CoTE, and bond used in this program were found effective and are again recommended. When testing CoTE with methods utilized in this testing program, care should be taken to ensure that the equipment can measure the extreme displacements produced by various repair products. Additionally, when testing bond strength it should be remembered that significant variation can be obtained and a larger sample size may mitigate this problem.

One thing that must be stressed for the results of all materials is that for some of the materials there is quite a bit of variability in how the product can be made. Many had a variety of chemical additives that could be used as well as a choice of aggregates. Additionally, the rate of mixing and the temperature of a mix all play a role. These factors will all affect the results. The key to using a product successfully is being familiar with it and being able to get consistently good results.

CHAPTER 5. FIELD EVALUATION AND PLACEMENT

INTRODUCTION

The best evaluation of a repair material is its successful installation and performance under service conditions. To assess the performance of a repair material, it is necessary to collect data from field sections to determine their in situ properties and to set a standard for acceptable values.

For collecting useful information on the performance of spall repair materials under field conditions, performance surveys were conducted and cores were taken within selected TxDOT districts that have concrete pavements manifesting spalling distress that were patched with a spall repair material. Additionally, the field placement of six products was performed on a special test section established on I-35 in the Ft. Worth District near Alvarado, Texas.

PERFORMANCE SURVEY

To investigate specific defects and mechanisms affecting the performance of spall repair materials, the field investigations of spall repair materials were carried out in the Houston and Waco Districts. Several cores were taken to visually observe the quality of the bond to the existing concrete surface.

Houston District

Researchers conducted field investigation in the Houston District at 11 locations using six materials. The first site investigated consisted of two locations approximately 200 feet south of the intersection of Loch Katherine Lane and SH 6. These two areas were inspected for specific defects and mechanisms affecting the performance of spall repair materials. The locations shown in Figure 5.1 were repaired with the Delpatch material. It is evident the patch materials suffer from concrete breaking out from the perimeter of the repair area as shown in Figure 5.2. This breakage tends to be very common among the different materials that are used to make spall repairs. The concrete that is broken out leaves jagged edges and areas to trap water adjacent to the repair patch. The most likely cause is micro cracks or delaminated concrete immediately below the original concrete surface adjacent to the repair that remain after the repairs are made.

Figure 5.1 Location 1: Near the Intersection of SH 6 and Loch Katherine Lane

The repair procedure typically is to use a 25 lb or less jackhammer to remove the delaminated concrete and then to sandblast the exposed concrete surface, and finally to place the repair material. However, it appears that improvements in the repair procedure should focus on removing all cracked and delaminated concrete in the vicinity of the repair. Several cores were taken from these sites where close inspection indicated a high quality bond to the concrete as shown Figure 5.3.

Figure 5.2 Spall Damage at Location 2

Figure 5.3 Core Taken from Location 2

The inspection also indicated that Delpatch can also bridge the transverse cracks in the concrete pavement (that are below the repair material and included in the confines of the repair) and actually show a high resistance to propagation of these cracks through the material while maintaining a good bond to the existing concrete. The patches investigated at these locations had been in place for approximately six years.

The spall repairs investigated at locations 3 and 4 shown in Figures 5.4 and 5.5 used FlexPatch. Cores taken from these locations indicated a low resistance to crack propagation in this repair material as evidenced by the reflection of the transverse cracking in the CRC pavement through the FlexPatch.

Figure 5.6 illustrates that FlexPatch had a tendency to break away from the underlying concrete pavement during the coring operation. It seems to suggest a weak bond between FlexPatch and the existing concrete surface. Even with these characteristics, FlexPatch appeared to be providing adequate performance. Apparently, in order to be a successful spall repair material, a material manifesting high crack resistance must also have good bond strength. If the material manifests low crack resistance, then the requirements for bond strength are not as stringent.

Figure 5.4 Location 3

Figure 5.5 Location 4

Figure 5.6 Cores Showing Broken Bond

Another spall repair material, WaboCrete, was investigated at Locations 5, 6, and 7 on the frontage road of Beltway 8 between Richmond Avenue and Cinema Hall. This material showed performance similar to that of Delpatch.

It manifested good bond and a high degree of resistance to crack propagation from the crack in the existing concrete. As observed in Figure 5.7, this particular patch suffered from further deterioration due to dislodgment of perimeter delaminated concrete. A view of a core taken from this location revealed continuation of the delamination from the spall repair area shown in Figure 5.8. Another interesting characteristic of this site was that all the cores taken from the repair area broke at a depth of approximately 4 to 5-inch below the concrete surface.

Based on previous experience, this particular area was most likely delaminated at multiple depths below the surface but apparently these several delaminations have not had a significant effect on the performance of the pavement. The rule of thumb that may be established based on this and other evidence obtained over several years of experience dealing with repairing spalled CRC pavement is that delaminations below 3-inch will typically create a spall in the pavement surface, and thus the majority of spall repairs will not be deeper than 2-inch.

Figure 5.7 Spall Damage at Location 5

Figure 5.8 Core Taken from Location 7

Location 8 was on SH 6 and consisted of Fibrescreed, the fourth repair material investigated. The stiffness of this material is apparently lower than any of the three previously cored materials. Inspection of one of the cores taken from this site indicated a high quality bond shown in Figure 5.10.

Figure 5.9 Location 8

Figure 5.10 Core Taken from Location 8

The other investigations were performed near SH 288 and consisted of three locations. Location 9 was on the bridge near the intersection between the Airport Road and SH 288 and overlaid with 5-inch of the asphalt. The pavement of Location 9 was repaired with FlexPatch before placing an overlay approximately two years ago. The investigation showed that saw cuts were not used during spall repairs.

The spall repair material at Location 10 was EucoSpeed, which includes the coarser aggregate near the intersection of SH 288 and Beltway 8. The investigation of Location 10 showed evidence of the saw cut that was applied before patching as shown in Figure 5.11. The transverse cracking of existing concrete pavement was reflected through the repair material as Figure 5.12; that is, the material indicated a low resistance propagation of these cracks.

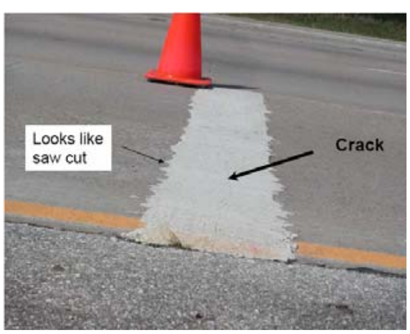

Figure 5.11 Location 10

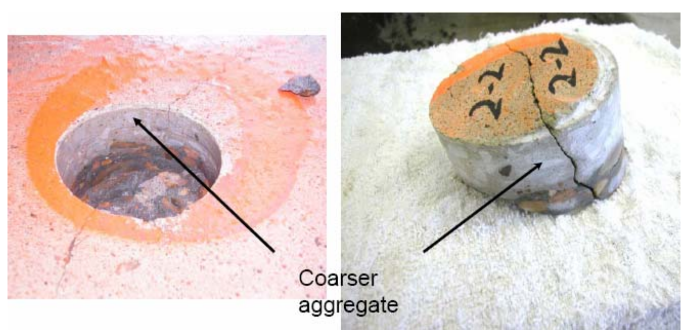

Figure 5.12 Core Taken from Location 10

However, the core taken from the location showed a good bonding quality between the concrete pavement and repair material as shown. The patches investigated had been in place for approximately five years.

Location 11 was on the northbound lane of the intersection of SH 288 and Beltway 8. The spall of the location was repaired using FlexPatch and Wabo Crete side by side. The repair materials were applied to the patch areas which were tapered by grinding and milling which was different from the repair methodology employed at Location 10 using a sawcut to eliminate a need for tapering. Nonetheless, the investigation showed adequate performance of materials. However, as shown in Figure 5.13, the de-bonding of Wabo Crete between the material and existing concrete appeared at a few patching areas while FlexPatch showed a good bonding quality. The de-bonding of repair material seems to result from delamination below the original concrete surface. The patching has been in service for approximately two years.

Figure 5.13 De-bonding of Repair Material at Location 11

Waco District

A field investigation and coring was carried out in the Waco District on the approach slab of a bridge spanning over railway on Highway 77 as shown in Figure 5.14. The spall repair material used in this area was Fibrecrete, which is black colored and consists of mineral fillers, various fibers, sand, granite aggregate, and synthetic polymers that have a soft viscous nature, distributed by Marketing Associate, Inc. The stiffness of this material is obviously lower than any of the materials investigated. Therefore, the Fibrecrete patched has viscous properties even after being in place for a year.

Figure 5.14 Highway 77 at Waco District

Figure 5.15 Patching Area with Fibrecrete

The cores taken from this location indicate that the repair material bridges the transverse cracks in the existing concrete pavement; that is, the material has a high resistance to crack propagation from the concrete pavement as shown in Figure 5.16. The cores also show good bond strength between the repair material and concrete pavement surface. The performance of the repair material seems to be fine because any distress could not be found on the spall repair area.

As illustrated in Figure 5.16, cores taken from the repair area show the delamination at a depth of approximately 0.5 to 1-inch below existing concrete pavement surface. Although the delaminations have not significantly affected the performance of the pavement repaired with Fibrecrete, further deterioration as a result of the dislodgement of delaminated concrete may be problematic.

Figure 5.16 Cores Taken from Waco District

LABORATORY TEST OF FIELD CORES

Many of the products investigated have been found to work well by TxDOT engineers, and an effort was made to correlate the properties of these successful repairs to the repairs made from the same materials created in the lab. A good correlation can help verify laboratory results as well as give further merit to testing specimens in the environment of the lab thereby avoiding some of the unknowns and uncontrolled conditions related to field placements.

In an attempt to relate tests completed in the laboratory with performance in the field, 4-inch diameter cores were taken from several locations recommended by TxDOT engineers. These cores were of known materials, which had been in service for a number of years. The field samples were then taken to the lab, cored with a 2-inch drill rig, and a tension bond pull off test was performed.

In Houston, researchers cored four different materials: Fibrescreed, Delpatch, FlexPatch, and WaboCrete (Wabo ElastoPatch). The photo of Figure 5.17 illustrates the pavement where a core was taken of Delpatch.

Figure 5.17 Delpatch Field Core from Houston

Bond tests were then performed on the materials in the same manner that was done for the laboratory test specimens. Each specimen was cored using a 2-inch diameter core drill to a depth of 0.5-inch below the spall interface. Aluminum plates were glued to the surface of the repair material, and a Dyna pull off tester was used to measure the tensile force required for failure to occur. Figure 5.18 is a photo of the Delpatch tensile bond strength specimen, and results for all specimens are given in Table 5.1. It should again be noted that it was not possible to obtain a tension bond strength for Fibrescreed since the material only crept under an applied tension load to the limits of the testing apparatus and never failed.

The FlexPatch specimen failed at the material surface, rather than at the bond surface, meaning that the repair material had a tensile strength of 168 psi, and the bond strength was greater than 168 psi. This is higher bond strength than the bond strengths experienced in the lab.

Figure 5.18 Delpatch Tested Tensile Bond Specimen

Table 5.1 Field Core Results

<table>
<tr><th colspan="4">TxDOT Field Core Results</th><th colspan="2">Bond Strength (psi)</th></tr>
<tr><td rowspan="2">Sample No.</td><td rowspan="2">Product</td><td colspan="2">Bond Strength</td><td rowspan="2">Field Cores Average</td><td rowspan="2">Lab Cores Average</td></tr>
<tr><td>(kN)</td><td>(psi)</td></tr>
<tr><td># 3a</td><td>FlexPatch</td><td>2.35*</td><td>168*</td><td>168*</td><td>108</td></tr>
<tr><td># 4</td><td>Delpatch</td><td>0.7**</td><td>50**</td><td>50**</td><td>91</td></tr>
<tr><td># 6b</td><td>Wabo</td><td>0.9</td><td>64</td><td rowspan="2">61</td><td rowspan="2">172</td></tr>
<tr><td># 6c</td><td>Wabo</td><td>0.8</td><td>57</td></tr>
<tr><td># 8c</td><td>Fibrescreed</td><td colspan="2">***</td><td colspan="2">***</td></tr>
</table>

* Broke at Material Surface
** Broke within Substrate
*** No failure/ creep only

The Delpatch specimen failed at a strength of 50 psi in the substrate material. Figure 5.19 illustrates how the concrete material was still attached to the repair material in the failed specimen. This means that the bond strength was greater than 50 psi and represents a lower bound for the material.

Both WaboCrete specimens failed at the bond line between the repair material and the substrate. The average tensile field bond strength was 61 psi, which was only a third of the bond strengths achieved in the lab tests. There are a number of reasons for this difference. Repairs have been in place a number of years while the test specimens have been in existence for only a few months. Additionally, since researchers were not present at the time of placement it is unknown how surface preparation was done in comparison to samples prepared in the lab. Another factor that must be considered with the comparison of bond data is the surface to which the material is bonded. The spalls in the field, as well as those created in the lab, are uneven and irregular. The bond strengths may be affected by these differences.

Comparison of field data to laboratory data was difficult because there is only a very limited amount of field data to compare. Researchers had only one core specimen for Fibrescreed, Delpatch, and FlexPatch, and only two specimens for WaboCrete. Since there is a very limited amount of data, with only one test per specimen, it is very hard to make a definitive conclusion about bond strength especially when only one specimen failed at the bond line.

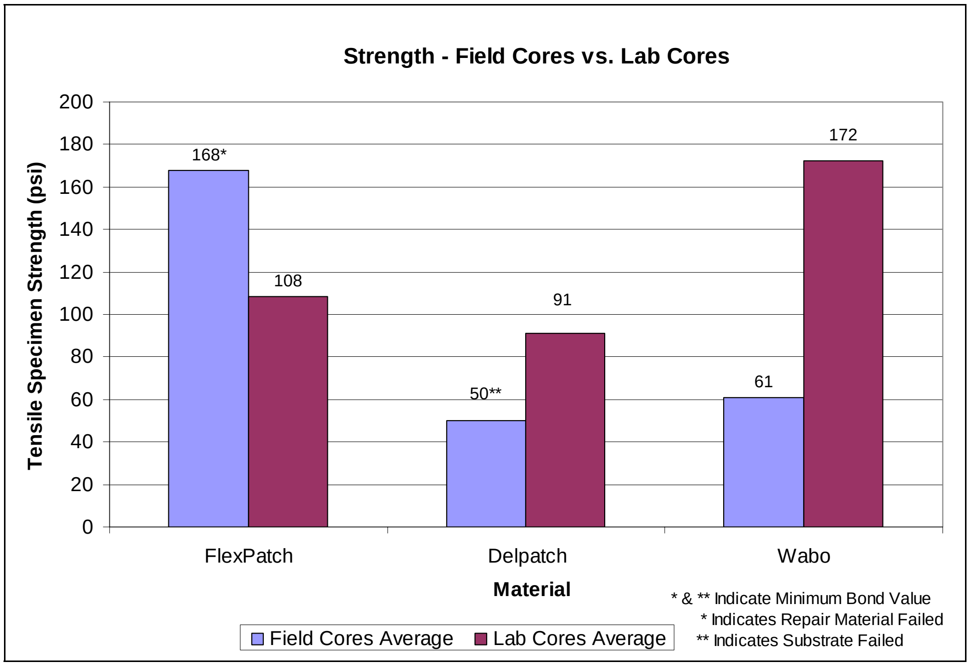

Figure 5.19 Bond Strength Field Comparison

FT. WORTH FIELD PLACEMENT

Field installations allow for the performance of materials to be observed during placement, demonstrating the practicality and ease of use of a particular repair material, as well as adding to both qualitative and quantitative information known about a material. As part of this project, an opportunity arose to observe the field placement of six products used in this project. While being reconstructed approximately 10 years ago, a vehicle drove onto the wet pavement of a portion of I-35 leaving two large permanent tracks. After more than 10, years the original repair material was deteriorating, and the Ft. Worth District coordinated with six of the manufacturers to install their products at this site to observe the field performance of each product side by side.

Observations and Data

The five cited materials used in the test were MgKrete, FlexPatch, Delpatch, EucoSpeed, and Pavemend TR. As part of this field placement, TxDOT also agreed to take samples of each material and run the tests required by their own specifications. The repair operations commenced with jack hammering to remove the deteriorated repair material. The surface of the concrete was thoroughly sandblasted and the site swept and air blasted to remove debris. The material was then mixed and placed by each manufacturer with the help of TxDOT personnel.

Figure 5.20 Placement of FlexPatch by Crews in Ft. Worth

For research purposes, three 4-inch x 8-inch cylinders were taken for each material and tested after 7 days to obtain both the compressive strength and the elastic modulus. In addition an attempt was made to determine the pot life of each product to establish the workability time. A plastic bag of each material was obtained and timed from initial mixing to the time when the material was deemed too stiff to be workable. Results from these tests are shown in Table 5.2 and Figure 5.21 with additional data located in Appendix F.

Table 5.2 Repair Material Pot Life

Product	Approximate Pot Life (Minutes)
EucoSpeed	10 min
MgKrete	14 min
Pavemend TR	25 min
FlexPatch	29 min
Delpatch	20 min

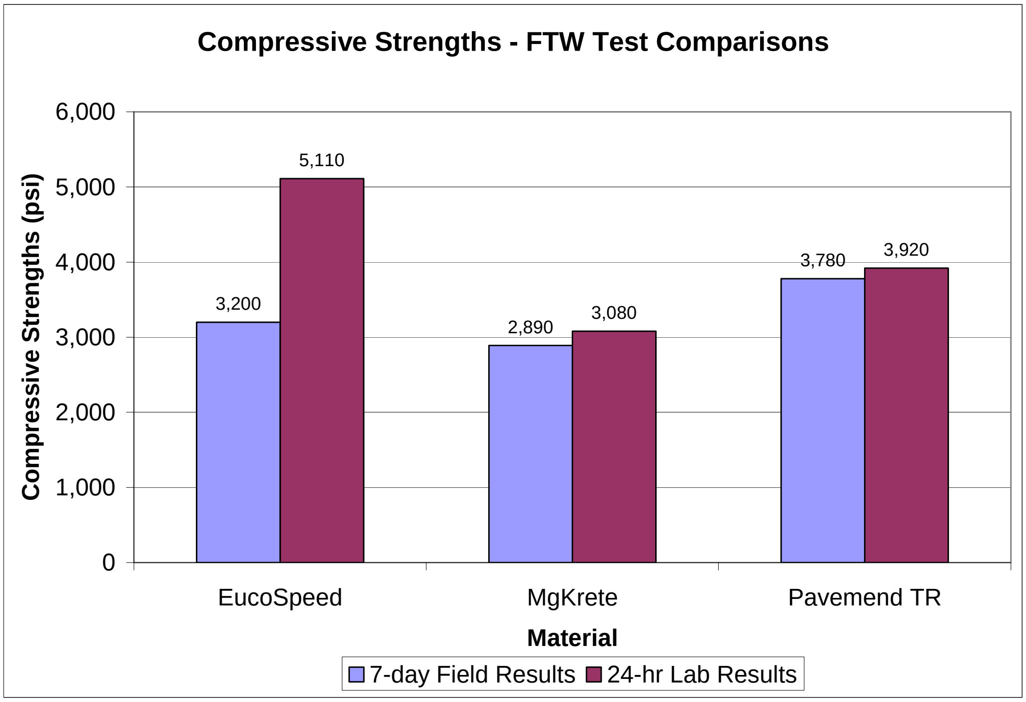

Figure 5.21 Compressive Stress – Ft. Worth Comparison

It is interesting to note that the compressive strengths from cylinders taken in the field are slightly lower than for cylinders created at the lab. This result is not a surprising considering that conditions in the lab are more ideal than conditions in the field.

The field placement of each material illustrated the manageability of a material when it is mixed in larger quantities and actual repair conditions. One problem that arose was the weather. A mid afternoon shower descended on the job site, which forced one of the manufacturers, FlexKrete, to leave early since the material cannot be applied to a wet surface. The field placement also demonstrated the importance of a material's viscosity and set time. A material should have sufficient viscosity to be trowelable and easily worked, but be stiff enough to keep its shape so that it does not flow beyond the spall limits. It must also have a set time long enough to allow for placement and surface finish. This problem was encountered in the placement of Pavemend TR. One of the primary conclusions drawn from the exercise was the importance of having a good familiarity with the product. Field trials give researchers a chance to view the placement of materials, but also a chance to monitor the materials under service conditions. It is recommended that repair materials at this location be periodically reviewed to compare performances.

Texas Department of Transportation Tests

The TxDOT testing laboratory took material from the Ft. Worth placement and performed the laboratory tests including wet bond strength, compressive strength, CoTE test, etc. FlexPatch and EucoSpeed showed high compressive strength. Appendix G indicates the results from the tests performed by TxDOT laboratory performed.

CHAPTER 6. MATERIAL SELECTION GUIDELINE

It is important for engineers to select a best spall repair material to yield the expected performance over the service life of the pavement. Therefore, repair materials to be applied in the field should be selected through the consideration and comparison of material acceptability and properties. The acceptability of material is determined based on the bond strength. The material cost, placeability, and overall utility are also considered with respect to the properties of repair material.

The spall repair materials can be ranked according to the criteria derived on the material properties and characteristics investigated in this research. The relative assessment of materials is used to make a recommendation on selecting an appropriate repair material to be applied under field conditions.

ACCEPTABILITY - BOND STRENGTH

Acceptability only accounts for the bond strength of the repair material to concrete substrate. The bond strength between the repair material and the concrete is the most significant factor in the performance of a spall repair material. The bond strength resists the shear stress induced at the interface between the concrete substrate and the repair material due to thermal contraction caused by the large differences in the thermal conductivity in the spall material and the concrete materials. The test procedures for the measurement of bond strength are outlined in DMS 6170 "Polymeric Materials for Patching Spalls in Concrete Pavement" *(24)* or Tex 618-J "Testing Elastomeric Concrete" *(25)*.

The acceptability of material is determined based on whether the bond strength of material satisfies the user specified Type I or Type II bond strength. The bond strengths of Type I material, which can bridge the cracks in existing concrete, should be over 100 psi. Type I materials include Wabo Crete, Delpatch, RSP, Fibrescreed, and FlexKrete. In the case of Type II, called crack reflective type materials, such as FlexPatch, Rapidest, MgKrete, EucoSpeed, and Pavemend, the bond strength of the materials should be larger than 250 psi.

MATERIAL RANKING CRITERIA

The spall repair materials should be ranked in accordance with the criteria based on the properties and characteristics of materials. The criteria for selecting repair material consist of material cost, placeability, and overall utility. The placeability that indicates the assessment on placing repair materials in the field includes pot life, mixing, workability, and time of setting. The overall utility refers the properties of each material and includes storage/safety/disposal, color, moisture susceptibility, and impact on future repair.

Material Cost

Cost of materials has a considerable weight in the ranking of spall repair materials. Although the overall cost includes material cost, labor and installation costs, and maintenance costs, only bulk material cost excluding labor and other incidental costs is considered for ranking purposes.

Placeability

This factor includes four items: pot life, materials mixing and preparation, material workability during placement and finishing, and the time of setting.

Pot Life

The pot life indicates available time in minutes that a material can be held on the job site prior to its installation into the patch area. As the pot life of a repair material increases, the greater the time the workers have to place the material.

Mixing

The criterion of mixing represents the ease or difficulty for blending and mixing of the materials required to produce a given repair product. Several factors are involved in combining the binder with the aggregate in the mixing process. For instance, dry batching is much dustier than wet batching but may require less batching cycles where premixing is involved. The rating is assigned according to the number of factors associated with the mixing and batching of a material type.

Workability

Material rheology affects how easily the material can fill in the repair area and is affected to some extent by the material setting characteristics. Materials with no or little aggregate are placed differently from those with large aggregate fractions. The workability as a factor represents the difficulty of placing, handling, and finishing a repair material in the patch area.

Time of Setting

The time of setting refers to the working time available for a given repair material type. The time is related to the gel time that is required for a liquid material to form a gel and determined by the test method Tex-614-J "Testing Epoxy Materials" (*25*).

Overall Utility

The overall utility refers the properties of each repair material and includes storage/safety/disposal, material color matching with existing pavement surface, moisture susceptibility in the field, and the future repair option.

Storage/Safety/Disposal

Storage life represents the time available in years that a given material can be stored prior to being used in the field. Some of the polymeric materials such as RSP, Delpatch, and FlexPatch may require cooled and/or heated storage facilities, which could add to the in place cost. Enough space in the controlled environment must also be available and included in this rating component.

Safety is rated by the number of the safety items that are related to handling or installing a repair material, such as flammability, or acts as an allergen and toxicity as suggested on the Material Safety Data Sheet (MSDS). Some combination of boots, gloves, goggles, dust mask, or open air ventilation and eyewash capabilities are commonly required for some materials. In addition, the following questions should be considered to assess the safety of a given material:

1. Are special expenses and hazards present with the material?
2. Do workers need to wear organic vapor masks and chemically protective suits?
3. Are there any special environmental concerns with rain runoff from the material?

The disposal is assessed by the condition of waste materials and leftovers to be disposed of. The following questions can be used to assess the disposal of a given repair material as a utility consideration;

1. Can the leftovers and waste materials for the products be simply disposed of?
2. Is a special hazardous materials hauler required to handle partially full or nearly empty cans and bags of the waste bags?

The issues above should be considered as factors in order to rank the repair material and can be found in the MSDS sheets provided on the material by the manufacturer.

Color

The factor of color is to measure how well the color of the repair material matches the color of the existing pavement surface. The materials can be rated by using the degree of matching based on personal preference.

Moisture Susceptibility

Moisture susceptibility indicates the expected effect on bond strength due to the presence of moisture on the interface between the concrete and the repair material during the placement in the field. A material having high sensitivity to moisture cannot be placed when the interface is wet, so that the placement should be stopped during a rain shower. In this assessment, the repair materials can be rated from high to low sensitivity to moisture.

Future Repair Option

Future repair option is to assess the impact on using a particular repair material on the future options available to rehabilitate a pavement that has been repaired with the material in question. A given material can be assessed as a material difficult to rework, bondable to either an asphalt or concrete overlay, or recyclable.

Figure 5.1 shows the procedure for materials selection and ranking. The spall repair material can be easily selected by using the spreadsheet made based on the research work. The manual of the spreadsheet is located in Appendix H. Also as an example, Appendix I shows the prioritized lists of the entire group of repair materials in accordance with conditions in both the Houston District and Ft. Worth District.

Since many of the requirements are specific for certain material types, it is important to determine exactly what is required for applying repair materials to the pavement surfaces. Therefore, the repair material should be prepared, placed, and finished through the repair procedure considering constraints and particular requirements for a given product. Appendix J presents the guidelines for repair procedures.

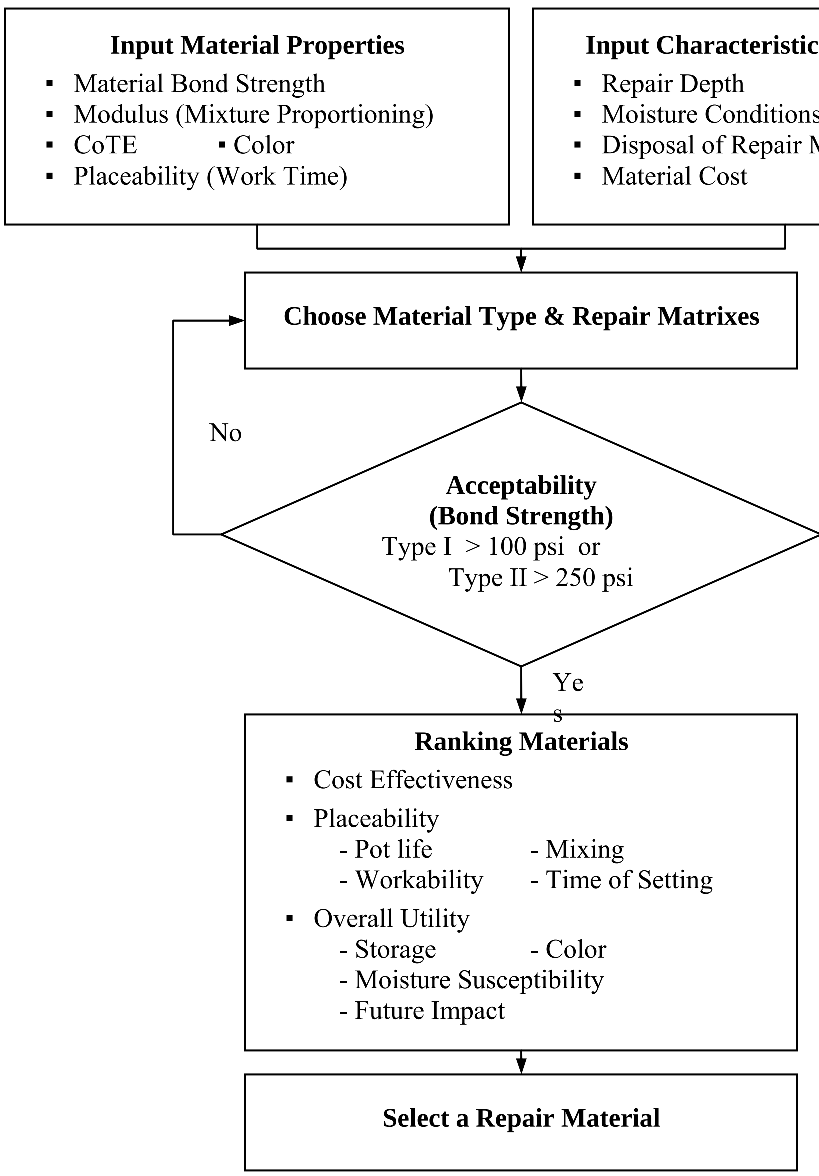

Figure 6.1 Material Selection Decision Tree

CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

This research identified the key characteristics of successful spall repair materials; tested a number of repair materials currently in use across the state; and compiled the information for use in a repair material selection process to be used by TxDOT engineers. Additionally, tests were performed on a number of field repairs, and the field placement of various tested materials was observed in an effort to correlate laboratory data to field data. Even though several tests were conducted in the laboratory to characterize selected material properties, keep in mind that none of them in and of themselves serve as indicators of performance. Nonetheless, with additional research it is anticipated that such parameters as material elastic modulus and coefficient of thermal expansion will be useful in that regard since their product represents a fully restrained thermal tensile stress level on an interfacial boundary between concrete and a spall repair material. Clearly, this type of a stress versus strength relationship, alluded to in the development of the material selection process previously described, constitutes an important aspect of future protocol development for consideration of new materials in the selection process.

An extensive literature search was performed collecting information on spall repair materials and procedures. Various TxDOT districts around the state were surveyed to obtain information on current practices as well as to identify successful products currently in use. From this information, 10 repair materials were selected for testing. Material types included three magnesium phosphates, one rapid setting hydraulic cement, three polyurethane polymers, one epoxy polymer, one thermosetting vinyl polymer, and one polymer modified bitumen. After researching the important properties of repair materials, a testing program was developed to determine the basic physical characteristics of the selected repair materials. Tests for set time, compressive and flexural strengths, modulus of elasticity, shrinkage, CoTE, and tensile bond strength were conducted at 40, 70, and 100 degrees F. Additionally, simulated spalls were created, repaired with the various materials, and thermal cycled to observe the performance and test bond strength. Researchers took field cores of successful repair materials in the Houston District with tensile bond tests performed and results compared to data from lab tests. A field installation occurred in Ft. Worth where several of the materials tested in this project were installed on a section of roadway with observations made at placement. Field surveys clearly indicated adequate performance of repair materials currently in use. The only deficiency noted was the incidence of secondary spalling, which occurs in and around the vicinity of the spall repair potentially trapping water adjacent to the spall repair. The cause of secondary spalling has been largely attributed to the lack of complete removal of the delaminated concrete.

The following conclusions can be drawn from this project:

1. While testing the mechanical properties of each material, it was found that the different repair materials had very different stiffnesses. Accordingly the repair materials were grouped into three categories; rigid, semi-rigid, and flexible with magnesium phosphates representing the more rigid materials, and the polymer concretes representing the more flexible materials. Ultimate compressive strengths could only be tested for rigid materials, and flexural strength could only be obtained from the rigid and semi-rigid materials.
2. Modulus of elasticity, shrinkage, and CoTE were the compatibility properties tested for each material. It was found that rigid materials like the magnesium phosphates had the highest values of elastic modulus, and flexible materials like the polymer concretes had the lowest values. In general materials with a low elastic modulus had a comparatively high CoTE value, while materials with a high elastic modulus had a comparatively low CoTE value. Shrinkage values were highly variable due to the wide range of material types and the amount of temperature change experienced while curing, but rigid materials experienced lower shrinkage values while semi-rigid and flexible materials experienced high shrinkage values.
3. Thermal cycling of simulated spalls produced no degradation of the repair materials. Tests for tensile bond values were taken from each of the repairs after cycling but results were variable partially due to the nature of the test and the varying bond surface. Certain types of rigid as well as flexible materials were found to bond well. Abrasion tests for durability showed that all of the polymeric materials performed well.
4. Materials from successful repairs in the field were cored and tensile bond strengths compared to core prepared in the lab. It was found that bond strengths from field specimens were lower than laboratory specimens but because of the very limited number of field cores obtained, results are less than definitive. Additionally, cylinders were obtained

from field placement of material in Ft. Worth. Compression and elastic modulus tests were taken after 7 days and compared. In general it was found that specimens created in the lab had higher compressive strength and elastic modulus values than those created in the field.

5. Spall repair materials to be applied in fields should be selected through the consideration and comparison of material acceptability and properties. The acceptability of material is determined based on whether the bond strength of a material satisfies the engineers' specified bond strength. Also, the materials can be ranked according to the following criteria derived from material properties: material cost, placeability, and overall utility. Overall utility includes consideration for future overlay operations and the ability of the spall repair material to bond to the overlay itself. The lower modulus repair material will not bond well to a concrete overlay, which should be given due consideration in this regard in the material selection process. The list of ranked materials is used to recommend appropriate repair material.

RECOMMENDATIONS

Compatibility properties should be considered when making a selection regarding a spall repair material. Materials which have a large amount of shrinkage or a high CoTE should have a low modulus to accommodate for the volume changes that can occur. Likewise materials with a high modulus should have a low amount of shrinkage and CoTE similar to that of its substrate to avoid the high internal stresses that can occur due to an associated change. By the field investigation, the materials with low modulus did not reflect the crack in existing pavement while the high modulus materials did. Both types of materials appeared to be providing adequate performance on the patching area.

The project determined testing for compressive strength is adequate for rigid materials but flexible materials should be tested for tensile strength to allow for comparison between materials. Additionally the study verified testing for modulus of elasticity, shrinkage, CoTE, and bond strength in determining the properties indicate of a successful repair material. Nonetheless, theoretical relationships between the material properties, climatic conditions, bond strength, and bond stress would provide a solid testing in which to base the material selection guidelines.

Research under Project 0-5110 relative to material selection procedures has identified a need to better understand a relationship between modulus and strength of the spall repair materials. There is a wide variety in material stiffness (modulus) and bond strength of repair materials available in the market and how this ties to stress and strength mechanisms over this wide range of repair depths, surface roughness and moisture as well as properties of the repair material needs to be evaluated. Furthermore, the repair patch is subjected to repeated load, temperature, and moisture effects and the related strains have an impact on performance of the patch. The relationship between these factors and strength for the spall repair materials needs to be better understood to improve the material selection procedure previously developed. Therefore, research is needed to further define the strength mechanism and the related factors that ultimately affect the performance of these materials in the field.

This report provides the information and data on the basic physical properties of selected repair materials necessary to develop a set of standardized guidelines for the best practices when dealing with spalls and selection of repair materials. This report also provides the information necessary to develop training seminars addressing the material selection process.

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APPENDIX A: LIST OF MANUFACTURERS

Table A.1 Manufacturer Contact Information

Product	Company	Sales Representative	Phone Number – Email
EucoSpeed MP	The Euclid Chemical Company	James Robbs	972-243-6400 jrobbsjr@aol.com
Delpatch	D.S. Brown	Ben Jacobus	651-748-8114 bjacobus@dsbrown.com
Fibrescreed	Marketing Associates, Inc.	Tony Morris	336-789-7259 tmorris@marketingassociatesinc.com
FlexKrete	FlexKrete Technologies	Greg Billings	817-808-8970 gbillingsly@netzero.net
FlexPatch (SSI)	Silicon Specialties, Inc.	Rick Waters	817-731-7890 rick_waters@ssicm.com
MgKrete	IMCO Technologies, Inc.	Carl Pocock	713-898-4365 cmraic@aol.com
Pavemend 15	CeraTech, Inc.	Don Simmons	817-534-4445 don.simmons@ceratechinc.com
Rapid Set	CTS Cement Manufacturing Corp.	Steve Younger	817-249-7940 syounger@ctscement.com
RSP	BMK Corporation	Jim Boehm	314-344-3330 Jboehm@Foamsupplies.com
Wabo ElastoPatch	Watson Bowman	Debra Steiger	1-800-677-4922 ext 210 debbie.steiger@degussa.com

APPENDIX B: RESULTS – MECHANICAL PROPERTIES

Table B.1 Summary of Repair Material Properties

	Temperature (Degrees F)	Average Compressive Strength (psi)		Average Flexural Strength (psi)		Elastic Modulus (psi)	Poisson Ratio
		1 hr	24 hrs	1 hr	24 hrs	24 hrs	24 hrs
Rigid	Product	**EucoSpeed**					
	40	3390	4010	390	480	3,800,000	0.37
	70	4220	5110	475	580	4,850,000	0.29
	100	4370	5010	545	580	4,550,000	0.35
	Product	**MgKrete**					
	40	n/a	n/a	n/a	n/a	n/a	n/a
	70	2860	3080	530	500	3,750,000	0.24
	100	n/a	n/a	n/a	n/a	n/a	n/a
	Product	**Pavemend**					
	40	2430	2940	360	445	1,600,000	0.31
	70	1920	3920	385	530	1,800,000	0.39
	100	190	4070	245	455	1,700,000	0.40
	Product	**Rapid Set**					
	40	1410	2920	245	360	2,500,000	0.21
	70	1500	2960	240	300	2,650,000	0.20
	100	2020	2840	275	245	2,200,000	0.17
Semi-Rigid	Product	**FlexKrete**					
	40	210	890	280	915	n/a	n/a
	70	170	1650	165	1045	n/a	n/a
	100	n/a	3800	n/a	1290	n/a	n/a
	Product	**RSP**					
	40	620	1310	335	585	n/a	n/a
	70	810	1140	520	805	n/a	n/a
	100	930	640	870	750	n/a	n/a
Flexible	Product	**Delpatch**					
	40	n/a	n/a	n/a	n/a	n/a	n/a
	70	n/a	n/a	n/a	n/a	n/a	n/a
	100	n/a	n/a	n/a	n/a	n/a	n/a
	Product	**FlexPatch**					
	40	n/a	n/a	n/a	n/a	n/a	n/a
	70	n/a	n/a	n/a	2281	n/a	n/a
	100	n/a	n/a	n/a	1605	n/a	n/a
	Product	**Wabo**					
	40	n/a	n/a	n/a	n/a	n/a	n/a
	70	n/a	n/a	n/a	n/a	n/a	n/a
	100	n/a	n/a	n/a	n/a	n/a	n/a

n/a indicates where material was deemed too soft to perform test

Table B.2 Compressive Strengths of Rigid and Semi-Rigid Materials by Temperature

Product	1-hr Average Compressive Strengths (psi)			24-hr Average Compressive Strengths (psi)		
	Temperature (Degrees F)			Temperature (Degrees F)		
	40°	70°	100°	40°	70°	100°
EucoSpeed	3390	4220	4370	4010	5110	5010
MgKrete	n/a	2860	n/a	n/a	3080	n/a
Pavemend	2430	1920	190	2940	3920	4070
Rapid Set	1410	1500	2020	2920	2960	2840
FlexKrete**	210	170	*	890	1650	3800
RSP**	620	810	930	1310	1140	640

* Material too soft to perform test

Table B.3 Flexural Strengths of Rigid and Semi-Rigid Materials by Temperature

Product	1-hr Average Flexural Strength (psi)			24-hr Average Flexural Strength (psi)		
	Temperature (Degrees F)			Temperature (Degrees F)		
	40°	70°	100°	40°	70°	100°
EucoSpeed	390	475	545	480	580	580
MgKrete	n/a	530	n/a	n/a	500	n/a
Pavemend	360	385	245	445	530	455
Rapid Set	245	240	275	360	300	245
FlexKrete**	280	160	*	915	1045	1290
RSP**	335	520	870	585	805	750
Flexpatch**	n/a	n/a	n/a	n/a	2280	1605

* Material too soft to perform test

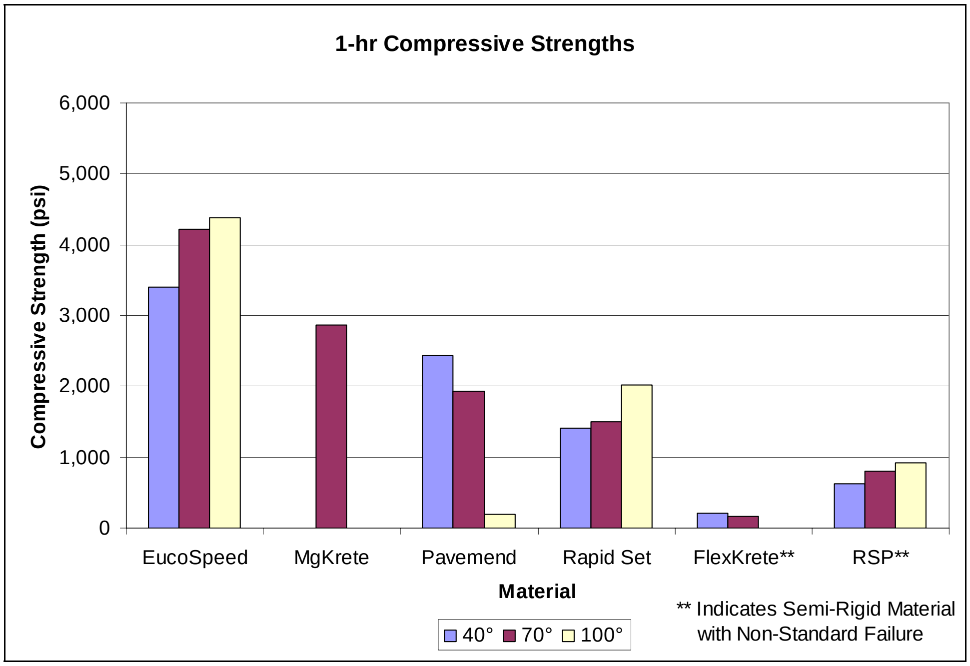

Figure B.1 1-hr Compressive Strengths

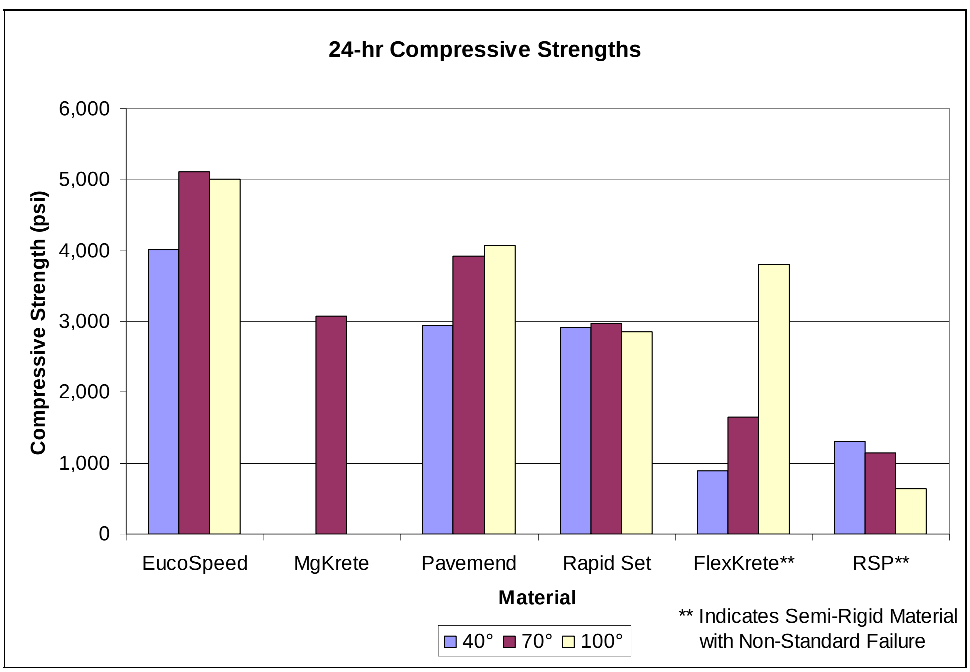

Figure B.2 24-hr Compressive Strengths

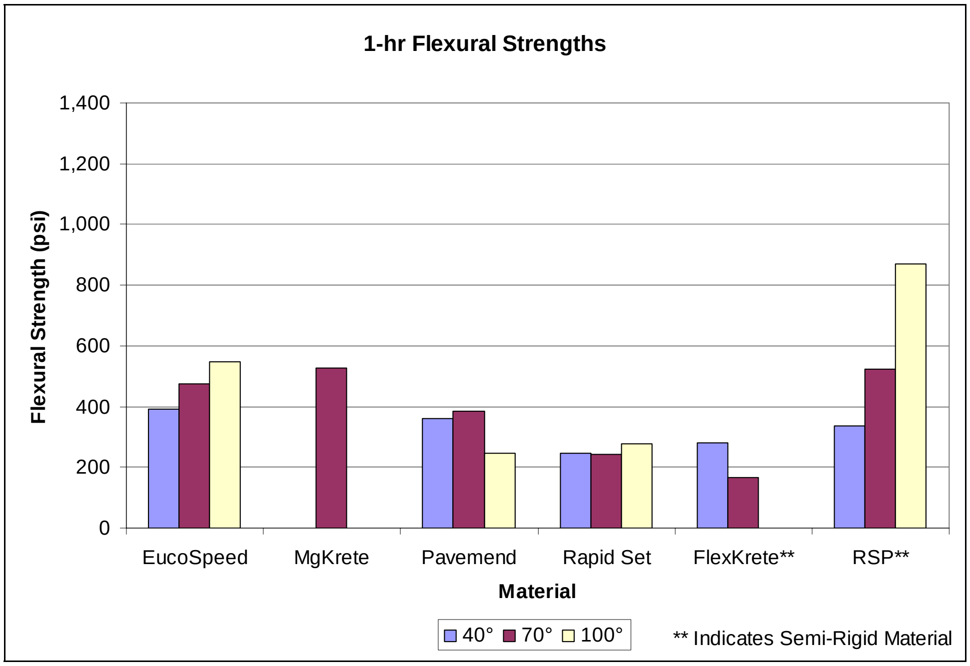

Figure B.3 1-hr Flexural Strengths

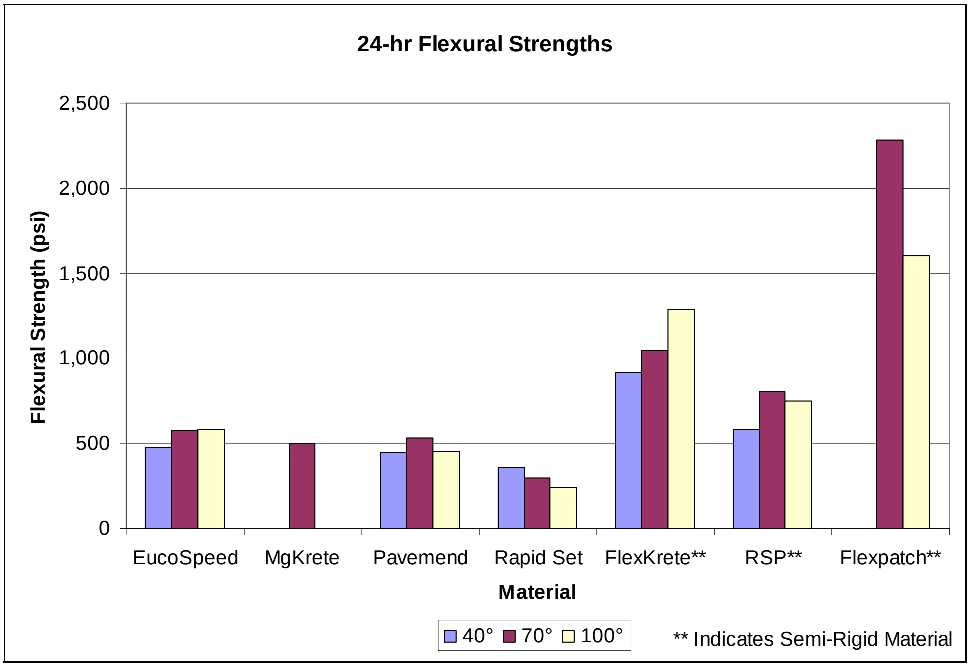

Figure B.4 24-hr Flexural Strengths

Table B.4 Elastic Modulus and Poisson Ratio

Product	Elastic Modulus (PSI)			Poisson Ratio		
	Temperature (Degrees F)			Temperature (Degrees F)		
	40°	70°	100°	40°	70°	100°
EucoSpeed	3,800,000	4,850,000	4,550,000	0.37	0.29	0.35
MgKrete	n/a	3,750,000	n/a	n/a	0.24	n/a
Pavemend	1,600,000	1,800,000	1,700,000	0.31	0.39	0.40
Rapid Set	2,500,000	2,650,000	2,200,000	0.21	0.20	0.17

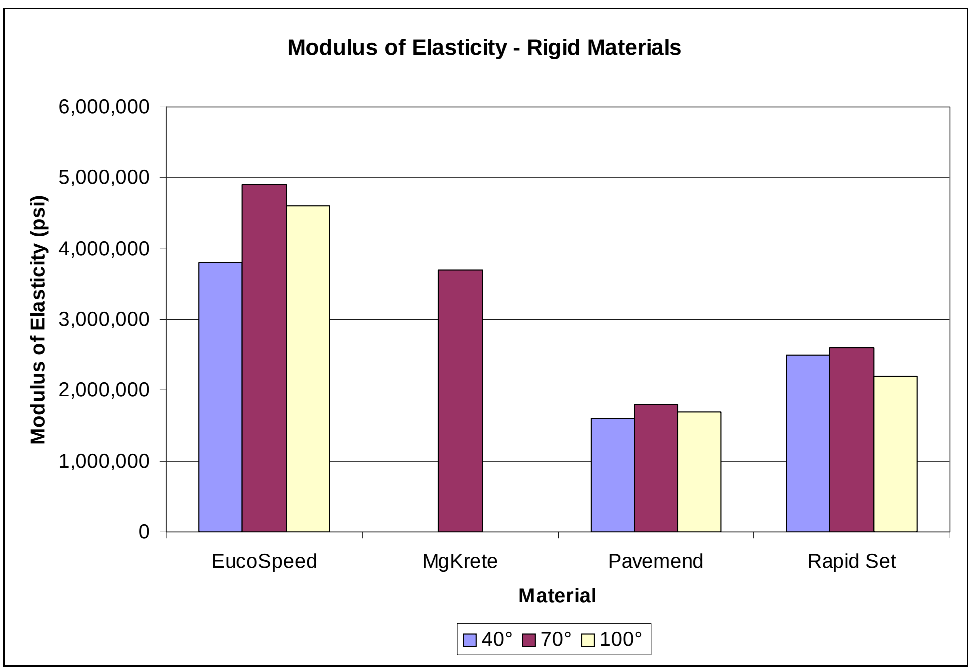

Figure B.5 Elastic Modulus

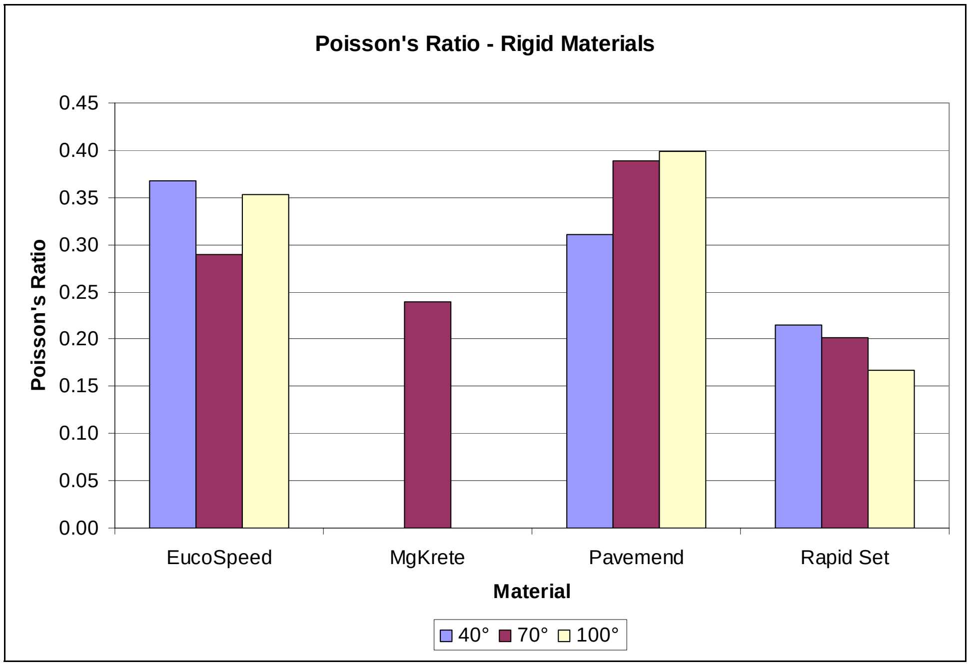

Figure B.6 Poisson Ratio

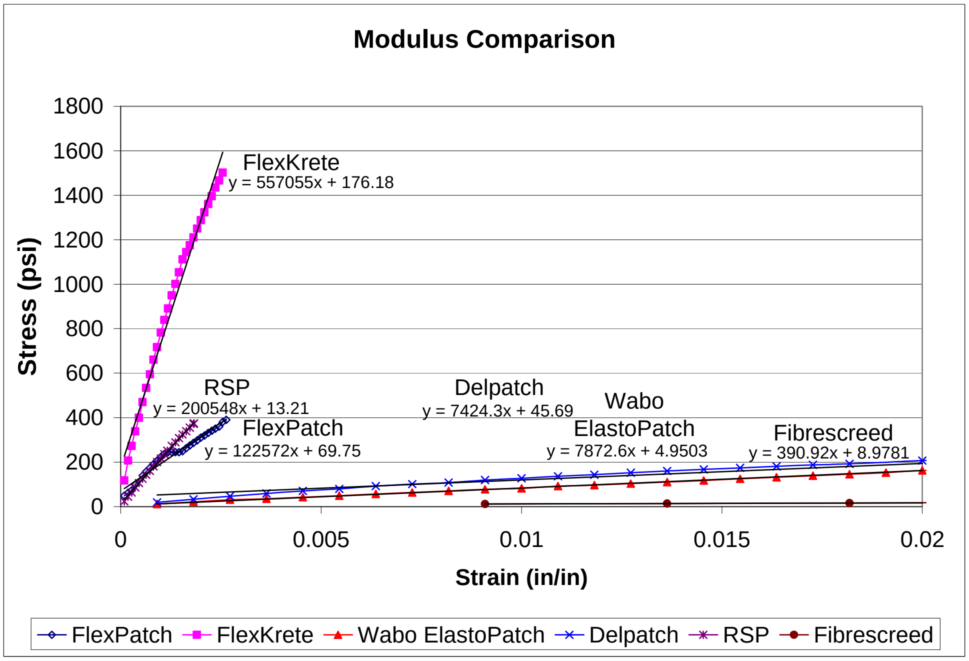

Figure B.7 Modulus Determination of Flexible Materials

Table B.5 Elastic Modulus

Product	Elastic Modulus (psi)
EucoSpeed	4,850,000
MgKrete	3,750,000
Rapid Set	2,650,000
Pavemend	1,800,000
FlexKrete	560,000
RSP	200,000
FlexPatch	120,000
Wabo ElastoPatch	7900
Delpatch	7400
Fibrescreed	400

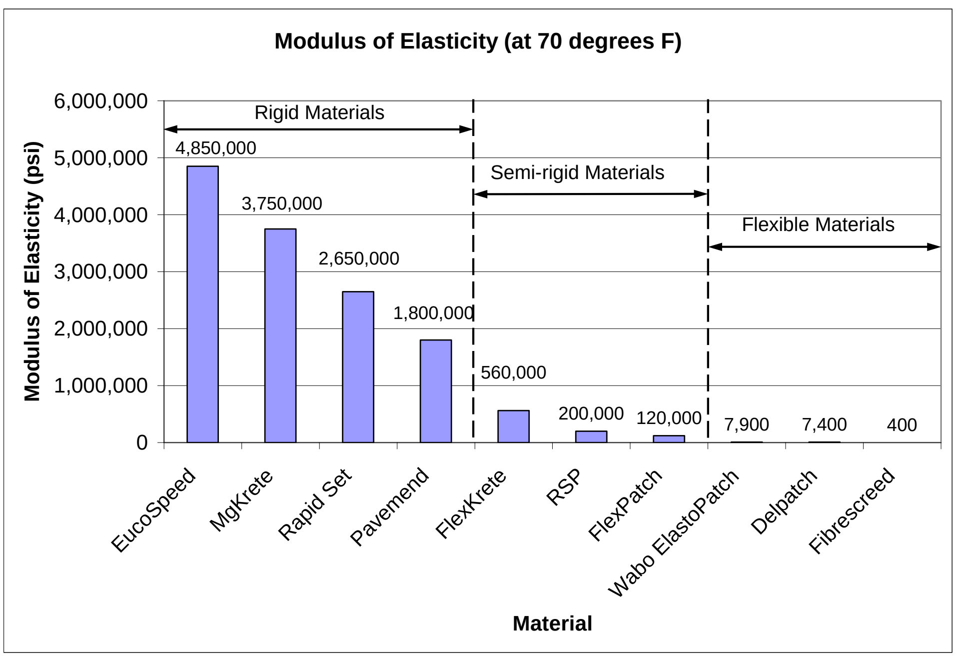

Figure B.8 Elastic Modulus

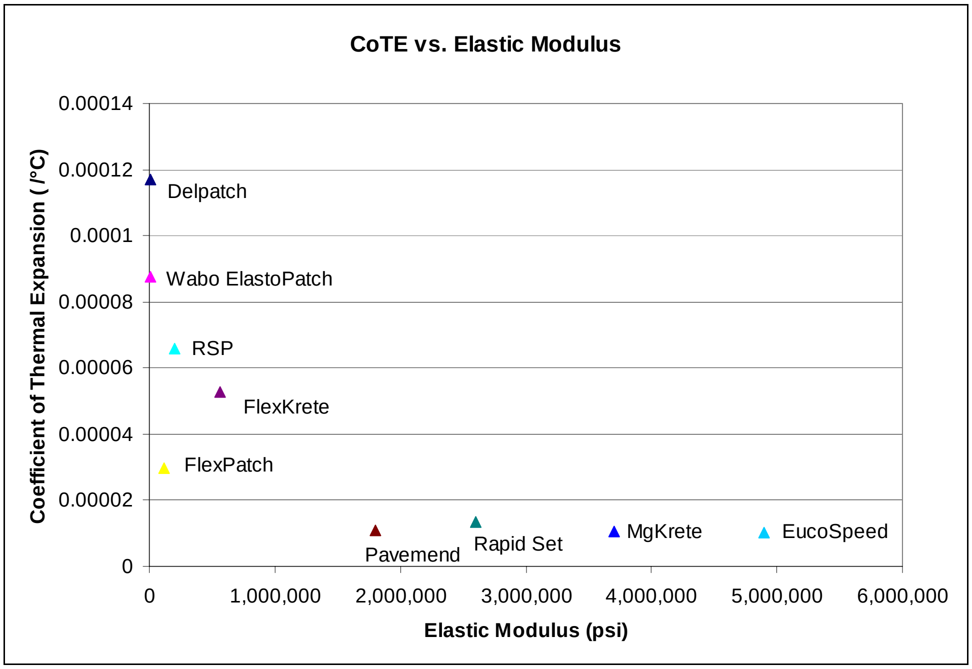

Figure B.9 CoTE vs. Modulus Comparison

APPENDIX C: RESULTS – COMPATIBILITY PROPERTIES

Table C.1 Shrinkage

Product	18-hr Initial Shrinkage (%)		
	40°	70°	100°
EucoSpeed	0.066	0.108	0.092
MgKrete	n/a	0.023	n/a
Rapid Set	0.072	0.091	0.143
Pavemend	0.041	0.037	0.049
FlexKrete	0.155	0.112	0.189
RSP	0.421	0.314	0.373
FlexPatch	n/a	0.053	0.085
Wabo ElastoPatch	0.065	0.328	0.305
Delpatch	0.057	0.120	0.349
Fibrescreed	n/a	n/a	0.174

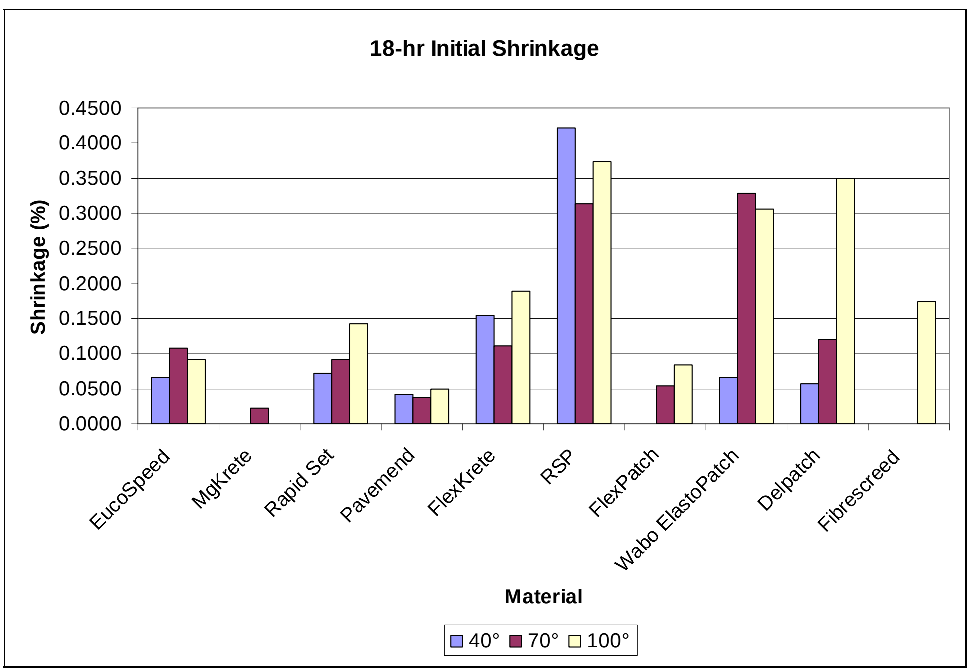

Figure C.1 Initial Shrinkage Comparisons

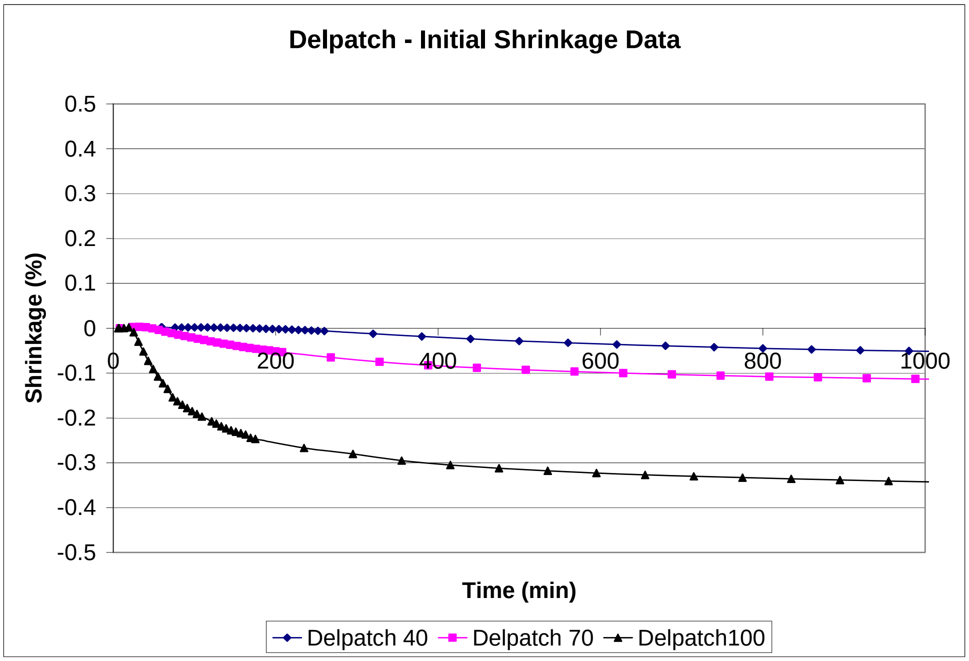

Figure C.2 Delpatch Shrinkage Data

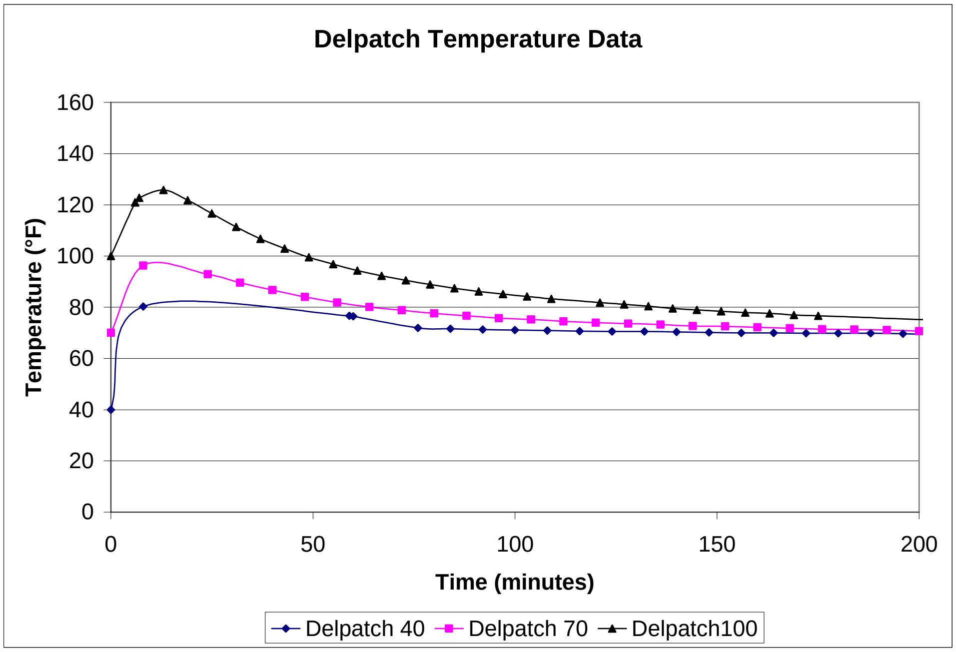

Figure C.3 Delpatch Temperature Data

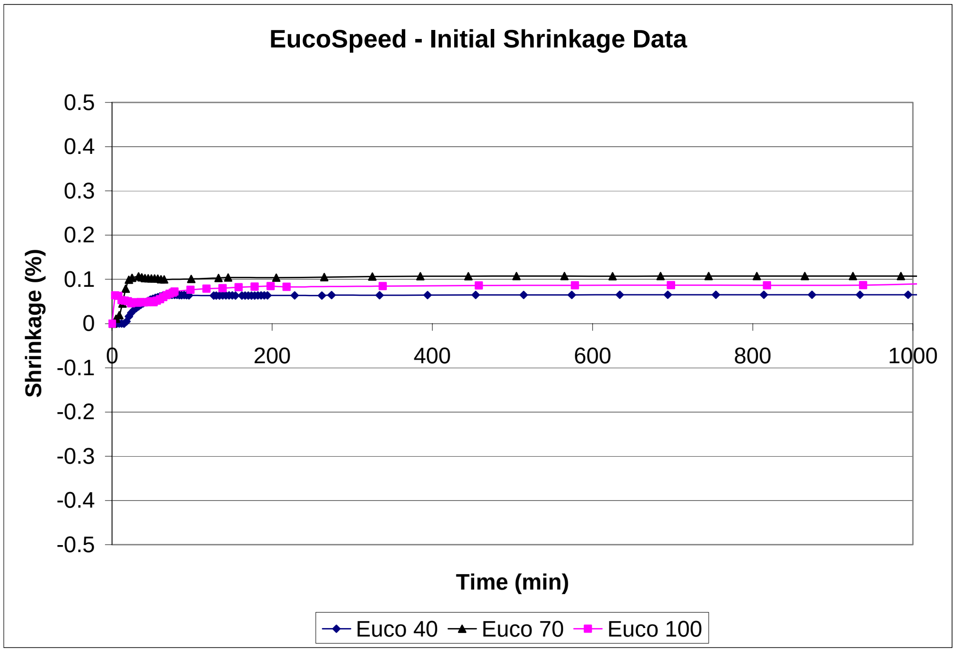

Figure C.4 EucoSpeed Shrinkage Data

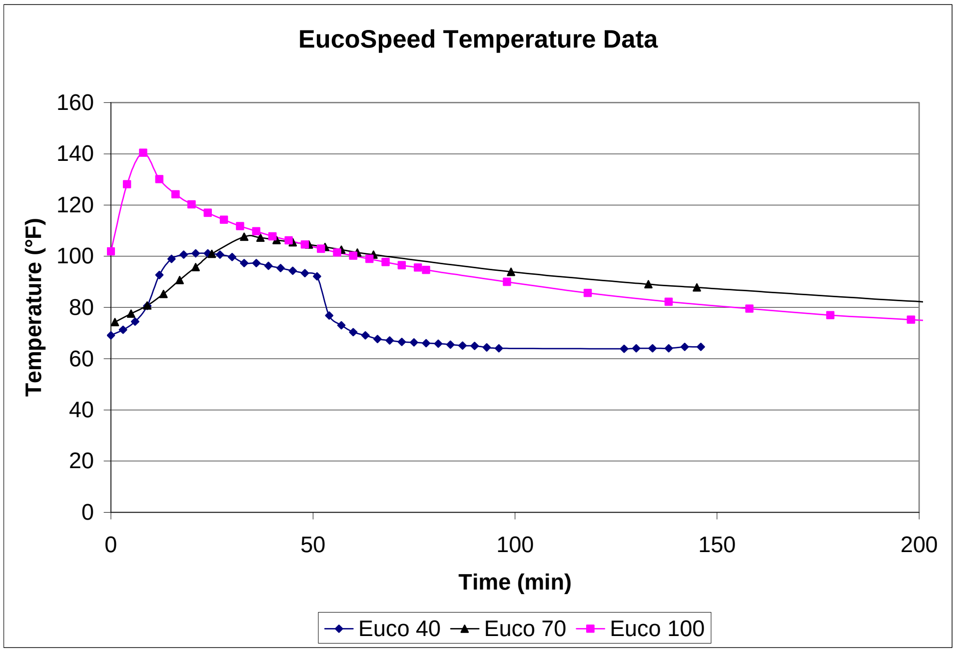

Figure C.5 EucoSpeed Temperature Data

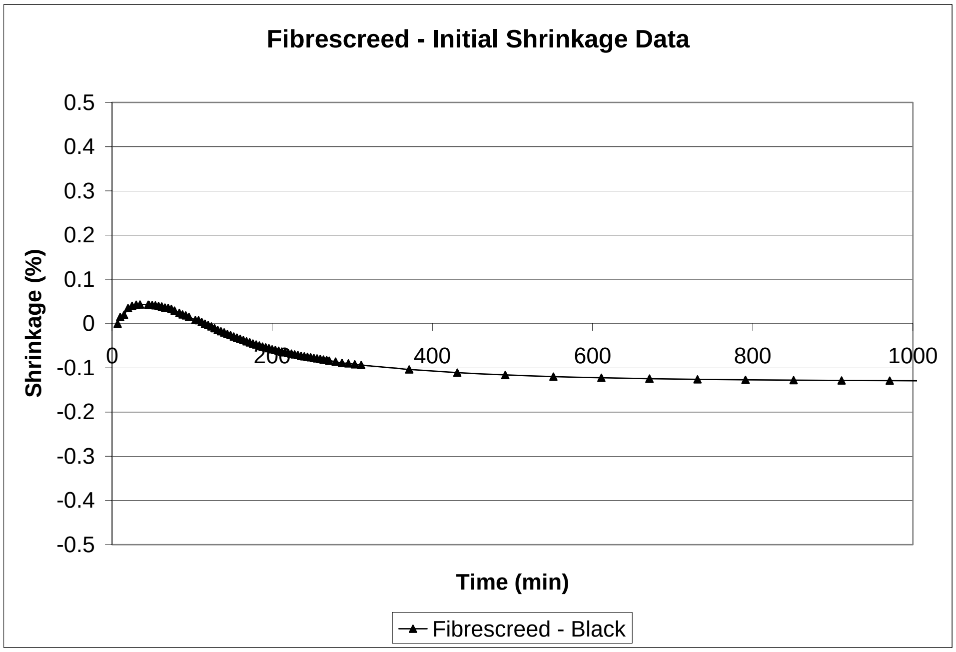

Figure C.6 Fibrescreed Shrinkage Data

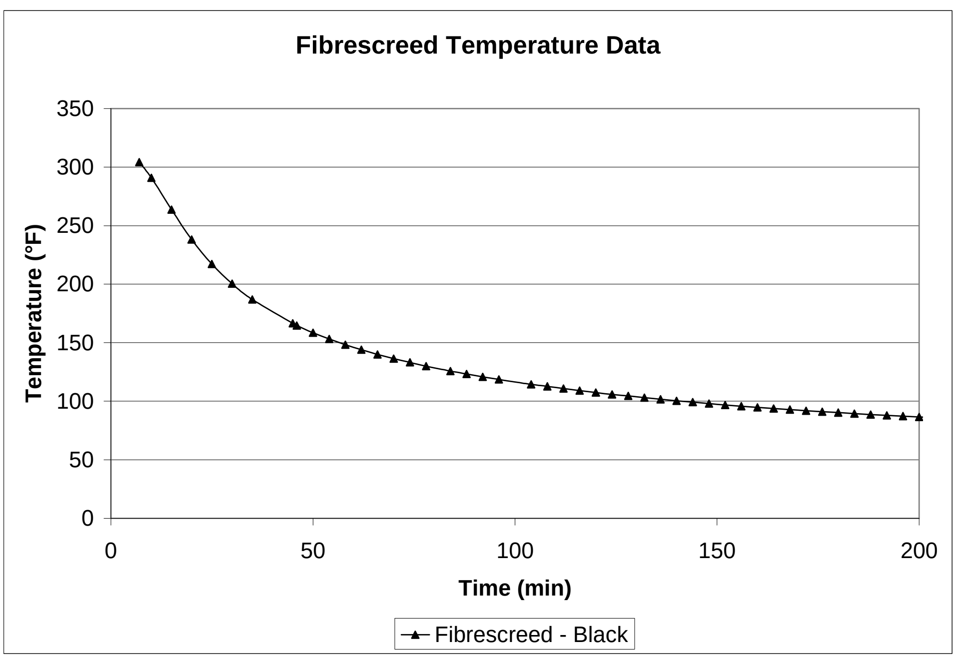

Figure C.7 Fibrescreed Temperature Data

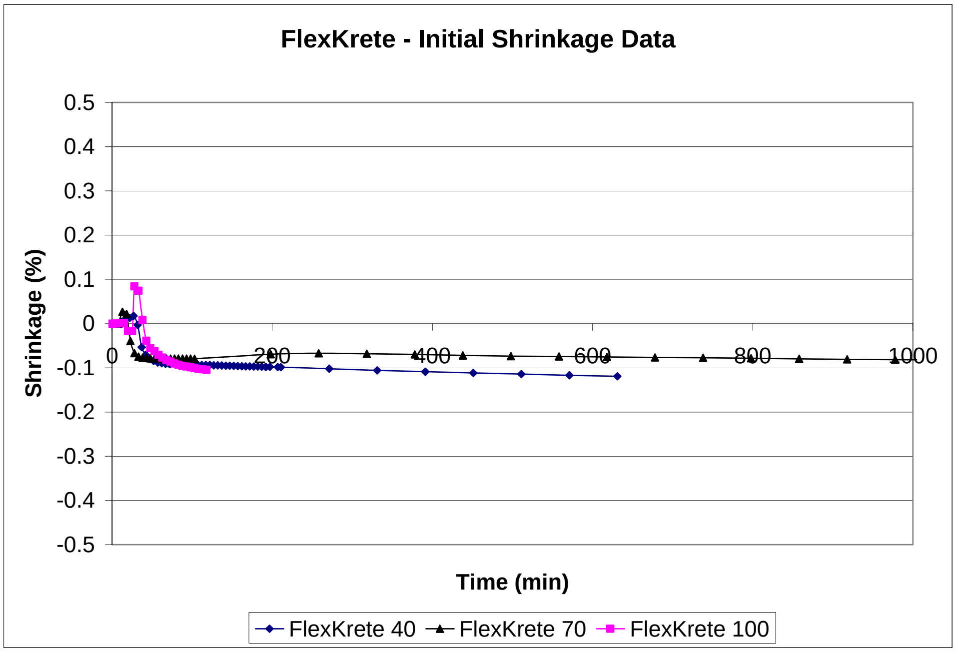

Figure C.8 FlexKrete Shrinkage Data

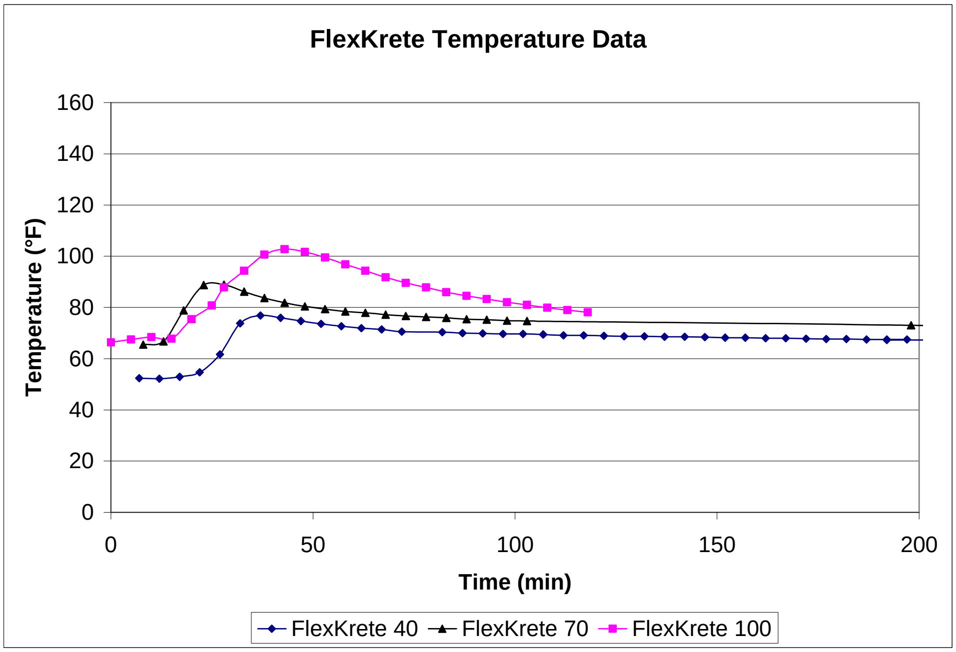

Figure C.9 FlexKrete Temperature Data

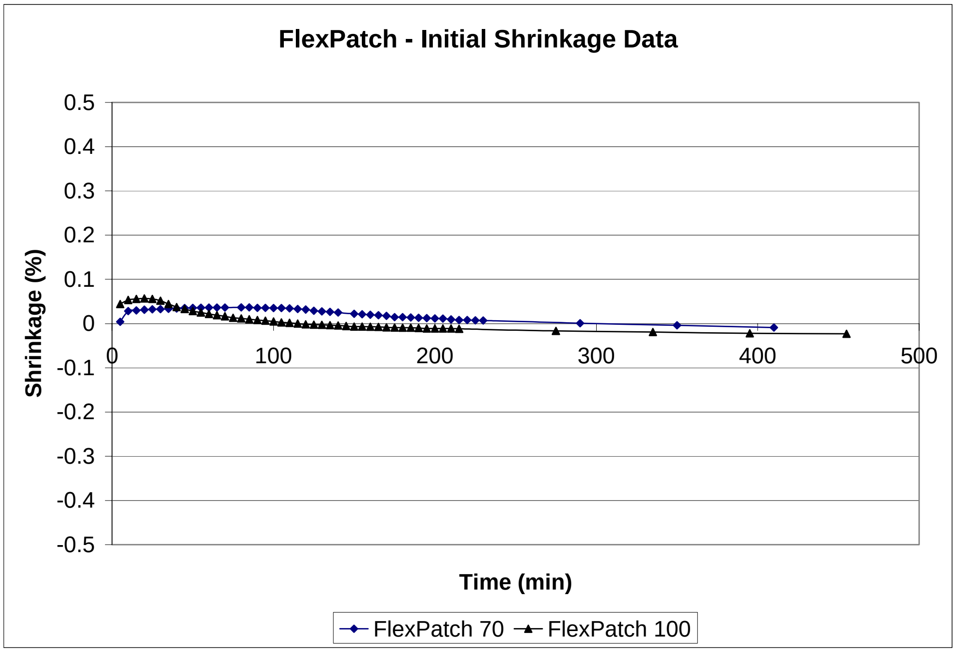

Figure C.10 FlexPatch Shrinkage Data

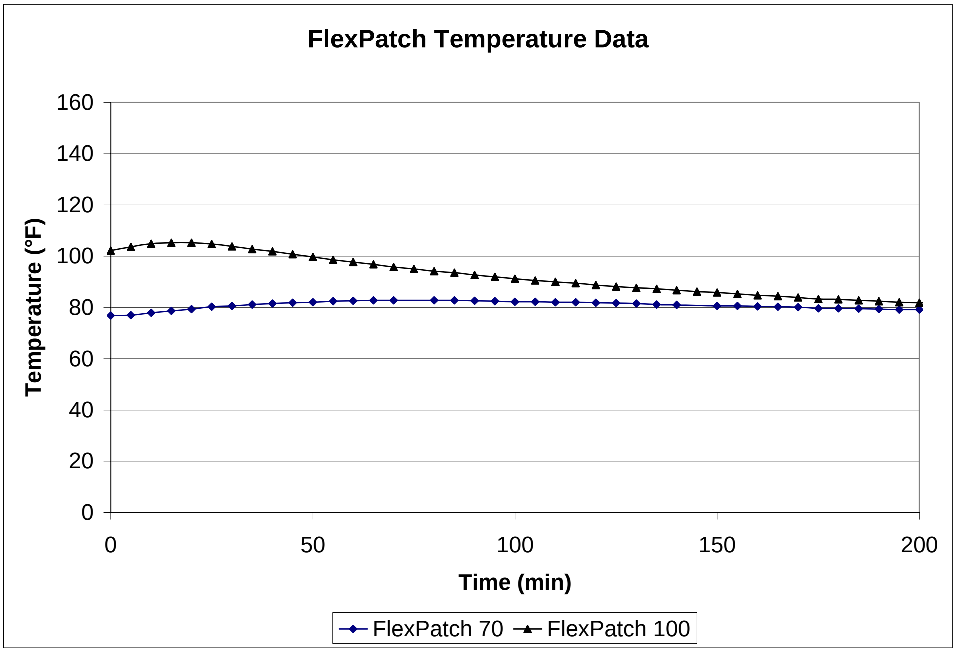

Figure C.11 FlexPatch Temperature Data

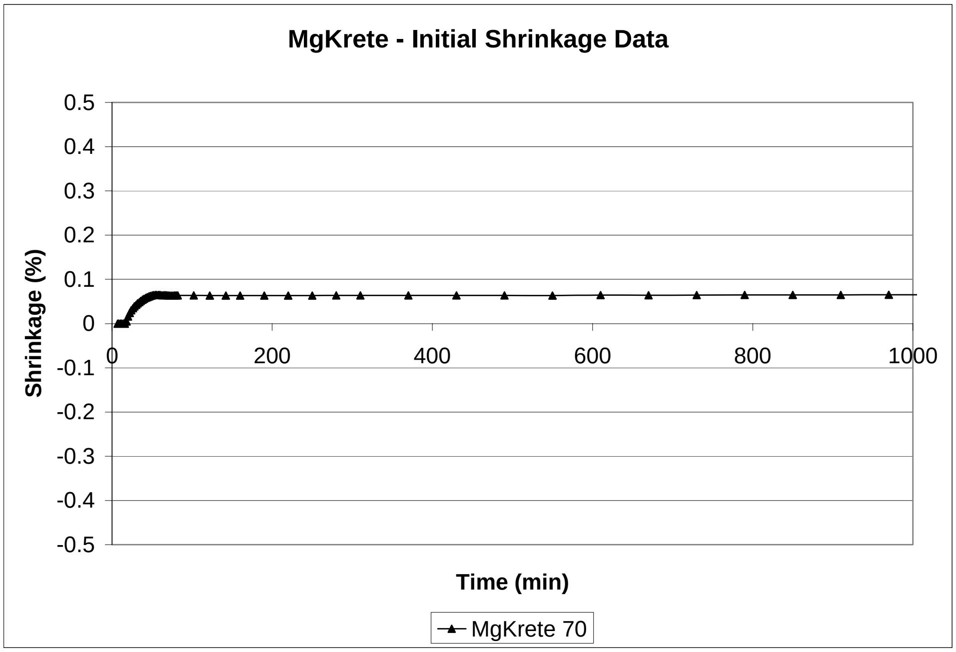

Figure C.12 MgKrete Shrinkage Data

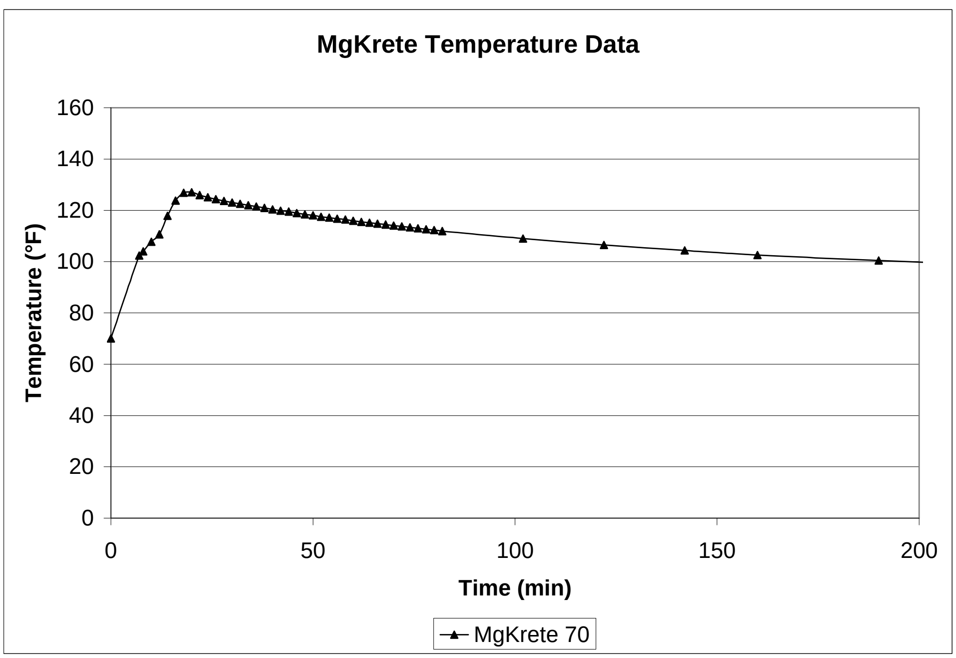

Figure C.13 MgKrete Temperature Data

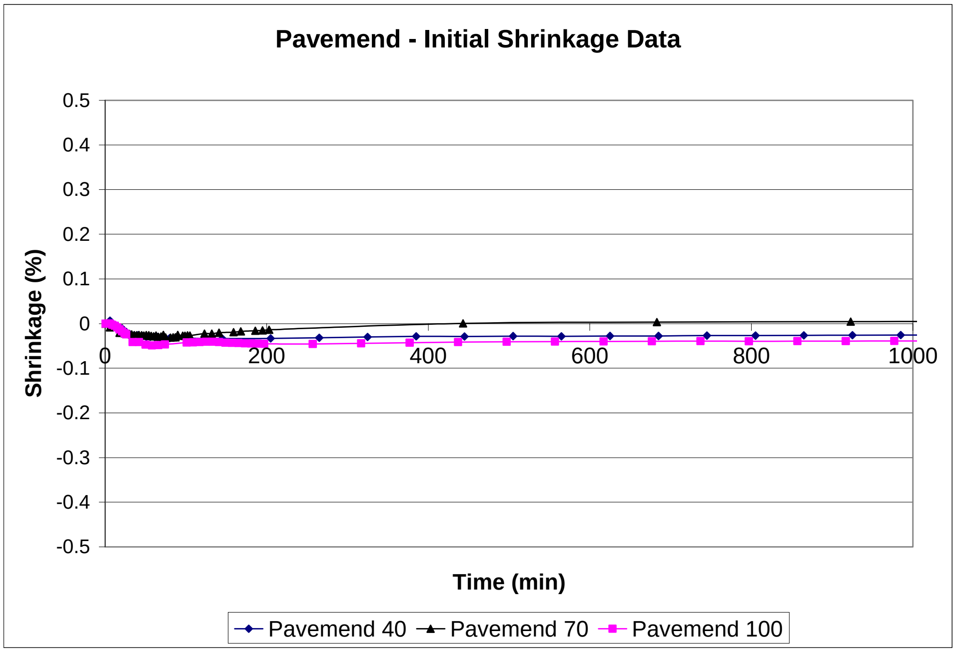

Figure C.14 Pavemend Shrinkage Data

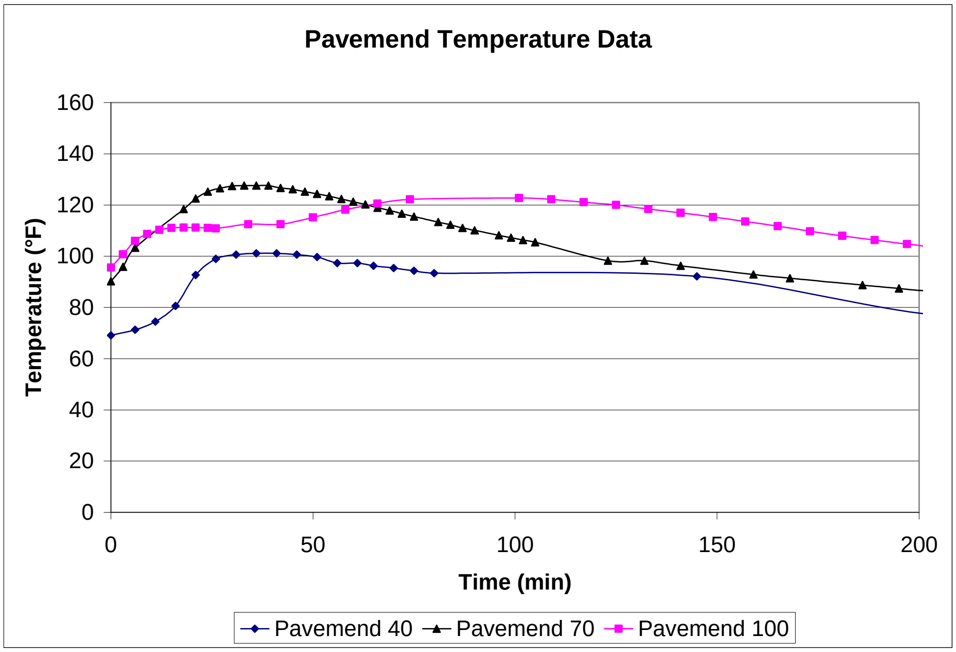

Figure C.15 Pavemend Temperature Data

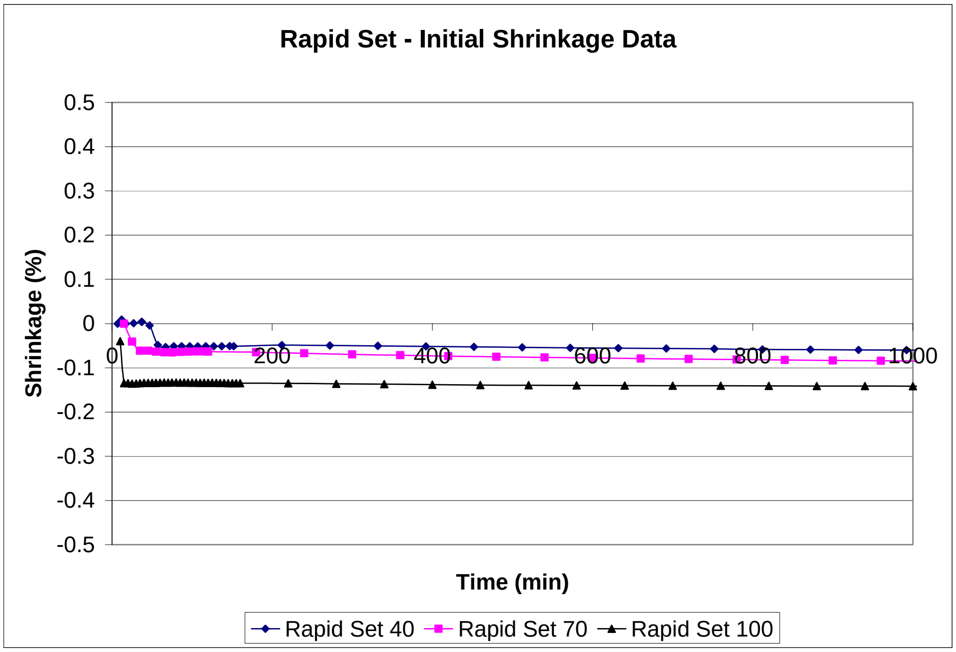

Figure C.16 Rapid Set Shrinkage Data

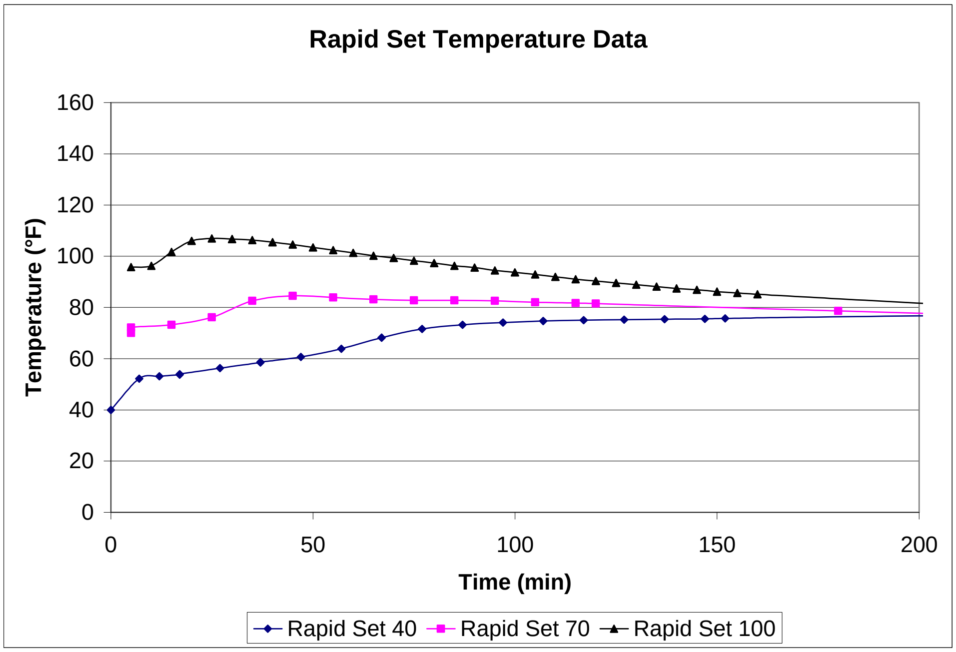

Figure C.17 Rapid Set Temperature Data

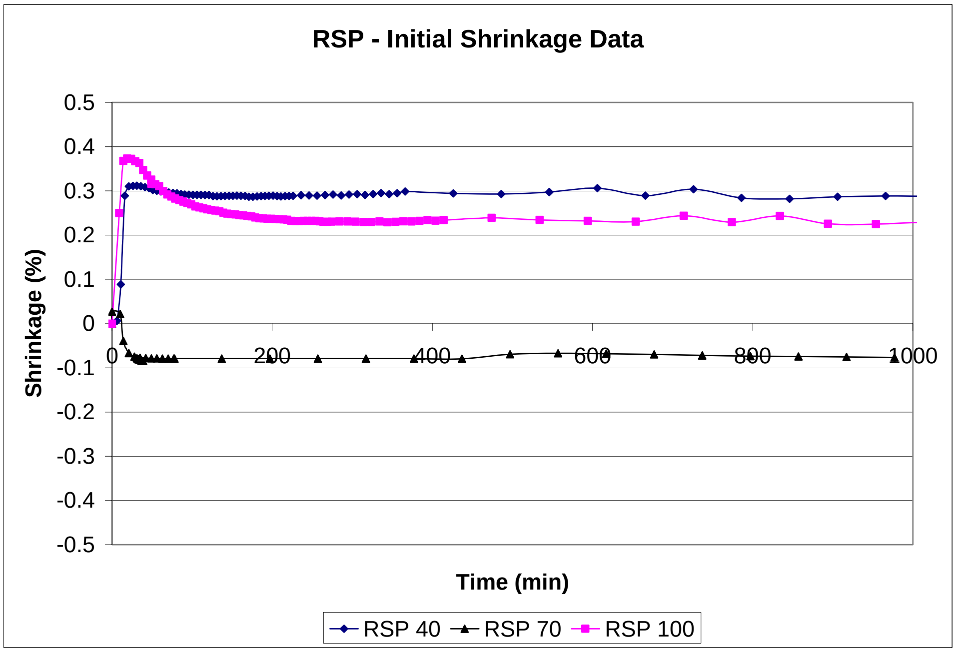

Figure C.18 RSP Shrinkage Data

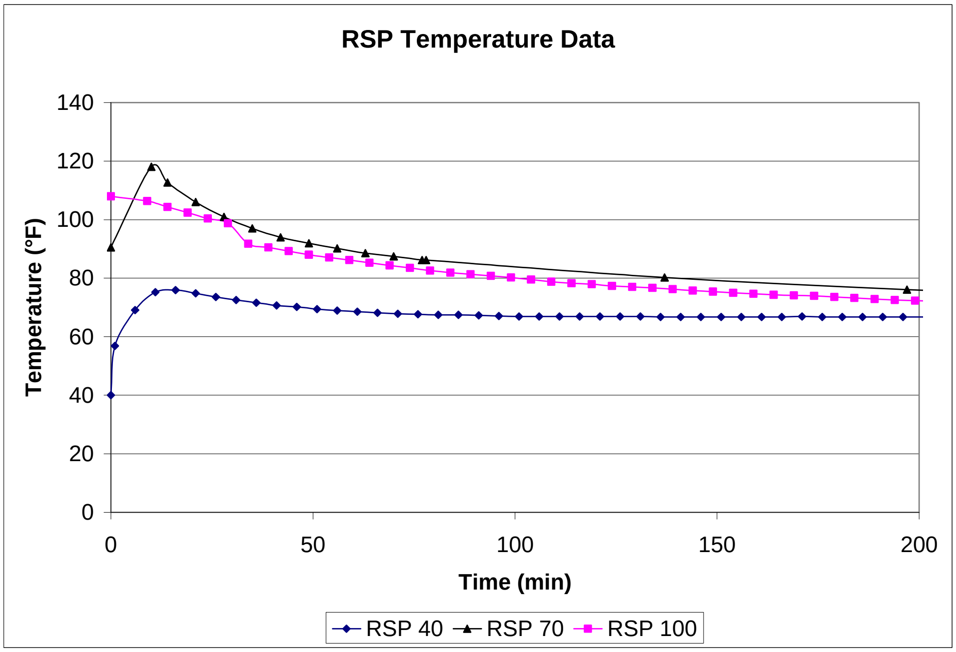

Figure C.19 RSP Temperature Data

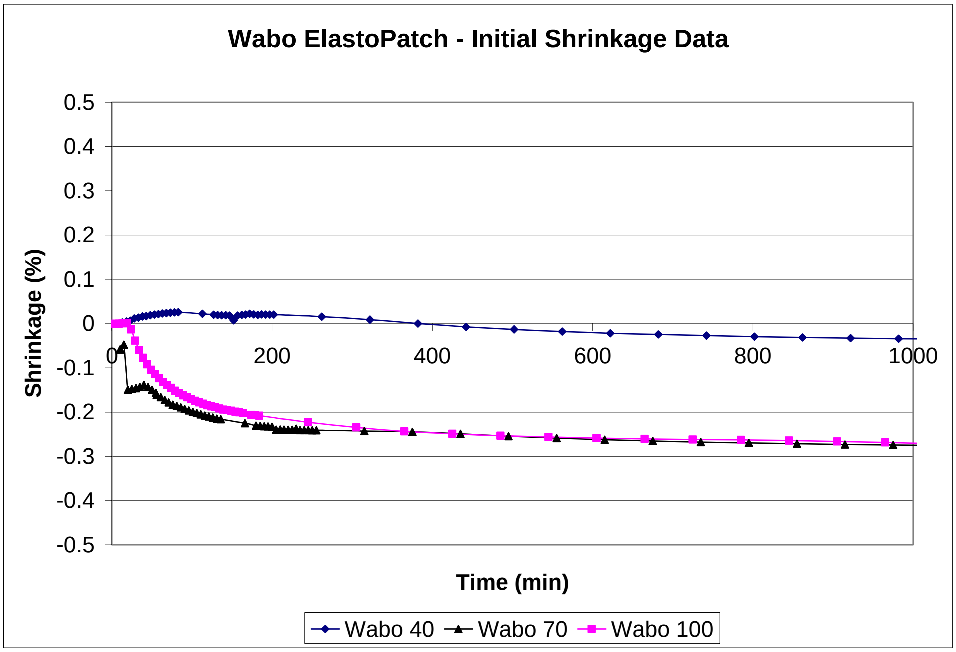

Figure C.20 Wabo ElastoPatch Shrinkage Data

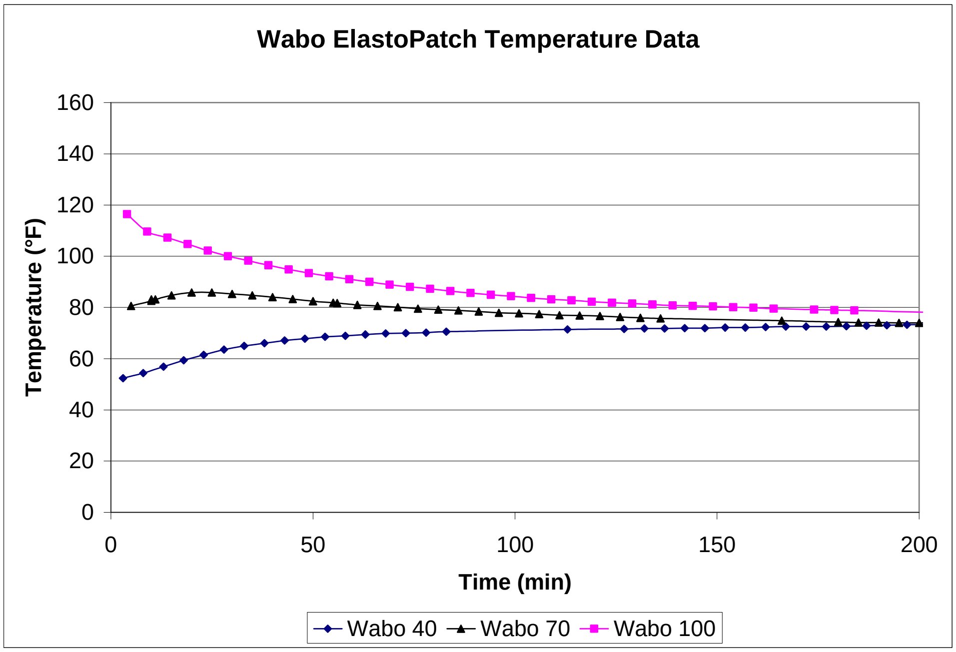

Figure C.21 Wabo ElastoPatch Temperature Data

Table C.2 Coefficient of Thermal Expansion

Product	CoTE (/°F)
Delpatch	65.1E-6
EucoSpeed	5.7E-6
Fibrescreed Black	*
Fibrescreed Grey	*
FlexKrete	29.3E-6
Flexpatch	16.5E-6
MgKrete	5.9E-6
Pavemend	6.1E-6
Rapid Set	7.5E-6
RSP	36.6E-6
Wabo ElastoPatch	48.6E-6

* Material too soft to measure

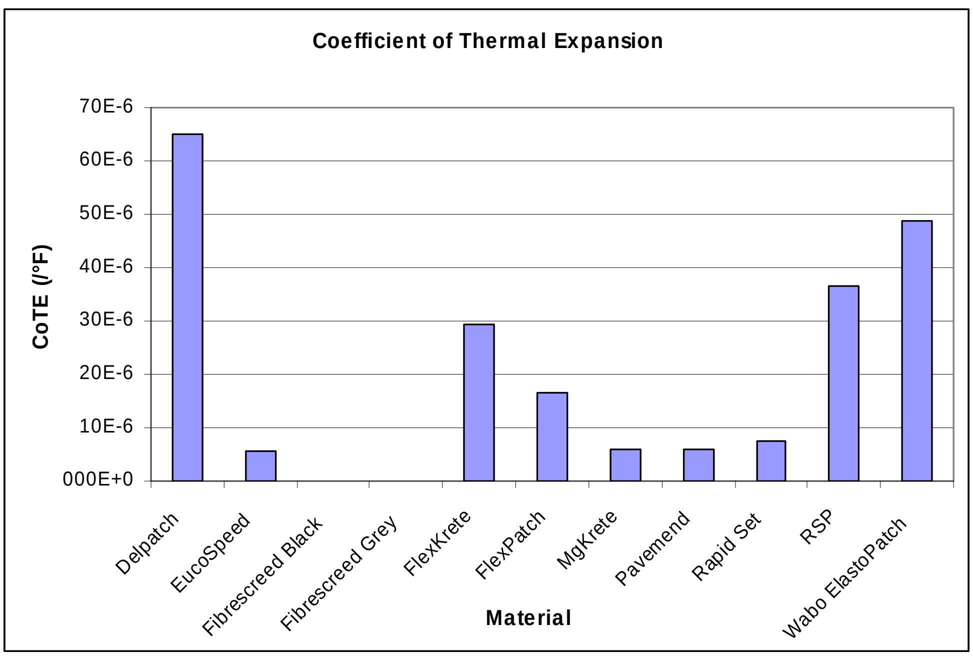

Figure C.22 Coefficient of Thermal Expansion

APPENDIX D: RESULTS – BOND AND ABRASION PROPERTIES

Table D.1 Tensile Bond Strength

Temp.	Product Bond Strength (psi)								
	Del-patch	Euco-Speed	Fibre-screed	Flex-Krete	Flex-Patch	Pave-mend	Rapid Set	RSP	Wabo Elasto-Patch
40°	110	59	n/a	132	168	30	113	14	120
70°	72	97	n/a	143	92	144	95	128	192
100°	103	153	n/a	151	86	61	39	89	210
Total Average	91	121	n/a	141	108	78	95	85	172

* Total Average is the average bond strength of all specimens taken from a material regardless of temperature.

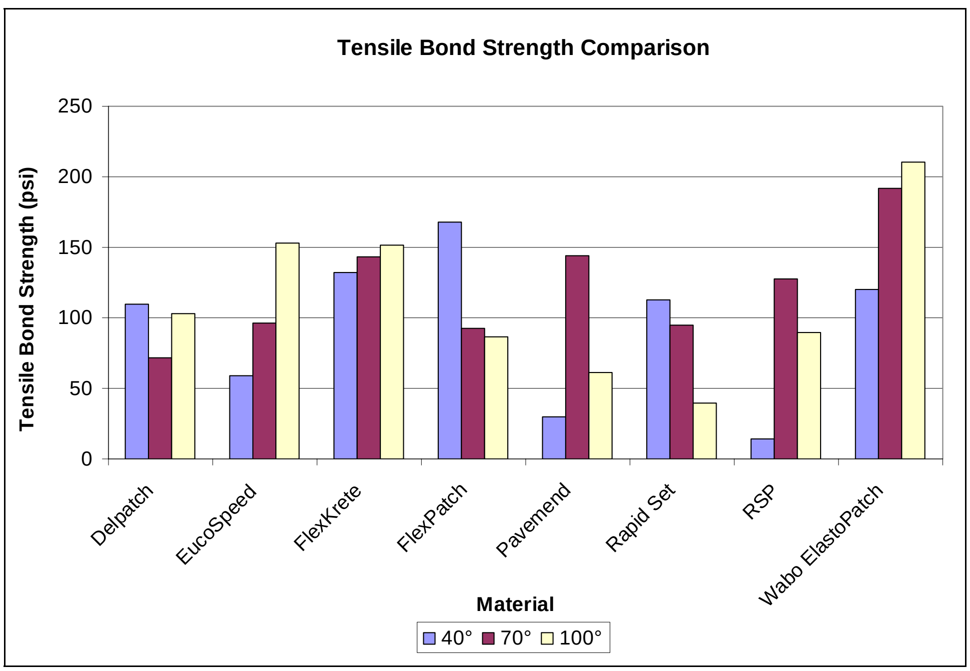

Figure D.1 Tensile Bond Strength

Table D.2 Bond Strength Field Comparison

TX DOT Field Core Results				Bond Strength (psi)	
Sample No.	Material	Bond Strength (kN)	Bond Strength (psi)	Field Cores Average	Lab Cores Average
# 3a	FlexPatch	2.35*	168*	168*	108
# 4	Delpatch	0.7**	50**	50**	91
# 6b	Wabo	0.9	64	61	172
# 6c	Wabo	0.8	57		
# 8c	Fibrescreed	***		***	

* Broke at Material Surface
** Broke within Substrate
*** No failure/ creep only

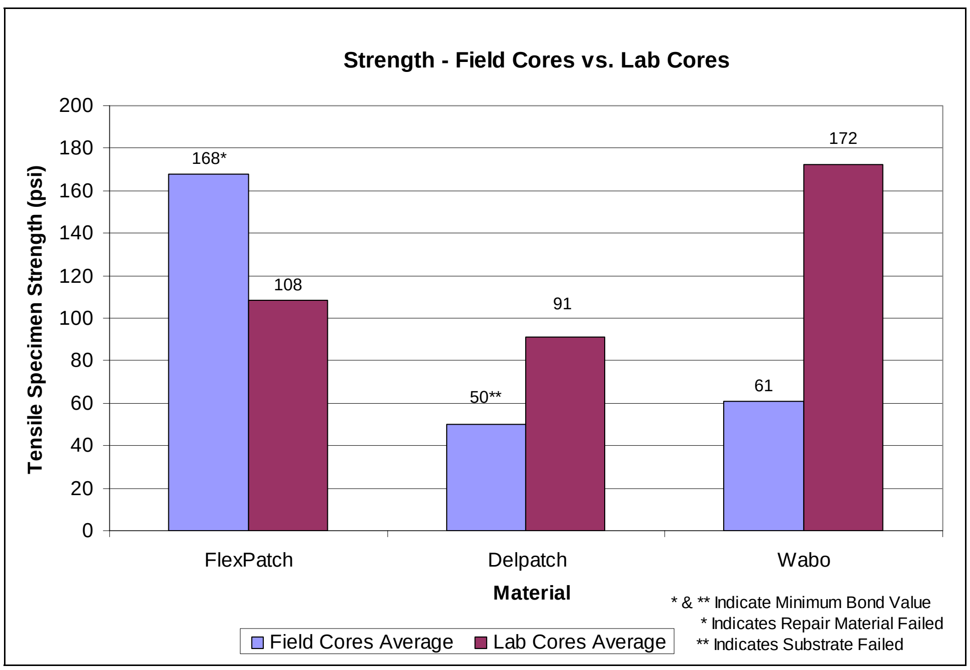

Figure D.2 Bond Strength Field Comparison

Table D.3 Abrasion Data

Product	Total Mass Lost (g)
Delpatch	0.5
Euco Speed MP	2.1
Fibrescreed	0.9
FlexKrete	4.1
FlexPatch	3.4
Pavemend 15	16.3
Rapid Set	13
RSP	4.5
Wabo ElastoPatch	1.6

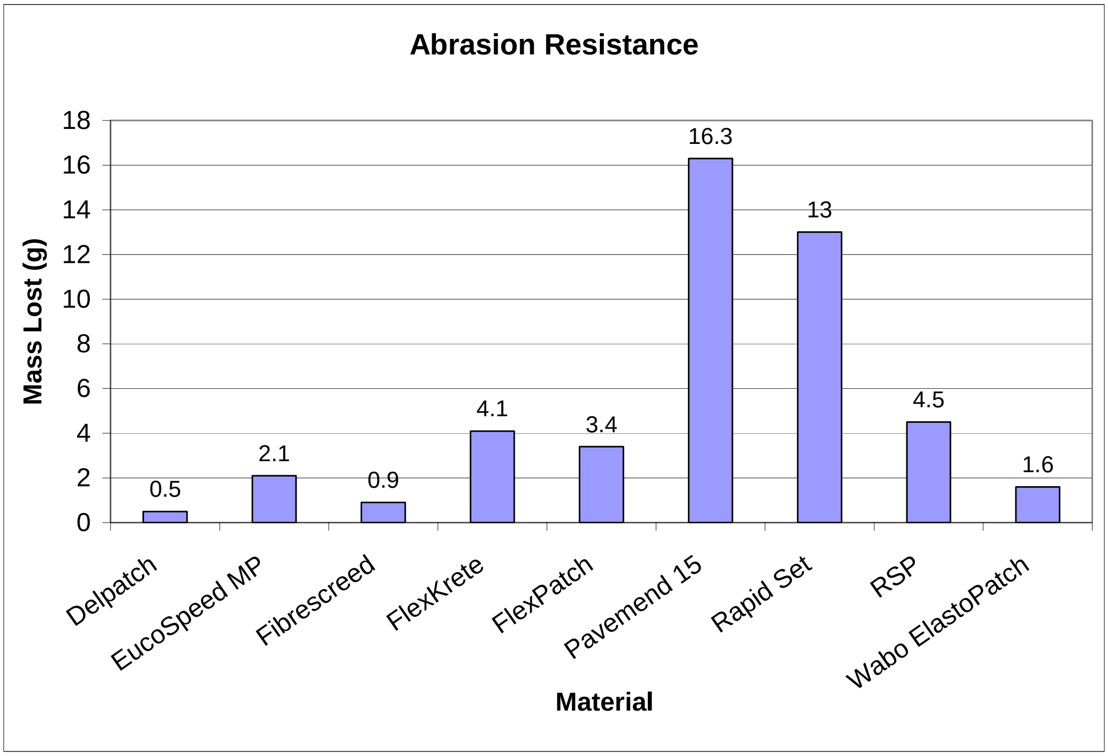

Figure D.3 Abrasion

APPENDIX E: RESULTS – SET TIME DATA

Table E.1 Approximate Initial and Final Set Times

Product	40°		70°		100°	
	Initial Set (min)	Final Set (min)	Initial Set (min)	Final Set (min)	Initial Set (min)	Final Set (min)
Delpatch	91	524	80	444	87	345
EucoSpeed	30	34	15.0	20	8.5	10
Fiberscreed	--	--	--	--	290	*
FlexKrete	19	26	11	18	18	24
FlexPatch	--	--	55	78	29	43
MgKrete	--	--	9	10	--	--
Pavemend	**	52	13	15	**	10
Rapid Set	59	65	23	28	10	13
RSP	**	6	**	6	**	6
Wabo ElastoPatch	38	66	23	47	13	27

* Material does not reach Final Strength
** Material changed viscosity too quickly to get adequate readings

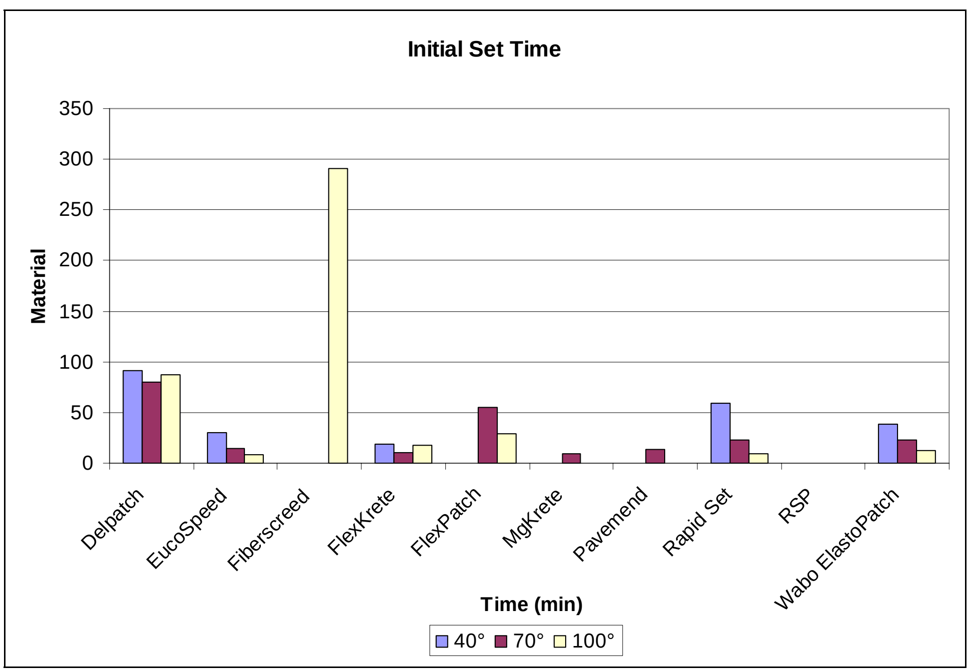

Figure E.1 Initial Set Time Comparison

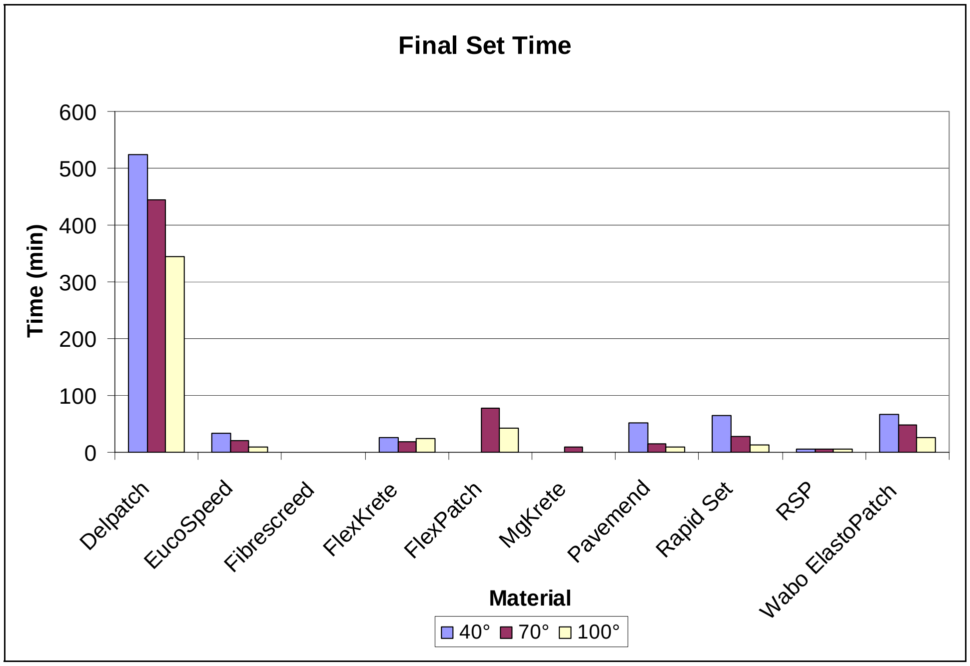

Figure E.2 Final Set Time Comparison

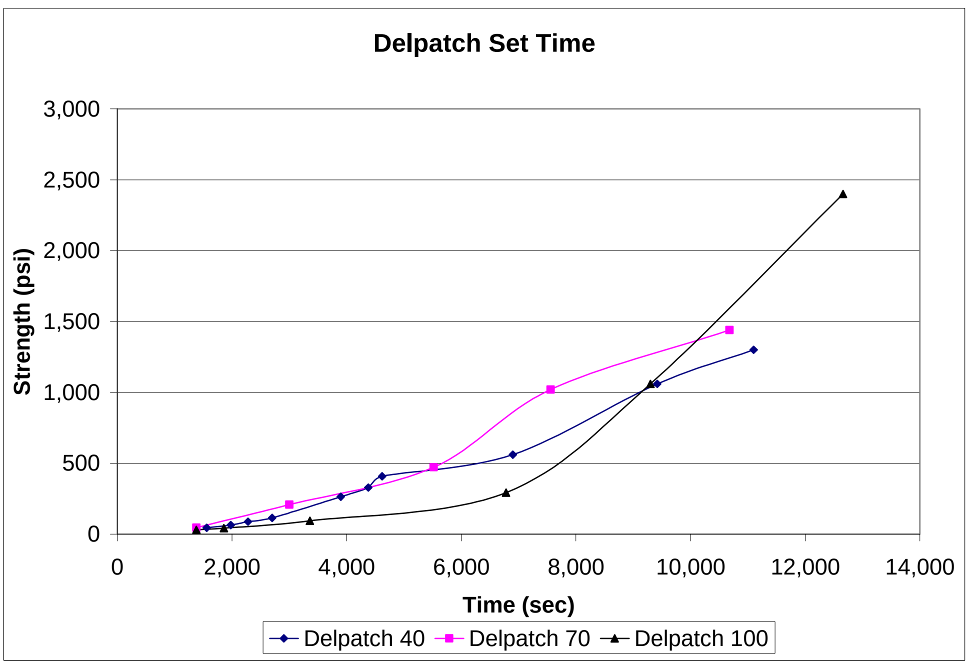

Figure E.3 Delpatch Set Time Data

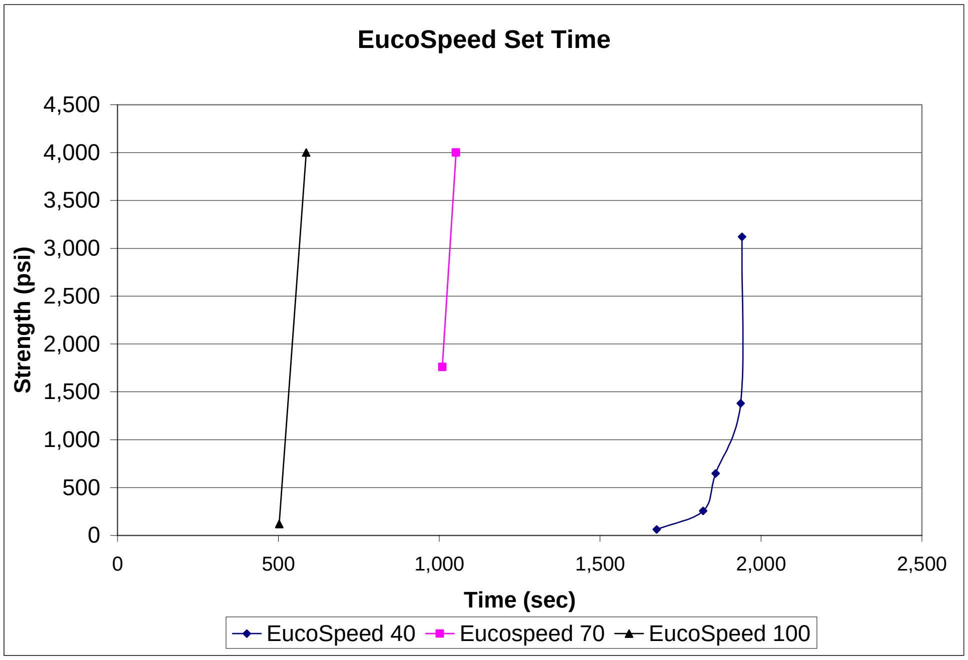

Figure E.4 EucoSpeed Set Time Data

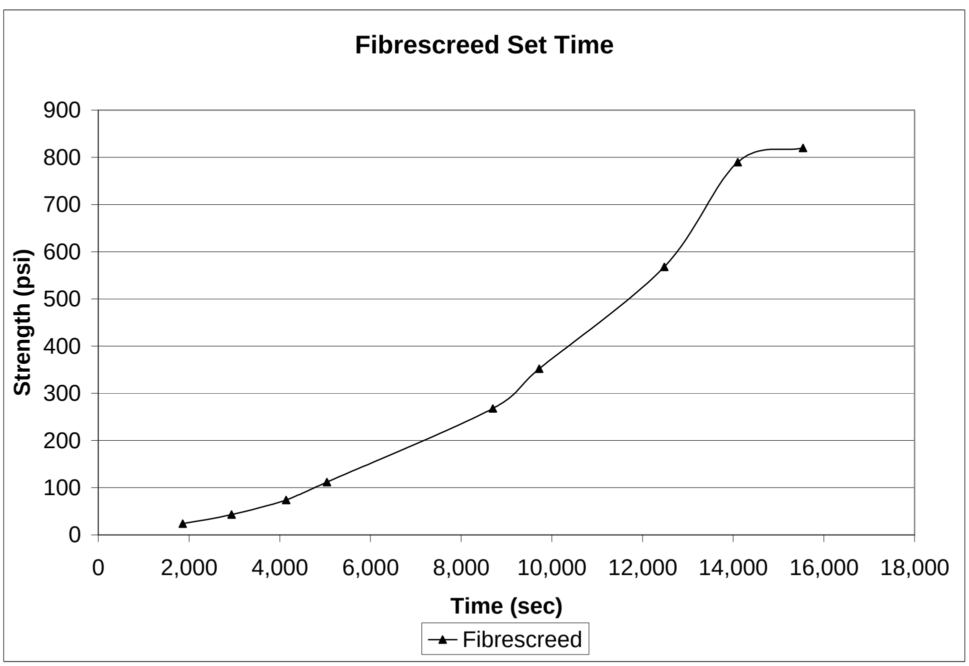

Figure E.5 Fibrescreed Set Time Data

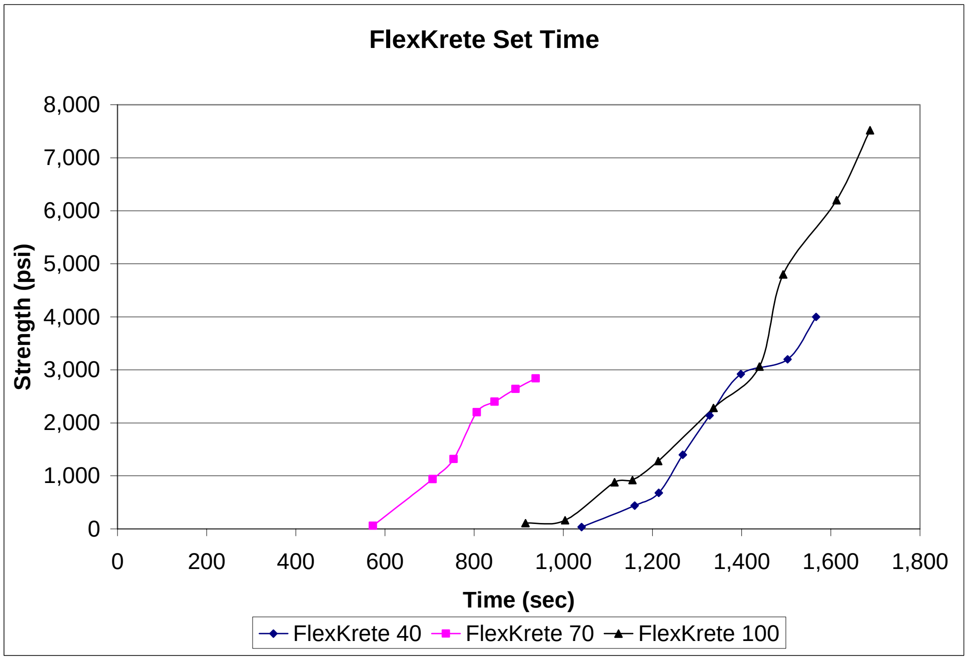

Figure E.6 FlexKrete Set Time Data

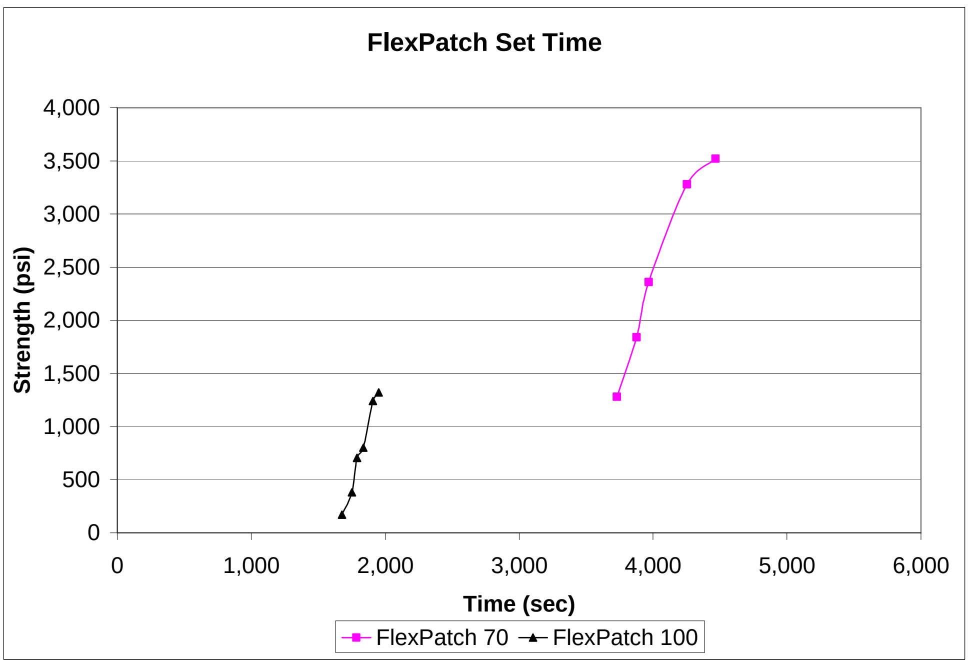

Figure E.7 FlexPatch Set Time Data

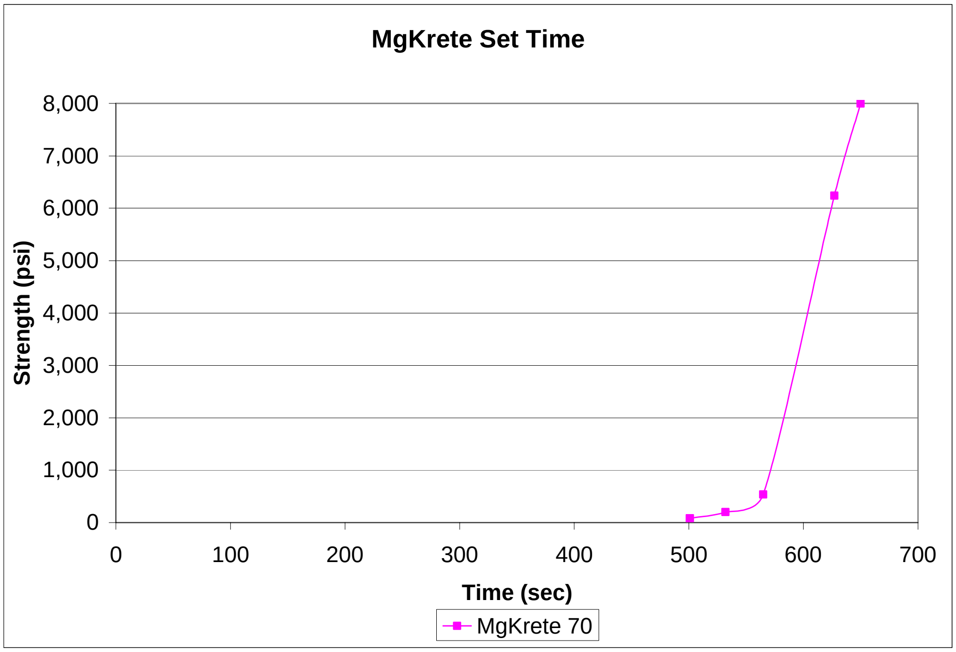

Figure E.8 MgKrete Set Time Data

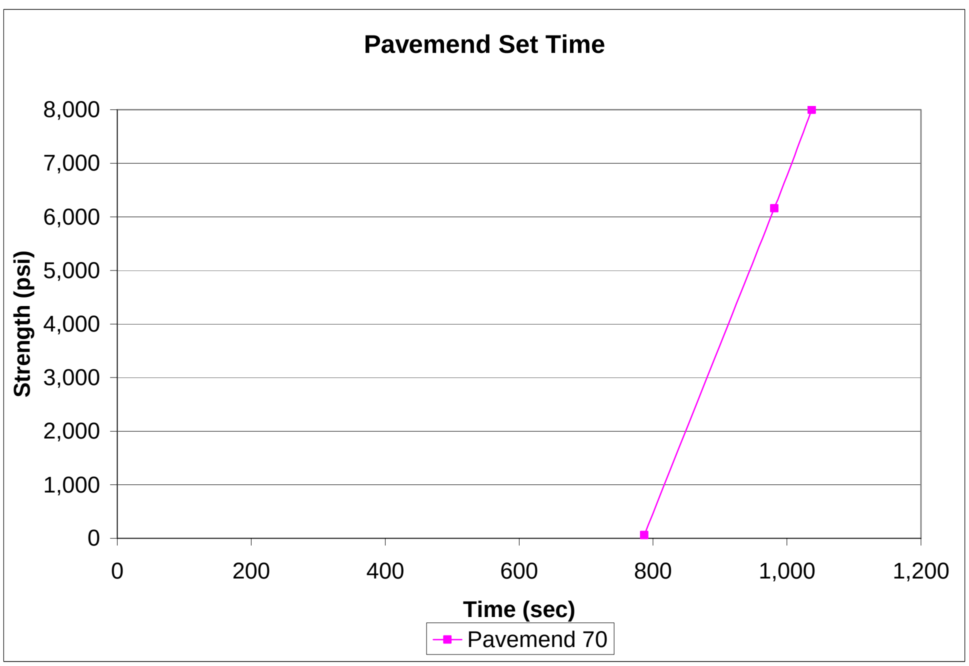

Figure E.9 Pavemend Set Time Data

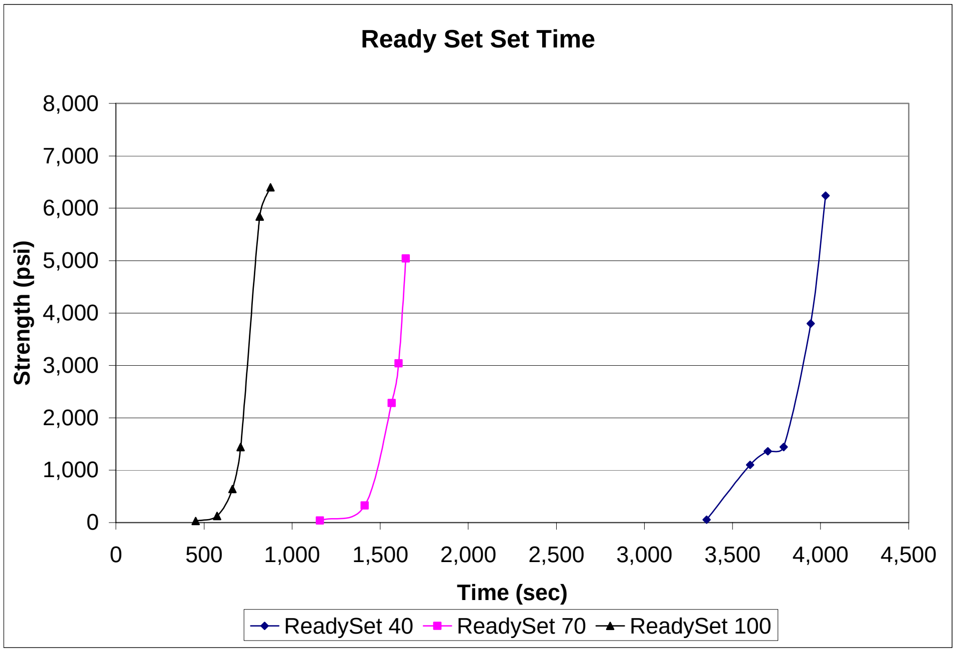

Figure E.10 Ready Set - Set Time Data

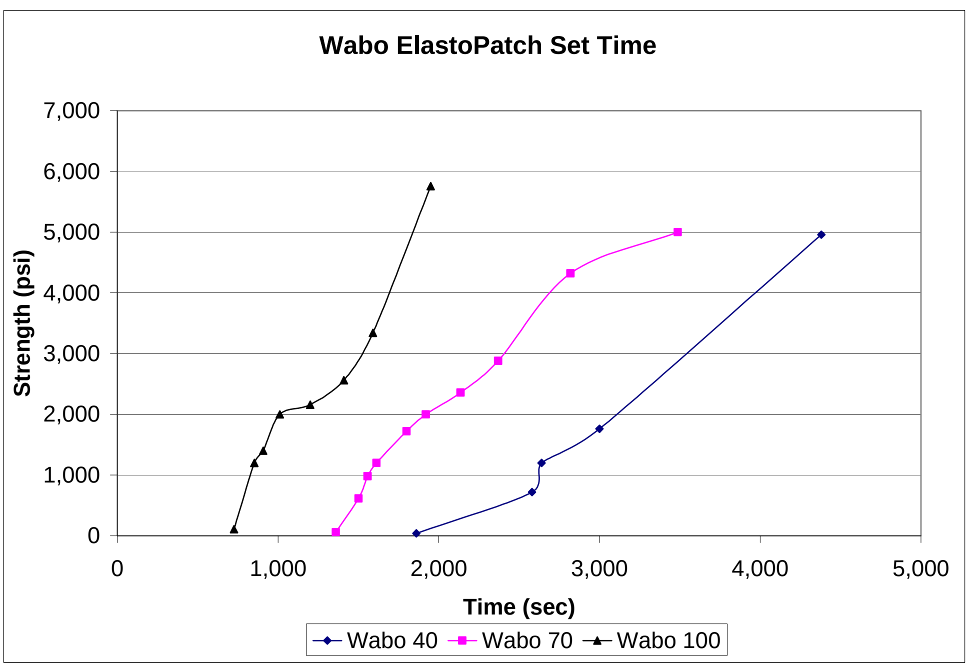

Figure E.11 Wabo ElastoPatch Set Time Data

APPENDIX F: RESULTS – FT. WORTH TESTING PLACEMENT

Table F.1 Ft. Worth Data Comparison

	Field - 7 day Results			Lab tests - 24 hours		
Product	Compressive Strength (psi)	Modulus of Elasticity (psi)	Poisson Ratio	Compressive Strength (psi)	Modulus of Elasticity (psi)	Poisson Ratio
EucoSpeed	3200	4,200,000	0.36	5110	4,900,000	0.29
MgKrete	2890	4,300,000	0.24	3080	3,700,000	0.24
Pavemend TR	3780	2,450,000	0.34	3920	1,800,000	0.39
Flexpatch*	n/a	160,000	n/a	n/a	120,000	n/a
Delpatch*	n/a	11,000	n/a	n/a	7400	n/a

* Lab Tests done after 1 month for Flexible Materials

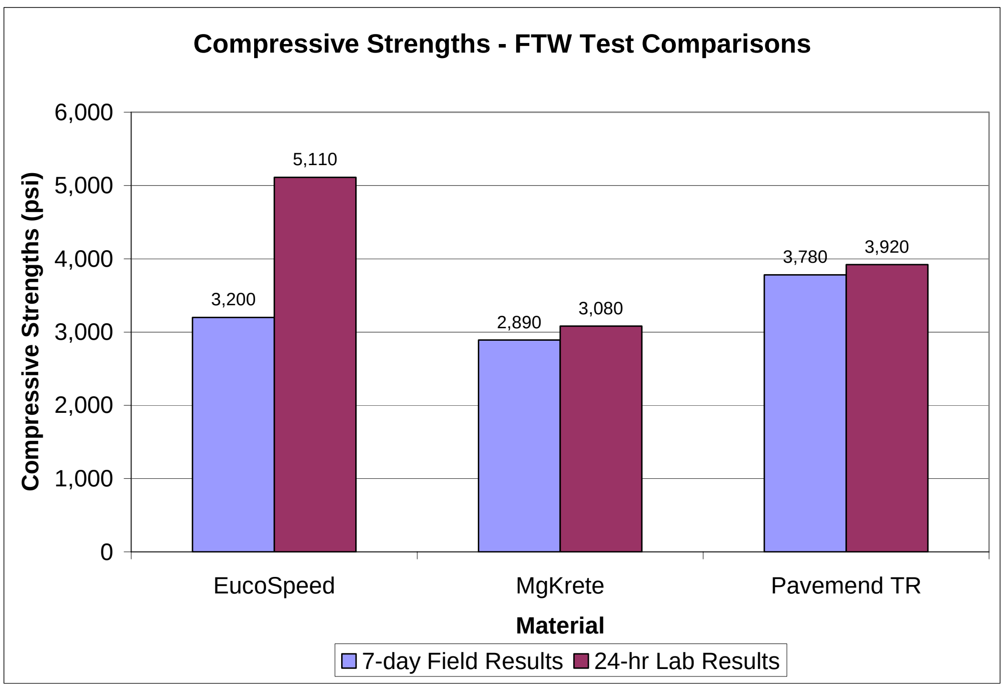

Figure F.1 Compressive Stress – Ft. Worth Comparison

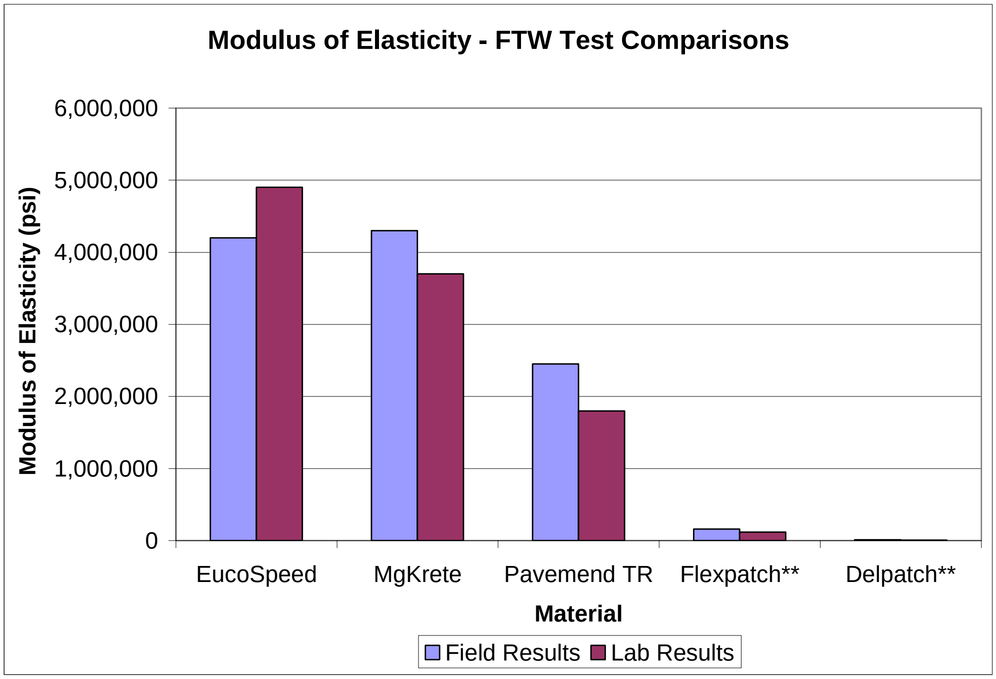

Figure F.2 Modulus of Elasticity – Ft. Worth Comparison.
**** Method of testing may be unreliable for this material.**

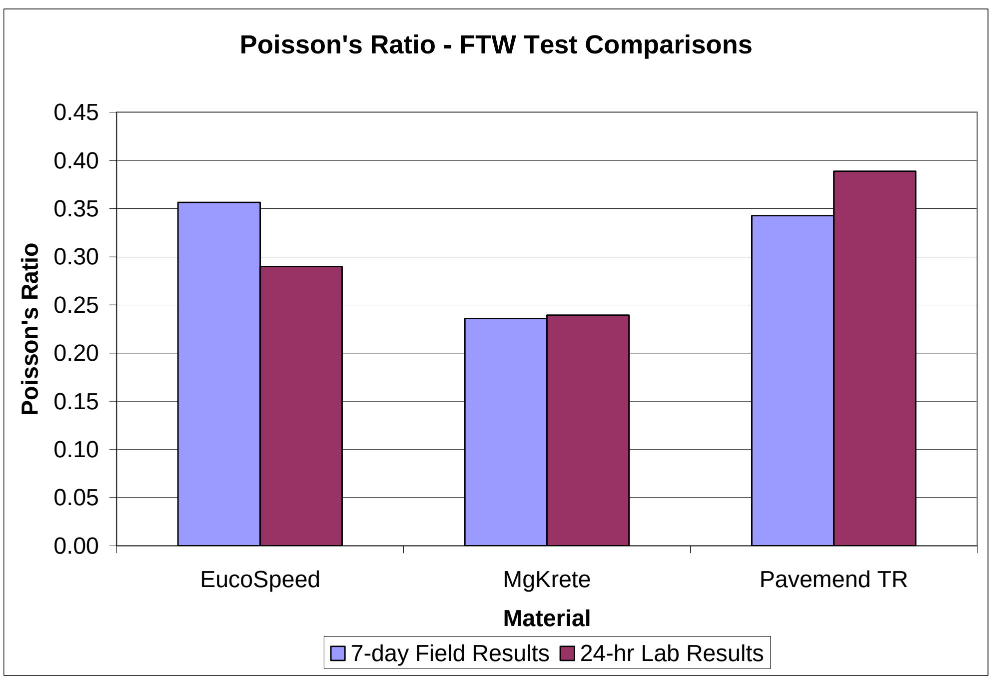

Figure F.3 Poisson Ratio – Ft. Worth Comparison

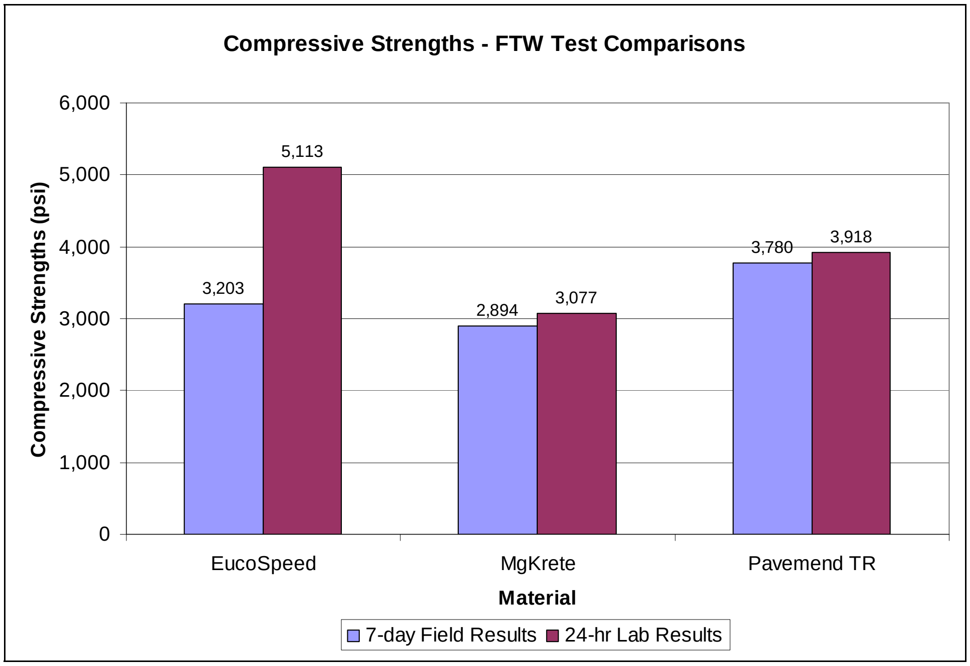

Figure F.4 Compressive Stress – Ft. Worth Comparison

Table F.2 Pot Life – Ft. Worth Specimens

Product	Approximate Pot Life (Minutes)
EucoSpeed	10
MgKrete	14
Pavemend TR	25
FlexPatch	29
Delpatch	20

APPENDIX G: RESULTS – TEST OF PLACEMENT MATERIALS

Table G.1 Test Result of Concrete Patching Material Type II

Producer	SSI Silspec	Imco	The Euclid Chemical Co.	Cedra Tech*
Product	FlexPatch	MgKrete	EucoSpeed MP	Pavemend TR
Chem Lab No.	J05481181	J05481182	J05481183	J05481184
Gel Time (min)	14	6	9	14
Wet Bond Strength (psi)	263	287	106**	143**
Compressive Strength after 24hrs (psi)	5510	3929	5462	1988**
Compressive Stress to 0.1" after 7 day cure (psi)	3744	Specimens broke before they got to 0.1", no data available**	Specimens broke before they got to 0.1", no data available**	1509**
Resilience (%)	96	0**	0**	0**
Thermal Compatibility, no delamination or cracking	Pass	Pass	Pass	Pass
Coefficient of Thermal Expansion, (µstrain/°F)	19.0	6.7	5.6	6.7

Samples were tested under DMS-6170 Polymeric Materials for Patching Spalls in Concrete Pavement and Tex-428-A Determining the Coefficient of Thermal Expansion of Concrete.

* Specimens were made by hand mixing following producer's instructions, no temperature gun was available at the time of the mixing.

** Failed to meet DMS-6170 for type II material.

APPENDIX H: MANUAL OF SPREADSHEET FOR MATERIAL SELECTION

Material Selection Worksheet

The pink cells are for the input data, and blue cells are for the output data.

1. **Review Material Properties Table.**
    a. Accept default material properties as listed.
    b. Or, input specific properties based laboratory test results.

2. **Material Choice.**
    a. Make 2 selections for repair.
    b. Select from the list of material types, "Type I (Non-Crack Reflective)" or "Type II (Crack Reflective)" in 1st drop down box. (Note: these categories are based on field performance.)
    c. Select the spalling repair matrix you want in 2nd drop down box.
    d. Select aggregate filler type in 3rd drop down box. If no aggregate is used then select "None."
    e. As appropriate, input the proportion of aggregate.
    If selecting "None," the proportion of aggregate will not be considered in the determination of the material modulus or CoTE. *(Currently neither of these parameters is actively considered in the selection process.)*

3. **Material Acceptability.**
    a. Input the repair depth.
    b. Acceptability only accounts for the bond strength of the repair material to wet concrete.
    c. The acceptability of selected materials is calculated automatically based on whether the input bond strength exceeds the user specified Type I or Type II bond strength.

4. **Material Ranking.**
    a. Material Cost (per SF) is automatically determined based on the amount of aggregate used.
    b. Under Placeability pot life and time of setting are automatically input from the material table. The user rates the ease of the mixing process and the workability of the material based on the capability of the material to fill the repair area on a scale of 0 to 10.
    c. Under Overall Utility, input the number of issues associated with the storage, disposal, and cleanup of the material plus rates the material on the basis color, the susceptibility of its bonding to moisture, and future options (on a scale of 0 to 10).
    d. The spreadsheet ranks each material automatically.

Material Acceptability Properties

1. **Bond Strength to Concrete Substrate.**
   a. Bond strength of the repair material to the concrete substrate is the most significant factor in the performance of a spall repair material. Test procedures for the measurement of bond strength are outlined in DMS 6170 "Polymeric Materials for Patching Spalls in Concrete Pavement" or Tex 618-J "Testing Elastomeric Concrete" (for wet bond strength to concrete (Type I > 100 psi or Type II > 250 psi)).
   b. The bond strength resists the shear stress induced at the interface between the concrete substrate and the repair material due to thermal contraction between the spall material and the concrete due to large differences in the thermal conductivity in these materials.

Material Ranking Criteria

1. **Material Cost.**
   a. The cost entered into the worksheet is the per square foot material unit cost. This cost is derived from the bulk material cost excluding labor and other incidental costs.

2. **Pot Life.**
   a. Pot life at room temperature refers to the time available in hours which a given material can be held on the job site prior to its installation into the patch area.

3. **Mixing.**
   a. Several factors may be involved in combining the binder with the aggregate in the mixing process. For instance, dry batching is much dustier than wet batching but may require less batching cycles where premixing is involved. User assigns a rating according to the number of factors associated with the mixing and batching of a material type:
      i. Low Level (0 to 1): 6 to 10
      ii. Medium Level (1 to 2): 3 to 6
      iii. High Level (more than 3):0 to 3

4. Workability.

a. Material rheology affects how easily the material can fill in the repair area and is affected to some extent by the material setting characteristics. Materials with no or little aggregate place differently from those that have large aggregate fractions. User assigns a rating according to the ease of placing a given material type:

i. Places with ease: 6 to 10

ii. In between: 3 to 6

iii. Places with difficulty: 0 to 3

5. Time of Setting.

a. The time of setting represents the working time available in minutes for a given repair material type. The time of setting is related to the gel time as determined by test method Tex-614-J "Testing Epoxy Materials."

6. Storage/Safety/Disposal.

a. Storage life refers to the time available in years which a given material can be stored prior to its use in the field. Cooled and/or heated storage facilities may be required for some of the polymeric materials, which could add to the in place cost. Separate storage areas are required by some of the constituents in some polymer-based repair materials. Enough space in the type of required controlled environment must be available.

b. Safety is rated related to the number is safety items (typically less than 5) that need to be taken into account relative to the use of a given spall repair material. Safety items related to handling or its installation would be included in this list such flammability, acts as an allergen, or toxicity. Some combination of boots, gloves, goggles, dust mask, or open air ventilation and eyewash capabilities while working with concrete or asphalt are commonly required for some materials. Are special expenses and hazards present with any of these new materials? Do workers need to wear organic vapor masks and chemically protective suits? Are there any special environmental concerns with rain runoff from these materials?

c. Disposal. Can the leftovers and waste materials for the products be simply disposed of or is a special hazardous materials hauler required to handle partially full or nearly empty cans and bags of the wasted mix?

7. **Color**.
   a. This is a measure (rated from 0 to 10) of how well the color of the repair material matches the color of the existing pavement surface. The degree of matching (based on personal preference) can be rated as follows:
      i. Low: 0 to 3
      ii. Medium: 3 to 6
      iii. High: 6 to 10

8. **Moisture Susceptibility.**
   a. This is a determination (rated from 0 to 10) of the expected effect on bond strength due to the presence of moisture on the interface between the concrete and the repair material during the placement in the field. The performance life can be rated as follows:
      i. Large Effect: 0 to 3
      ii. In Between: 3 to 6
      iii. Low Effect: 6 to 10

9. **Future Repair Options.**
   a. This is an assessment (rated from 0 to 10) of the impact using a particular repair material on the future options available to rehabilitation of a pavement that has been repaired with the material in question. This assessment is made as follows:
      i. Difficult to rework: 0 to 3
      ii. Bonds to either an asphalt or concrete overlay: 3 to 6
      iii. Recyclable: 6 to 10

APPENDIX I: RANKING OF REPAIR MATERIALS FOR HOUSTON AND FT. WORTH DISTRICTS

Ranking of Repair Materials

The 10 repair materials listed were ranked by using the spreadsheet developed for material selection. The information required to rank materials was obtained from the results of the laboratory test and the field tests of the Houston and Ft. Worth Districts. The bond strength test was conducted using the cores taken from the Houston District, so this result was used to rank repair materials for the Houston District. For the Ft. Worth District, the repair materials were ranked using the results of pot life and elastic modulus tests with samples obtain from the field placement.

Tables I-1 and I-2 show the material properties, the scores for ranking materials, and the ranking for each district.

Table I.1 Ranking of Repair Materials for the Houston District

Rank	Product		Bond Strength		Scores			
	Type	Matrix	Value (psi)	Adequacy	Cost (0.4)**	Placeability (0.2)	Overall Utility (0.4)	Total
1	II	MgKrete	250	No	9.8	4.5	7.8	7.94
2	I	RSP	85	No	9.8	6.5	6.8	7.93
3	II	RapidSet	95	No	9.8	6.2	6.8	7.89
4	II	Pavemend	78	No	9.7	4.1	7.8	7.83
5	II	EucoSpeed	121	No	9.8	5.7	6.8	7.79
6	II	FlexPatch	168*	No	9.7	3.9	7.8	7.77
7	I	Delpatch	50*	No	9.6	4.1	7.8	7.76
8	I	FlexKrete	141	No	9.7	5.7	6.8	7.74
9	I	Fibrescreed	250	No	9.7	3.5	7.8	7.70
10	I	WaboCrete	61*	No	9.5	5.7	6.8	7.68

* Bond strength was determined through the test of cores obtained from the field.
** Weight

Table I.2 Ranking of Repair Materials for the Ft. Worth District

Rank	Product		Bond Strength*		Scores			
	Type	Matrix	Value (psi)	Adequacy	Cost (0.4)	Placeability (0.2)	Overall Utility (0.4)	Total
1	II	EucoSpeed	121	No	9.8	6.5	6.8	7.94
2	I	RSP	85	No	9.8	6.5	6.8	7.93
3	II	RapidSet	95	No	9.8	6.2	6.8	7.89
4	II	MgKrete	200	No	9.8	4.2	7.8	7.88
5	I	FlexKrete	141	No	9.7	5.7	6.8	7.74
6	I	Fibrescreed	250	No	9.7	3.5	7.8	7.70
7	I	WaboCrete	172	No	9.5	5.7	6.8	7.68
8	II	Pavemend	78	No	9.7	3.2	7.8	7.67
9	I	Delpatch	91	No	9.6	3.5	7.8	7.65
10	II	FlexPatch	108	No	9.7	3.2	7.8	7.63

* Bond strength was determined through the laboratory test.

APPENDIX J: GUIDELINES FOR REPAIR PROCEDURES

Guidelines for Repair Procedures

The following guidelines are provided to summarize good practices associated with successful repair techniques. Since many of the requirements are specific for certain material types, it is important to determine exactly what is required by the manufacturer before the final product is selected. In some cases, because of time or seasonal temperature constraints, particular requirements for a given product might preclude its use in the spall repair project under consideration.

1. Identify Types of Repair Materials

The spall repair materials have different chemistries and physical properties, so that, first of all, engineers should identify the properties and behavior of repair materials to expect the good performance of spall repair.

A. Polymeric (Polyurethane, Vinyl Esters, Epoxy)

1) These resins start out as pourable liquids that will cure into hardened plastic glues or binders. For repairs, the resins are mixed with curing agents, sometimes called hardeners or initiators, and then with aggregates, usually sand and sometimes pea gravel. The key is to get the resin systems to harden at just the right speed, so the polymer doesn't cure too fast or too slow. The working time must allow the repair team enough time for complete mixing, placing into the spall and finishing to a smooth surface flush with the surrounding concrete. At the same time traffic control costs and return-to-traffic criteria constraints require that the material cures sufficiently for trafficking in a very short period after the end of working time. If this isn't enough to consider, all these materials are affected greatly by ambient temperature changes. To help users solve this curing rate problem specific, 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.
2) This type of repair material is called polymer concrete, which simply means aggregates glued together with polymers or plastics. Polymer concrete is very

durable, water tight, and wear resistant. It bonds very well to dry aggregates and dry concrete but, this is important, usually the aggregate and concrete need to be dry. Some epoxies and polyurethanes are different in that they can work with wet surfaces and possibly even damp aggregate.

3) Polymer concretes can be made very flexible, so that they have the ability to stretch without breaking (think of chewing gum). This makes them better for repairs than a very brittle material which cracks easily. 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 clean, dry coarse aggregate makes it more rigid. It is important to note that polymers cost a lot more than portland cement, but their ability to bond and stay in the repair without cracking may make them very cost effective. When making a repair, it is a good thing not to have to return for re-repairs any time soon. So, initial material costs in a labor-intensive job may not be nearly as important for repairs as for new construction.
4) Polymer concrete brand names:
    i. FlexKrete – Vinyl Ester
    ii. FlexPatch – Epoxy
    iii. Delpatch – Polyurethane
    iv. Wabo ElastoPatch – Polyurethane
    v. RSP – Polyurethane

B. Modified Bitumen

1) This binder system, basically an asphalt upgraded with polymers, requires special equipment to heat the bitumen, similar to making hot mix. That renders it a material available for large contracted jobs. It does not have the strength or wear resistance of most of the other repair materials, but it has remained in the spall where it has been applied.
2) Fibrescreed – a hot applied synthetic polymer modified resin and bitumen compound containing mineral fillers, chopped fibers, sand, and graded granite aggregate.

C. Rapid Setting HydraulicCement

1) These systems are physically similar to normal portland cement concrete, grouts, or mortars. They cost considerably more, but they set much more quickly to accommodate early return-to–traffic times. Because they are brittle, edge sawing is typically required.

2) Rapid Set- Chemically, this material is 33 percent calcium sulfoaluminate and 67 percent dicalcium silicate.

D. Magnesium phosphate

1) This binder system is a special chemical that reacts with water and sets very quickly in a rigid binder system. It is mixed with aggregate very similarly to portland cement. In hot weather, it must be retarded or it will set faster than it can be placed and finished. It rapidly cures to a relatively brittle material.

2) Commercially available magnesium phosphates:

i. EucoSpeed

ii. Pavemend

iii. MgKrete

2. Prepare the Spalled Area

Preparation for spall repairs are typically begun by cleaning all contaminants and unsound concrete from the spalled area.

A. Remove all cracked and delaminated concrete - Depending on the type of contaminant this may even require some chipping with a light jackhammer or bush-milling. Many materials also require that the edges be well defined and of a minimum depth to avoid feathered edges that often ravel. For materials with this requirement, the spalled edges are typically sawed 0.25 to 0.5-inch deep before sandblasting. Other materials, like epoxy or vinyl-ester systems may not require any special edge preparation and may only need the area to be sandblasted or dry air blasted.

B. Clean Rebar (If required) - When the depth of the spall is such that rebar is exposed, repair material manufacturers may recommend or require that the rebar be cleaned (sandblasted, shotblasted, or wire brushed) down to clean white-metal condition. This is particularly true for hydraulic cement repair materials such as Rapid Set, EucoSpeed, Pavemend, and MgKrete.

C. Prime Surface (If required by manufacturer) - Some of the materials depend upon a little extra effort to ensure proper wet out or bond advantages to the substrate. The manufacturers of these materials require that a primer be applied to the cleaned spall before it is filled with their repair material. If this little extra step ensures minimal maintenance on the repairs in the coming years it is well worth the effort. Priming is required by:

1) Fibrescreed
2) Delpatch
3) FlexKrete
4) Wabo ElastoPatch
5) FlexPatch – Only if repair is less than 1-inch deep

3. Consider Weather during Repair

It is important to keep in mind that different materials have different properties and different requirements. There are at least two things they all have in common, though, and it is important to keep this in mind during actual repairs.

A. Temperature

1) Cool temperatures retard and slow down cure times, so if return-to-traffic time is an important job constraint and the repairs will take place during the cooler period of the year, determine whether special accelerators are available to establish low temperature limits for the repair material selected.
2) Warmer temperatures accelerate cure time and could prevent sufficient working time. Determine whether special retarders are available or what high temperature limits must be established.

B. Moisture

3) Most of the materials do not like water contamination. Substrate surface must be kept dry.

4. Mix, Place, and Finish a Repair Material

Here are the summarized specific instructions for mixing and placing individual repair systems that were evaluated in this research project. They are listed below for the user's convenience.

A. Delpatch

1) Mix 3000 ml part "A" component with 1500 ml part "B" component for 10 seconds. Add pre-bagged aggregate and mix an additional minute.
2) Pour material into spall.
3) Texture surface with trowel.

B. FlexKrete

1) Mix 1 gallon of FlexKrete with 1.2 oz of catalyst. Mix for 30-60 seconds. Add 3 to 4 gallons of sand and mix thoroughly for 2 minutes.
2) Pour material into spall.
3) Trowel into place.

C. Wabo ElastoPatch

1) Mix part "A" component with "B" in a 1:1 ratio for 2 minutes. Add packaged aggregate and mix an addition 2 minutes until well blended.
2) Pour material into spall.

D. FlexPatch

1) Mix prepackaged part "A" component with "B" for 3 minutes. Slowly stir in part "C" component (aggregate) until well blended.
2) Pour material into spall.
3) Finish with steel trowel.

E. RSP

1) Place aggregate into spall area.
2) Mix part "A" component with "B" component in 1:1 ratio.
3) Pour material over aggregate in spall.

4) Apply sand to top of repair.

F. EucoSpeed

1) Add 0.4 – 0.5 gallons of water to 50 lb bag of Material. Mix for 2 minutes. May extend with an additional 30 lb of pea gravel, mix an additional minute.
2) Pour material into spall.
3) Trowel material, broom finish.

G. Pavement 15

1) Add 1.0 gallon of water to 45 lb bucket of material. Mix until temperature has reached 95 degrees F.
2) Pour material into spall.

H. Rapid Set

1) Add 3 – 5 quarts of water for each 60 lb bag of material. Mix for 2 minutes. Mix 1 – 3 minutes until of uniform consistency.
2) Pour material into spall.
3) Trowel, float, or broom finish.

I. Fibrescreed: Material placed by contractor with proper equipment.

1) Place packaged material in machine.
2) Once material has reached the proper temperature (375-380 degrees F), apply to spall area in 2-inch lifts. Add 3/4-inch bulking stone with each lift. Continue until flush with surface.
3) Apply top coat for skid resistance.

Table H.1 indicates the initial set time, the time required to open traffic, and the type of each spall repair material.

Table J.1 Type and Set Time for Each Material

Product	Initial Set Time (minutes)	Return to traffic	Type
Wabo ElastoPatch	22	1 hr	Elastomeric Polyurethane
Delpatch	60	1 hr	Elastomeric Polyurethane
RSP	6	1 hr	Elastomeric Polyurethane
Fibrescreed	*	15 min – 1 hr	Visco-Elastic Polymer-modified bitumen
FlexKrete	8	1.5 hrs	Semi-Rigid Vinyl Ester
FlexPatch	63	1 – 2 hrs	Semi-Rigid Epoxy
RapidSet	24	1 hr	Rigid Hydraulic Cement
EucoSpeed	17	1 hr	Rigid Magnesium Phosphate
Pavemend	13	1.5 hrs	Rigid Magnesium Phosphate
MgKrete	-	-	Rigid Magnesium Phosphate

* Not chemically activated, temperature controlled

5. Re-establish Joint for Rigid Material

In order to ensure similar differential movements with regard to opposite sides of a full depth pavement crack or joint, it is recommended that the joint be re-established in the surface of any rigid repair materials over existing cracks or joints as shown in Figure H.1.

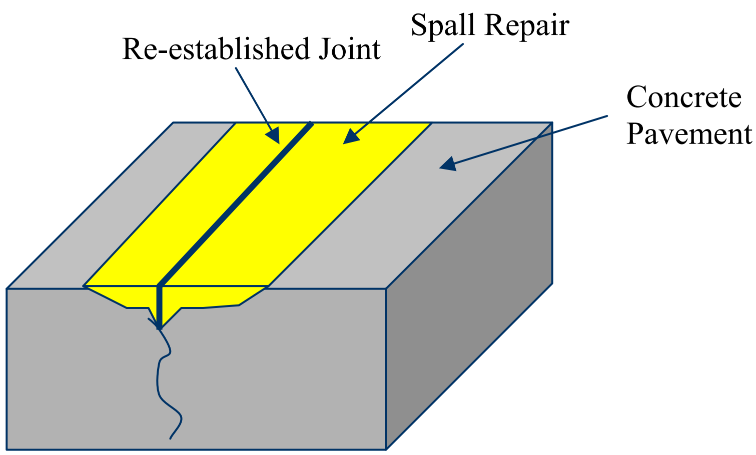

Figure J.1 Re-established Joint in Rigid Repair Material