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16. Abstract

Cold patching asphalt mixtures constitute an essential element for the maintenance and rehabilitation of pavement infrastructure. Although this maintenance technique is both expensive and time consuming, it can minimize further damage and costly future repairs as well as increase user and vehicle safety. As a result, cold patching mixture performance is critical. Unfortunately, there is a lack of standard mixture design guidelines for homemade mixtures and performance-based mixture specifications for both homemade and containerized mixtures to ensure satisfactory field performance. This report presents a homemade mixture design for cold and wet weather areas by identifying the failure mechanisms of cold patching mixtures and analyzing the effects of gradation, aggregate shape, binder content and viscosity, curing time, temperature, and admixtures on the mixture workability and stability. Laboratory and accelerated pavement testing (APT) procedures are specifically defined for use with cold patching mixtures. Protocols and procedures are also defined for the field evaluations of these mixtures. Results from field evaluations are used as overall relative measures of field performance and as validation for those results obtained from laboratory and accelerated pavement tests. Furthermore, testing results, in conjunction with testing procedures developed as part of this project, are used to provide recommendations for performance-based specifications for homemade and containerized cold patching mixtures. Such recommendations provide interim guidelines for the rejection or approval of such mixtures. Overall, the protocols and testing procedures discussed in this report help ensure the material characteristics necessary for desired patch performance in the field, which in turn reduces the failure rate and makes cold patching a more cost-effective maintenance operation.

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Mixture Design and Performance-Based Specifications for Cold Patching Mixtures

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Appreciation is also expressed to the manufacturers of the cold patching materials for their support and involvement in this project (in alphabetical order): Asphalt Patch, PermaPatch, Proline, QPR, Stayput, and UPM. Their generosity in donating materials facilitated testing throughout the research project. This research was performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.

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1. Introduction

1.1 Background

Pavement maintenance is essential to cost-effectively extend the life of the pavement infrastructure system. If performed correctly, it can enhance the effective life of the pavement and reduce further deterioration, which could result in costly repairs. An important form of pavement maintenance is the use of cold asphalt mixtures to patch potholes. Potholes often occur as a result of the introduction of water into the base of the pavement and subsequent high-traffic loads. The presence of water softens the pavement base and results in a loss of support on the pavement surface. This loss of support causes asphalt breakup and material loss, leaving the pavement structure particularly susceptible to pavement deterioration. Consequently, timely and proper application of the cold patching mixture is imperative. When applied correctly and in a timely manner, this operation can prevent further damage to the pavement structure. Timely and proper application of cold patching mixtures can also ensure the safety of the particular pavement area being maintained. Properly patched potholes reduce the possibility of vehicle damage and dangerous situations that could result in accidents.

Cold patching mixtures are often used to complete repairs in areas with cold and wet weather or during the winter months, when hot mix asphalt (HMA) is not available because of, for instance, closure of the plants during winter. These mixtures are often considered a temporary repair to prevent further damage to the pavement until formal maintenance can be performed. Texas Department of Transportation (TxDOT) maintenance crews use stockpiled or containerized cold patching mixtures based on the size and severity of the distressed area to be maintained. Some of the stockpiled mixtures are designed and mixed by the maintenance crews in the yards, while other stockpiled mixtures are purchased by the ton from third party suppliers. Containerized mixtures are also purchased from third party suppliers in bags or buckets weighing between 50 and 60 pounds. Stockpiled mixtures can be stored for up to two months, while containerized mixtures have a reported shelf life of 12 months. Major drawbacks of this maintenance technique are that it is both expensive and time-consuming. The use of large quantities of containerized mixtures is very costly. As a result, cold patching performance is critical. Unfortunately, homemade and some containerized mixtures have exhibited poor field performance in cold and wet weather conditions.

1.2 Problem Statement

Although several standards attempt to define and standardize the properties of cold patching mixtures, these standards do not necessarily help identify those mixtures that perform adequately. There is a need for standard mix design guidelines for homemade mixtures and mixture specifications for both homemade and containerized mixtures to ensure satisfactory field performance.

Problems encountered with cold patching mixtures include moisture susceptibility, inadequate workability, instability, short stockpile life, and overall inconsistent mix behavior during preparation and application (Estakhri and Button, 1995). Moisture susceptibility, which is the mixtures' propensity to moisture damage, is frequently exhibited in the form of raveling and stripping. Workability is a mixture's handling ability and is essential both in the stockpile during storage and in the field during placement. A mixture lacking workability can result in inadequate compaction and poor performance in the field. The use of soft binders or certain aggregates, such as sands and uncrushed gravels, can improve the workability of the mixture. Yet, a very workable mixture can display instability and result in pushing and shoving under traffic loads (Estakhri et al., 1999). Stability, the mixture's ability to resist deformations under traffic loads, is particularly problematic in deep patch installations. Often, workability and stability conflict with each other, thus, achieving a balance between these two qualities is essential to ensure mixture performance. Another problem affecting mixture workability is the short stockpile life. Stockpiled mixtures left unprotected develop a hard crust formation of two to six inches deep, which adversely affects mixture workability. Furthermore, the lack of standard mix design guidelines and mixture specifications result in overall inconsistent mixture behavior during mix preparation, installation, and in-field service. Specimens with properties similar to those mixtures compacted in the field can seldom be reproduced by standard laboratory sample preparation. Consequently, no method has been established to correlate laboratory results with field performance (Estakhri and Button, 1995).

In recent years, expectations of patch mixture performance, particularly in cold and wet weather, have increased. Unfortunately, expectations frequently surpass existing research and technology (Estakhri et al., 1999).

1.3 Objectives

The six major objectives of this research study are as follows:

- To identify failure mechanisms and review materials used, current homemade mix designs, field application procedures, and performance evaluation methods to establish design needs and criteria;
- To develop a cold-weather mix design procedure for homemade mixtures and establish performance-based mixture specifications for both homemade and containerized mixtures;
- To perform laboratory tests on homemade and containerized patching mixtures to evaluate their cold-weather workability and estimate their performance;
- To perform accelerated pavement tests (APT) on homemade and containerized patching mixtures to evaluate their performance;
- To evaluate the performance of homemade and containerized patching mixtures in the field; and
- To evaluate the effectiveness of various containers.

1.4 Research Scope

This study used laboratory and field tests to evaluate the performance of containerized and homemade cold patching mixtures. In alphabetical order, the six containerized patching mixtures evaluated in this study were Asphalt Patch, PermaPatch, Proline, QPR, Stayput, and UPM (Summer and Winter). Homemade mixture designs from the Lubbock and Lufkin districts, in conjunction with laboratory homemade mixture designs, were also evaluated as part of this study. The laboratory homemade mixtures were designed with materials consistent with those used by the TXDOT districts in their homemade mixture designs. Field evaluations were also conducted in Lubbock and Lufkin. The Lubbock District is representative of cold and dry weather whereas the Lufkin District is representative of warm and wet weather.

The homemade mixture design procedure and performance-based specifications have vast potential for statewide implementation and for pre-qualification of adequate patching materials. Furthermore, protocols for field patch installation, field evaluation, and accelerated pavement testing provide a framework for future studies.

1.5 Report Organization

All research results are presented in the following chapters. Chapter 2 is a literature review of the failure mechanisms, current designs, and procedures. The experimental mixture design procedure (preliminary and modified) is described in Chapter 3, while the ensuing laboratory tests and results are presented in Chapter 4. Accelerated pavement testing results are presented in Chapter 5. Chapter 6 discusses the field assessment of containerized and homemade cold patching mixture performance. Winter field evaluation results are presented in Chapter 7. Chapter 8 presents the interim results of the cost-effectiveness analyses, and Chapter 9 presents the final conclusions and recommendations for the homemade mixture design and performance-based specifications.

2. Literature Review

2.1 Failure symptoms and mechanisms

Multiple problems have been identified with the use of cold patching mixtures. These problems, or failure symptoms, may emerge during storage in the stockpile, during material installation, or throughout the service life of the mixture. The varying types of failure symptoms and mechanisms, which are well documented and previously identified in literature, are summarized in Table 2.1 (Anderson et al., 1988; Estakhri and Button, 1995, Evans, Mojab, at al., 1992).

2.1.1 In Stockpile

Problems encountered in the stockpile usually involve poor workability, binder draindown, and stripping. Workability and potential draindown are particularly influenced by the stiffness of the binder and the binder content, where either extreme in the binder stiffness can cause these problems. Inadequate coating during the mixing process or the use of cold or wet aggregate can cause stripping, or loss of coating, in the stockpile. Other failure symptoms include clumpy and stiff mixtures. Clumpy mixtures are a direct consequence of the binder curing rate. Mixtures stored in an unprotected stockpile typically form a thin crust with the evaporation of volatiles. The thickness of this crust should be kept to a minimum so as to minimize the clumpiness of the mixture and avoid workability degradation. Workability degradation is a prominent issue in cold weather. The temperature susceptibility of the binder can generate stiffer mixtures in cold weather that are less workable.

2.1.2 During Placement

Workability and stability are the most essential characteristics during mixture placement. A lack of these material characteristics must be avoided so as to prevent poor material performance. Extremes in the binder stiffness are often the failure mechanisms of these symptoms. Other causes of loss in workability may consist of excessive fines or dirty aggregate in a mixture or a mixture with a gradation that is too coarse or too fine. A lack of aggregate voids in the mineral aggregate or aggregate lock can cause a loss in stability. Since material properties designed to improve these characteristics often conflict, they must be carefully balanced to ensure proper installation and resistance to possible in-service failure symptoms.

2.1.3 In-service

The distresses typically detected in the field, which include pushing, shoving, raveling, and dishing, are frequently a direct result of inadequate compaction during installation. Other causes of shoving and raveling may include a lack in binder stiffness or moisture damage. The presence of these distresses is particularly detrimental to the integrity and performance of the patch installation since it can drastically accelerate the deterioration of the patching mixture. Another source of deterioration in areas with temperatures below freezing and large differentials is the freeze-thaw cycle. Moisture damage and mixture permeability may instigate freeze-thaw deterioration. Poor skid resistance and shrinkage are other, less observed, failure symptoms.

Table 2.1: Failure Symptoms and Mechanisms (Anderson et al., 1988)

Symptom	Failure Mechanism
In Stockpile	
Poor Workability	Binder too stiff; excessive fines or dirty aggregate; mix too coarse or too fine
Binder Draindown	Binder too soft; stockpiled or mixed at high temperatures
Stripping	Inadequate binder coating during mixing; cold or wet aggregate
Clumpy Mixture	Binder cures prematurely
Cold Weather Stiffness	Significant binder susceptibility to temperature; excessive fines or dirty aggregate; mix too coarse or too fine
During Placement	
Poor Workability	Binder too stiff; excessive fines or dirty aggregate; mix too coarse or too fine
Poor Stability	Binder too soft or excessive binder; insufficient voids in mineral aggregate; poor aggregate interlock
Excessive Softening (when used with hot box)	Binder too soft
In-Service	
Pushing, Shoving	Poor compaction; binder too soft or excessive binder; significant binder susceptibility to temperature; contaminated mixture; slow curing rate; moisture damage; insufficient voids in mineral aggregate; poor aggregate interlock
Dishing	Poor compaction
Raveling	Poor compaction; binder too soft; poor mixture cohesion; poor aggregate interlock; aggregate binder absorption; moisture damage; excessive fines or dirty aggregate; mix too coarse or too fine
Freeze-Thaw Deterioration	Mix too permeable; poor mix cohesion; moisture damage
Poor skid resistance	Excessive binder; aggregate not skid resistant; gradation too dense
Shrinkage or lack of adhesion to sides of hole	Poor adhesion; tack coat not used or mix not self-tacking; poor hole preparation

2.2 Desirable Mixture Properties

In order to ensure the performance of cold patching mixtures, special consideration must be given to certain mixture properties. A lack of these characteristics translates into poor performance and, ultimately, failure. These desired mixture properties and their subsequent benefits are summarized in Table 2.2 (Herrin, 1979; Roberts et al., 1996). A very important characteristic in the stockpile and during placement is workability. A workable mixture facilitates placement and compaction, forestalling many of the distresses often observed in- service by ensuring stability and durability. Stability is desirable because it provides shear strength to resist horizontal and vertical displacements under traffic loads. These displacements manifest themselves in the form of dishing and shoving. On the other hand, raveling can be prevented by ensuring mixture durability and stripping resistance. This is especially critical immediately after installation when the patched area is opened to traffic. Another essential mixture characteristic is stickiness. Sufficient stickiness ensures that the material adheres to itself as well as to the bottom and sides of the pothole. This characteristic is useful in the installation and compaction process, particularly when the pothole is not cleaned and dried thoroughly prior to installation. Although storageability is a characteristic required of both stockpiled and containerized mixtures, it is particularly important in stockpiled mixtures. Stockpiles with adequate storage life will remain workable and resistant to binder draindown and stripping. For containerized mixtures, storageablity is designated by the product shelf life. A shelf, or storage, life of 6 to 12 months is desirable to ensure satisfactory mixture performance. Freeze-thaw resistance is necessary in areas with freezing temperatures to ensure that the durability of the material is not compromised by the weakening effects of cyclic thermal expansion and contraction forces. Skid resistance is a necessary characteristic for large patch installations to prevent skidding.

Table 2.2: Desirable Mixture Properties and Benefits

Mixture Property	Benefits
Workability	Eases placement and compaction
Stability	Resistance to horizontal and vertical displacements under load
Durability	Resistance to raveling under traffic loads
Stripping Resistance	Resistance to binder and aggregate separation and raveling in the presence of water and traffic loads
Stickiness	Adherence to itself, pavement, and sides of potholes
Storageability	Resistance to binder draindown, stripping, and crusting
Freeze Thaw Resistance	Withstand weakening effects of freeze thaw cycle; durability
Skid Resistance	Safety, particularly over large patch areas

2.3 Variables Affecting Mixture Properties

There are many factors that affect the properties of cold patching mixtures. These factors should be carefully considered in the homemade mixture design process. Each design consideration may be modified to attain desired mixture properties and performance. Nevertheless, thorough deliberation must be given prior to any design modification as there is an inherent tradeoff between the mixture properties. For example, a design modification intended to increase workability will also often result in a decrease in stability. These design considerations are presented in Table 2.3 (Anderson et al., 1988; Estakhri and Button, 1995).

Table 2.3: Mixture Design Consideration (Anderson et al., 1988)

Design Consideration	Effect on Mixture
Aggregate Gradation	Well graded mixtures enhance stability Open graded mixtures provide workability and can prevent bleeding or thin binder coating Dense graded mixtures provide stability and durability and may avert water ingress and provide freeze-thaw resistance Less fines improve workability and stickiness More fines may improve stability
Aggregate Shape	Angular aggregate provides good stability by resisting rutting and shoving Rounded aggregate provides good workability
Binder Curing Rate	Slower curing rates ensure workability Faster curing rates ensure cohesion and stability
Binder Content	Lower binder contents prevent draindown, bleeding, shoving, and rutting Larger binder contents increase aggregate film thickness and improve workability, stickiness, and cohesion
Binder Viscosity	Soft binder ensures adequate binder coating and workability Stiff binder reduces stockpile draindown and stripping, tenderness during compaction, and in-service stripping, rutting, shoving, and bleeding
Additives	Reduce moisture damage; increase workability and cohesion

2.4 TxDOT Mixture Designs

Currently, TxDOT's Lubbock District formulates the mixture design for their stockpiled mixtures for pothole repairs throughout the year. Aggregates for their homemade mixtures are often purchased from local quarries and include Grade 5 crushed river gravel or crushed limestone. The binder used is a rapid-curing cutback: RC-250. During the winter months, diesel or kerosene is added to "thin" the binder and make it more workable. Although similar materials are used throughout the district, the homemade mixture design is not standardized and varies among maintenance sections.

Homemade mixture designs from the Muleshoe, Lamesa, and Morton maintenance areas in the Lubbock District were analyzed. The homemade mixture designs used in these areas, as provided by maintenance area personnel, are summarized in tables 2.4, 2.5 and 2.6. The Muleshoe maintenance area modifies their homemade mixture design based on the depth of potholes. Shallow potholes are patched with a light mixture consisting of Grade 5 aggregate, while deeper patches use a heavy mixture of Grade 4 and 7 aggregate. The Lamesa maintenance area, on the other hand, modifies their homemade mixture design for batch and blade mixes. The blade mix in Lamesa, like the Muleshoe heavy mix, includes Grade 4 aggregate. For the Morton maintenance area, a range of mixture proportions, by volume, was provided.

Although summer installations of these materials perform well, this is not the case for mixtures installed in the winter. Workability is particularly a problem in winter installations of cold patching mixtures. Poor workability hinders proper installation and compaction, ultimately leading to distress manifestation and consequent failure. A decrease in workability can be caused by different factors. For example, the use of an angular aggregate, such as Grade 5 crushed limestone, will increase stability at the expense of workability. Another factor in the poor performance of winter installations is the use of RC-250. This binder cures rapidly, particularly when left unprotected in a stockpile, decreasing the storage life and workability.

Table 2.4: Muleshoe Homemade Mixture Design

Material	**Percentage (By weight)**	
	Light Mix	**Heavy Mix**
Grade 4 or 7	--	27.3
Grade 5	81.8	54.5
Sand	18.2	18.2
RC-250	4.75	4.75
Diesel (in winter)	0.3	0.3
Additional RC (in summer)	0.25	0.25

Table 2.5: Lamesa Homemade Mixture Design

Material	Percentage (By volume)	
	Batch Mix	Blade Mix
Grade 4	--	25.4
Grade 5	50.8	25.4
Screenings	16.9	16.9
Dry Blow Sand	25.4	25.4
RC-250	6.0	6.0
Kerosene	0.55	0.55
Diesel	0.35	0.35

Table 2.6: Morton Homemade Mixture Design

Material	Percentage Range (By volume)
Grade 5	48.7 – 50.7
Screenings	24.3 – 25.4
Blow Sand	16.9 – 20.3
RC-250	6.0 – 6.3
Diesel	0.7

2.5 Containerized Mixture Designs

The Lubbock District seldom uses containerized mixtures. Nonetheless, they did report occasionally using Instant Road Repair, a rapid curing product containerized in a bucket. Even though the performance of the containerized material was satisfactory, the mixture was deemed too expensive to be used on a regular basis or over large areas. One of the objectives of this study was to determine if the performance of containerized mixtures was significantly better than that provided by homemade mixtures. Specifically, the goal was to establish the cost effectiveness of the different homemade and containerized mixtures.

The containerized mixtures considered in this study are, in alphabetical order, Asphalt Patch, Pacher, Perma Patch, Proline, QPR, Stayput, and UPM (Summer and Winter). These containerized mixtures offer a range of characteristics affecting the cold patching mixture design. Mixture designs for the containerized mixtures are not readily available and modified binders are often used to radically change binder properties. Gradations for these containerized mixtures, with the exception of Pacher, were determined. Homemade and containerized gradation curves are presented in Figure 2.1. The three homemade mixtures were provided by the Muleshoe, Littlefield, and Bovina maintenance areas for gradation analysis. The Muleshoe and Bovina homemade mixtures are relatively dense, whereas the Littlefield mixture has a high percentage of fines. Of the containerized mixtures, Asphalt Patch shows the finer gradation. QPR and Stayput are open gradations, whereas all others are denser.

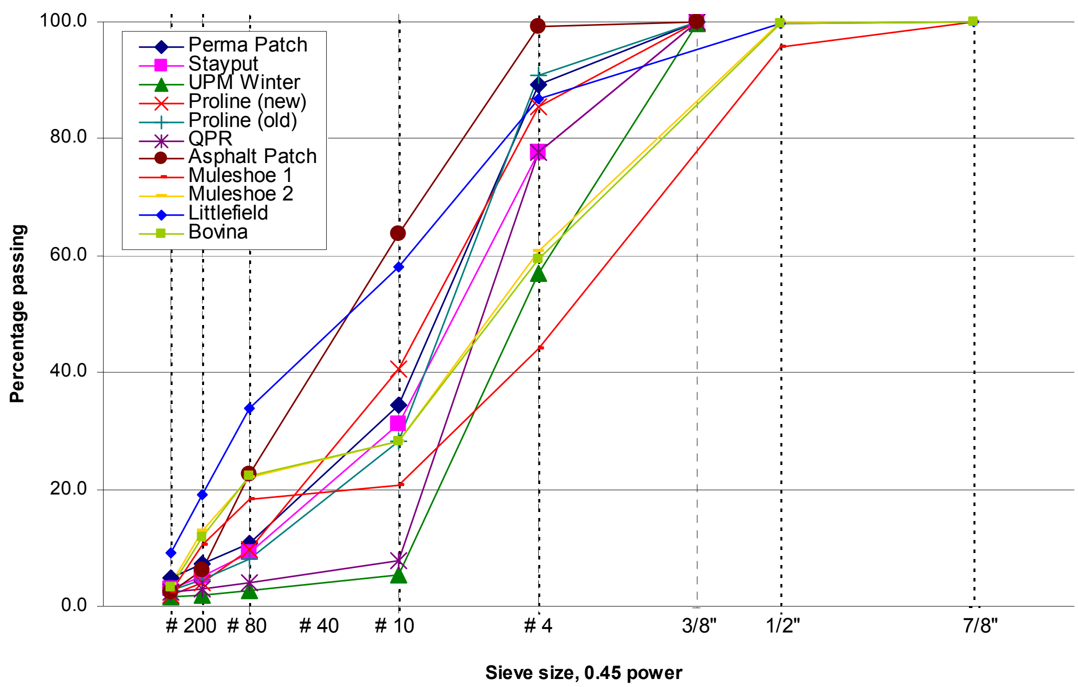

Figure 2.1: Gradation Curves for Homemade and Containerized Mixtures

2.6 TxDOT Mixture Procedures

2.6.1 Mixing Procedure

The homemade mixtures are often prepared in large batches and the volumetric proportioning used is only approximate. Different aggregates used in the mixture are proportioned by the truckload. The windrow of aggregate components is then mixed using a maintainer. Binder is heated in the range of 160˚F to 185˚F (71˚C to 85˚C), added to the mixed material, and mixed with the maintainer. The completed mixture is then placed into a stockpile, where it has a reported storage life of 45 to 60 days. The nature of this mixing procedure has also been identified as a potential cause of poor mixture performance, and may often produce a mixture that is not uniform. The lack of uniformity in the mixture makes the in-service performance variable. This random performance makes the identification of an optimum homemade design more difficult.

2.6.2 Installation Procedure

The Lubbock District identified two different patch installation methods as permanent and semi-permanent. TxDOT Function Code 241 specifies the installation procedure for semi-permanent repair of potholes. According to this temporary corrective method, the hole is prepared by removing and sweeping loose debris from the hole and applying a tack coat. The hole is then filled with patching material and leveled and compacted with hand or power equipment. The permanent installation procedure is contained in TxDOT Function Code 242. In this case, the hole is prepared by creating a square, saw-cut area. Unfortunately, in practice, patches are seldom installed following either method. Instead, patches are often installed using a “throw and roll” technique. In such cases, the material is placed in the pothole, with little or no hole preparation, and compacted by rolling the tire of the maintenance truck over the patched area.

3. Experimental Mixture Design Procedure

3.1 General Design Considerations

Based on the literature review, an experimental mixture design was created to develop a homemade mixture design procedure. The experimental design considered six variables as design considerations in the procedure. The effects of design variations on mixture properties were continually monitored through laboratory and field tests to identify those mixtures displaying desirable mixture properties. The design considerations used as variables in the experimental mixture design are presented in Table 3.1 and discussed in the following sections.

Table 3.1: Design Considerations

Factor	Low	Center	High
Gradation	Dense	Open	Fine
Aggregate Shape	Rounded	--	Angular
Binder Viscosity	Low	--	High
Binder Content	3.0 %	--	6.0 %
Compaction Temp	50˚F	77˚F	212˚F
Curing Time	0 hours	--	96 hours

3.1.1 Gradation

In order to represent the homemade mixtures currently designed in the Lubbock District, four aggregate stockpiles representative of the aggregate blends used in the district were collected. Grade 5 crushed river gravel and crushed river gravel screenings were collected from the R. E. Janes Quarry near Lubbock. Grade 5 crushed limestone was collected from the Vulcan Quarry in Brownwood. The Lubbock District provided the field sand.

Target gradations were established based on literature review and recommendations from TxDOT districts. Table 3.2 outlines aggregate proportion recommendations. In order to observe the gradation effects on the mixture properties, multiple open, dense, and fine mixtures were evaluated in the mixture design.

Table 3.2: Recommended Aggregate Proportions

Sieve Size	Percent Passing
3/8 in (9.5 mm)	100
No. 4 (4.75 mm)	85-100
No. 8 (2.36 mm)	10-40
No. 16 (1.18 mm)	0-10
No. 200 (0.075 mm)	0-2

3.1.2 Aggregate Shape

The experimental design also considered the effects of rounded and angular aggregate shapes. The use of angular aggregates in a mixture generally provides higher stability, whereas rounded aggregates tend to increase workability. Two types of Grade 5 aggregate (river gravel and crushed limestone) were used to attain the rounded and angular mixtures, respectively.

3.1.3 Binder Viscosity

Special consideration must be given to binders used in stockpile patching mixtures. To meet the objectives of this study, the viscosity of these binders should remain relatively low at low temperatures to ensure that the mixture remains workable. Moreover, the rate at which volatiles are lost must be controlled. Otherwise, the stockpile will cure prematurely and become an unworkable mass.

Both cutbacks and emulsions are used in stockpiled mixtures. This study only focused on the use of cutbacks. Cutbacks may be slow, medium or rapid curing with varying grades of viscosity between 250 and 800 cSt. Lower viscosity grades are desirable for longer stockpile life and during winter months.

3.1.4 Binder Content

A residual binder content of 4.5 percent is recommended in literature for stockpile patching mixtures. This recommendation is specific to mixtures with aggregates whose water absorption is less than one percent. The residual binder content should be increased for those mixtures containing aggregates with water absorption greater than 1 percent. A residual binder content range was used to determine the effect of varying binder content in cold patching mixtures.

3.1.5 Curing Time

In order to simulate aging in the field, all mixtures were cured prior to compaction. Screening experiments considered curing times of 0, 24, 48, 72, and 96 hours at temperatures of 77˚F (25˚C) and 140˚F (60˚C). Results from the screening experiments demonstrated that mixtures cured for shorter time at lower temperatures were less stable than those cured for longer time or at higher temperatures.

3.1.6 Compaction Temperature

The experimental mixture design procedure considered the effects of compaction temperatures at 50˚F (10˚C), 77˚F (25˚C), and 212˚F (100˚C). Screening experiments revealed that compactions performed at lower temperatures generated specimens with high air voids in the range of 11 to 14 percent. The high air void percentage is a significant limitation for testing procedures.

3.1.7 Admixtures

There are many commercially available admixtures with varying effects on cold patching mixtures. The most commonly used admixture is an anti-stripping agent. This admixture helps the mixture retain its coating under adverse weather conditions in the stockpile, during placement, and in-service. A small fraction of mixtures was prepared without an anti-stripping agent in the screening experiments. These mixtures quickly failed under the Hamburg Wheel Tracking Device (HWTD) due to stripping. It was determined that the use of anti-stripping agent was crucial.

3.2 Preliminary Mixture Design

The preliminary mixture design procedure was developed based on screening experiments on the various design considerations. Tables 3.3 and 3.4 summarize the different angular and rounded mixtures prepared and tested as part of the preliminary mixture design. The design considerations are discussed in the following sections.

Table 3.3: Angular Aggregate Preliminary Mixture Design

Binder (%)	**Aggregate Gradation**					
	Dense		**Open**		**Fine**	
3.0			X			
3.5	X		X			
4.0	X	X	X			
4.5	X		X			
5.0	X					
5.5						
6.0						
	No Diesel	Diesel	No Diesel	Diesel	No Diesel	Diesel

Table 3.4: Rounded Aggregate Preliminary Mixture Design

Binder (%)	**Aggregate Gradation**					
	Dense		**Open**		**Fine**	
2.5			X			
3.0			X			
3.5	X		X			
4.0	X	X	X		X	
4.5	X	X	X			
5.0	X		X		X	
5.5					X	
6.0					X	
	No diesel	Diesel	No Diesel	Diesel	No Diesel	Diesel

3.2.1 Gradation

The target gradations for the so-called fine, open, and dense graded mixtures were based on the gradation curves of various containerized and Lubbock homemade mixtures. These target gradations were achieved by blending in different proportions based on gradation curves of aggregate stockpiles. However, the maximum aggregate size of the mixtures was limited to 3/8 inch. Figure 3.1 depicts the aggregate stockpile and target gradations used in the preliminary mixture design procedure.

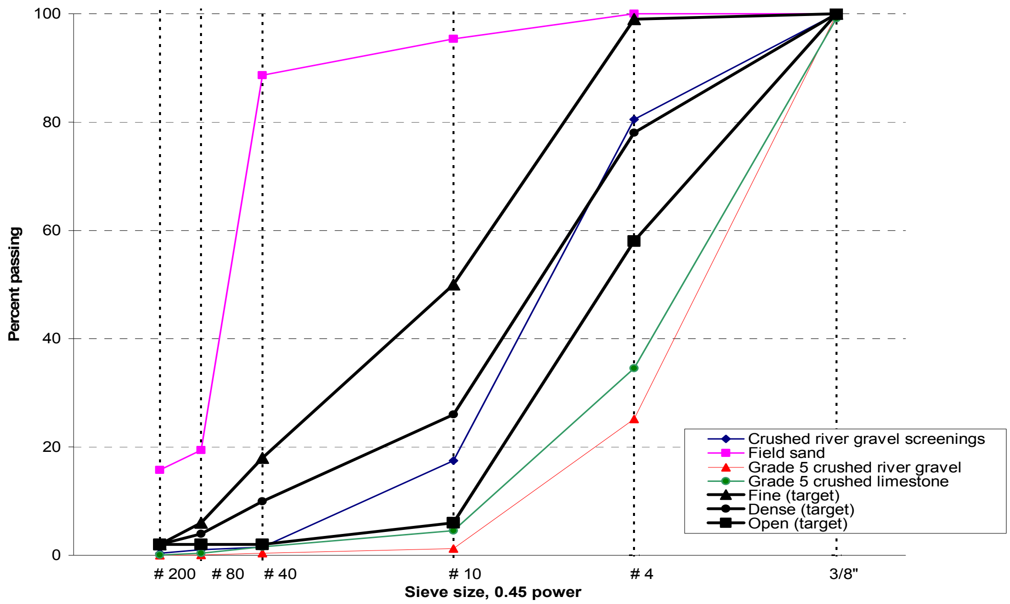

Figure 3.1: Aggregate Stockpile and Target Gradation Curves

3.2.2 Aggregate Shape

The preliminary design focused on the characteristics of rounded and angular mixtures. The rounded aggregate blends were produced with Grade 5 crushed river gravel. Conversely, the angular blends were produced with Grade 5 crushed limestone. All mixture designs included Lubbock field sand.

3.2.3 Binder Viscosity

Researchers observed that the Lubbock homemade mixtures using the rapid curing RC-250 binder appeared to be fully cured when containerized field trials were performed. On the other hand, commercial mixtures are generally produced with slow or medium-curing cutback asphalt to prolong the material storageability. Consequently, the experimental design incorporated the use of medium-curing kerosene-based cutback, MC-250, produced by Valero Marketing. The low viscosity grade was selected because of the focus on mixture performance in winter months. This binder is produced by mixing approximately 35 percent PDA (pure asphalt) with a viscosity of 9,781 poise and 65 percent MC-30 binder. The final mix contains about 67 percent residual binder by volume. In the Lubbock District, diesel is often added to lower the binder viscosity and increase workability. The amount of diesel added is generally 9:1 RC-250 to diesel by volume. In order to capture the effects of a change in binder viscosity on the mixture design, mixtures with and without diesel were considered in the experimental design.

3.2.4 Binder Content

The residual binder content in the preliminary mixture design centered on the recommended 4.5 percent, and ranged from 3.0 to 6.0 percent. Dense and open mixtures had residual binder contents ranging from 3.0 to 5.0 percent. On the other hand, fine mixtures had a residual binder content range of 4.0 to 6.0 percent.

3.2.5 Curing Time

In order to conduct the necessary laboratory testing on the preliminary mixtures, sound specimens were required. Materials cured for less time at lower temperatures often resulted in unstable specimens that collapsed immediately after extrusion from their molds. As a result, all mixtures in the preliminary mixture design were cured at 140˚F (60˚C) for 96 hours before compaction.

3.2.6 Compaction Temperature

Compaction temperature is a significant factor during compaction in the field and several temperatures were considered during the screening experiments. However, screening experiments revealed that compactions at the lower temperatures generated Superpave gyratory specimens with high air voids (11 to 14 percent). The large percentage of air voids was detrimental to the HWTD stability results. Therefore, compactions were done at higher temperatures to simulate hot mix preparations, and reduce the air void percentage to less than 10 percent at 200 gyrations under the Superpave gyratory compactor (SGC).

3.2.7 Admixtures

Screening experiment results from the HWTD highlighted the importance of anti-strip agents in the design of homemade mixtures. Various mixtures with and without anti-strip were prepared as part of the preliminary mixture design. The anti-strip agents considered were hydrated lime and two liquid anti strips, UPM and Tomah DA-17. These mixtures were all dense gradations with rounded aggregate and binder content between 3.5 and 4.5 percent. The mixtures were tested as part of a winter field trial discussed in a later chapter. The mixes are summarized in the following table.

Table 3.5: Rounded Anti-Strip Mixture Design

Binder (%)	**Dense Gradation**	
2.5		
3.0		
3.5	OXUD	
4.0	UD	XUD
4.5	UD	D
	No Diesel	Diesel
Legend:	O = without anti-strip agent	
	X = hydrated lime	
	U = UPM liquid anti-strip	
	D = Tomah DA-17 anti-strip	

3.2.8 Preliminary Conclusions

All testing, and corresponding results, of the preliminary mixtures are described in the following chapter. Based on preliminary results from these tests, a very workable candidate mixture was identified as encompassing all the desirable properties for good in-service performance. The candidate mixture identified was a dense gradation with rounded aggregate. Materials included Grade 5 crushed river gravel, crushed river gravel screenings, field sand, and lime, with a 4.0 to 4.5 percent residual binder content. The effect of angular versus rounded aggregate used during the screening experiments, surprisingly, did not show any significant differences. These mixtures were prepared and installed as part of a winter field trial in the Lubbock District (to be discussed fully in a later chapter). Unfortunately, the abnormally hot weather prevailing during the preliminary field trials rendered this mixture too workable and lacking in initial stability. The mix design was then revisited and modified based on testing and field observations, with a particular emphasis on stability.

3.3 Modified Mixture Design

Based on test results from the preliminary mixture design, modifications were made. The modified mixture design was more refined and focused on mixture stability and workability. The rounded mixtures prepared and tested as part of the modified mixture design are summarized in Table 3.6. The design modifications are discussed in the following sections.

Table 3.6: Rounded Aggregate Modified Mixture Design

Binder (%)	Aggregate Gradation					
	Dense		Medium		Open	
3.5	X		X	X	X	
4.0			X			
4.5			X			
	1% Lime	2% Lime	1% Lime	2% Lime	1% Lime	2% Lime

3.3.1 Gradation and Aggregate Shape

The same materials used in the candidate mixtures, identified in the preliminary mixture design, were used in the modified mixture design. However, the modified mixture design only considered rounded mixtures prepared with Grade 5 crushed river gravel. This material is often used and less expensive than the Grade 5 crushed limestone. Target gradations were modified as a result of the preliminary mixture design and preliminary testing results. Figure 3.2 below displays the modified target gradation curves. For consistency the target gradations are labeled open, medium, and dense. Yet, they are relatively open as a result of laboratory and field observations. It is important to note that the available materials usually lack fines or dust.

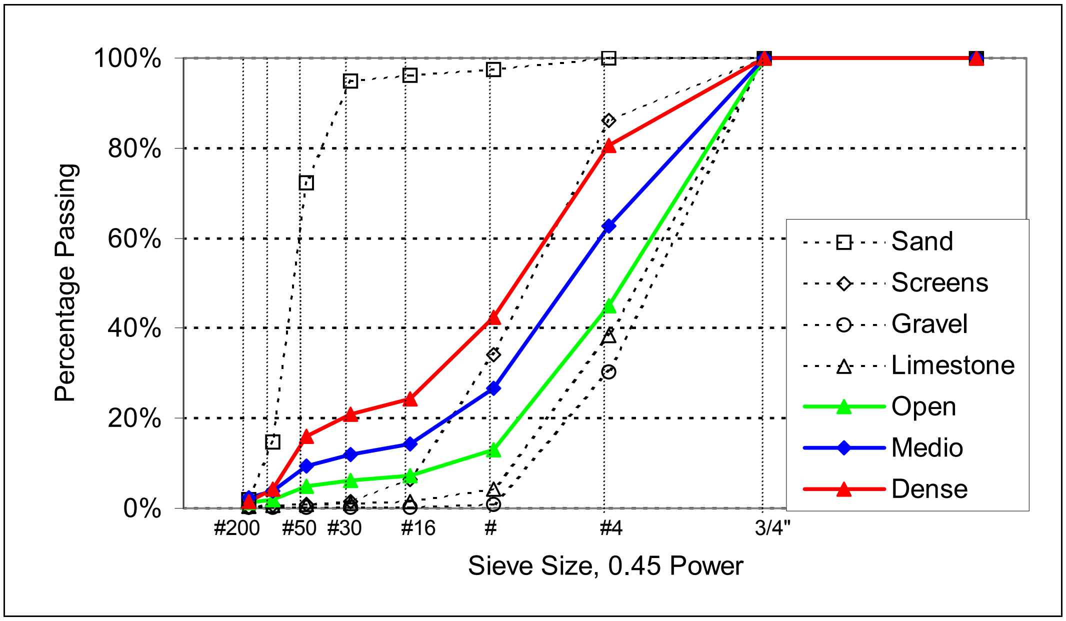

Figure 3.2: Modified Target Gradation Curves

3.3.2 Binder Content and Viscosity

Since the problem in the field was excessive workability, the use of diesel was discontinued in the modified mixture design. The low viscosity grade cutback, MC-250, was still used in the preparation of the mixtures.

The residual binder content range was narrowed based on preliminary Cold Patch Slump Test (CPST) and Hamburg Wheel Tracking Device (HWTD) testing results, as described in sections 4.2 and 4.4, respectively. The residual binder content considered in the modified mixture design ranged from 3.5 to 4.5 percent. This smaller range was identified in an effort to identify the optimal residual binder content for the target gradations under consideration.

3.3.3 Compaction Temperature and Curing Time

As a result of the limitations encountered with some of the preliminary testing, cold patch mixtures were cured and compacted at elevated temperatures to simulate hot mix materials. Results from the preliminary winter evaluation proved this approach to be invalid as it drastically changed the characteristics of the cold patching material specimens previous to testing. In order to capture the stability specific to cold mixtures, a new test was developed as part of the modified mixture design. The Texas Stability Test (TST) used the Texas Gyratory Compactor (TGC), as described in Section 4.5, to produce specimens that did not require compaction at the elevated temperatures used with the SGC. The effects of curing at 0, 168, and 336 hours were also considered as part of the TST. Curing was only performed after the specimens had been compacted.

3.3.4 Admixtures

Despite issues arising from the preliminary winter field evaluation, the benefits of anti-stripping agents in the mixtures was evident as a result of preliminary laboratory testing. As part of the modified mixture design, all mixtures were prepared only with hydrated lime. The lime also provided some of the fines lacking in the available aggregates. The effects of various lime percentages were analyzed with the laboratory and accelerated pavement testing under the Model Mobile Load Simulator (MMLS3). MMLS3 procedure and results are presented in Chapter 5.

3.3.5 Modified Conclusions

All testing procedures and results obtained as part of the modified mixture design are described in the following chapters. The most promising candidate mixture was identified for installation in a modified winter field evaluation. The mixture was the medium gradation with 3.5 percent residual binder and two percent lime. Materials included Grade 5 crushed river gravel, crushed river gravel screenings, field sand, and lime. Results from all laboratory and accelerated pavement testing, in conjunction with field evaluation data, was used to develop the suggested homemade mixture design and performance-based specifications presented in Chapter 8.

3.4 Mixing Procedure

The mixing procedure used, as summarized below, was based on the Lubbock mixing procedure and the literature review. The mixing process takes anywhere from 5 to 10 minutes depending on the size of the mix to be prepared.

- Dry aggregates by heating them at 230±9ºF (110±5ºC) for 24 hours
- Allow aggregates to cool at room temperature prior to mixing
- Determine aggregate stockpile percentages based on desired gradations
- Place aggregate stockpile proportions in mixer
- Add appropriate amount of lime to dry aggregate
- Blend dry mixture for a few minutes until aggregate is coated with lime
- Heat binder to approximately 160ºF (72ºC)
- Determine binder amount to be added to aggregate blend
- Mix binder into aggregate blend until mixture is uniform

4. Laboratory Testing

The laboratory tests performed throughout the preliminary and modified mixture design procedures are described in this chapter. Screening experiments were conducted to establish the appropriate laboratory tests and procedures to be used in the development of the mixture design procedures and specifications.

4.1 Gradation Analyses and Aggregate Screening

Gradation analyses were conducted on the containerized mixtures, aggregate stockpiles, and homemade mixtures from the Lubbock District in order to develop the dense, open, and fine target gradations for the preliminary mixture design procedure. Angular and rounded dense-graded aggregate blends were used as part of the screening experiments.

A sieve analysis was also conducted on the aggregate blends used in the screening experiments. According to Tex-210F, "Extraction of Bituminous Mixtures," an aggregate blend was prepared directly from the aggregate stockpile while another was blended after sieving portions of the stockpile and blending according to the aggregate fractions retained on the various sieves. Since no significant difference was observed between the aggregate blends, all subsequent aggregate blends were prepared from the aggregate stockpiles.

4.2 Cold Patch Slump Test

Workability is the material's handling ability or ease of placement in the field. This material property is essential both in the stockpile during storage and in the field during installation to ensure adequate patch performance. A workability test is particularly important in conjunction with stability testing because desirable properties such as workability and stability often conflict.

The Cold Patch Slump Test (CPST) was developed as part of this study to evaluate the workability of cold patching material during cold weather (Chatterjee et al., 2006). The effects of compaction, temperature, and curing on the workability of cold patching mixtures were considered in the development of this test. The test consisted of two objective measures of workability and one subjective measure.

4.2.1 Procedure

The CPST apparatus and testing procedure were developed in the Bituminous Materials Laboratory at The University of Texas at Austin (Chatterjee et al., 2006). The apparatus used to complete the CPST is displayed in Figure 4.1. Cylindrical specimens of 4-inch diameter by 8-inch height were prepared by compacting a pre-measured amount of cold patch material in polyvinyl chloride (PVC) tubes in two lifts with the standard Marshall hammer. Specimens were prepared with varying compaction efforts of 5 and 10 blows of the Marshall hammer. This was conducted at room temperature of about 77˚F (25˚C). The specimen, with an aspect ratio of approximately 2, was placed in a sealed PVC tube and conditioned in a temperature controlled chamber at 35˚F (1.7˚C), 55˚F (12.8˚C), and 75˚F (23.9˚C) for 24 hours. Once conditioned, the material was extracted from the PVC tube and placed on the cavity of the wooden containment unit at room temperature. The time to slump was recorded as the first measure of workability.

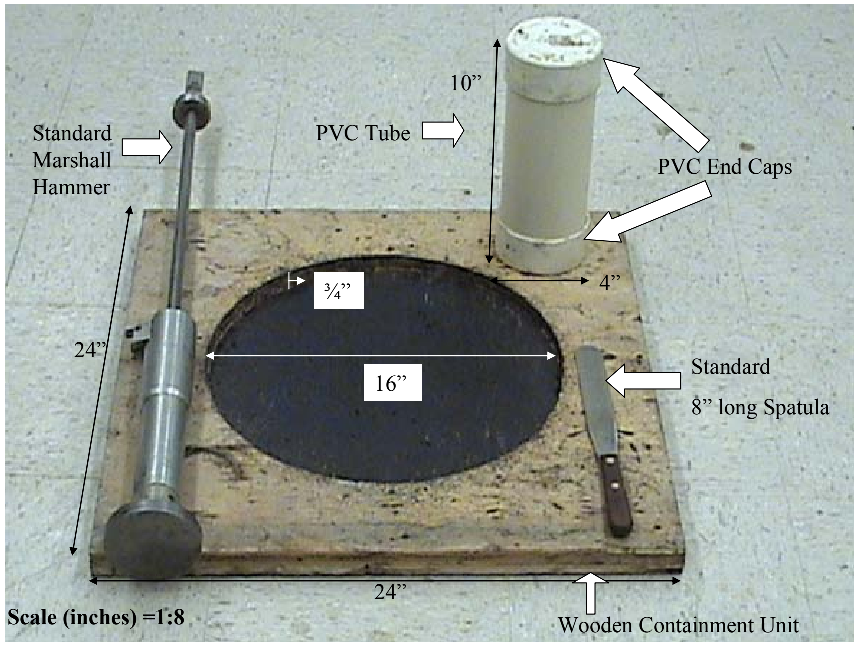

Figure 4.1: Cold Patch Slump Test Apparatus (from Chatterjee et. al., 2006)

The second component of the CPST was to have a rater spread the cold patching material into the cavity of the wooden containment unit using a standard 8-inch spatula. Time to fill the cavity was recorded as the second measure of workability. The rater also provided a subjective rating of the material. The subjective ratings were based on a range of 1 to 5 where very workable was denoted by 1 and not workable was denoted by 5. A standard procedure for specimen preparation and testing with the CPST is presented in Appendix A.

4.2.2 Results

Containerized Materials

The CPST was used to test the workability of six containerized cold patching materials (Asphalt Patch, Perma Patch, Proline, QPR, Stayput, and UPM Winter). Replicates of all the materials were applied different compactive efforts and tested at varying temperatures. The two objective measures of the CPST, time to slump under own weight and time to fill containment unit, are presented on a logarithmic scale in Figure 4.2. This chart can be divided into four quadrants that represent the material workability and cohesion. Those materials in the upper right quadrant, such as Stayput, represent mixtures that require a long time to slump and work into the containment unit. These mixtures are denoted as unworkable and would require a significantly longer time to install in the field. On the other hand, the lower left quadrant represents those materials that require shorter time to slump and fill and are very workable. This includes, for the most part, Perma Patch, QPR, and UPM Winter. Although workability is a desired property in cold patching mixtures, excessive workability may be an indicator of poor material stability. Most importantly, the lower right quadrant represents those materials that are workable and cohesive. Materials in this quadrant include mostly Perma Patch and Proline. The small time to fill the containment unit is representative of good workability while the large time required to slump is indicative of good material cohesion.

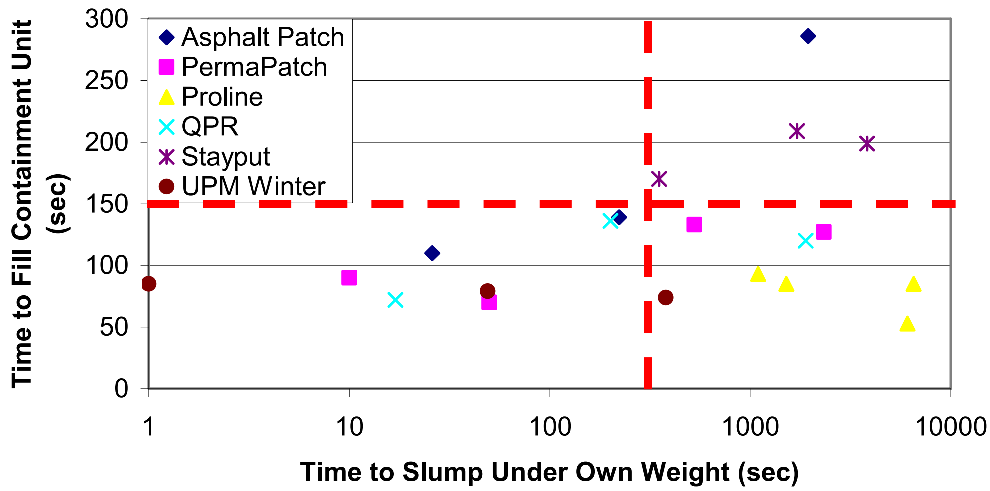

Figure 4.2: CPST Containerized Objective Results at Ten Blows per Lift

Another interesting result from the CPST was the change in time to fill the containment unit with varying conditioning temperatures as presented in Figure 4.3. Although variability is introduced into the time to fill data as a result of the effort applied by the rater to work the material into the wooden containment unit, results give a general indication of the relative workability of the materials. Materials such as Perma Patch, Proline, and UPM consistently have lower time to fill, which indicates good material workability. Conversely, Stayput tends to take longer time to fill, demonstrating poor workability. At lower temperatures, the different containerized materials have significantly different measures of workability. However, as the temperature increases, the objective workability measures of all the materials, with the exception of Stayput, appear to converge. In addition, there is a slight increase in time to fill at lower temperatures, which coincides with poorer workability encountered in cold weather material installations.

Similarly, the time to slump can be used to evaluate the effects of the conditioning temperature on material cohesiveness. Figure 4.4 displays the change in time to slump with varying conditioning temperatures on a logarithmic scale. The graph demonstrates that there is a well-defined negative linear correlation between the time to slump and the conditioning temperature. At lower temperatures the time to slump is larger, which is indicative of good material cohesiveness in colder weather. Excessive cohesion coupled with poor workability can result in clumpy mixtures that are hard to work and install. Proline, which previously displayed good workability, also exhibited good material cohesion at all conditioning temperatures. This increase in material cohesion is most likely a result of the use of modified binders in their design. UPM Winter, although workable, consistently demonstrated low cohesion.

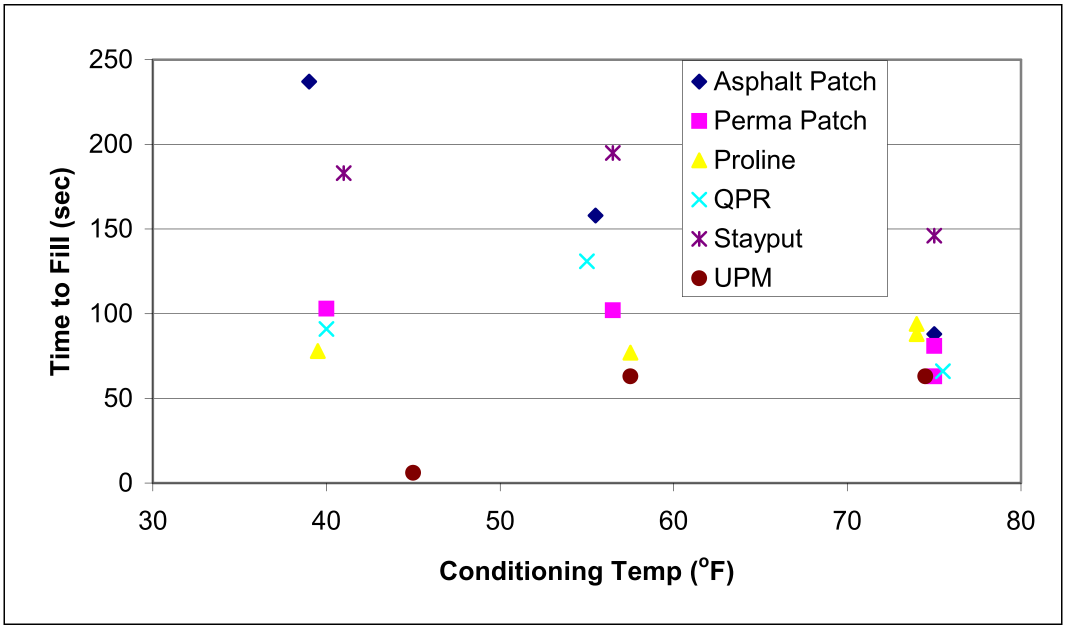

Figure 4.3: Temperature Effects on Time to Fill at Five Blows per Lift

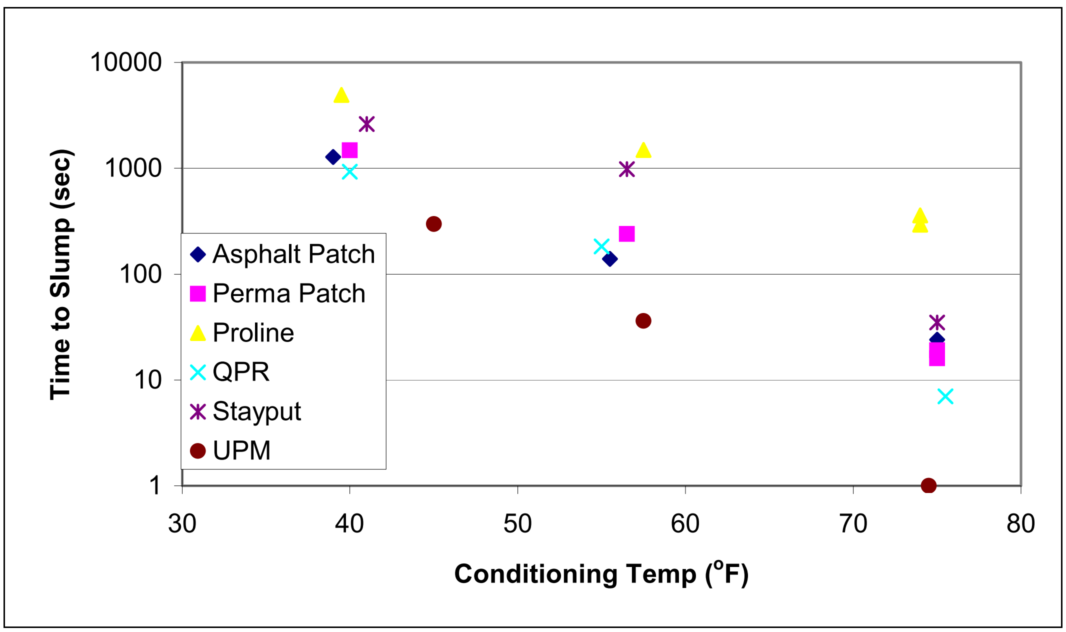

Figure 4.4: Temperature Effects on Time to Slump at Five Blows per Lift

The third component of the CPST was a subjective workability rating assigned by the rater working the material into the containment unit. Materials were assigned subjective ratings from one to five, with five representing the poor workability extreme. Figure 4.5 displays the correlation between the objective and subjective measures of workability in the laboratory, time to fill and subjective ratings. While variability is an inherent result of subjective ratings and effort applied by rater, there is a general linear correlation between the time to fill and the subjective measure of workability. In order to validate the laboratory workability results, correlation with field workability measures will be performed in the field evaluation section of this report.

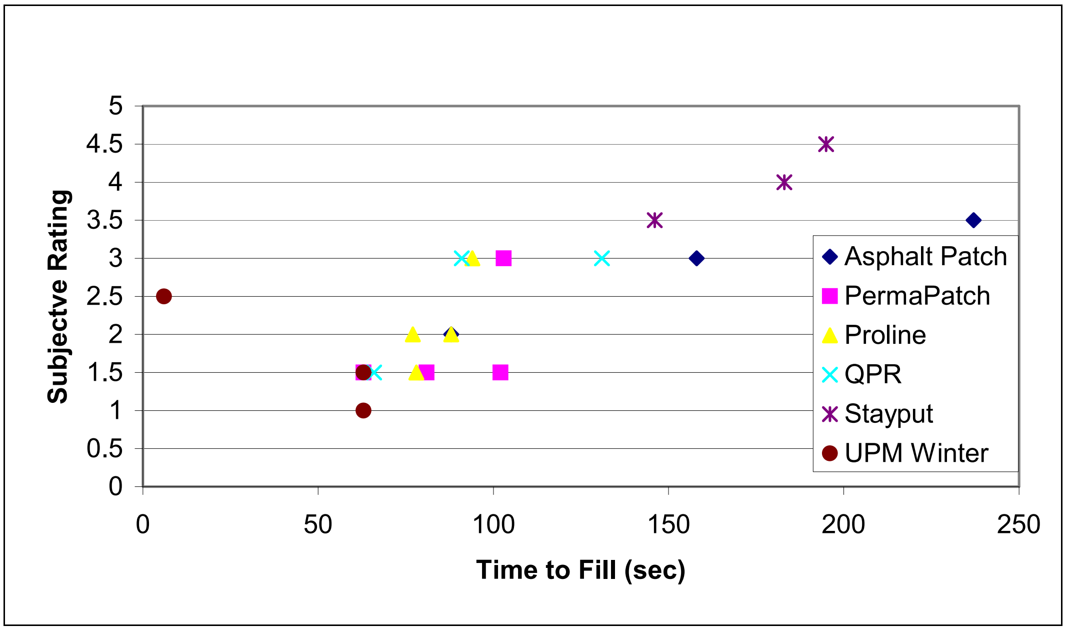

Figure 4.5: Objective/Subjective Containerized Laboratory Workability

Homemade Materials

As per the preliminary mixture design, the homemade mixtures tested with the CPST were dense and open-graded mixtures with rounded and angular aggregates. In order to capture the effects of aging on the workability of cold patching mixtures in the stockpile, the mixtures were cured at 77˚F (25˚C) for 0, 24, and 72 hours. Since the objective of this study is to evaluate the workability of cold patching mixtures in cold weather, it was decided to conduct the CPST on homemade materials conditioned only at 35˚F (1.7˚C) for 24 hours and prepared with a compaction effort of ten blows per lift. The residual MC-250 binder content ranged from 2.5 to 4.9 percent.

Figure 4.6 presents the time to slump under own weight and time to fill containment unit for dense angular and dense rounded mixtures at the different curing times. This figure is similar to Figure 4.2 in that it can be divided into quadrants that represent material workability and cohesiveness. All homemade mixtures were encompassed in the workable quadrants. Time to fill and slump under own weight show a general increasing trend as curing time increases. This shows that the mixtures become more cohesive and less workable as a result of curing. The dense rounded mixtures have a slightly smaller time to fill values, indicating a more workable mixture, as compared with the dense angular mixture.

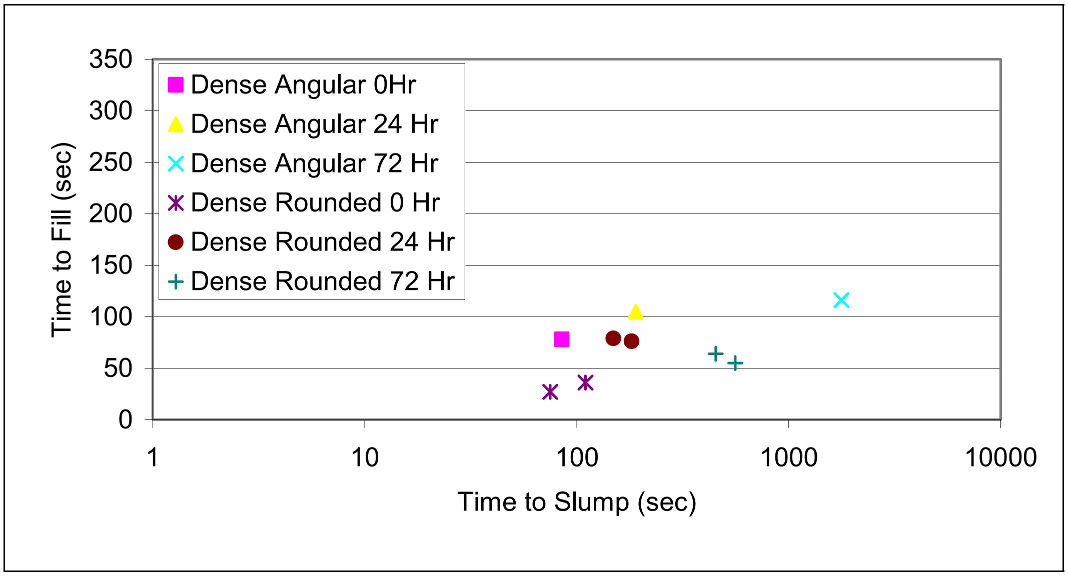

Figure 4.6: CPST Homemade Objective Results at Ten Blows per Lift

The effects of the residual binder on the time to fill and time to slump are presented in figures 4.7 and 4.8, respectively. According to Figure 4.7, the workability of open rounded mixtures increases with decreasing residual binder content. On the other hand, the workability of open angular mixtures appears to be decreasing as the residual binder content is reduced. Even though workability is a desirable property, too much can be detrimental to the stability of the mixture. Therefore, a medium workability range is optimal. Trends in the time to fill measurements seem to indicate that residual binder content in the range of 3.0 to 4.0 percent may be desirable for workability purposes in open gradations, regardless of the aggregate shape.

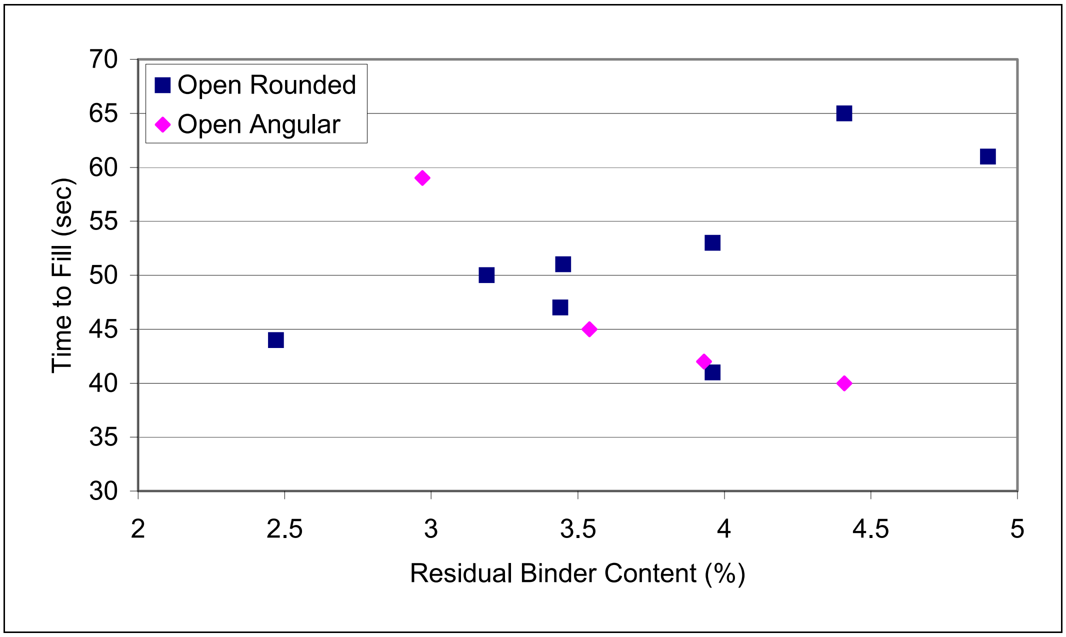

Figure 4.7: Effect of Residual Binder on Time to Fill

The time to slump and the residual binder content of homemade open rounded mixtures appear to have a negative linear correlation on a logarithmic scale. As the residual binder content of the mixtures increase, the cohesion of the mixture decreases. The cohesion rates of decrease change with curing time. At higher curing times, the loss of cohesion as a result of increasing residual binder content is less pronounced.

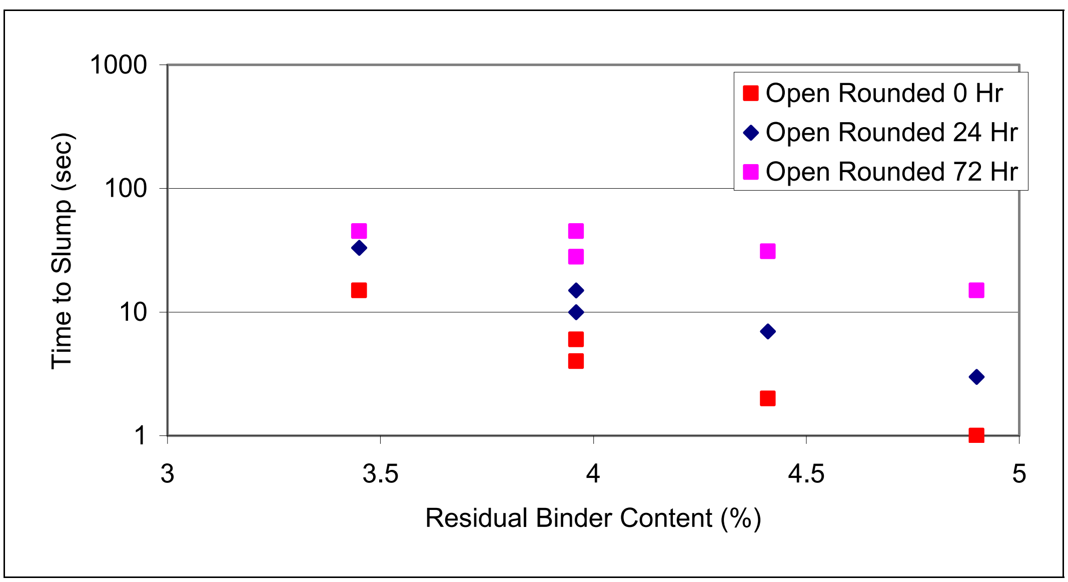

Figure 4.8: Effect of Residual Binder on Time to Slump

Figures 4.9 and 4.10 display the effects of curing on time to fill and slump for open rounded and open angular mixtures of varying residual binder contents. Both figures display a positive correlation. The time to fill generally increases for all mixtures with increasing curing time. Yet, the correlation seems exponential, as the rate of increase also appears to increase as a function of curing time. This is representative of the loss in workability phenomenon encountered in the stockpile as a result of aging. At 0 hour, the time-to-fill measurements are relatively comparable for all mixtures. As curing time increases, the angular mixtures have significantly larger values. This suggests the cured angular mixtures are less workable than the cured rounded mixtures. The time to slump on a logarithmic scale as a function of curing time follows a linear, more uniform, increasing trend. Open angular mixtures consistently show higher time to slump values, which qualifies them as the more cohesive mixtures.

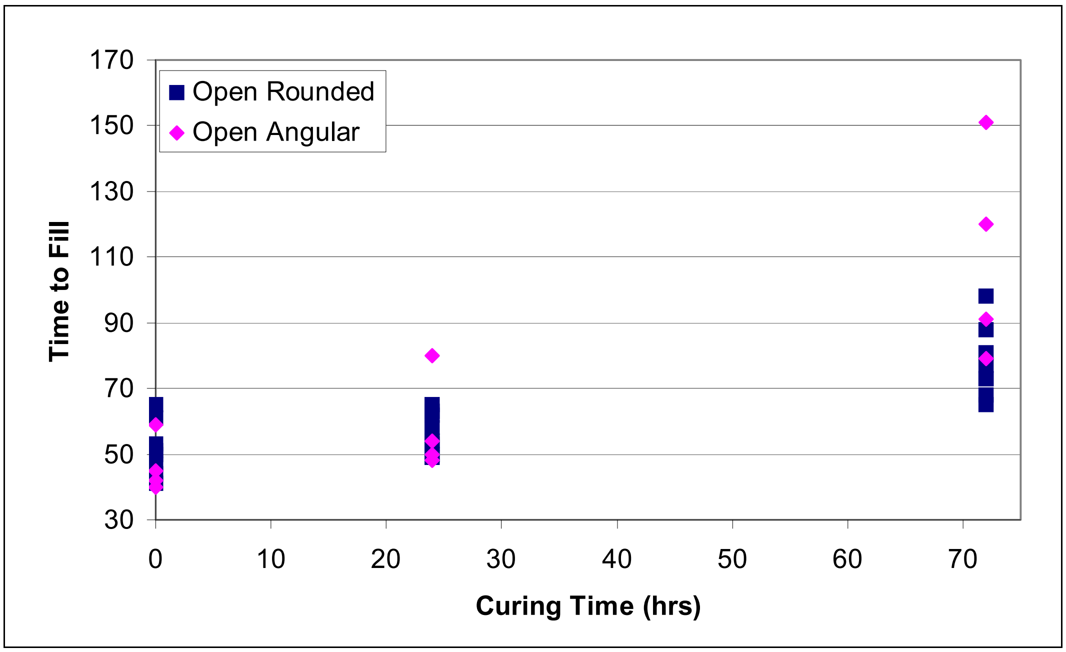

Figure 4.9: Effect of Curing Time on Time to Fill

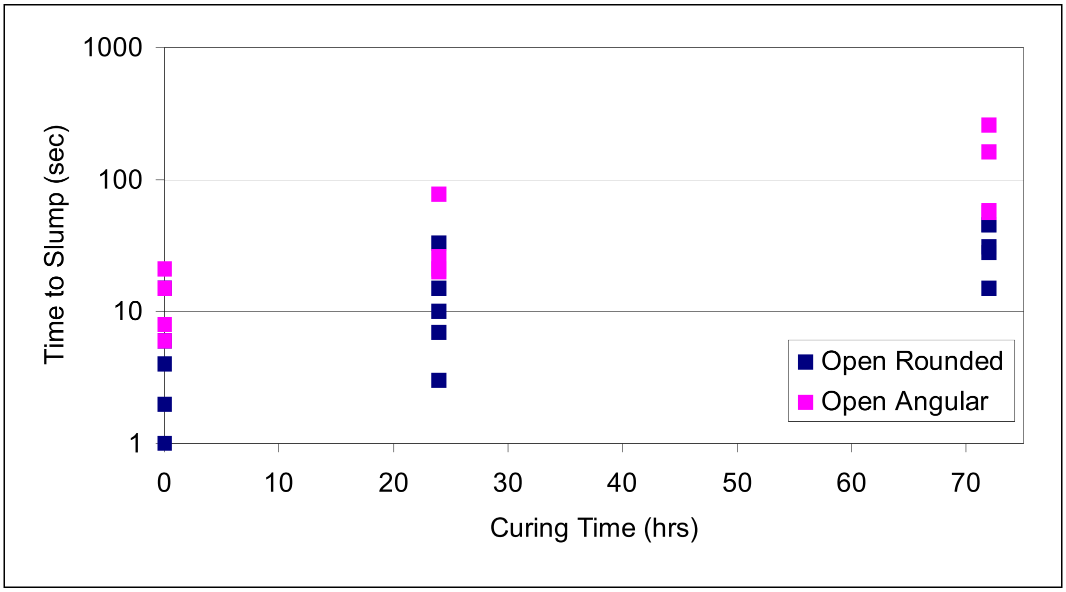

Figure 4.10: Effect of Curing Time on Time to Slump

In order to validate time-to-fill as an adequate objective measure of workability for homemade mixtures, the subjective workability values assigned by the raters were compared. Figure 4.11 displays the correlation between the objective and subjective measures of workability in the laboratory for all the homemade mixtures. Despite the inherent variability, there is a distinct linear correlation between the time to fill and the subjective measure of workability.

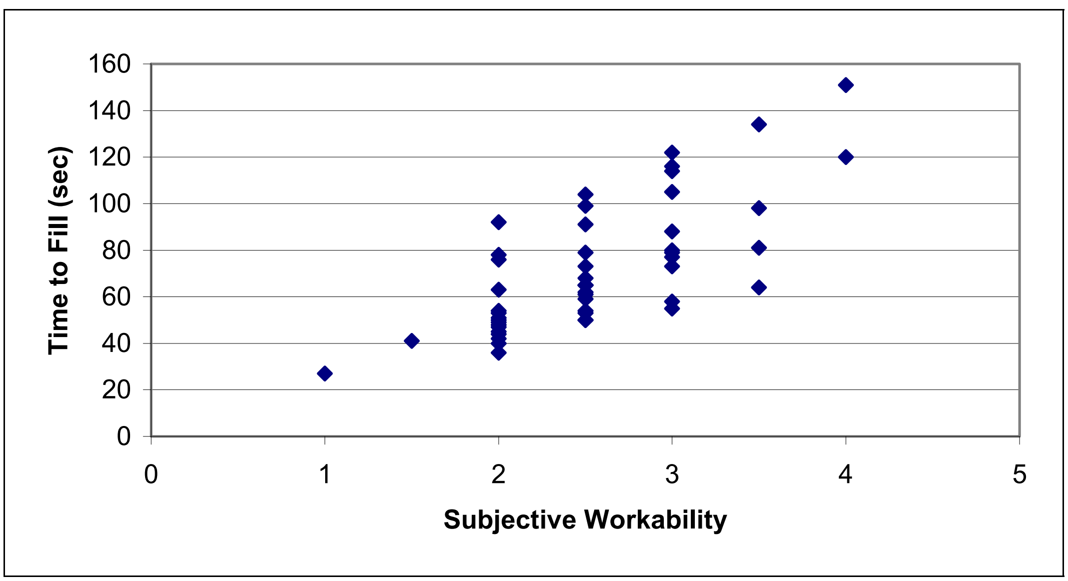

Figure 4.11: Objective/Subjective Homemade Laboratory Workability

4.3 Superpave Gyratory Compaction

Initially, the intention was to use the Superpave Gyratory Compactor (SGC) to prepare specimens for the Hamburg Wheel Tracking Device (HWTD). However, Superpave gyratory compaction is intended for hot-mix asphalt, and its use on cold patching mixtures was limited.

4.3.1 Procedure

In preparation for the compaction procedure, cold patching materials were cured for 0, 48, and 96 hours. Both cured and uncured cold patching materials were compacted according to established procedures with a standard vertical stress of 600kPa, a gyratory angle of 1.25º, and gyrations at 30 rpm. In order to simulate hot-mix mixtures, the cold patching material was compacted at relatively high temperature of 212˚F (100˚C). Compaction concluded at a final specimen height of 63 mm or 200 gyrations, whichever occurred first. In an attempt to achieve both termination conditions at the same time, a consistent and adequate material amount was used for specimen preparation. Since many specimens did not undergo the desired 200 gyrations and the Hamburg stability testing tolerance limit for compacted specimen heights is 62±2 mm, the height criterion was lowered to 60 mm.

4.3.2 Results

Homemade mixtures compacted with the SGC included dense and open gradations with rounded and angular aggregate. The binder content varied from 3.5 to 5.0 percent. According to the preliminary investigation, compaction densities of more than 90 percent are desirable for durability of cold patching mixtures. However, Superpave gyratory compaction could not achieve final air voids of less than 10 percent for mixtures cured for 0 and 48 hours. Nearly all of the compacted specimens achieved air voids in the range of 11 to 14 percent with curing times of 48 hours. Those specimens cured for 96 hours approached densities of 10 percent at 200 gyrations. More than 200 gyrations were not implemented because this high compaction effort would lead to aggregate crushing, especially when softer limestone aggregates were used. A reasonable observation gathered from Superpave gyratory compaction curves was that those mixtures with higher residual binder contents had lower air voids.

4.4 Hamburg Wheel Tracking Test

Stability is representative of the material's resistance to vertical (densification) and horizontal (shear) deformation under traffic loads. The Hamburg Wheel Tracking Device (HWTD) was originally considered to perform stability testing on the preliminary mixtures. Specifically, it was used to determine the material's resistance to rutting. The HWTD was designed for testing hot-mix specimens, which are compacted uncured while still hot. Unlike hot-mix, cold mix specimens have a high air void percentage after Superpave gyratory compaction. The result was less stable specimens which would often fall apart upon extrusion from the mold. In order to achieve adequate specimens for testing under the HWTD, researchers decided that the air void percentage had to be minimized to less than 10 percent at 200 gyrations under the SGC. Unfortunately, cold patch specimen stability was also a problem during testing. A previous study indicated that mixtures tested uncured or at temperatures greater than 77˚F (25˚C) (regardless of curing time) were particularly unstable during testing.

4.4.1 Procedure

Special consideration was given to material conditioning to address the high air void percentage and ensure the integrity of the cold patch specimens during preparation and testing under the HWTD. In preparation for compaction, cold patch materials were cured for 96 hours at 140˚F (60˚C). The material was then compacted at an "elevated" temperature of 212˚F (100˚C) for 200 gyrations. The maximum number of gyrations was used, with special consideration for the final specimen height requirements, in order to minimize the percentage of air voids in the specimens. Compacted specimens were tested under water at 77˚F (25˚C) according to standard HWTD procedures. Testing under the HWTD was concluded at 20,000 cycles or 12.5 mm rut depth, whichever occurred first.

4.4.2 Results

The stable homemade mixture specimens prepared with the SGC were tested under the HWTD. This included open rounded, dense rounded and dense angular mixtures. All homemade mixtures included lime to reduce stripping under the HWTD. Results from preliminary tests are presented in Figure 4.12. The measured rut depth, in mm, is displayed as a function of the number of applied cycles. All three aggregate shapes and combinations were produced with 4.0 percent residual MC-250 binder content. The graph illustrates that the dense rounded mixture is significantly more stable than the other mixtures under the HWTD. The open rounded mixture was the least stable, after failing at 6,500 cycles under the HWTD.

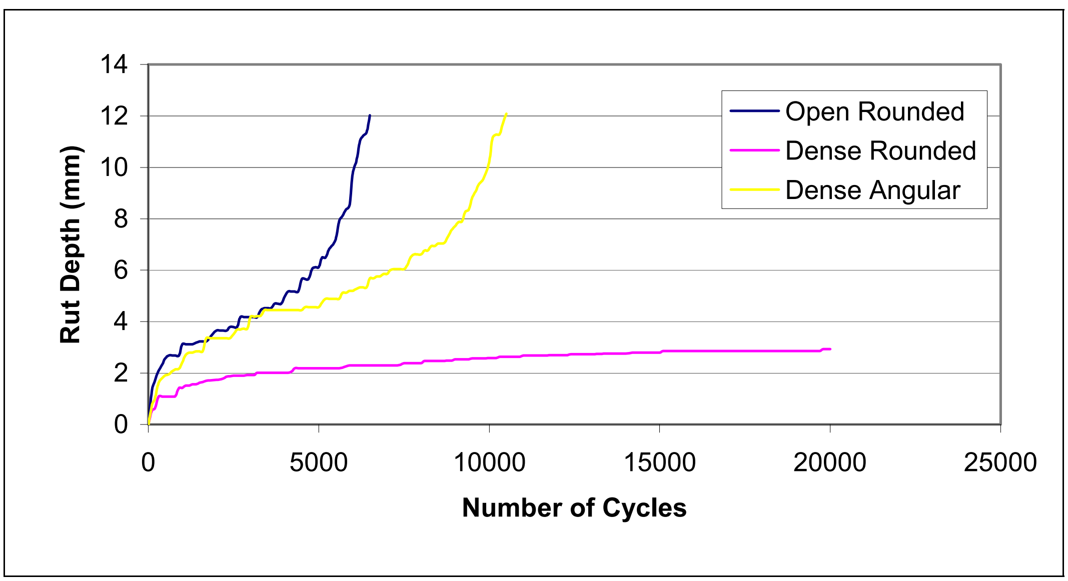

Figure 4.12: Gradation and Aggregate Shape Effects on Stability

Figure 4.13 demonstrates the effect of varying residual binder content on the stability of open rounded mixtures. The mixture prepared with 3.5 percent residual binder content displayed significantly less stability than the other three mixtures, whereas the mixture prepared with 4.0 percent residual binder content was slightly better than the others. This could be indicative of an optimum residual binder content for that aggregate shape and gradation. Although the HWTD is a good indicator of the relative stability of the mixtures, the majority of the mixtures failed prematurely. The premature failures were observed even after "cooking" the cold patching material to obtain stable testing specimens. Consequently, this test was deemed too harsh for cold patching mixtures and its use was discontinued in the development of the homemade mixture design procedure.

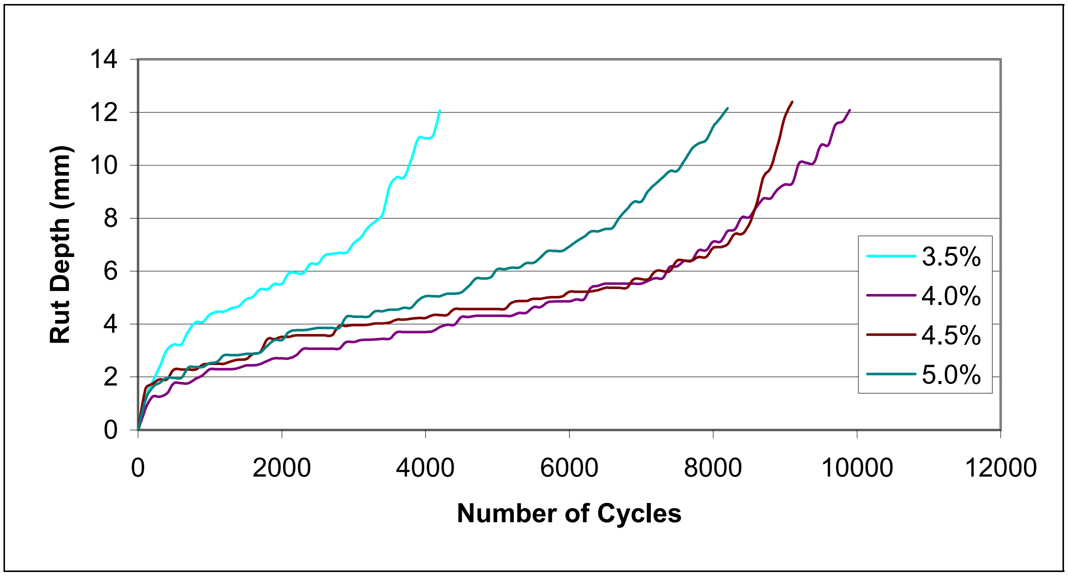

Figure 4.13: Residual Binder Content Effect on Stability for Open Rounded Mixtures

4.5 Texas Stability Test

Since the HWTD was deemed too harsh for the cold patching material, a new test that was specific to measuring the stability of cold patching mixtures had to be devised. The "cooking" process of the cold patching mixtures prior to testing under the HWTD created stable specimens, yet drastically changed the characteristics of the materials. In order to avoid this drastic change, stable specimens had to be generated without curing or compaction at extremely elevated temperatures.

In the development of the Texas Stability Test (TST), careful consideration was given to the testing equipment readily available in most asphalt laboratories in the TxDOT districts. Based on the limitations previously encountered with the SGC, researchers decided to discontinue its use and instead generate specimens with the Texas Gyratory Compactor (TGC). Compacted specimens were then placed on a Marshall Stability apparatus and subjected to loads at the same rate as the Marshall procedure.

4.5.1 Procedure

The experimental design of the TST is depicted in Figure 4.14. For each mix, a total of eighteen specimens were compacted for each cold patching material. The objective was to capture the effect of curing and temperature on the material stability. Specimens were compacted using the TGC according to Tex-206-F, "Compacting Test

Specimens of Bituminous Mixtures," included in the TxDOT Manual of Testing Procedures (1999). Because Rice gravities were difficult to obtain for these mixtures, a common weight of approximately 950 grams was used for each specimen. Specimens were then cured for 0, 168, and 336 hours at room temperature prior to conditioning and testing. The six, 0-hour specimens were immediately wrapped in plastic wrap to avoid the loss of volatiles. Specimens were then placed in three different refrigerators for conditioning at 35, 50, and 75˚F (1.7, 10, and 23.4˚C) for 2 days prior to testing. The 168- and 336-hour specimens were placed on a laboratory shelf to cure for 1 and 2 weeks, respectively, prior to the 2-day conditioning in preparation for testing. Cured and conditioned materials were placed on a Marshall stability breaking head and subjected to a compressive load under the Marshall frame of 2 inches per minute. Testing terminated when the specimen failed and the maximum load and displacements were recorded.

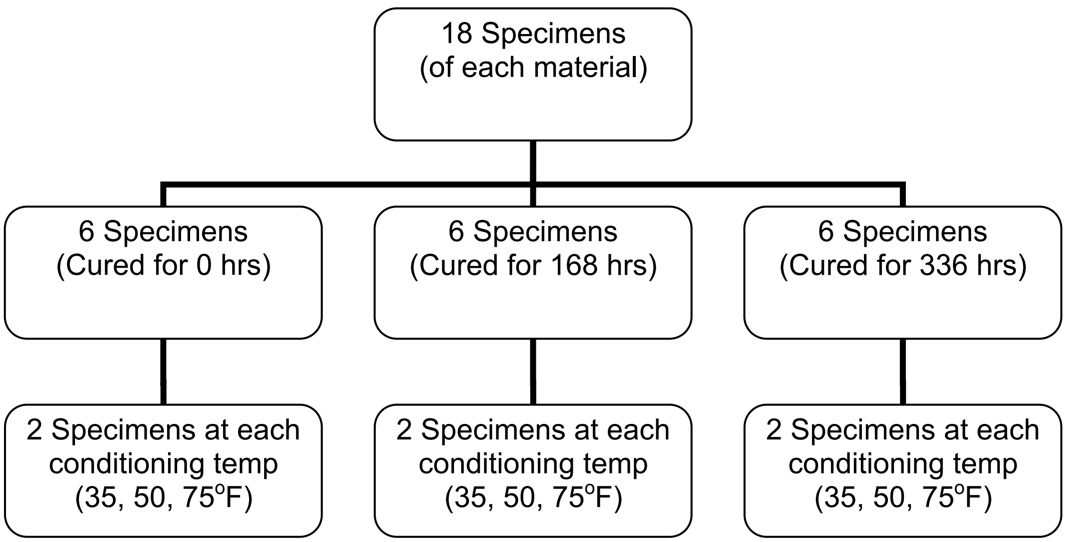

Figure 4.14: TST Experimental Design

Because a constant mass of material was used in the preparation of specimens, there was a slight variation in specimen height after compaction. The maximum load values were corrected to account for the variations in thickness. These corrected load values were used as stability indicators of the cold patching mixtures. A standard TST procedure developed as part of this study is included in Appendix B.

4.5.2 Results

Containerized Material

The containerized materials used with the TST were Asphalt Patch, Perma Patch, Proline, QPR, Stayput, UPM, and Instant Road Repair (IRR). Currently, IRR is the only containerized material approved for used by TxDOT. While it displays good performance, there is an increase in cost associated with the use of buckets as opposed to bags. IRR was tested for benchmarking purposes and was used as a reference for other containerized materials. In addition, containerized materials that had been stored for 8 and 24 months in the laboratory were tested side by side to identify any loss of volatiles or change in stability as a result of storage time.

Figure 4.15 presents the stability results of UPM as a function of the actual specimen temperature at the time of testing. There is a general decrease in the stability measure for all mixtures as the temperature increases. The differences in load values are more pronounced at lower temperatures than they are at higher temperatures. There is also an increase in stability with increasing curing time. However, the load values for both 8- and 24-month stored UPM materials are consistently well below the 0-hour values for IRR. UPM exhibited excessive workability in the CPST and may have low stability, as indicated by the TST results. Results for other materials such as Asphalt Patch, Perma Patch, and QPR had similar trends and stability values remained below those of IRR.

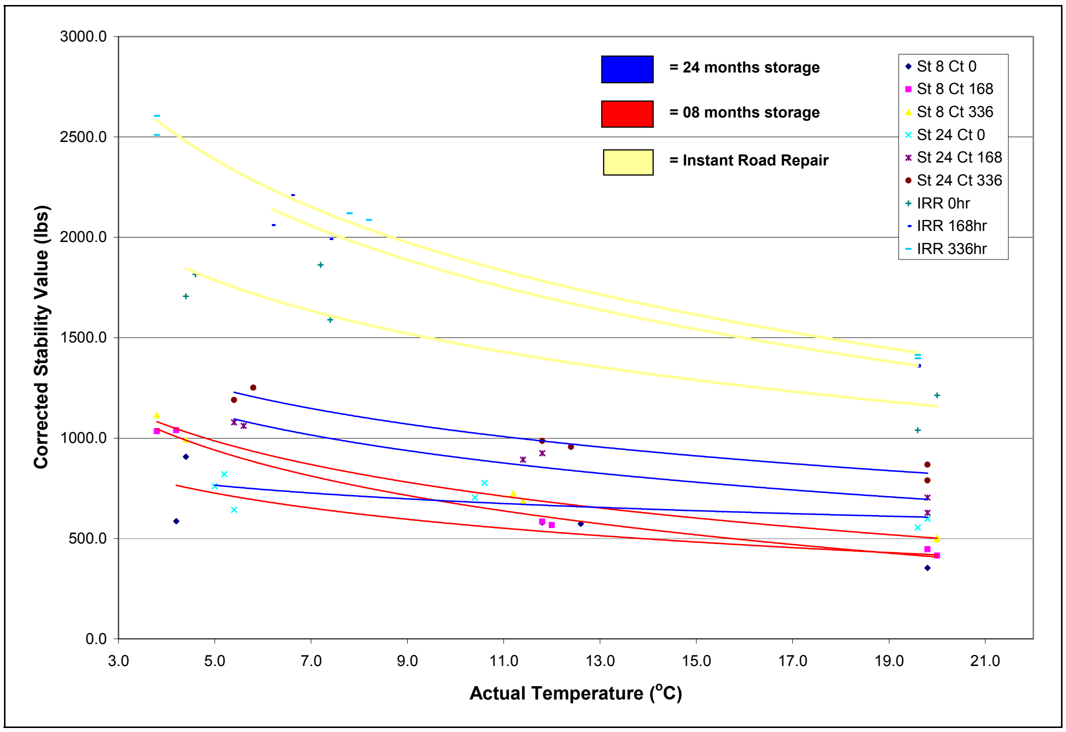

Figure 4.15: TST UPM Results

One material that achieved similar load values as IRR was Proline. Results in Figure 4.16 demonstrate that both materials have similar susceptibility to temperature. As was the case with other materials, stability increased at lower temperature and with increasing curing time. Material stored for 24 months sustained slightly larger loads than that stored for 8 months. Unlike the previous materials, the load values for Proline were slightly better than those attained by IRR. This is an indication that Proline will have similar stability, or slightly better, than IRR. Not only that, but CPST results revealed that this material was both workable and cohesive.

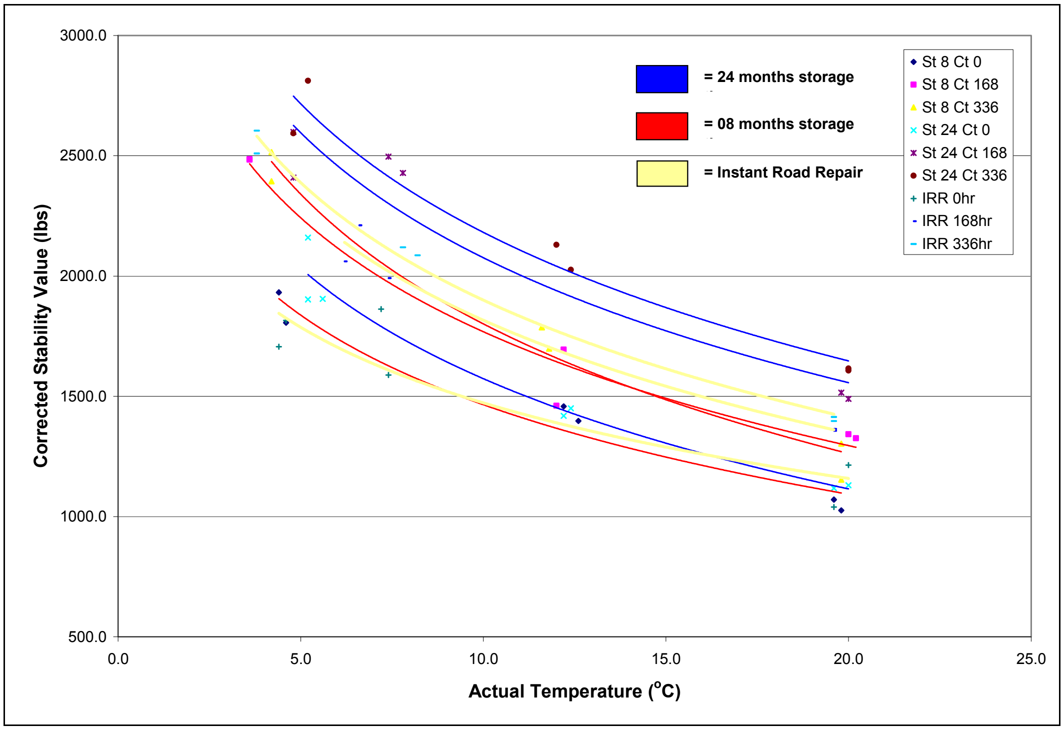

Figure 4.16: TST Proline Results

Results for Stayput, depicted in Figure 4.17, were significantly different than those observed with any other containerized mixture. As was the case with Proline, the load values for Stayput are larger than IRR. Stayput appears to be significantly more susceptible to changes in temperature than any other material tested. Maximum load values attained by other materials were in the range of 3,000 pounds, whereas Stayput sustained over 7,500 pounds. In contrast to all other mixtures, there is a significant change in stability with an increase in storage time. In terms of stability, Stayput may appear as a desirable material. Yet, CPST results identified Stayput as a very unworkable mixture and, therefore, unsuitable for the purposes of this study. An optimal material will not have disproportionate workability or stability, as these two properties counteract. Instead, these material properties must be carefully balanced.

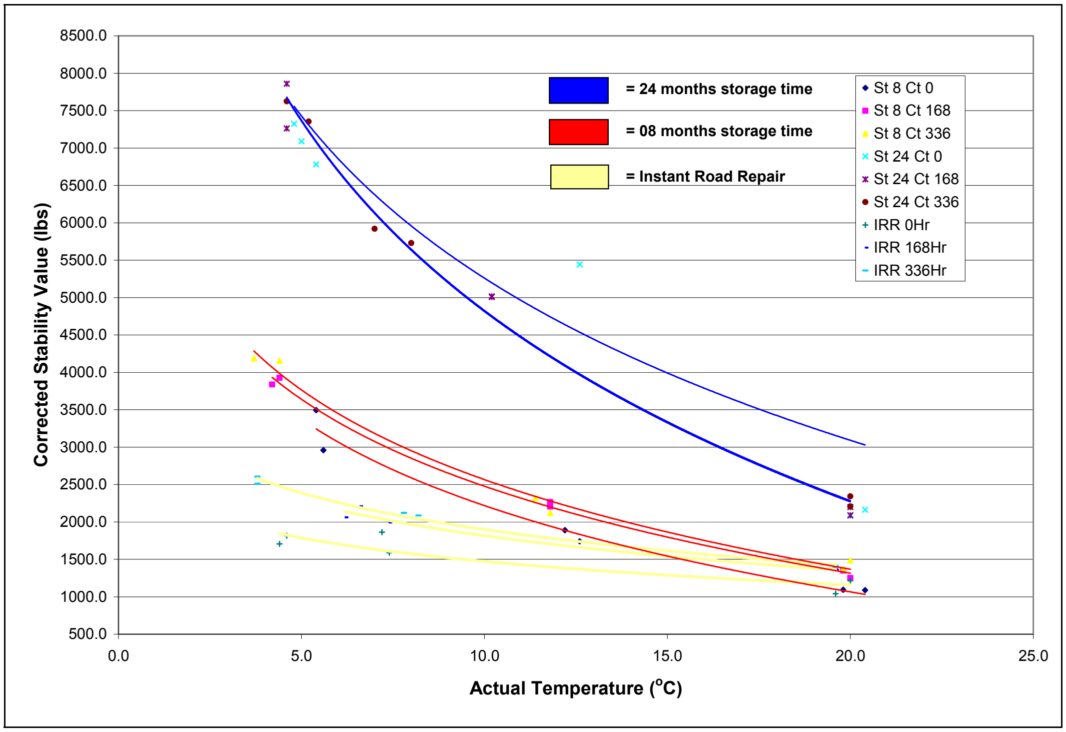

Figure 4.17: TST Stayput Results

Homemade Material

The homemade mixtures tested with the TST were based on the target gradations from the modified mixture design. These target gradations are relatively open. All mixtures had 1 or 2 percent lime added and had residual binder ranging from 3.5 to 4.5 percent. A homemade mixture produced in the Bovina maintenance area in the Lubbock District was also tested as part of the homemade mixtures. TST was only conducted on homemade mixtures cured for 0 and 168 hours. Also, only the extreme conditioning temperatures of 35˚F (1.7˚C) and 75˚F (23.4˚C) were considered in the homemade mixture analysis.

All TST results for the homemade mixtures are presented in Figure 4.18. The load values at 0 hour are represented by solid shapes, while those for 168 hours are represented by the corresponding shape outline. As was the case with containerized mixtures, there is a significant increase in stability at lower temperatures. There is also a less pronounced increase in stability at higher temperatures as a consequence of curing time. Stability values for the different target gradations remained relatively close. At lower temperatures and zero curing time, which is the focus of this study, the medium target gradations appear to have stability values slightly larger than the other gradations. For the mixtures produced with medium target gradations and 1 percent lime, a residual binder content of 4.0 percent appears to be optimal based on observations at all temperatures. There is an apparent increase in stability with an increase in the percentage of lime added. However, larger lime percentages may not be feasible due to cost implications. Load values sustained by all the homemade mixtures remained below those of containerized mixtures. It is believed that this is due to the use of modified binders in the containerized mixtures.

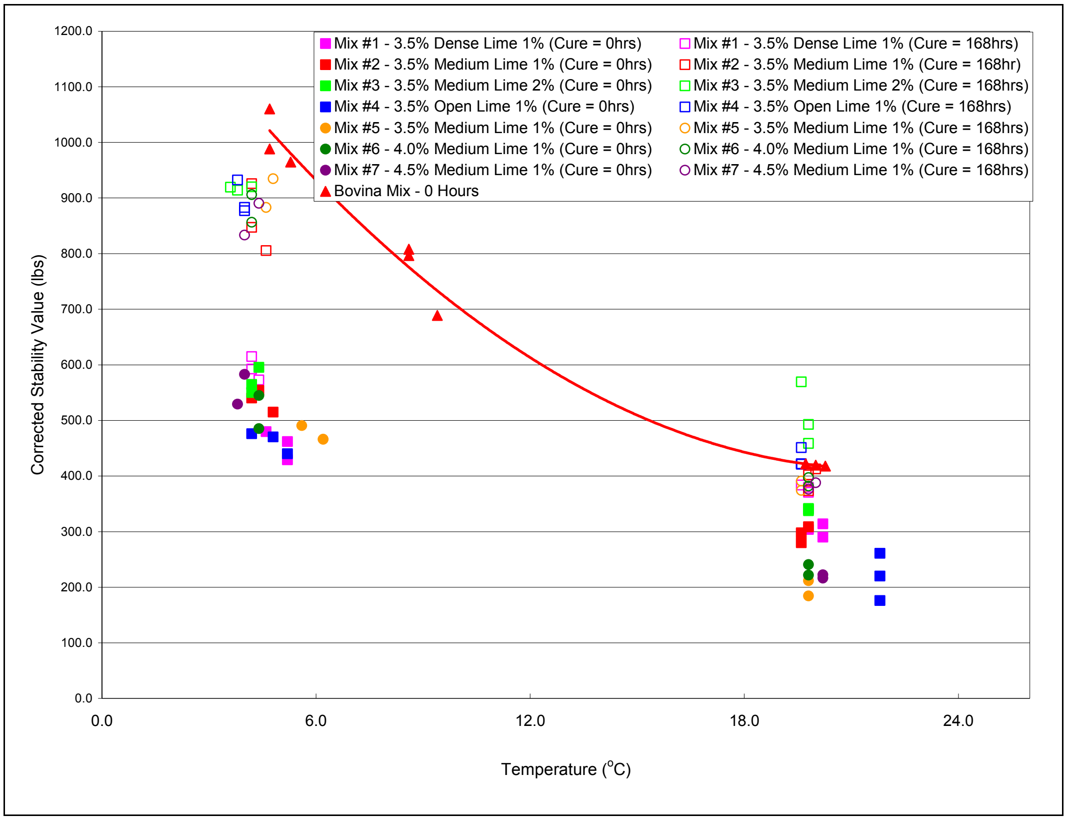

Figure 4.18: TST Homemade Results

4.6 Drop Test

Workability and durability are essential material properties in cold patching mixtures. Storageability is vital in safeguarding these properties. For example, a storage life of at least 6 months is desired to ensure workability during installation. An advantage of containerized mixtures over stockpiles is the increase in storage life. Commercially-produced containerized mixtures have reported shelf lives of more than 12 months. All of the containerized mixtures, with the exception of IRR, are packaged in bags. These bags are often handled manually and tossed from location to location once in the maintenance yards, resulting in potential problems as some of the bags are less resistant to impact and tear easily. This is particularly a problem if there is a significant loss in material.

The drop test was devised to evaluate the impact resistance of cold patch containers to free falls. The objective of the test was to submit the bags to free falls from a predetermined height and observe the progressive container deterioration and ultimate failure. This test can be used as a measure of container effectiveness and an indicator of storage life. Those bags more resistant to impact will not lose the expensive material and will minimize the loss of volatiles as a result of tears or slits on the bags.

4.6.1 Procedure

All containerized materials were used in the drop test. This consisted of material that arrived on two sets of pallets at varying times throughout the project. One set of materials that arrived in the laboratory about 30 months prior to drop testing was denoted as older material. The other set arrived in the laboratory about 18 months prior to drop testing and was denoted as newer material. These sets were tested separately to evaluate any change in the effectiveness of the container with storage time. All bags tested were in relatively good condition as they had been stored in the laboratory.

In order to standardize the drop test procedure, a drop test apparatus was designed and constructed. Figure C1 in Appendix C is a design schematic of the drop test apparatus to be used in the testing. The top view shows the dimensions of each trap door to be 1.5 x 2.0 feet for a total of approximately 2 x 3 feet. This area ensures that all bagged material can be laid evenly on its largest side, or face. The drop test apparatus was built of wood and had a steel tubing mechanism on the underside that allowed the trap doors to open instantaneously upon release. The steel tubing release mechanism is pictured in Figure 4.19.

Figure 4.19: Drop Test Release Mechanism

The standard drop test procedure developed as part of this research project is included in Appendix C. There was no need for material conditioning as all bagged material testing was conducted at room temperature. Material temperature at time of testing was gathered. All container faces were identified and labeled according to Figure 4.20. The main, or front, face of the bags was identified as Face 1. Faces 2 and 3 are immediately to the right and left of Face 1, respectively. Face 5 denotes the bottom face, while Face 6 denotes the top. The face labels aid throughout the drop testing procedure in ensuring the proper face is impacted.

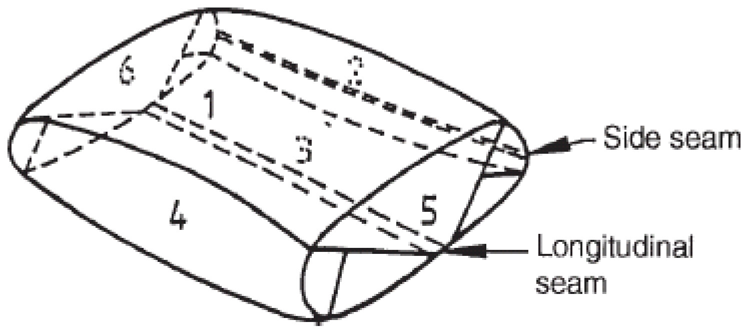

Figure 4.20: Faces of Cold Patch Material Bags (ASTM, 1992)

To begin, a large, level concrete surface was identified in the laboratory as the impact surface to be used. A small forklift big enough to hold the drop test apparatus by its long flanges, as seen in Figure 4.19, was used to elevate the apparatus to a predetermined height of 5 feet. The bagged material was then placed on top of the trap door with Face 1 facing down. To ensure that Face 1 fell parallel to the floor and impacted uniformly, the load was distributed evenly prior to testing. The trap door mechanism was released by tapping the steel tube with a mallet. After impact, the bag was analyzed for any visible damage. Any visible damage was recorded and cyclical testing on faces 2, 3, 4, 5, and 6 continued. The drop testing data collection form used as part of this procedure is included in Appendix C. Inspections for damage were done after every drop. Any visible hole or opening was measured and monitored and was indicative of the progressive deterioration. Testing continued until failure, which was designated as an opening larger than three inches as it was observed that material loss was significant for holes larger than this size.

During the preliminary testing of the older containerized mixtures, a hazard, or removable solid object, was also considered to accelerate the deterioration of bagged materials. Two standard concrete half cylinders were placed on the impact surface (similar to road humps). These hazards created points of stress and resulted in considerably less drops to failure.

4.6.2 Bag Analysis

The container effectiveness of six bagged containerized materials was analyzed, including Asphalt Patch, Perma Patch, Proline, QPR, Stayput, and UPM (Winter and Summer). The characteristics of the tested bags, such as weight, material, and construction, are summarized in Table 4.1. The weight and bag construction information was gathered from observation, while some of the bag material information was provided directly from the vendors. Most bag material is a poly or thick plastic with seams along the top and bottom. Perma Patch is the only material bagged in heavy-duty craft paper.

Table 4.1: Bag Descriptions

	Weight (lbs)	Bag Material	Bag Construction
Asphalt Patch	60	Poly plastic with special additives	Thin seams on both sides with a thick top seal
PermaPatch	60	3-ply heavy-duty craft paper with a poly coated plastic liner	Tube with stitched seams at top and bottom
Proline	50	Banded, thick plastic	Seams along top, bottom, and back
QPR	50	Light resistant and biodegradable plastic	Seams along top and bottom
Stayput	50	Banded, thick plastic	Seams along top, bottom, and back
UPM	50	Poly plastic with nylon reinforcing	Seams along top and bottom

4.6.3 Test Results

Older Materials

The numbers of drops to failure for all older materials are presented in Figure 4.21, and include those drop tests conducted with the concrete hazards. Results for the materials tested with the hazards ranged from one to five drops and were practically indistinguishable for the different materials. As a result, drop testing with the use of hazards was discontinued. Drop test results for the materials tested without the hazards ranged from two to thirty-four drops. This broad range allowed researchers to differentiate the impact resistance of the bags. The Perma Patch bag came completely undone at the seams on the top and bottom after just two drops. This was the only material packaged in a heavy duty paper bag. Stayput also performed poorly, failing after just one cycle of drops (six drops). Although the Stayput bag material was similar to that used by Proline, it was significantly less resistant to impact. The most pronounced difference between the two materials was that Stayput was extremely stiff in the bag whereas Proline showed more flexibility. The failure of the Stayput bag was produced by the sharp edges resulting from factures of the stiff material upon impact. All other materials appeared resistant to impact with number of drops to failure in the range of seventeen to thirty-four.

The primary limitation in testing all materials until failure without the use of a hazard is the time required. In some instances the testing of one bag lasted over 1 hour. These long testing durations are not feasible. However, it was noted that materials that endured more than one cycle of drops, denoted by the red line in Figure 4.21, typically lasted significantly longer than those materials enduring less than one cycle. A more feasible approach to the drop test would be to test the bags for one cycle. Those materials enduring the cycle of drops without significant damage would meet the impact resistance requirements under the drop test.

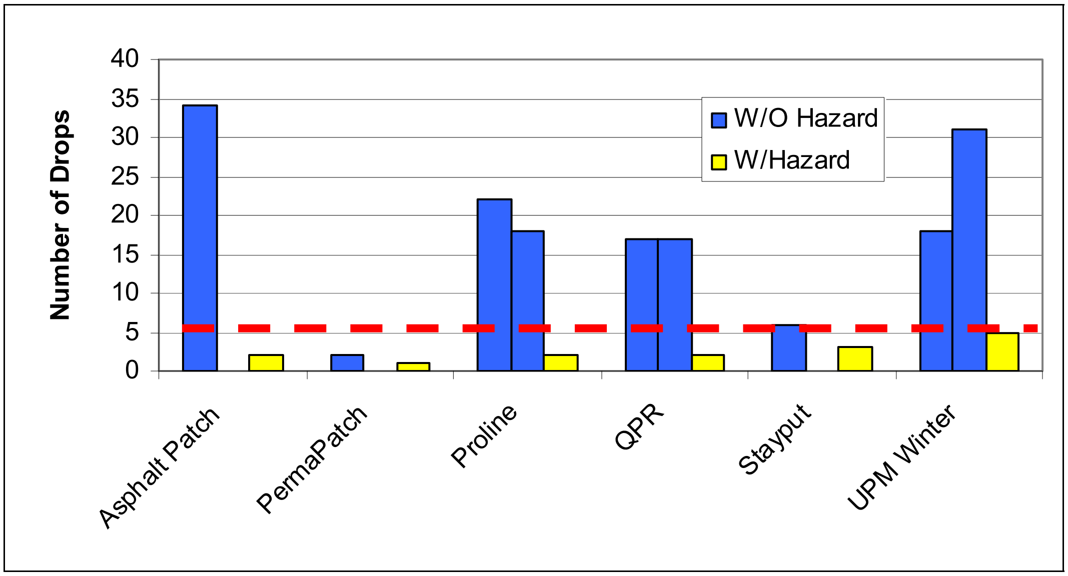

Figure 4.21: Older Material Drop Test Results

Newer Materials

The numbers of drops to failure for all newer materials are presented in Figure 4.22. All the newer material was tested without the use of hazards. Drop testing continued for all materials until an opening of 3 inches or larger was observed, as specified in the procedures, regardless of the time requirements. Results similar to those obtained with the testing of older material were obtained for the newer material. Perma Patch and Stayput were unable to sustain more than six drops, which indicates that the material bags are not impact resistant. The number of drops to failure for Asphalt Patch and Proline were well above the six drop threshold. Bagged material with number of drops to failure larger than the six drop threshold would be acceptable based on impact resistance. The one stark contrast between results of the older and newer material was the impact resistance of UPM. The older material testing used UPM Winter and the newer material testing included UPM Summer. While the bag design remained the same between the two, there was a difference in binder content and hence material workability and flexibility within the bag. Results for UPM Winter were well above the established threshold and comparable to Asphalt Patch and Proline, while those for UPM Summer were comparable to Perma Patch and Stayput. These results indicate that impact resistance may be dependant on both bag material type and material stiffness in the bag.

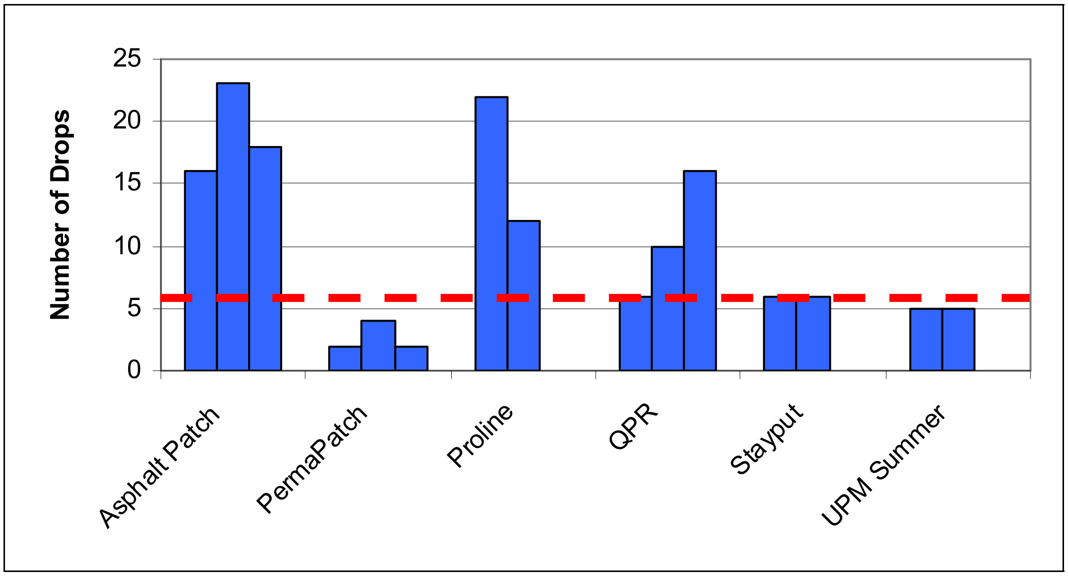

Figure 4.22: Newer Material Drop Test Results

5. Accelerated Pavement Testing

The 1/3-scale Model Mobile Load Simulator (MMLS3) was used to determine the stability of containerized and homemade mixtures under accelerated pavement testing (APT) conditions. The varying performance of the cold patching material under the reduced scale traffic simulation of the MMLS3 was used to validate the laboratory and field results under a performance-related test. Correlation with field results and validation of this test method for the testing of cold patching mixtures will be invaluable in the development of performance-based specifications for the use of cold patching mixtures. Figure 5.1 shows the MMLS3 used as part of the APT conducted at UT Austin's Pickle Research Center (PRC).

Figure 5.1: Model Mobile Load Simulator(MMLS3)

5.1 Site Preparation

In preparation for testing, potholes were fabricated at the APT facility at PRC. The pavement structure at the testing facility consists of 1.5 to 2 inches of Item 340 Type D asphalt concrete over 8 inches of flexible base. A total of twelve square potholes with dimensions of 12 x 12 x 6 inches were created with the use of a gas-powered pavement saw. To create a stable base for the patching material, the bottom two inches of the pothole were filled with hydraulic cement concrete. The resulting pothole dimensions were then 12 x 12 x 4 inches. These dimensions were chosen based on the size of the wheels applied by the MMLS3 and the material required to fill the pothole. The intent was to have a pothole volume that would require approximately one bag of cold patching material, or 50 pounds, for material installation.

5.2 Material Installation

Patching material was installed in two lifts. The first lift consisted of enough material to fill 2 inches of the pothole. This material was then compacted with a 6-inch square compaction hammer. Pothole corners and centers each received a compaction effort of five blows. The second lift consisted of 5 inches of material so that 3 inches of material form a mound above the existing pavement for compaction purposes. The second lift was compacted by three passes of a vibratory plate compactor. During each pass, the vibratory plate compactor was held in place over the patch for 5 seconds. This compaction process insured that all patches obtained the same compaction effort during installation.

5.3 Testing Procedure

The MMLS3 testing procedure is outlined in Appendix D. The MMLS3 must be carefully positioned and lowered over the patch so that the wheel path runs through the center of the material installation. Furthermore, leveling of the machine relative to the slope of the pavement should be done. After lowering and leveling, the spring gap size in the loading frame of the wheel should be checked. This gap should be roughly 3/8 inch to ensure that the applied wheel load is constant. If necessary the MMLS3 can be lowered or raised to attain the desirable spring gap size.

A combination of containerized and homemade mixtures was tested at 0, 48, and 168 hours after patch installation. Prior to initializing MMLS3 testing, the initial mound height (S_0) demonstrated in Figure 5.2 should be recorded. Measures for the shove and total rut depth should be recorded at predetermined time intervals or number of wheel passes. The rut depths due to shoving and densification can be calculated according to the equations presented below. Testing was terminated when a rut due to densification greater than 3/8-inch was observed.

$$R_s = S_h - S_0 \tag{1.1}$$

$$R_d = R_t - R_s \tag{1.2}$$

Where the variables are defined as follows:

R_s = Rut due to Shoving
S_h = Shove Height
S_0 = Initial Mound Height
R_d = Rut due to Densification
R_t = Total Rut Depth

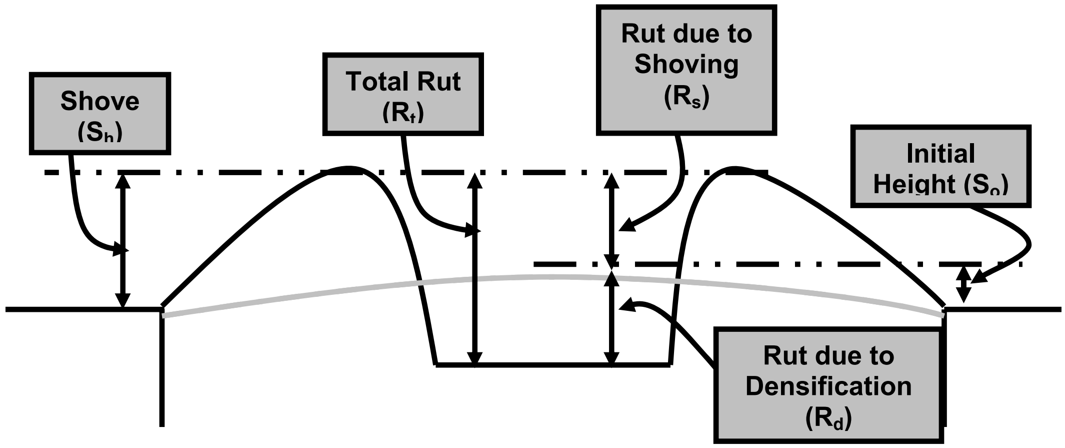

Figure 5.2: MMLS3 Measurements

5.4 Results

MMLS3 testing of cold patching mixtures was conducted at various stages in the study. Results obtained from testing performed as part of the preliminary and modified mixture design procedure are presented and discussed in the following sections.

5.4.1 Preliminary Containerized

In the preliminary testing of containerized materials, only Asphalt Patch, Perma Patch, Proline, and Stayput were tested. Three patches of each material were installed at the same time and then tested at 0, 48, and 168 hours after installation. This was done to observe the effects of curing on the stability of the materials. The MMLS3 was run at approximately seven revolutions per minute and rut depths and shove heights were measured every 15, 30, 60, 90, 120, or 150 seconds. The interval used for recording measurements was dependant on the rut progression of the material.

Results for the containerized materials at 0, 48, and 168 hours are presented in figures 5.3 through 5.5, respectively. Rut depths and shove heights were measured every 15 seconds for all materials at 0 hour. The average of the material temperatures for the duration of testing was about 79˚F. For materials at 0 hour, Proline showed a faster initial rut progression than other materials. However, this material sustained the largest number of wheel passes before reaching a rut depth of 3/8 inch. Perma Patch sustained considerably less number of wheel passes before reaching failure conditions.

The total number of wheel passes applied at 48 hours was substantially higher than those obtained at 0 hour. This increase in stability results from the lower average material temperature at time of testing and the effects of curing. Testing on the Proline material was discontinued as a result of time restraints. Yet, the rut progression had stabilized at 1/8 inch for over 1,000 wheel passes. This indicates that Proline was again the material displaying the best stability. Asphalt Patch was significantly more stable than Perma Patch and Stayput. Perma Patch displayed an accelerated rut progression and was the least stable material.

Test results at 168 hours displayed a slight decrease in total number of wheels applied. This decrease could have resulted from a combination of the increase in average material temperature and an isolated rain event that occurred between the 48- and 168-hour tests. Despite the variability in temperature and moisture, Proline again exhibited the best stability. The number of wheel repetitions to failure for Asphalt Patch, Perma Patch, and Stayput were significantly lower. The low Asphalt Patch results seem to indicate a noteworthy susceptibility to moisture, as this material had performed comparably to Proline at 0-hour tests that were conducted with similar material temperatures. In an attempt to minimize the variability resulting from large changes in temperature and the permeation of rain into patch installations, researchers decided to build an insulated shed over four of the fabricated potholes. This shed would protect the patch installations from rain and minimize the variation in temperatures. All subsequent MMLS3 testing was performed on the patches protected by the insulated shed.

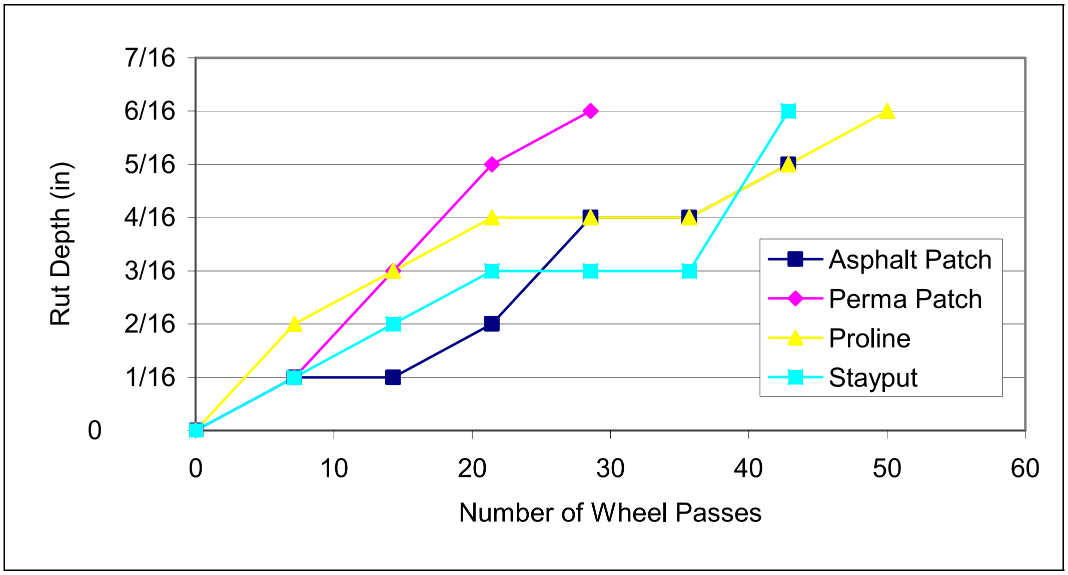

Figure 5.3: MMLS3 Rut Depth Results at 0 Hour (79˚F)

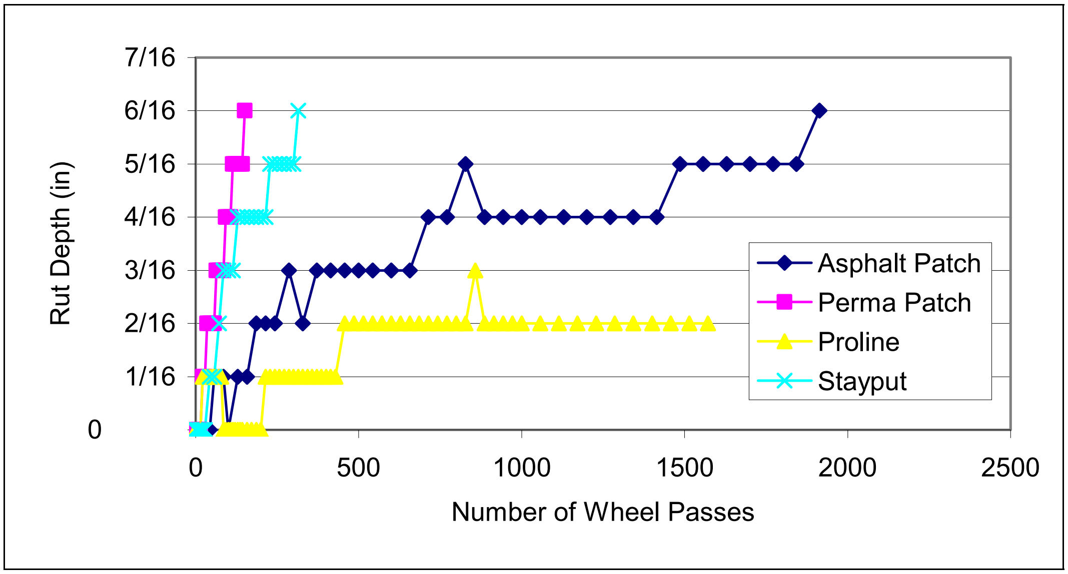

Figure 5.4: MMLS3 Rut Depth Results at 48 Hour (67˚F)

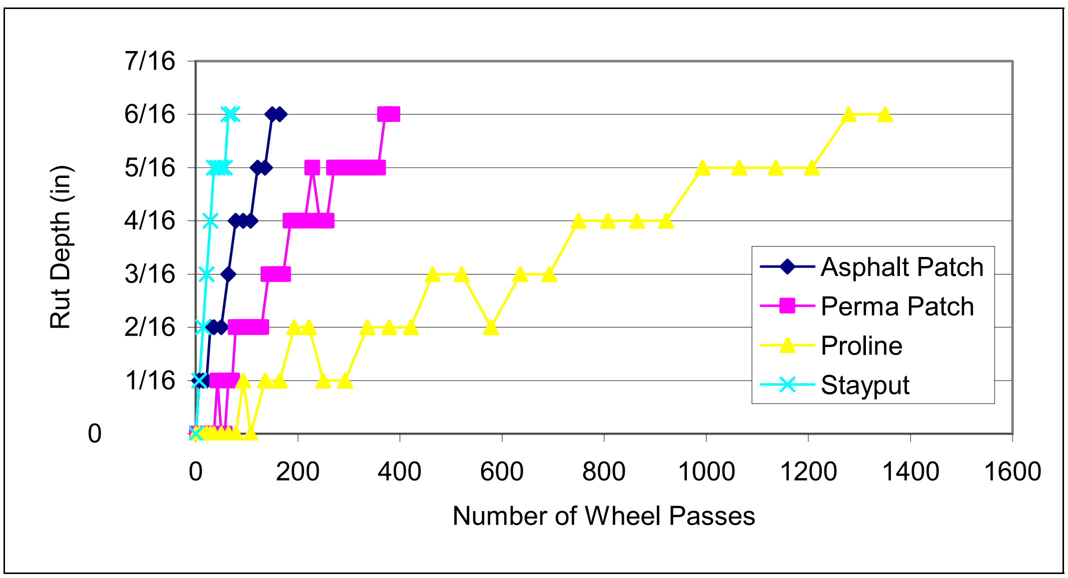

Figure 5.5: MMLS3 Containerized Rut Depth Results at 168 Hour (77˚F)

5.4.2 Preliminary Homemade

The homemade mixtures tested under the MMLS3 after the installation of the shed were those designed as part of the modified mixture design and tested under the TST. According to TST results, one of the better homemade mixtures at 0 curing time and lower temperatures was designed with a medium gradation, rounded aggregate, lime, and a residual binder content of 3.5 percent. Results also indicated an increase in stability as a result of increasing lime content. To further analyze the effects of lime percentage in homemade mixtures, the 3.5 percent medium graded homemade mixture was tested under the MMLS3 with varying percentages of lime. Mixes #1, #2, and #3 were designed with

1, 2, and 3 percent lime. Testing was conducted at 0, 96, and 168 hours after patch installation.

Results for the three homemade mixtures at 0 hour are presented in Figure 5.6. Mix #2 with 2 percent lime content sustained the greatest number of wheel applications. The homemade mixture with 1 percent lime sustained the least number of wheel applications. The total number of wheels applied on the best homemade mixture was similar to those attained by Proline and Asphalt Patch during containerized testing. However, the average material temperature during the testing of homemade mixtures was over 10 degrees lower at about 66˚F. This indicates that homemade mixture stability is slightly less than that of containerized mixtures.

Figure 5.7 displays the homemade mixture results at 96 hours. This testing was also conducted at an average material temperature of 66˚F. All results (number of repetitions to failure) obtained from the homemade mixtures at 96 hours were significantly lower than those obtained by Asphalt Patch and Proline at only 48 hours. Among the three mixture variations tested, Mix #1 was significantly less stable than the other two. The other two mixtures displayed comparable results. Testing of Mix #1 was discontinued due to lack of stability.

Stability results for mixes #2 and #3 at 168 hours are depicted in Figure 5.8. Total number of wheels to failure was relatively the same for the two mixtures at 96 and 168 hours. Similarity in the results could be attributed to a 6-degree increase in the average material temperature at 168 hours. Although Mix #3 performed slightly better than Mix #2, there is no significant difference in their performance under the MMLS3. Despite the small temperature deviance, the use of the insulated shed was useful in mitigating the effects of the large ambient temperature differences outside.

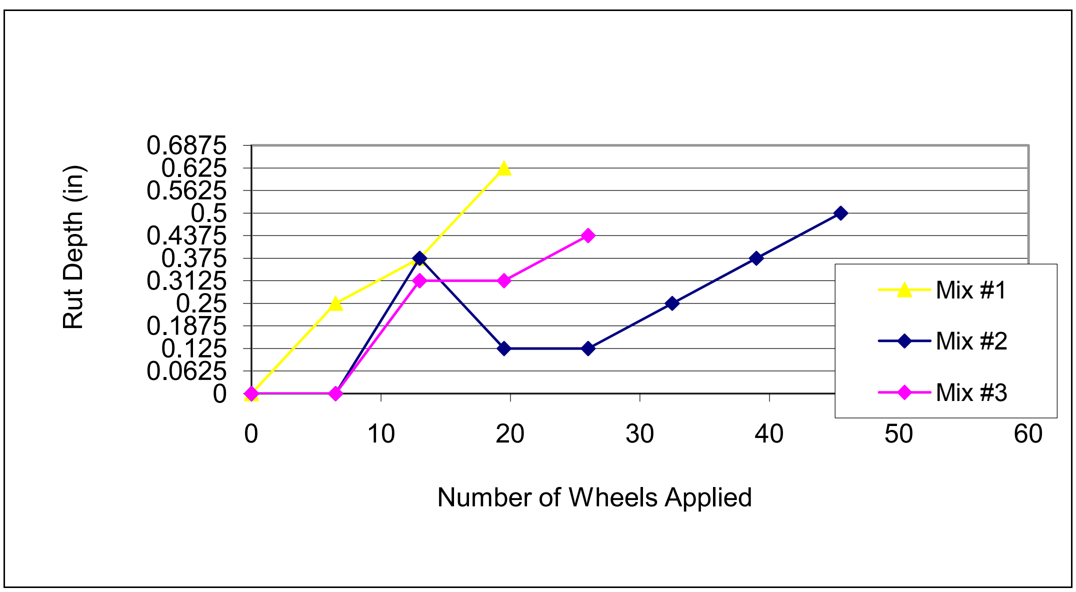

Figure 5.6: MMLS3 Homemade Rut Depth Results at 0 Hour (66˚F)

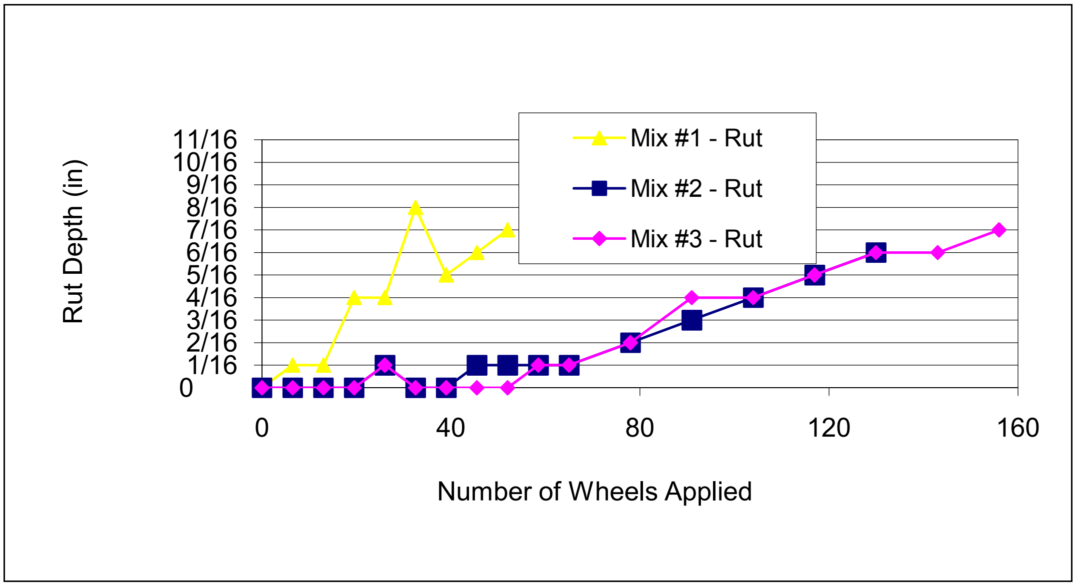

Figure 5.7: MMLS3 Homemade Rut Depth Results at 96 Hours (66˚F)

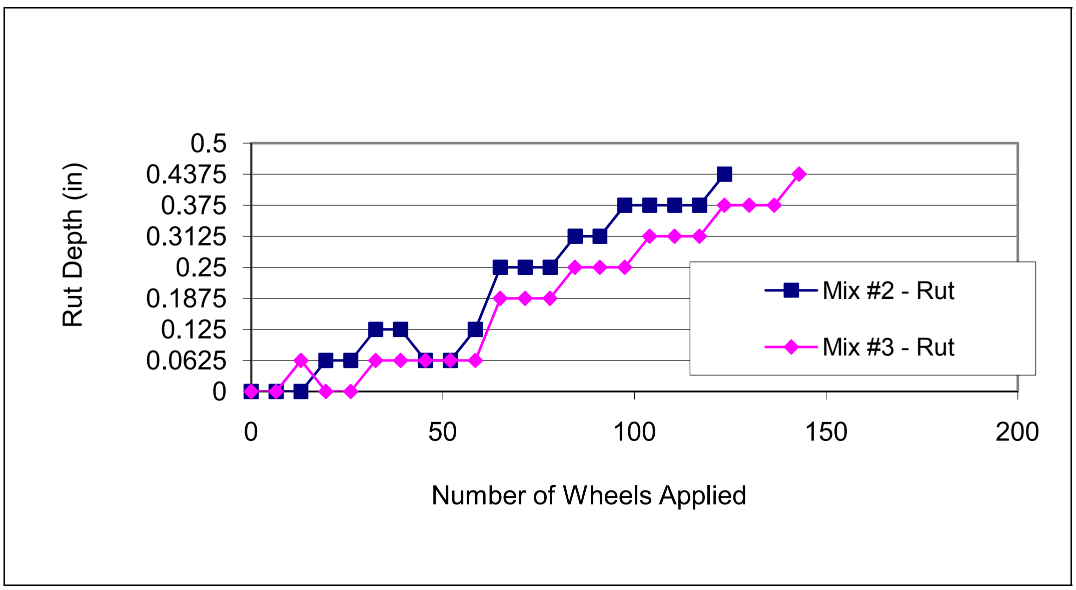

Figure 5.8: MMLS3 Homemade Rut Depth Results at 168 Hours (72˚F)

5.4.3 Modified Containerized

The materials evaluated as part of the second containerized MMLS3 testing were Asphalt Patch, Proline, QPR, Stayput, UPM Winter and IRR. IRR was used as the basis for this testing. The use of Perma Patch was not considered as preliminary MMLS3 and drop testing results were unsatisfactory.

Materials were installed four patches at a time, under the insulated shed, and tested at 24 hours after installation. Testing at various time intervals was abandoned in order to focus on the stability of the cold patching materials shortly after installation. In addition, multiple replicates were installed and tested to gauge the variability in MMLS3 testing results. The replicates, per material, tested under the MMLS3 are summarized in Table 5.1.

Table 5.1: MMLS3 Testing Replicates

Material	Replicates
Asphalt Patch	6
Proline	3
QPR	10
Stayput	4
UPM Winter	13
IRR	6
TOTAL	**42**

The MMLS3 was run at approximately six revolutions per minute and rut depths and shove heights were measured after a predetermined number of wheel passes were applied. A data collection form was developed and used as part of the MMLS3 testing. This form is presented in Appendix D. The interval used for recording measurements was modeled after the logarithmic trend observed in the rut progression of previous MMLS3 tests.

Results for IRR, QPR, and Proline are presented in Figures 5.9 through 5.11, respectively, and represent the referenced, worst and best performing materials tested under the MMLS3. All figures present the rut due to compaction as a function of the total number of wheel passes applied. For IRR and QPR, the average material temperature during testing was 67˚F, whereas that for Proline was 63˚F.

IRR is the only cold patching material currently approved for use by TxDOT and served as the reference for MMLS3 testing. Figure 5.9 presents the rut depth results obtained from the six IRR patch installations. In the legend, patch installations are identified by location numbers. Since only four patches can be tested at one time under the insulated shed, those patches tested on the same day were identified with a letter suffix. The figure displays a linear correlation between the rut depth due to compaction and the number of wheel passes applied on a logarithmic scale. The rut depth due to compaction remained constant for the first couple of wheel passes and then began increasing linearly. Although variability is present in the material rut progressions, general observations can be made regarding the performance of the material installations. The average number of wheel passes to failure for IRR was 76. Interestingly, IRR installations did not exhibit significant displacement in the form of shoving throughout testing. All but one of the IRR installations exhibited shove heights of less than 1/16 inch at failure.

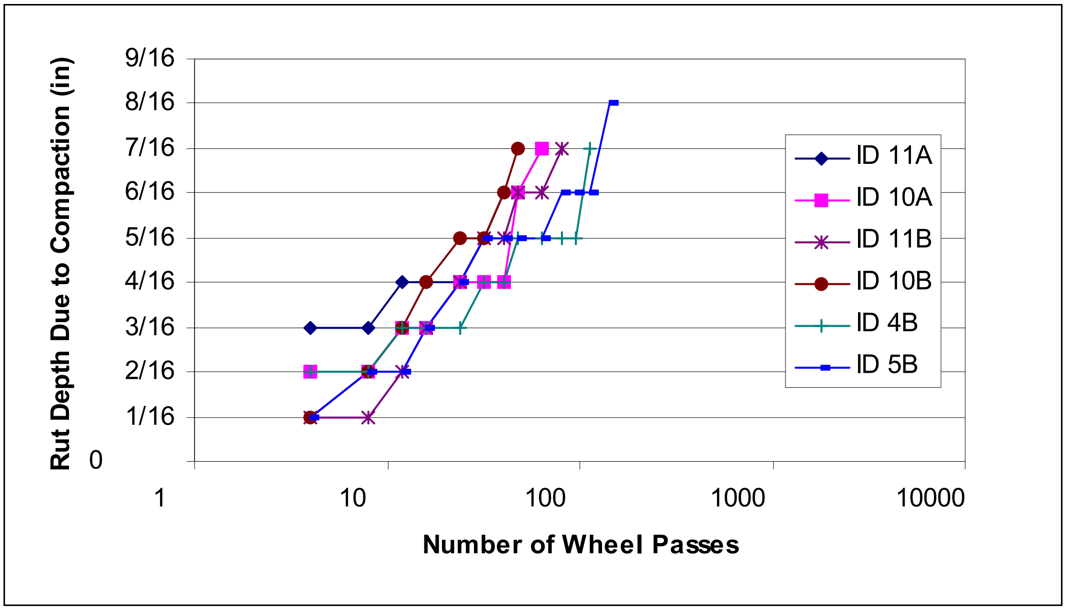

Figure 5.9: MMLS3 Testing Results for IRR at 24 Hours (67˚F)

Rut progressions for the ten QPR material installations are presented in Figure 5.10. QPR sustained the lowest number of wheel passes before reaching a rut depth due to compaction greater than 3/8 inch. The rut depth due to compaction began increasing immediately upon testing inception. The average number of wheel passes to failure was 60. This value is just below that of IRR. However, unlike IRR, QPR exhibited significant material deformation in the form of shoving in addition to rutting. Shove heights for this material were as large as 7/16 inch at the time of failure. This serves as a straightforward indication that QPR materials are highly susceptible to deformation under load application.

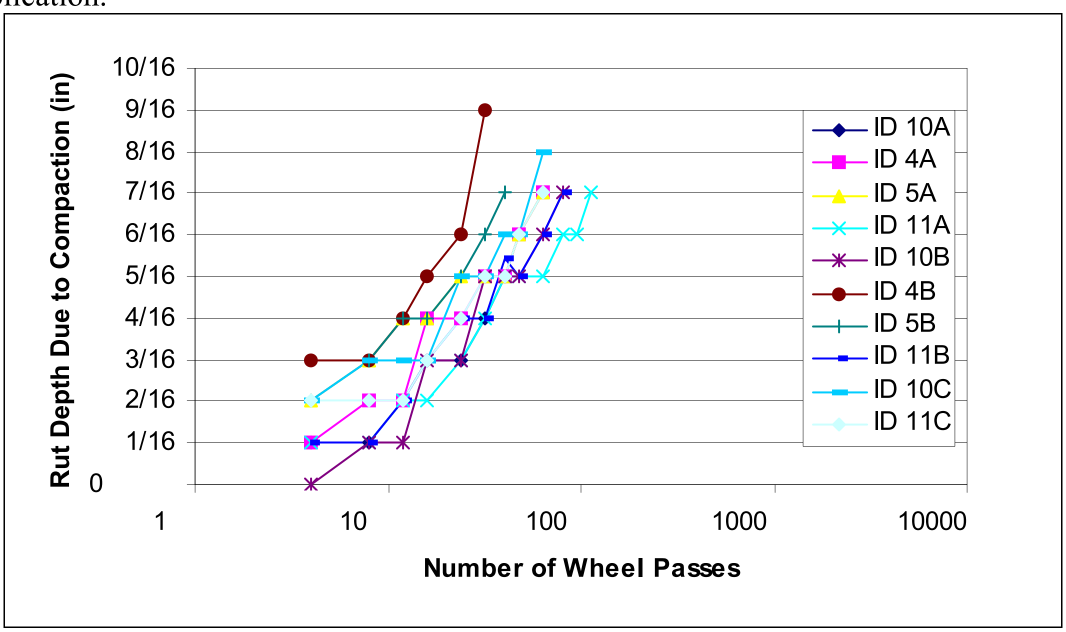

Figure 5.10: MMLS3 Testing Results for QPR at 24 Hours (67˚F)

Rut depth testing results for Proline are presented in Figure 5.11. Proline sustained the largest number of wheel passes before reaching a rut depth due to compaction greater than 3/8 inch. The average number of wheel passes to failure was 816, which is more than 10 times larger than that attained by IRR. In fact, one Proline material installation did not achieve a rut depth due to compaction greater than 3/8 inch and testing was terminated after 1,008 wheel passes were applied. The constant initial rut progression of this material is a good indication of the material's resistance to deformation under the application of load. The shove height remained below 4/16 inch throughout MMLS3 testing. This value is well below that for QPR, but slightly larger than that for IRR. As was the case in previous tests, Proline demonstrated the best performance under the MMLS3.

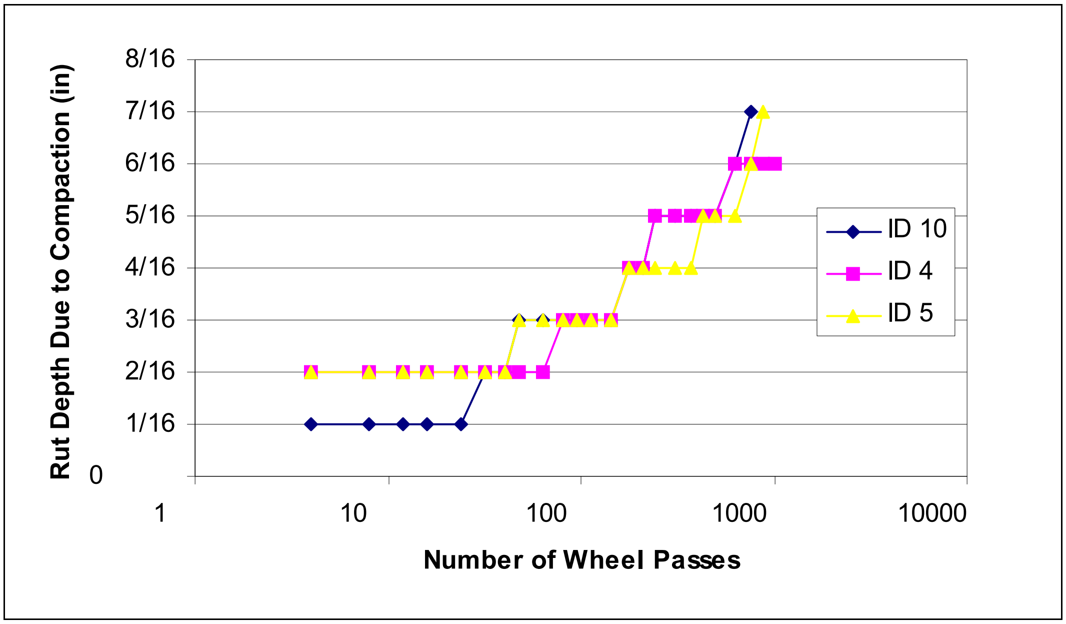

Figure 5.11: MMLS3 Testing Results for Proline at 24 Hours (63˚F)

5.4.4 Containerized Overall Results

Although looking at all the rut depth and shove height data segregated by material gives a general indication of the materials displaying the worst and best performance, it is difficult to quantify the relative performance of all other materials. To do this, a linear regression was used as an estimate of relative patch performance. Since both rut depth due to densification and shove height have significant effects on patch installation performance, the total measured rut depth, R_t in Figure 5.2, was used as the indicator of relative patch performance. The independent variables in the model were the patching material and logarithmic number of wheel passes applied. The basis for the model was IRR patch installations.

The results of the MMLS3 patch performance model are displayed in Table 5.2. The constant term in the model captures the performance of IRR patches. The R-squared value for this model is 0.8278. P-values indicate that all materials perform statistically significantly different than the basis, IRR. The positive standardized beta value for the logarithmic number of wheel passes quantifies the increase in total rut depth with increasing load applications. This represents the development of rutting and shoving with increasing traffic in the field.

The beta values can be used to identify the material relative performance under the MMLS3. Materials with positive beta values, such as QPR and UPM, displayed larger rutting and shoving values, which indicates poor performance relative to IRR. On the other hand, materials with negative beta values generally performed better than IRR. The largest beta value was obtained by QPR, which reinforces the previous observation that this material demonstrated the worst performance under MMLS3 testing. The small beta value for Proline also confirms the previous observation that this material is resistant to deformation and ultimately performs well. These results were also consistent with laboratory testing.

Table 5.2: MMLS3 Containerized Testing: Total Rut Depth Model

	Unstandardized Coefficients		t	p-value
	B	Std. Error		
Constant	-0.195	0.0165	-11.8	0.000
Asphalt Patch	-0.0715	0.0150	-4.77	0.000
Proline	-0.268	0.0172	-15.5	0.000
QPR	0.180	0.0144	12.5	0.000
Stayput	-0.0509	0.0177	-2.88	0.004
UPM	0.131	0.0142	9.28	0.000
Log Passes	0.377	0.00742	50.8	0.000

6. Field Evaluations

One of the primary objectives of this project was to evaluate the performance of containerized and homemade cold patching mixtures in the field under actual traffic loads and environmental conditions. The ultimate goal was to correlate field performance with laboratory and accelerated pavement testing in order to develop performance-based specifications for the selection and use of containerized mixtures. Such correlation would also aid in the development and establishment of homemade mixture design guidelines for cold patching mixtures.

In an attempt to standardize the field evaluation procedure, standard procedures and protocols were developed. These protocols ensure that all materials were installed and evaluated consistently. The protocols developed as part of the procedure for installation and field evaluation are described in detail in this chapter. Results from separate field evaluations conducted by The University of Texas at Austin's Center for Transportation Research (CTR) and TxDOT are also discussed.

6.1 Material Installation

All potholes used as part of the field evaluations were created by removing patching material from existing potholes or fabricating potholes in distressed pavement. The size of the potholes was monitored to ensure they were large enough to carry the full weight of a truck tire, yet small enough to fill with less than two and one-half bags of containerized materials. The latter constraint was based on the available inventory of containerized materials. Based on these criteria, a desirable pothole diameter ranged between 1 and 2.5 feet, depending on depth.

Once pothole locations were identified, TxDOT's maintenance crews provided traffic control. Pothole preparation, fabrication, and material placement, as discussed in the following section, were also performed by the maintenance crews. Researchers supervised the field installation procedure and recorded important patch information at the time of installation.

6.1.1 Installation Protocol

A combination of TxDOT's Function Code 241—"Potholes, Semi-Permanent Repair" (Code Chart 12)—and recommendations from the cold patch manufacturers were used to establish the field installation protocol. TxDOT's Function Code 241 provides guidelines for repairs in areas of less than one square yard and generally satisfies the minimum recommendations of all the cold patch manufacturers. However, none of the manufacturers' recommendations include the application of a tack coat prior to material placement and two vendors recommend the compaction of the base/subbase/subgrade to obtain suitable support for the patching material. Based on these recommendations, the following field installation protocol was developed and implemented as part of the containerized and homemade cold patching mixture field trials.

Fabricated potholes should be created with an electric jackhammer over heavily distressed areas.

- Existing patches should be removed with hand tools.

- Potholes should be filled with water prior to material installation. Water should be allowed to stand for one hour or until the water soaks into the base. Water should not be added in temperatures below 32ºF (0ºC).
- Loose pavement materials, debris, and excess water should be removed from the pothole with hand tools or compressed air.
- Maintenance crews shall follow their standard pothole preparation procedure, such as the application of tack coat, when the district-produced homemade mixtures are installed. In accordance with manufacturers' recommendations, a tack coat will not be used in the installation of the containerized patching material.
- Potholes should be filled with patching material in 2-inch lifts.
- Hand tools may be used to level the patch.
- Material should be compacted with the roll of the truck tires.

6.1.2 Initial Data Collection Protocol

As part of the installation procedure, an initial data collection form was developed. These forms were used to record such information as pothole location, pothole characteristics, weather conditions, material characteristics, and pavement information. A subjective workability rating was also collected from the TxDOT crew installing the material for comparison with the laboratory objective and subjective measures. All pertinent data was collected at the time of material installation. The installation data collection form used is included in Appendix E.

6.2 Field Evaluation Procedure

6.2.1 Condition Survey Protocol

The condition survey protocol consisted of monitoring and recording the condition of the patches at specified time intervals after installation. The suggested time intervals after patching for condition surveys were 1, 3, and 6 months, but varied among TxDOT districts. Symptoms of distress in the patch or adjacent pavement area were recorded with severity levels of none, slight/moderate, or severe per descriptions in the "Patch Condition Survey Manual" developed in Chatterjee et al. (2006).

The "Patch Condition Survey Manual" was developed based on the "Pavement Surface Condition Rating Manual" produced by the Washington State Transportation Center (1992). The "Patch Condition Survey Manual" describes the patch and pavement distresses of interest in the condition surveys. In addition, it explains how to evaluate and designate the severity of the patch and pavement distresses. Table 6.1 summarizes information from the "Patch Condition Survey Manual".

Condition survey forms were developed based on the distress severity descriptions summarized in Table 6.1 to ensure that all pertinent information was recorded during field evaluations of the patch installations. The "Patch Condition Survey Manual" was distributed to the TxDOT districts to serve as a reference in the completion of the patch condition survey forms. The "Patch Condition Survey Manual" and condition survey form distributed to TxDOT are included in Appendix F.

Table 6.1: Patch Condition Survey Manual Summary

	Distress Severity	
	Slight/Moderate	**Severe**
Patch Distress		
Raveling	Worn aggregate, moderately rough surface texture, loose or missing aggregate, slightly aged and rough appearance.	Significantly worn aggregate, very rough surface texture, missing aggregate to a depth greater than one half the coarse aggregate sizes.
Bleeding	Asphalt covers slight to significant area of the surface aggregate, much of the coarse aggregate still exposed.	Asphalt covers most of the surface aggregate, wet and sticky appearance in hot weather.
Dishing (Consolidation)	Less than ¾ of an inch in patch consolidation.	More than ¾ of an inch in patch consolidation.
Edge Disintegration	Edge patching extent is greater than 25 percent of the segment length.	Edge raveling or edge lane less than 10 feet extent is less than 25 percent of segment length.
Pushing/Shoving	Less than ½ of an inch in vertical displacement of patch material, does not require maintenance.	More than ½ of an inch in vertical displacement of patch material, requires maintenance.
Adjacent Pavement Distress		
Rutting	Average rut depth of ¼ to ¾ of an inch.	Average rut depth greater than ¾ of an inch.
Longitudinal Cracking	Little or no crack spalling, cracks are greater than ¼ of an inch wide, few low-severity connecting cracks near main cracks or at intersecting corners.	Crack spalling, several low-severity connecting cracks near main cracks or at intersecting corners, missing pieces along the cracks.
Transverse Cracking	*See longitudinal cracking above.*	*See longitudinal cracking above.*
Alligator Cracking	Fully interconnected cracking, none to slight crack spalling, cracking forms predominantly large pieces (>12 in.), cracks may be greater than ¼ inch wide, pavement pieces are still in place.	Apparent crack spalling, well-developed crack pattern, cracking forms predominantly small pieces (<12 in), loose or missing pieces, pumping of fines through cracks may be evident.
Block Cracking	Block size 5 ft x 5 ft or larger, crack size of more than ¼ inch.	Block size of 2 ft x 2 ft to 4 ft x 4 ft, crack spalling.
Bleeding	*See bleeding in patch distress above.*	*See bleeding in patch distress above.*
Raveling	*See raveling in patch distress above.*	*See raveling in patch distress above.*

6.2.2 Condition Score Designation

Results from the condition surveys were used to evaluate the performance of the various cold patching mixtures. Condition scores were assigned based on the severity of visible distress in order to discretely characterize the condition of a patch at a particular time. Values for the condition score ranged from 100 (flawless) to 0 (failed). An underlying assumption in the condition score designation was that the patch was flawlessly installed. Consequently, all patches were designated a condition score of 100 at installation, or 0 time. An amount was then deducted from 100 based on the type of distress visible, if any, and the severity of the distress. Deduction values varied based on distress type and its relative significance to patch failure. Factors such as the potential for pavement degradation and the effect on public safety were considered in the allocation of the distress and severity weighting. The deduct values were then calculated by multiplying the distress and severity weighting. Cumulative deduct values corresponding to all visible patch distresses were then subtracted from 100 to obtain the patch condition score. As reviewed and accepted by TxDOT personnel, the distress weight, severity weighting, and deduct values used in the field performance evaluation are presented in Table 6.2.

Table 6.2: Deduct Values for Field Performance Evaluation

Distress	Distress Weight	Severity Weighting		Deduct Values	
		Slight/Moderate	Severe	Slight/Moderate	Severe
Cracking/Peeling	25	0.3	1	7.5	25
Raveling	35	0.5	1	17.5	35
Dishing	15	0.2	1	3	15
Pushing/Shoving	20	0.3	1	6	20
Bleeding	5	0.2	1	1	5

Raveling was awarded the highest distress weight because it is considered the distress to most likely lead to patch failure. On the other hand, bleeding was designated the lowest distress weight because this distress does not pose a significant safety threat for the patch dimensions being considered. In fact, bleeding could even serve to prolong the life of the patch due to enhanced waterproofing properties.

The severity weighting was based on the distress severity potential to cause degradation, or failure, to the patch. Although not noted in the table, the severity weighting for no visible distress is 0, which results in a deduct value of 0. The severity weighting for patches displaying a slight/moderate distress ranged from 0.2 to 0.5 and varied depending on the distress. The largest severity weighting for a slight/moderate distress was allocated to raveling, while dishing and bleeding were allocated the smallest severity weighting. Patches with severe distresses had a severity weighting of 1, which would result in a deduct value equal to the distress weight. As a result, severe raveling would have the highest deduct value.

6.3 CTR Field Evaluation

A combination of homemade and containerized mixtures was considered in the CTR field evaluation. In the development of the CTR field evaluation it was essential to first identify those areas that would provide the traffic and climate characteristics under consideration in this study. Special consideration was given to areas with cold or wet weather within the TxDOT districts. In order to capture the effects of both climate extremes, researchers decided to conduct the CTR field evaluation in the Lubbock and

Lufkin districts. The Lubbock District represents cold and dry climate, whereas the Lufkin District is representative of wet and warm climates.

6.3.1 Lubbock

Materials and Locations

A total of fifty-six patches were installed in the Lubbock District by the Bovina, Littlefield, and Muleshoe maintenance areas. All patches were installed in February 2005. In addition to the six containerized mixtures previously considered in the laboratory testing, each maintenance area provided a homemade mixture for installation. Material installations were performed with warm (65˚F to 75˚F) and cold (40˚F to 50˚F) material to assess the effects of material temperature at time of installation on material performance. In addition, the effects of traffic volume were also considered as part of the evaluation. Table 6.3 is the Lubbock patching matrix. A total of eight patches were installed per material. Of these eight patches, four were installed on low volume roads while the others were installed on moderate volume roads. The material was warmed by keeping it indoors overnight and transporting it inside heated vehicles. This warming process was not conducted on homemade mixtures. The cold material temperature was a result of the cold ambient temperature.

All twenty-eight moderate volume patches were installed in the Bovina area on US 60, which carries approximately 6,200 vehicles per day, with a high percentage of heavy trucks. The low volume, ambient temperature installations were conducted in the Littlefield area on FM 1055. Low volume, warm material installations were performed in the Muleshoe area on FM 746.

Table 6.3: CTR Lubbock Field Evaluation Materials, Traffic, and Temperature

Cold Patching Materials	Low Volume		Moderate Volume		TOTAL
	Ambient	Warm	Ambient	Warm	
Homemade	4	0	4	0	**8**
Asphalt Patch	2	2	2	2	**8**
Perma Patch	2	2	2	2	**8**
Proline	2	2	2	2	**8**
QPR	2	2	2	2	**8**
Stayput	2	2	2	2	**8**
UPM Winter	2	2	2	2	**8**
TOTAL	**16**	**12**	**16**	**12**	**56**

Results

Selected results from the CTR Lubbock field evaluation are presented in Figures 6.1, 6.2 and 6.3. The first letter in the legend name denotes traffic volume. "L" and "H" represent the low and moderate volume installations, respectively. Similarly, "C" and "W" represent the ambient and warm material temperatures and are denoted by the second letter. Therefore, a warm material installed in a low volume road would be LW. Figure 6.1 presents calculated condition scores for all Asphalt Patch installations. Results for all moderate volume (H) installations were censored at 13 weeks due to an unforeseen maintenance procedure performed on the section of US 60 used in the field evaluation. However, their condition scores previous to being maintained were comparable to all other Asphalt Patch installations. The consistently high condition scores indicate that this material performs satisfactorily regardless of traffic volume or material temperature. This material was also one of the better performers under the MMLS3.

Stayput did not perform well in the field evaluation. Results for this material are presented in Figure 6.2. Although no patch failed completely after 26 weeks, some were deteriorating at an accelerated rate. The patch demonstrating the lowest condition score was a warm installation on a low volume road. However, the other LW patch had one of the highest condition scores throughout the field evaluation. Other patches that demonstrated accelerated deterioration (before censorship) were HW and HC patches.

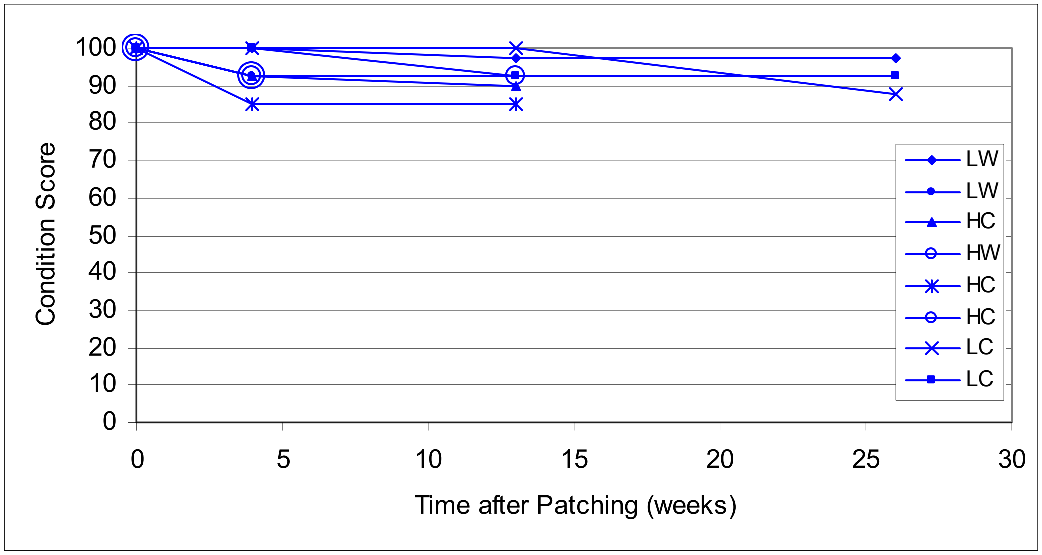

Figure 6.1: CTR Lubbock Field Evaluation for Asphalt Patch

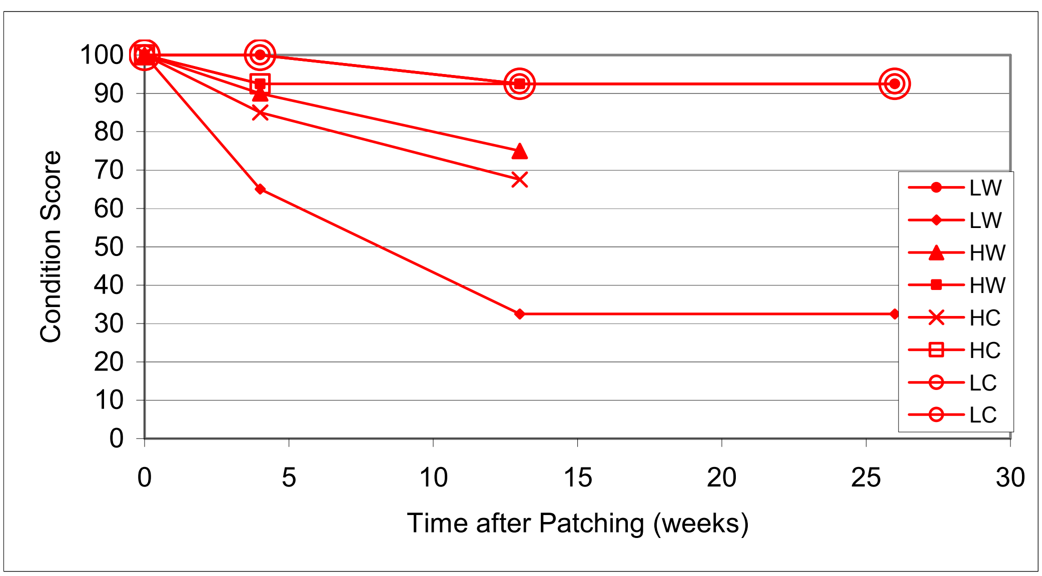

Figure 6.2: CTR Lubbock Field Evaluation for Asphalt Patch

The mixture that experienced the greatest number of failures was homemade. Results are presented in Figure 6.3. Of the eight patches, two failed at 4 weeks and two failed at 13 weeks. Only one mixture, an LW installation, remained above a condition score of 70. Interestingly, the two patches that failed after just 4 weeks were installed at cold ambient temperatures on low volume roads (LC), which could indicate that this material is particularly susceptible in cold weather installations.

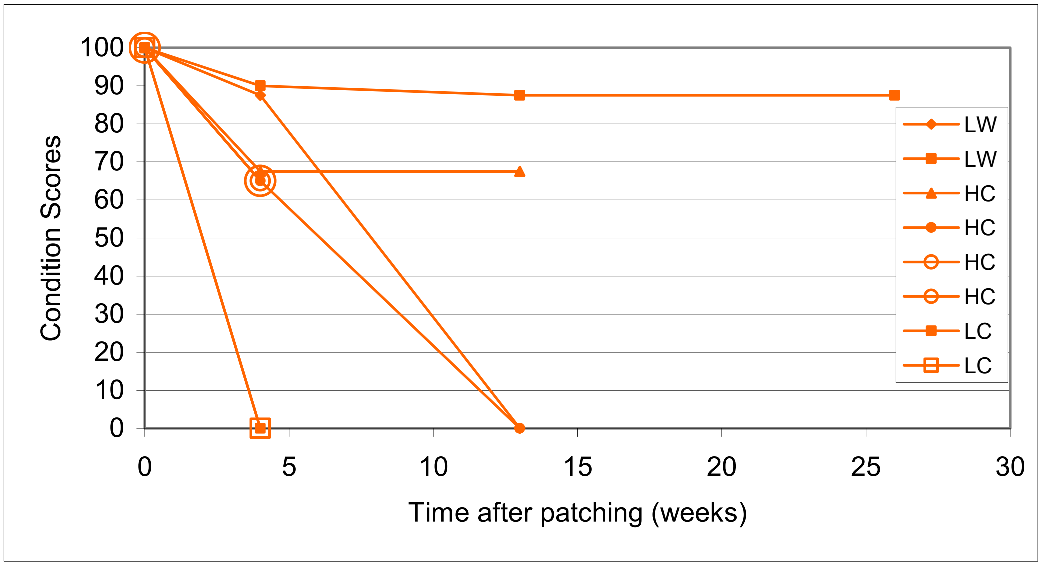

Figure 6.3: CTR Lubbock Field Evaluation for Homemade

6.3.2 Lufkin

Materials and Locations

A total of twenty-eight patches were installed in the Lufkin District. Instead of providing a TxDOT-mixed homemade mixture, the district provided a commercially-produced mixture from a local provider. This mixture is produced in a plant using local aggregates. These patches were installed in April 2005 with material at a warm ambient temperature (77˚F to 93˚F). The effect of traffic volume on patch performance was also considered in the Lufkin area. The Lufkin field patching matrix is presented in Table 6.4. A total of four patches of each material were installed. Low-volume patches were installed on FM 1087, whereas moderate volume installations were done on SH 204.

Table 6.4: CTR Lufkin Field Evaluation Materials, Traffic, and Temperature

Cold Patching Materials	Low Volume	Moderate Volume	TOTAL
	Ambient	Ambient	
Homemade	2	2	**4**
Asphalt Patch	2	2	**4**
Perma Patch	2	2	**4**
Proline	2	2	**4**
QPR	2	2	**4**
Stayput	2	2	**4**
UPM Winter	2	2	**4**
TOTAL	**14**	**14**	**28**

Results

All patch installations in the Lufkin area, including the homemade, performed well. The homemade, however, was produced from local materials but mixed in a plant by a vendor. Figures 6.4 through 6.6 show selected results from the Lufkin field evaluation. These results were representative of all the other mixtures as no patch installation obtained condition scores below 80. UPM Winter, which is designed specifically for cold weather, performed comparable to all other mixtures. The most observed patch distress in the Lufkin District was dishing, which had a maximum deduct value of 15. The widespread dishing problem could have resulted from poor compaction.

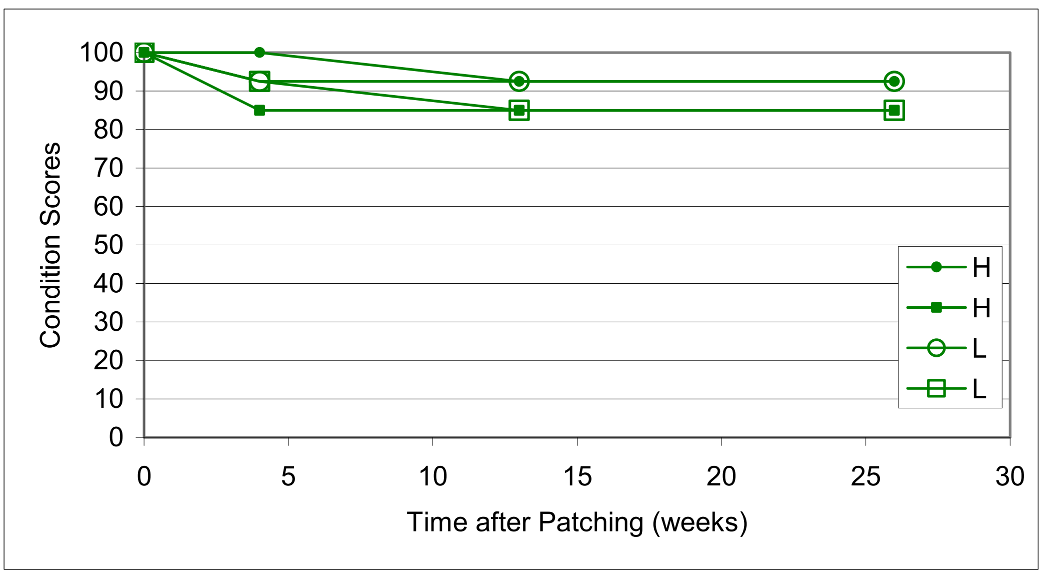

Figure 6.4: CTR Lufkin Field Evaluation for Proline

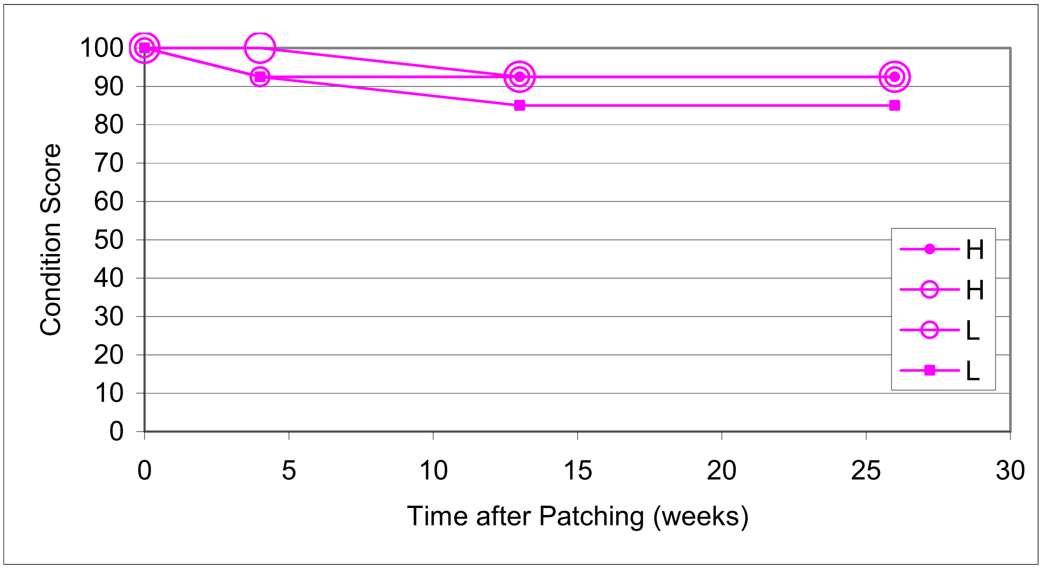

Figure 6.5: CTR Lufkin Field Evaluation for UPM Winter

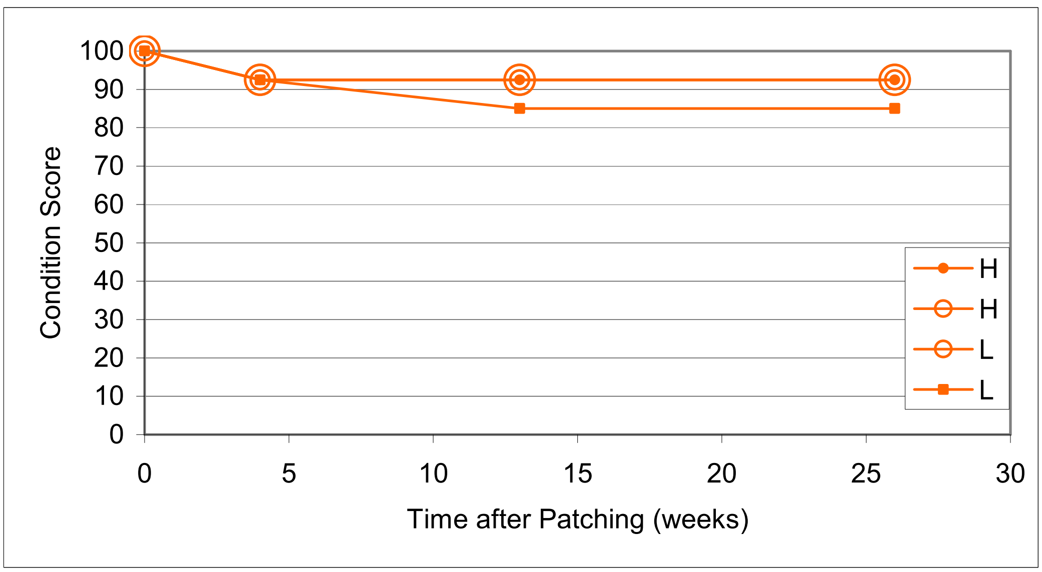

Figure 6.6: CTR Lufkin Field Evaluation for Homemade

6.4 TxDOT Field Evaluation

As part of the TxDOT field evaluation, TxDOT's Maintenance Division purchased 1,000 bags of four different containerized patching materials. These materials were then distributed to the TxDOT districts for installation in areas where other hot mixed or hot mix cold laid products would normally be used. TxDOT district maintenance crews were instructed to follow the established installation protocol, described in Section 6.1, during material placement. In addition, the maintenance crews were directed to collect installation and condition survey data for each patch installation, per established protocols.

6.4.1 Materials and Locations

The containerized materials included in the TxDOT field evaluation were, in alphabetical order, Pacher, Perma Patch, Proline, and Stayput. Of these materials, Pacher had not previously been tested in the laboratory or under accelerated pavement tests. TxDOT distributed these materials to different districts throughout the state. Each of the districts installed the materials according to the patching protocol and maintained installation and condition surveys for every patch installed. These patches were installed from March 2005 to May 2006 in eighteen districts. The districts collectively reported a total of 598 patch installations. Table 6.5 presents the participating districts and the total number of patches installed in each district. Furthermore, the table breaks down the total number of patches installed in each district by patch material.

Table 6.5: All TxDOT Field Evaluation Materials and Locations

District	Pacher	Perma Patch	Proline	Stayput	TOTAL
Abilene	2	2	2	2	**8**
Amarillo	29	18	22	16	**85**
Atlanta	11	13	10	4	**38**
Beaumont	3	5	7	3	**18**
Childress	1	1	1	1	**4**
Corpus Christi	10	8	11	7	**36**
El Paso	1	2	3	1	**7**
Fort Worth	13	20	19	21	**73**
Houston	0	6	7	0	**13**
Laredo	7	8	8	7	**30**
Lubbock	17	20	15	17	**69**
Lufkin	18	35	26	23	**102**
Paris	1	0	1	1	**3**
Pharr	3	5	2	3	**13**
San Antonio	4	4	4	6	**18**
Tyler	2	0	3	5	**10**
Waco	10	3	3	6	**22**
Yoakum	11	14	12	12	**49**
TOTAL	**143**	**164**	**156**	**135**	**598**

Note that the five districts with the highest number of patch installations were Amarillo, Fort Worth, Lubbock, Lufkin, and Yoakum.

6.4.2 Data Selection

In the analysis of the field performance, only the five districts with the highest number of patch installations were considered. These districts also correspond to the zones in Texas where patch installations are exposed to cold or wet weather and are most susceptible to failure. Figure 6.7 displays the different environmental zones and district boundaries in Texas. Of the five selected districts, Amarillo and Lubbock represent those in the dry-cold zone in the Texas Panhandle. Lufkin and Yoakum represent those districts in the wet-warm zone close to the Texas coast and Fort Worth represents the wet-cold zone in Northern Texas.

Moreover, the analysis focused on those patches that were more susceptible to failure in asphalt pavements. Therefore the analysis only considered those patches installed in the wheel path and on high volume asphalt roads for these five districts. Patches for these districts were installed from February to August 2005. The total number of patches included in the patch performance analysis was 124. Table 6.6 reflects those patch installations considered in the analysis of the TxDOT field evaluation.

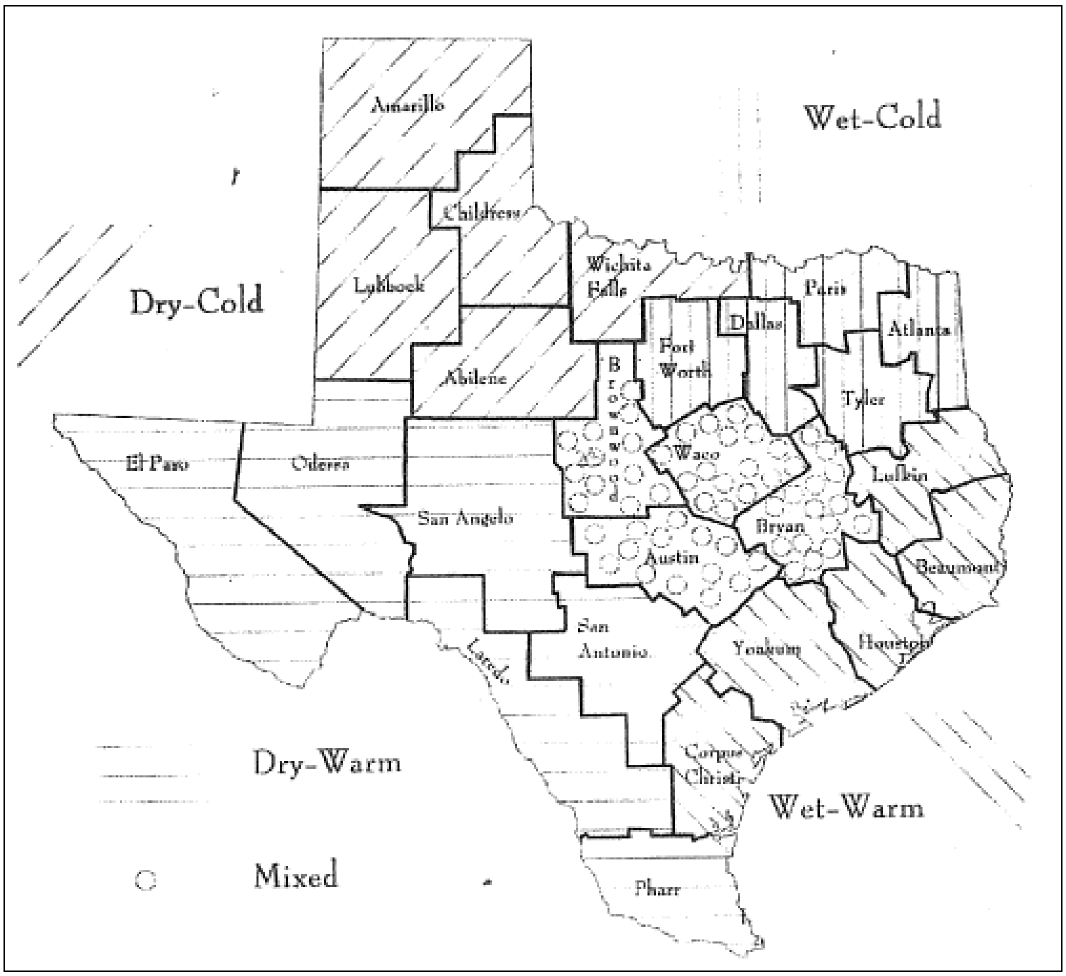

Figure 6.7: Texas District Boundaries and Environmental Zones

Table 6.6: Selected TxDOT Field Evaluation Materials and Locations

District	Pacher	Perma Patch	Proline	Stayput	TOTAL
Amarillo	4	9	6	8	27
Fort Worth	7	11	9	10	37
Lubbock	5	5	2	2	14
Lufkin	5	9	11	5	30
Yoakum	3	4	5	4	16
TOTAL	24	38	33	29	124

6.4.3 Amarillo

All patching materials installed in the Amarillo District experienced at least two failures. The best and worst performing materials were Proline and Stayput, respectively, as shown in figures 6.8 and 6.9. A total of six Proline patches were installed in the Amarillo District. Of these patches, two failed while all others remained with condition scores greater than 90. For Stayput, six of the eight patches installed failed after just 6 weeks. Pacher and Perma Patch had two failures each.

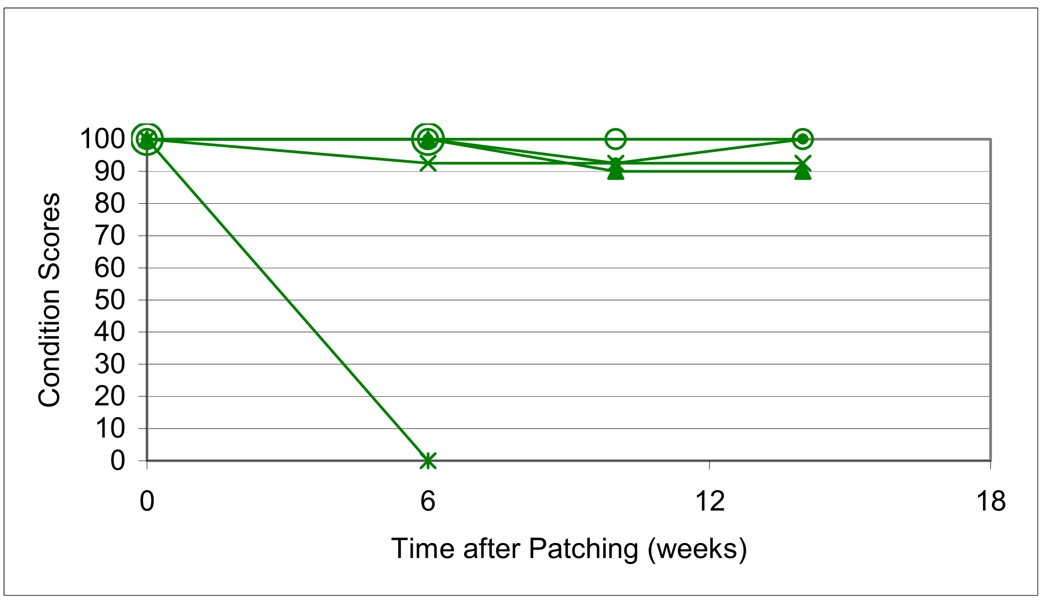

Figure 6.8: Amarillo TxDOT Field Evaluation Results for Proline

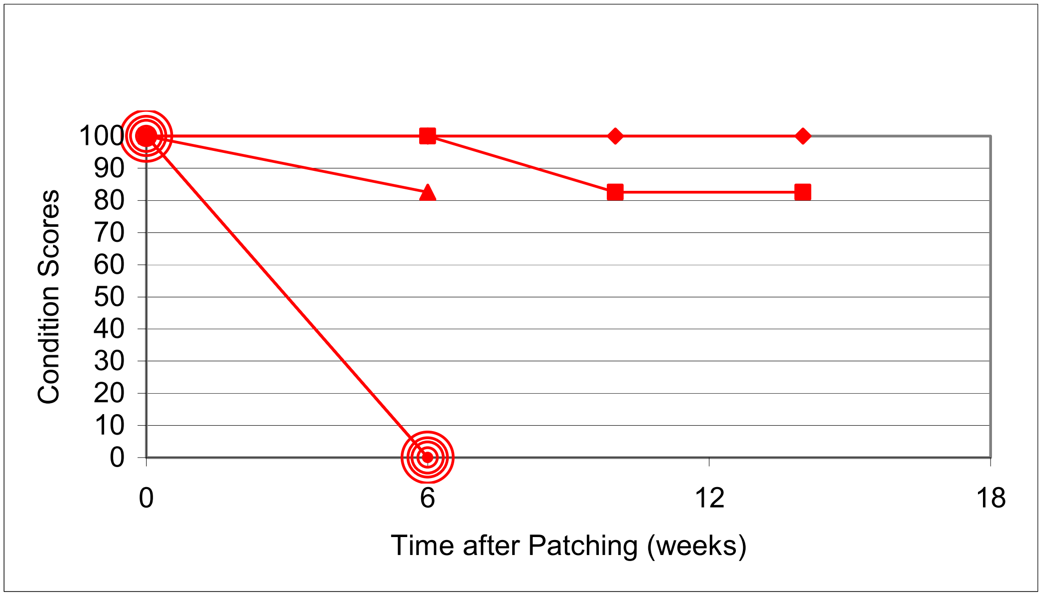

Figure 6.9: Amarillo TxDOT Field Evaluation Results for Stayput

6.4.4 Fort Worth

Unlike Amarillo, none of the patch installations in the Fort Worth District failed. Proline and Pacher were the best and worst performing materials, respectively. Results for these materials are presented in figures 6.10 and 6.11. Proline was installed in nine locations from which condition scores remained above 80. Pacher was the only material with condition scores under 70. Although collection of condition surveys was discontinued by 12 weeks, the deterioration trends are good indicators of material performance.

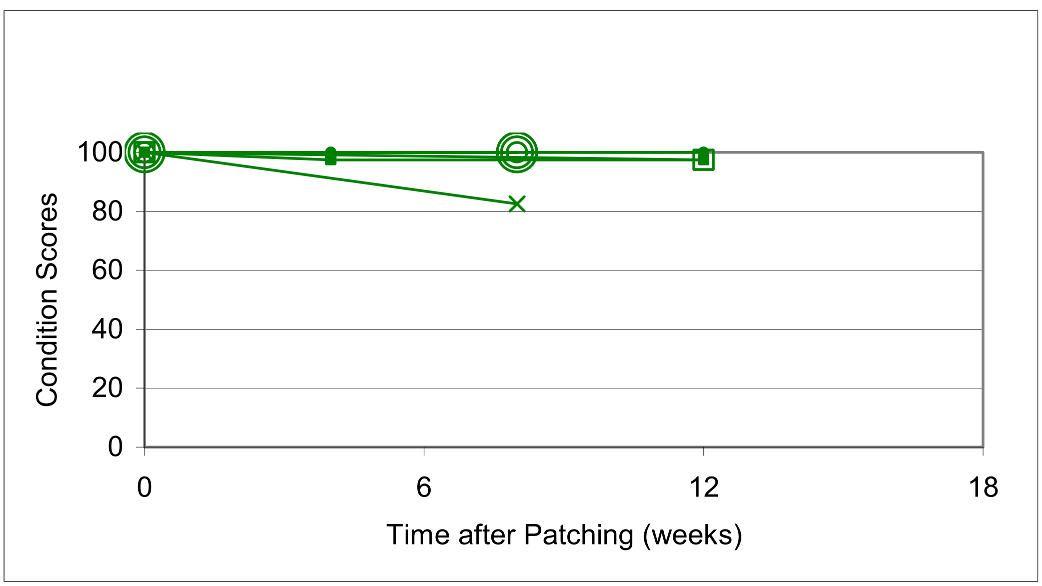

Figure 6.10: Fort Worth TxDOT Field Evaluation Results for Proline

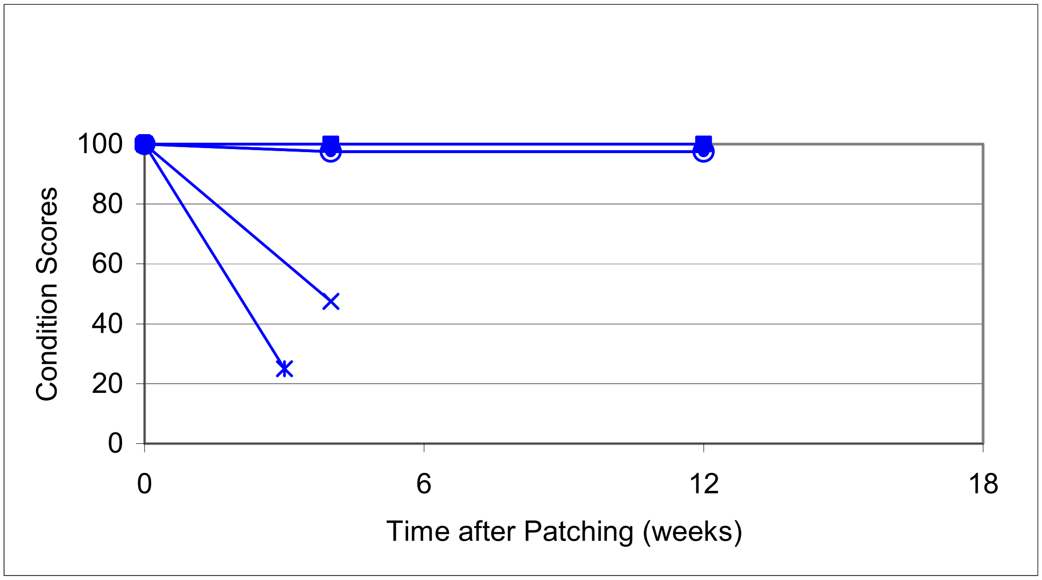

Figure 6.11: Fort Worth TxDOT Field Evaluation Results for Pacher

6.4.5 Lubbock

Lubbock was the district that maintained condition surveys for the longest period of time. In most cases, condition surveys were taken up to 28 weeks. Unfortunately, the materials used were not evenly distributed. Only two patch installations each of Proline and Stayput were installed. Of these, one Stayput failed. Results for the other two materials are presented in Figures 6.12 and 6.13. Pacher performed relatively well with only one out of five patches scoring below 95. Perma Patch experienced two patch failures out of the five installations. Overall, Perma Patch and Stayput did not perform as well as Pacher and Proline.

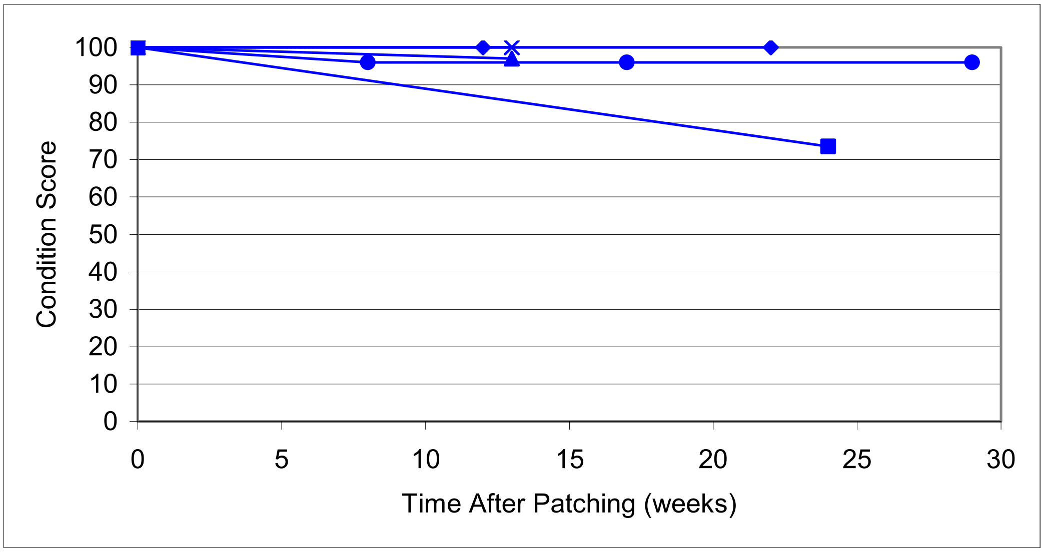

Figure 6.12: Lubbock TxDOT Field Evaluation Results for Pacher

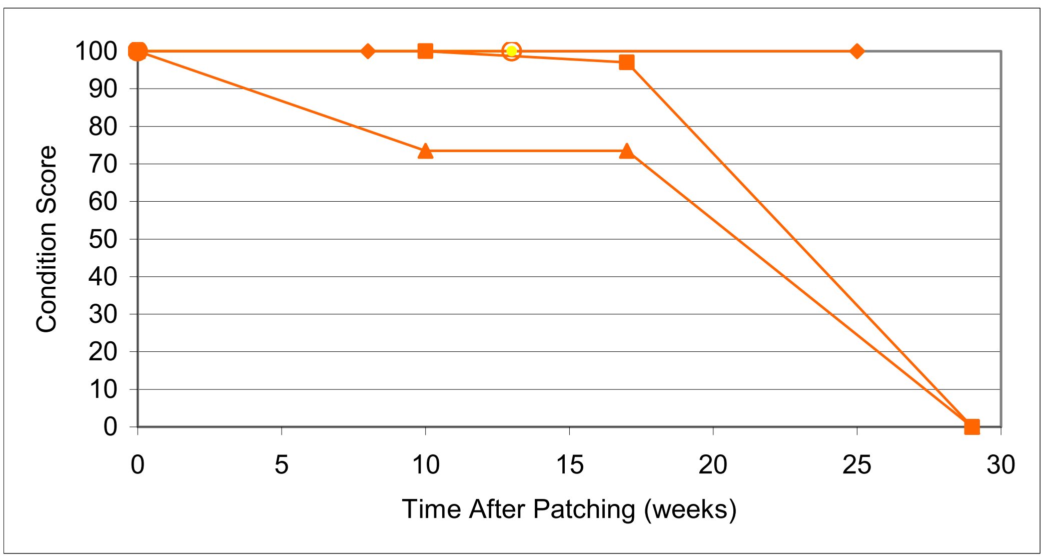

Figure 6.13: Lubbock TxDOT Field Evaluation Results for Perma Patch

6.4.6 Lufkin

Many of the condition surveys performed on the patch installations in the Lufkin District were discontinued early. Exemplifying this is Figure 6.14, which demonstrates that condition surveys for Stayput patches were only conducted after 4 weeks. TxDOT personnel explained that hurricane events in their area caused them to shift their maintenance activities, resulting in the lack of available data. However, not all data was lost. Figure 6.15 demonstrates results typical of Lufkin. All patches in the district maintained a condition score greater than 80.

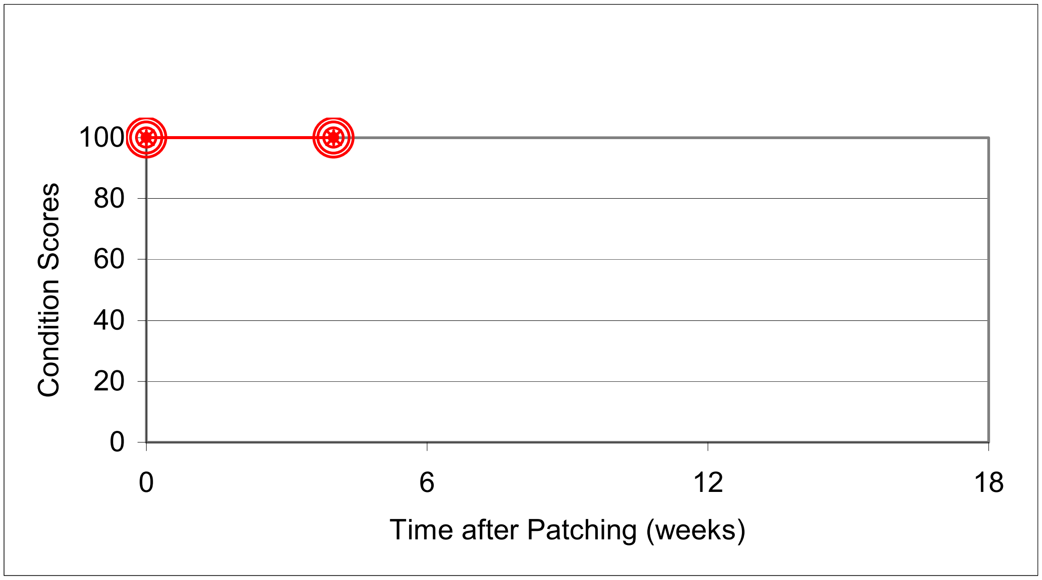

Figure 6.14: Lufkin TxDOT Field Evaluation Results for Stayput

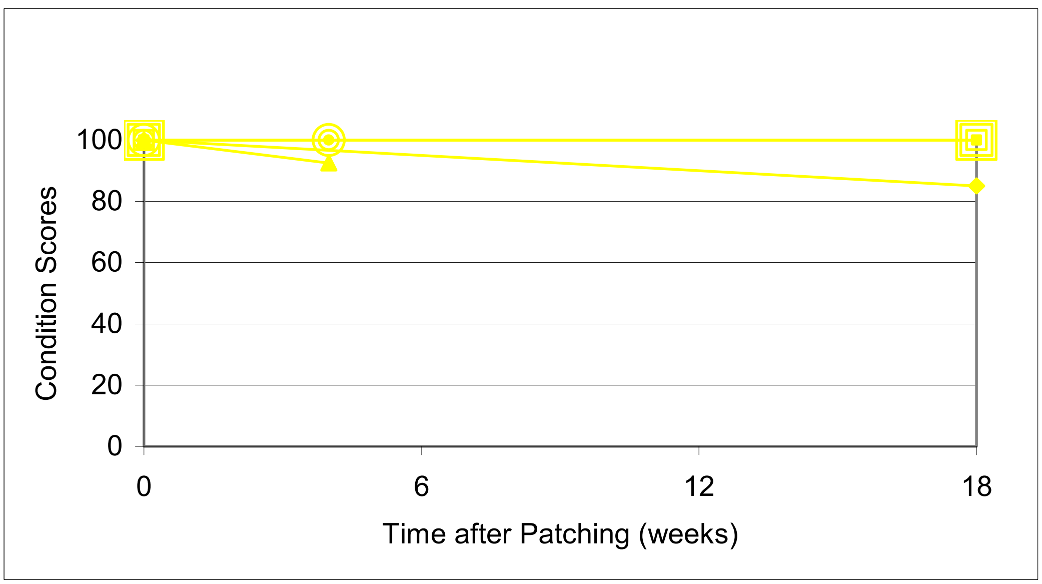

Figure 6.15: Lufkin TxDOT Field Evaluation Results for Perma Patch

6.4.7 Yoakum

Results for the Yoakum District were consistent with those obtained in other districts. Pacher and Proline (Figure 6.16) exhibited very good performance. Condition scores for all patches in these two materials remained well above 90. On the other hand, Perma Patch and Stayput (Figure 6.17) experienced one failure each. Stayput experienced the most premature failure at only 2 weeks. The Perma Patch failure was observed at 4 weeks after installation.

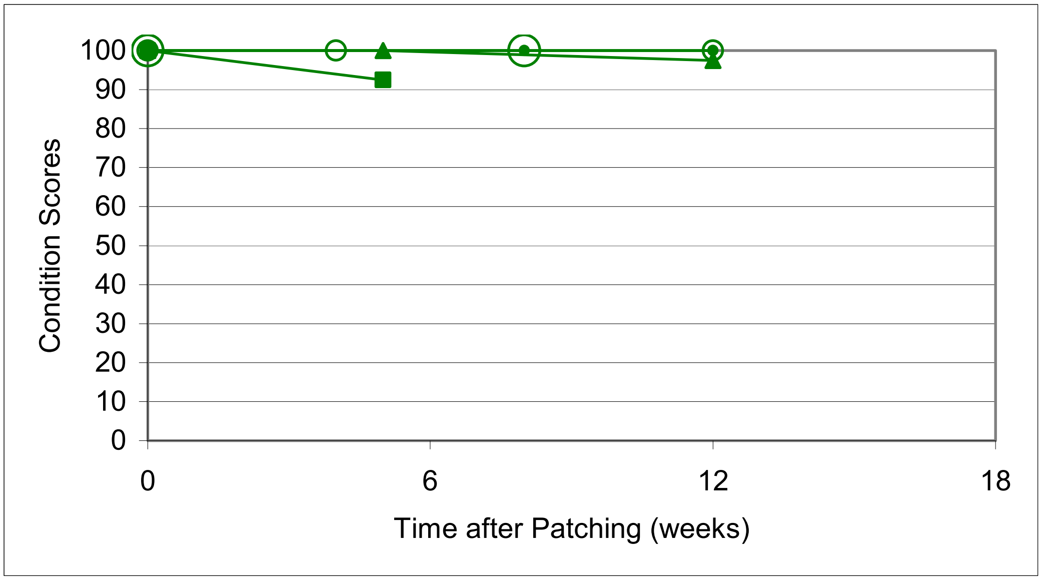

Figure 6.16: Yoakum TxDOT Field Evaluation Results for Proline

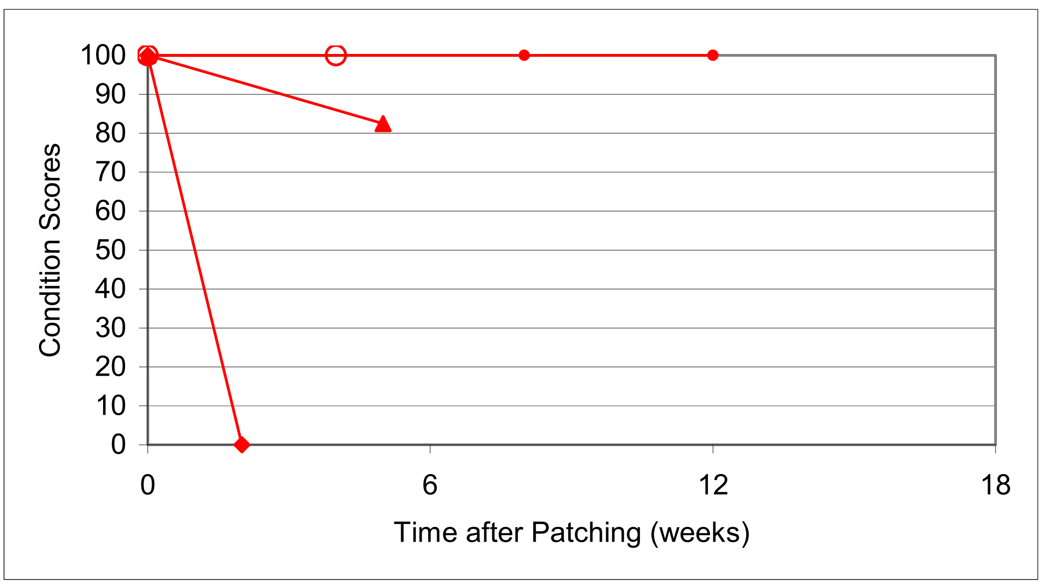

Figure 6.17: Yoakum TxDOT Field Evaluation Results for Stayput

6.4.8 TxDOT Overall Results

Although looking at all the TxDOT data segregated by district gives a general indication of the materials displaying better field performance, the data is difficult to quantify. In an attempt to do this, a linear regression was used to estimate the patch performance over time. The basis for this model was the Perma Patch installations in the Lubbock District with the condition score as the dependent variable. The independent variables in the model were the other four districts (Amarillo, Fort Worth, Lufkin, and Yoakum), time after patching in weeks, and the material type (Pacher, Proline, and Stayput).

The results of the patch performance model are displayed in Table 6.7. The Perma Patch installations in the Lubbock District are captured by the constant term in the model. According to the constant term, the expected patch condition for Perma Patch soon after installation in Lubbock is 96.4. The p-value of 0.755 and standardized beta of -0.027 for the Yoakum District suggests that, on average, there is no significant difference in how all patches perform in the Yoakum District compared to the Lubbock District. Some individual products, however, may perform better in one district than another district. The negative standardized beta value for time after patching in weeks reinforces, and quantifies, the intuitive idea that as time after installation increases, the condition score will decrease, which indicates patch deterioration. Perhaps the most significant information in this model lies in the patching material statistics.

The significance values (p-values) indicate there is no statistical significant difference in the performance of Pacher, Perma Patch, and Proline. Nevertheless, model results suggest that patching material Proline generally performed better than, or comparable to, the basis for the model, Perma Patch. Stayput, on the other hand, did not perform as well as Perma Patch. The standardized beta value for Proline suggests that this is the patching material that performs the best in the field. Stayput, however, demonstrated the worst in-field performance for the conditions tested. These results were consistent with laboratory and accelerated pavement testing.

Table 6.7: TxDOT Field Evaluation: Patch Performance Model

	Unstandardized Coefficients		Standardized Coefficients	t	p-value
	B	Std. Error	Beta		
Constant	96.411	11.762		8.197	0.000
Amarillo	-33.772	8.927	-0.405	-3.783	0.000
Fort Worth	8.749	9.750	0.096	0.897	0.371
Lufkin	9.256	10.265	0.080	0.902	0.368
Yoakum	-3.474	11.123	-0.027	-0.312	0.755
Time (weeks)	-0.858	0.511	-0.115	-1.679	0.095
Pacher	-1.587	6.829	-0.015	-0.232	0.817
Proline	5.441	6.393	0.058	0.851	0.396
Stayput	-19.394	6.261	-0.210	-3.098	0.002

Note that this model cannot precisely indicate the performance of a particular mixture. Uncertainty is inherent and errors are induced through the subjective condition survey ratings by multiple maintenance crews in different districts. Other sources for error included censored data and varying time intervals between condition surveys. Nevertheless, this performance model is a fair general indicator of how the patching mixtures included in the TxDOT field evaluation performed relative to one another.

7. Winter Field Evaluations

The winter field evaluations were modeled exactly after the CTR field evaluations. Their objective was also to establish a correlation between field performance and laboratory and accelerated pavement testing. The specific goal was to evaluate the performance of the homemade mixtures in cold weather conditions. All field installation and evaluation procedures developed for the previous field evaluations were used.

7.1 Preliminary Winter Evaluation

Based on the design considerations and test results from the preliminary mixture design, four different homemade mixture designs were selected for the preliminary winter field evaluation:

- Dense, Rounded, 4.0 percent residual binder content with lime
- Dense, Rounded, 4.5 percent residual binder content with lime
- Dense, Rounded, 4.0 percent residual binder content with DA-17
- Dense, Rounded, 4.5 percent residual binder content with DA-17

These mixture designs were selected because HWTD results demonstrated that dense rounded mixtures were more stable than the other gradation/shape combinations (refer to Figure 4.12). In addition, results from HWTD tests also indicated a possible optimal residual binder content between 4.0 and 4.5 percent (refer to Figure 4.13) and emphasized the benefits of anti-stripping agents.

The preliminary winter evaluation was conducted in February 2006 in the Bovina maintenance area in the Lubbock District. That winter was unusually warm and temperatures between 85˚F to 90˚F were recorded the day of installation. A total of 16 patches were installed along US 60 in locations previously patched as part of the CTR field evaluation. Containerized material previously used to patch the potholes was removed and new homemade mixtures were placed according to established installation protocols.

7.1.1 Results

All four mixtures were very workable during installation. Unfortunately, the excessive workability resulted in unstable material once installed. As a quick remedy, fines were sprinkled on the surface of the patches. This immediately helped increase the stability of the patch installations. Maintenance personnel decided adequate stability was achieved and left the material in place. These patches were monitored and showed acceptable performance. In fact, the material was still in place 1 year later.

Due to preliminary winter evaluation conditions, researchers decided to postpone the winter field evaluations in order to ensure material installation during cold weather. In the meantime, the mixture designs and testing methods were modified to increase warm weather stability. The use of the MMLS3 was introduced to verify the 0 hour stability of the mixtures.

7.2 Modified Winter Evaluation

The TST and MMLS3 were used to evaluate variations of the mixtures considered in the modified mixture design with a focus on stability. TST results indicated that for colder material temperatures a medium graded mixture with rounded aggregate, 3.5 percent residual binder content, and 2 percent lime would display good stability compared to other homemade mixtures (refer to Figure 4.18). This mixture design was denoted as Lab homemade. The three mixtures used in the modified winter evaluation are:

- Lab Homemade
- Bovina Homemade
- Proline

The Bovina homemade mixture was also installed alongside the Lab homemade to establish their relative performance. However, this mixture was prepared with pre-coated Grade 4 aggregates that were not available for use during the research. In addition to these homemade mixtures, Proline was installed as a benchmarking product. This material performed consistently well (and comparable to the TxDOT approved IRR) in all laboratory tests, accelerated pavement tests, and field evaluations.

The modified winter evaluation was conducted in February 2007 in the Bovina maintenance area. Temperatures on the day of installation were somewhat cooler at 60˚F to 65˚F. A total of nine patches were installed on US 60 where the preliminary winter evaluation mixtures were installed. Interestingly, the homemade material installed the year before was still in place. The plan was to install three patches of each material. However, researchers only took one bag/bucket per patch. The size of the patch required about 1.5 bags/buckets. Consequently, only two patches of homemade and Proline were installed. The other five patch installations were Bovina homemade.

7.2.1 Results

All patch installations were both workable and stable. Daily visual inspections were performed by maintenance personnel to ensure the material remained in place. Formal condition surveys were recorded every 2 weeks.

Figure 7.1 displays preliminary results from condition surveys recorded at 2, 4, and 8 weeks after installation. Condition scores were calculated based on the condition surveys, as described in Section 6.2.2. Preliminary results from the modified winter evaluation demonstrate that Proline performs slightly better than both Lab and Bovina homemade mixtures. One Proline patch installation did not demonstrate any sign of distress, whereas the other Proline patch demonstrated minimal dishing at 8 weeks after installation. Of the two homemade mixtures, the Bovina homemade performed slightly better than the Lab homemade. This is most likely as a result of the use of pre-coated Grade 4 aggregates in the Bovina homemade. For the most part, Bovina homemade mixtures experienced slight dishing and some bleeding. Lab homemade patch installations deteriorated at a faster rate. At 2 weeks after installation, one Lab homemade patch experienced both dishing and shoving.

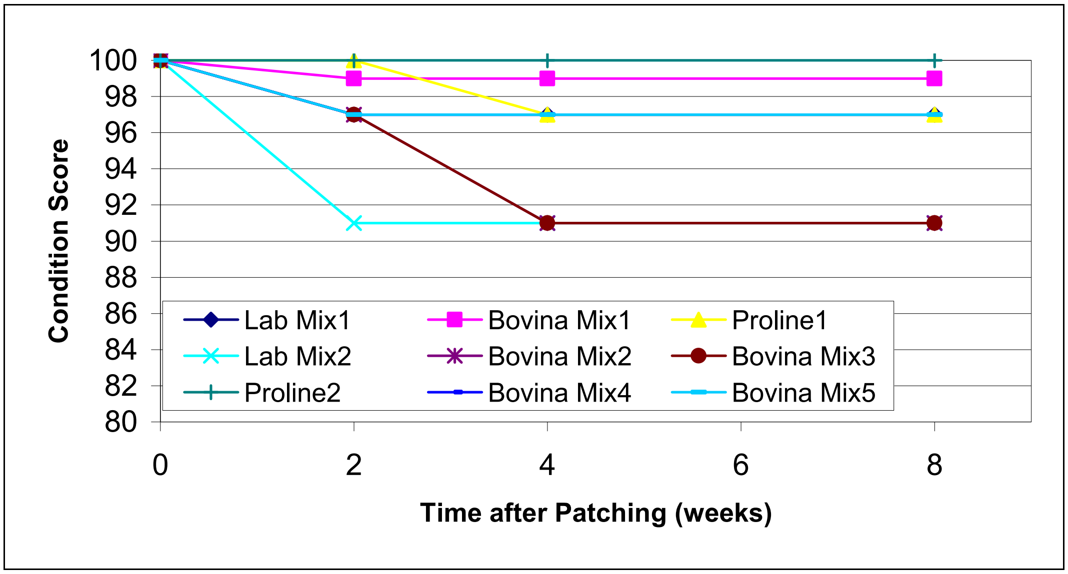

Figure 7.1: Winter Field Evaluation Results

8. Cost-Effectiveness Analyses

Chapter 8 contains the analyses carried out as part of this research study to identify the most cost-effective mixtures for patching operations. The chapter documents the data gathered, the various cost considerations, and the calculations performed in evaluating the different commercial, experimental, and homemade mixes.

8.1 Methodology

The research team identified a number of factors that influenced the costs or perceived costs of various cold patch mixtures during the literature review and through discussions with TxDOT and the vendors[1]. A questionnaire was prepared (see Appendix G) and administered to TxDOT personnel in the Lubbock District to obtain an understanding of the different cost components involved in mixing the homemade mixtures, when and how cold patching mixtures are used, patching methods used, as well as to identify any cost considerations that are unique to the containerized and homemade mixes. The latter is important because costs were included and quantified only to the degree necessary to distinguish between alternative mixes. In this regard, it was assumed that traffic control costs and associated user delays would be similar irrespective of the mixture used. This assumption ignores the possibility that a particular mixture will have such poor workability that it could take longer to patch a pothole, resulting in additional time and, thus, user delays. However, measuring the impact on traffic control and user costs associated with the time differentials to patch a pothole attributable to differences in workability was considered rather speculative and also cost prohibitive. It was therefore assumed that the differential would be negligible. Also, some cost components (e.g., shelf life, and loading and unloading costs) were very difficult to quantify and consequently a multi-attribute criteria approach[2] was adopted to distinguish and account for cost differences associated with the different mixtures.

To understand how TxDOT is currently purchasing cold patching material, the research team interviewed a representative from the General Services Division (see Appendix H for the questions that were asked). The research team learned that TxDOT has four Regional Supply Centers (RSC) that purchase cold patch materials in relatively

[1] The research team interviewed a number of employees from the TxDOT Lubbock District, the General Services Division, and the vendors of the commercial cold mixtures to identify and understand the various cost components, how cold mixtures are used, and to formalize assumptions that were required in conducting the analysis. For example, based on discussions with the Lubbock District the width of an average size pothole was assumed to be 2-4 sq ft, requiring 200-300 lbs of material to fill under the "Throw and go" method and 500- 600 lbs of material if the pothole is filled according to the guidance given in Function Code 241: Potholes, Semi-Permanent Repair and Function Code 242: Potholes, Permanent Repair, Square Cut.

[2] Multi-attribute criteria analysis is founded in benefit costs analysis (BCA), but unlike BCA, which requires the quantification of all impacts (benefits and costs), multi-attribute criteria analysis does not require the expression of all impacts in monetary terms. This type of analysis allows the analyst to rank identified impacts in a structured framework.

large quantities–on average about 22 tons of product or 864, 50-lb buckets (see Figure 8.1 below and Table H.1 in Appendix H). On average, it takes 12 days for the vendor to fill an order of 864 buckets. The only material purchased was Instant Road Repair (IRR). Usually, a RSC orders more product when a stock level of 654 buckets is reached.

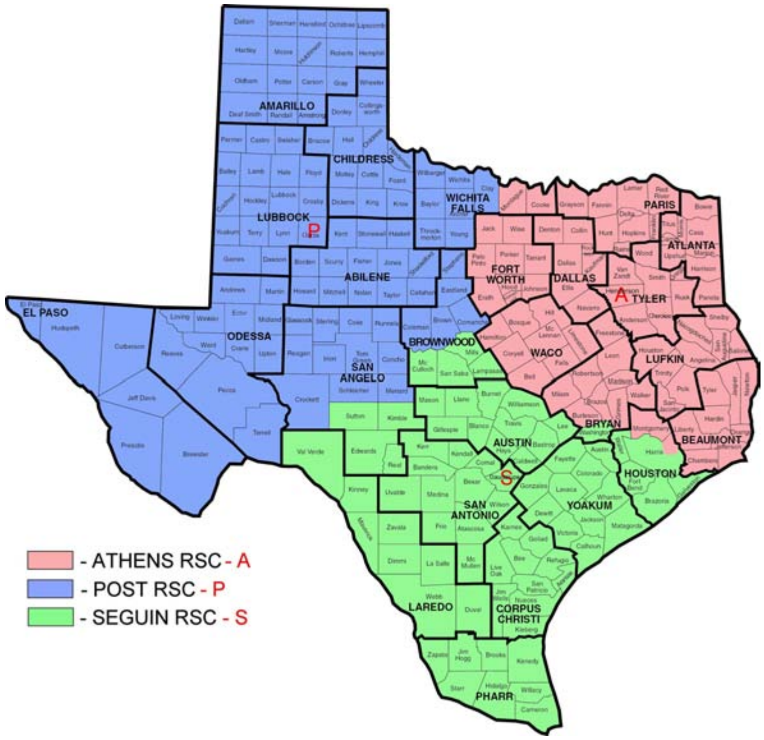

Figure 8.1: Regional Supply Center Location and Districts Served

Based on the responses obtained from the General Services Division, the research team revised the questionnaire that was administered to the commercial vendors. For example, all vendors were asked to provide a cost estimate for delivering 22.5 tons of their products to the TxDOT RSC in Post. All the vendors were contacted by telephone and e-mail to request their participation by answering the questionnaire (see Appendix I). Telephone interviews were conducted with the vendors that sold Perma Patch, Proline, QPR, and UPM in Fall 2006 and Spring 2007. The answers obtained were documented and shared with each of the vendors to verify that their answers were recorded correctly. In the case of Asphalt Patch, the vendor completed the questionnaire and faxed it to the research team. Repeated voice messages and e-mails were unsuccessful in convincing the vendor of IRR and Stayput to answer the research questions. The information included in this section of the report for IRR and Stayput is, therefore, based on the purchase records obtained from TxDOT and the tests conducted by the research team. Unfortunately, no information on cost or estimated time to fill an order could be obtained for the Stayput product.

8.2 COST CONSIDERATIONS

The first step is to identify the important cost components and criteria (impacts) associated with each of the cold patch mixtures. The following cost components or criteria were considered in this analysis:

- Material cost, including shipping cost,
- Time to fill order,
- Specific storage requirements,
- Shelf life,
- Bag durability,
- Stability,
- Special handling requirements,
- Performance, and
- Other, specifically environmental impact.

As previously indicated, the information required for evaluating these components/criteria was obtained from the vendors, TxDOT personnel, and the tests conducted by the research team. For most of these variables, it was either not possible or would have been cost prohibitive to quantify the differentials among the different mixtures. A scoring method was thus used to distinguish the differential costs. In other words, the costs and criteria associated with each of the mixtures were rated on a scale of 1 to 5, where 1 represents a very high cost or inferior quality/service and 5 represents a very low cost or superior quality/service. Also, because all cost components and criteria were not considered equally important, a weighting scheme[3] was adopted.

8.2.1 Material Costs

Table 8.1 lists the material costs–including shipping cost to the RSC in Post–obtained from the vendors for UPM, Proline, QPR, Perma Patch, and Asphalt Patch. The material cost for IRR was estimated based on information obtained from TxDOT's General Services Division as follows: In 2006 the RSC in Post purchased 3,574 buckets (50 lbs each) at a cost of $49,248 from International Roadway Research, translating to a cost of ~ $13.78/bucket.

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[3] When parameters of differing importance are combined into a single decision-making tool, a weight should be assigned to each of the parameters to prevent less important parameters from driving the decision.

Table 8.1: Materials and Shipping Costs at RSC

Cold Mixes	Material Cost/ Ton (Incl. Shipping to Post)
UPM	$316.00 (Bags)
Proline	$396.00 (Bags)
QPR	$330.00 (Bags)
Perma Patch	$450.00 (Bags)
Asphalt Patch	$329.67 (Bags)
IRR	$551.18 (Buckets)

It is important to note that these cost estimates were received at the time of the interview with the vendor and that the actual costs to TxDOT will vary.

From RSC to District Maintenance Sections

To compare the product cost of the containerized mixtures with the Lubbock mix and the various Laboratory homemade mixes, the shipping cost from the Post RSC to district maintenance sections had to be calculated. For IRR, this cost could be calculated by subtracting the product cost/bucket delivered to the Post RSC from the Average Price per bucket issued to the districts' maintenance sections. The average price per bucket issued to the districts was calculated as follows: Post RSC issued 3,610 buckets on 86 issue documents at a total price of $51,442.50, translating to an average price per bucket of $14.25. The shipping cost from the RSC to the maintenance sections in the district thus amounted to $14.25/bucket minus $13.78/bucket. This translated to a cost of $18.80/ton. A shipping cost of $18.80 was thus assumed for moving 1 ton of containerized mixture between the Post RSC and the maintenance sections in the district for all the containerized cold mixtures.

Table 8.2: Materials, including Shipping Costs at Maintenance Sections

Cold Mixes	Material Cost/ Ton (Incl. Shipping to Maintenance Sections)
UPM	$334.80 (Bags)
Proline	$414.80 (Bags)
QPR	$348.80 (Bags)
Perma Patch	$468.80 (Bags)
Asphalt Patch	$348.47 (Bags)
IRR	$569.98 (Buckets)
Lubbock Mix	$64.25 (Bulk)
Lab Homemade Mix	$74.25 (Bulk)

From Table 8.2, it is evident that the mixture sold in buckets is substantially more costly than the mixtures sold in bags. The IRR mixture costs more than a $100/ ton more than the most expensive bagged product (i.e., Perma Patch), which is attributable in part to the cost of the buckets. Most vendors indicated that they preferred not to supply in buckets[4] because of the cost of the bucket (approximately $2.50 to $3.00 per bucket) and higher shipping costs. However, most vendors will sell their product in buckets if the client desires (see Table 8.3).

On the other hand, the bulk mixes are substantially cheaper than the bagged mixes. The most inexpensive bagged mix (i.e., UPM) is still more than 5 times as expensive as the Lubbock mix.

Table 8.3: Packaging Options

Cold Mixes	Packaging
UPM	Bags or bulk – prefer not to supply in buckets
Proline	Bags or bulk– buckets if client desires
QPR	Bags or bulk – do not sell in buckets
Perma Patch	Bags – buckets if client desires
Asphalt Patch	Bags or bulk – buckets if client desires

However, most of the vendors interviewed (i.e., UPM, Proline, QPR, and Asphalt Patch) indicated that their product is available for bulk purchasing (see Table 8.4). The bulk prices provided by two of the vendors are more comparable to the costs of the Lubbock and Lab Homemade mixtures, which indicate the potential for considerable costs savings if TxDOT purchases the bulk instead of the bagged product from the vendor.

Table 8.4: Mixtures Available for Bulk Purchasing

Cold Mixes	Available for Bulk Purchase
UPM	Yes ($90/ton delivered to Waco; $85/ton delivered to San Antonio)
Proline	Yes
QPR	Yes ($68/ton if delivered within 45 miles from Bridgeport, Dallas)
Perma Patch	No
Asphalt Patch	Yes

8.2.2 Inventory/Storage Cost

Inventory/storage cost is a function of the time to fill an order and the specific storage requirements associated with the mixture. Tables 8.5 and 8.6 show the responses from the vendors in terms of the time to fill a truckload order and the specific storage requirements of the various containerized mixtures. As seen from Table 8.5, most of the vendors indicated that a truckload order can be filled within 48 hours. Asphalt Patch

[4] Proline, QPR, Perma Patch, and Asphalt Patch also indicated that they would be willing to fill buckets provided by TxDOT, which could potentially result in a reduction in the product cost.

required up to 4 days for filling a truck load order. Also, the records from the General Services Division revealed that it took approximately 12 days for the vendor to fill a truckload order of IRR.

Table 8.5: Time to Fill Truckload Order

Cold Mixes	**Time to Fill Truckload Order**
UPM	24 hours
Proline	24 - 48 hours
QPR	48 hours
Perma Patch	24 hours
Asphalt Patch	72 - 96 hours
IRR	12 days
Lubbock Mix	24 hours*
Lab Homemade Mix	24 hours

* Interviews with TxDOT personnel from Lubbock revealed that it usually takes 1 day to prepare the mixture.

Regarding storage requirements, most of the vendors–Perma Patch is the exception because their product is stored in a paper bag–indicated no specific storage requirements for their product. Ideally, the QPR product should be stored inside and Proline and Asphalt Patch vendors mentioned that if the product is stored outside for long periods of time, it should be covered with a tarp.

Table 8.6: Storage Requirements Expressed by Vendors

Cold Mixes	**Specific Storage Requirements (Bags)**
UPM	No
Proline	No – If bags are stored in direct sunlight for long time period, cover with tarp
QPR	No – Ideally stored inside
Perma Patch	Ideally stored inside. Cover with tarp when stored outside. Bags water resistant, not water proof
Asphalt Patch	No – If stored outside cover with tarp

8.2.3 Shelf Life/Durability Cost

The shelf life of the product is a function of the characteristics of the various cold mixtures and the durability of the bags in the case of the bagged mixtures. As indicated previously in Chapter 2, a shelf, or storage, life between 6 and 12 months is desirable to ensure satisfactory mixture performance. From Table 8.7, it is evident that the shelf lives of the bagged products were all stated to be in excess of 12 months. On the other hand, the homemade stockpile mixtures (of the Lubbock District) have a reported storage life of between 45 and 60 days. The latter is also inferior to the shelf lives provided by the commercial vendors for their bulk product. Table 8.7 shows that the shelf lives ranged from 3-12 months for Asphalt Patch and 7-14 months for Proline to beyond 12 months for QPR's bulk product.

Table 8.7: Storage life of various mixes evaluated

Cold Mixes	Shelf Life (months)	
	Bags	Bulk
UPM	12-18	
Proline	12+	7-14*
QPR	12**-24	12**-24
Perma Patch	24	NA
Asphalt Patch	Up to 30	3-12
Lubbock Mix		< 2
Lab Homemade Mix		< 2

In the case of Proline and Asphalt Patch, the vendors recommended that the bulk product be covered with a tarp.

* A thin crust will form on top of the stockpile. If only worked out of one area–only turning the load that is required before using it–stockpile will last 14 months

** Guaranteed for 12 months

A potential factor that could impact shelf life is the durability of the bags[5] that the mixtures are stored in. When asked, none of the vendors were aware of any concerns surrounding the durability of their bags (see Table 8.8).

Table 8.8: Bag Durability Concerns Expressed by Vendors

Cold Mixes	Durability Concerns (Bags)
UPM	No
Proline	No
QPR	No
Perma Patch	No, unless in the rain for many days
Asphalt Patch	No

The drop test devised by the research team, however, indicated that the bags used by Asphalt Patch and Proline were the most impact resistant, while the bags used by Perma Patch and Stayput were the least impact resistant. The bags used by QPR were somewhere in between. Finally, the impact resistance of the UPM bags differed substantially between the older UPM Winter bags (30 months prior to drop test) and the newer UPM Summer bags (18 months prior to drop test).

8.2.4 Patching/Productivity Cost

Both the prescribed patching method and the workability of the mixtures–i.e., ability or ease of placement in the field–influence the costs of using a specific mixture. Table 8.9 summarizes the responses of the various vendors when asked about the

[5]The bag descriptions and characteristics are provided in Chapter 4.

recommended patching method for their product. In essence these mixtures are "throw and go" materials.

Table 8.9: Patching Method Recommended by Vendors

Cold Mixes	Patching method
UPM	Sweep the hole, put the mixture in the hole, tamp it down and compact (e.g., with a truck)
Proline	Remove mud and any loose debris (not water) from hole, put mixture in the hole and compact with truck
QPR	Remove debris (e.g., chunks of asphalt) and loose sand, pour 2 inches of mixture at a time in the hole and compact (hand tamp, mechanical tamp, or wheel compaction), compact one last time when hole is filled
Perma Patch	Remove any large and loose aggregate from hole, pour mixture into the hole and spread with a rake or shovel, compact with the wheels of a truck
Asphalt Patch	Throw and go material, but best to clean the hole, check for good base and apply product in 2-inch lifts and tamp each lift

In the case of the homemade mixes a tack coat needs to be applied when the mixtures are installed, which adds to both the costs and the time that it takes to fill a pothole, but the latter was not considered in this analysis.

8.2.5 Workability

The Cold Patch Slump Test (CPST) was used to measure the workability of the various mixtures. The laboratory results are summarized in Chapter 4 for both the containerized and homemade mixtures. The various mixtures were ranked considering the results from the field tests, CPST results, and the MMLS evaluation.

Containerized Mixtures

In terms of the two objective measures–time to slump under own weight and time to fill containment unit–Stayput was denoted as unworkable and as such would require a longer time to apply in the field. On the other hand, UPM Winter was found to be very workable. Proline was found to be workable and cohesive. QPR, Perma Patch and Asphalt Patch[6] had more variable results, but were found to be mostly workable and cohesive. These results largely correlated with the subjective workability rating assigned by raters working the material into the containment unit.

Homemade Mixtures

In terms of the two objective measures, all the homemade mixtures were found to be very workable. However, curing time affected the time to fill and slump of the homemade mixtures. As such, the time to fill generally increased for all mixtures as

[6] The results for Asphalt Patch ranged between very workable and unworkable.

curing time increased. However, the time to fill measurements for the angular mixtures were significantly larger as the curing time increased, suggesting that the cured angular mixtures were less workable–yet more cohesive–than the cured rounded mixtures. Also, the results from the subjective measures of workability indicated a linear correlation between the time to fill and the subjective rating assigned to measure workability.

8.2.6 Special Handling Requirements

Table 8.10 indicates special handling requirements associated with the bags. As can be seen, most of the vendors did not require any special handling requirement of their product. Asphalt Patch did indicate that when stored in pallets, the pallets of product should not be double stacked.

Table 8.10: Special Handling Requirements

Cold Mixes	Special Handling Requirements
UPM	Do not poke with forklift
Proline	Forklift is required for loading product, otherwise manual labor
QPR	No
Perma Patch	No
Asphalt Patch	No, but do not double stack pallets of product

All vendors (except Perma Patch) will refund TxDOT if bags were damaged by vendor or freight carrier during delivery, but not if TxDOT damages bags during unloading. In the case of Perma Patch, the vendor will not refund TxDOT if the bags have a slight tear, but if an entire pallet is destroyed then the vendor will refund TxDOT for the product in the damaged bags.

8.2.7 Other

QPR was the only vendor that informed the research team about the company’s environmental policy initiatives and provided the supporting documentation to substantiate the statements made by the representative. To comply with their business policy to be consistent with pollution prevention and sustainable development principles, the material used to manufacture the QPR product is biologically non-toxic, thereby alleviating any concerns about runoff into underground water supplies, and the product has a zero mortality rate for fish in lakes and streams. QPR has clients that are very aware of the environmental concerns associated with water runoff and thus purchase the QPR product exclusively.

8.3 Analysis Results

As indicated before, each of the mixtures was rated on a scale of 1 to 5 in terms of the criteria discussed in the previous section and listed below:

- Material cost, including shipping cost,
- Time to fill order,
- Specific storage requirements,
- Shelf life,
- Bag durability,
- Stability,
- Special handling requirements,
- Performance, and
- Other, specifically environmental impact.

A rating of 1 represents a very high cost or inferior quality/service and 5 represents a very low cost or superior quality/service. Also, because all the criteria were not regarded of equal importance, weights were used to differentiate the most important criteria by assigning a higher weight[7] to criterion that was deemed more important (i.e., stability and patch life). The results of this simple yet effective approach are summarized in Table 8.11.

The overall ranking of the mixtures, given the criteria used, in descending order is as follows:

- Proline (Best)
- Lubbock Mix and UPM
- Asphalt Patch
- Lab Homemade Mix
- QPR
- Perma Patch (Worst)

Unfortunately, the information for IRR and Stayput was incomplete since the vendor was not willing to participate in the study. These mixtures were therefore not ranked, but available information on each of the criterion is summarized in Table 8.11

From the results, it is evident that the Lubbock mix compares well with the commercial mixes. However, two factors can change these results: (1) the weights

7 The results will change if the weights are altered and it is recommended that TxDOT review these weights to reflect the considerations and priorities of the agency. For example, if pollution control becomes a priority for the agency in the future, a higher weight for the Environmental Impact criteria would be justified.

assigned to each of the criteria (see footnote below) and (2) if TxDOT decides to purchase the commercial products in bulk. As indicated earlier, UPM, Proline, QPR, and Asphalt Patch will sell their product in bulk to TxDOT, which could result in considerable cost savings while complying with the desirable shelf life requirement of 6 to 12 months.

Table 8.11: Multi-Attribute Criteria Approach

Weight	Criterion	Asphalt Patch	IRR	Lab Mix	Lubbock Mix	Perma Patch	Proline	QPR	Stayput	UPM
10	Material cost	3	1	5	5	2	2	3		3
5	Time to fill order	2	1	5	5	5	4	3		5
5	Specific storage requirements	5		5	5	3	5	5	5	5
5	Shelf life	5		1	1	4	1	3	1	2
5	Bag durability	5	5	5	5	2	4	3	1	3*
15	Workability	2		5	5	4	4	3	1	5
20	Stability	3	5	2	3	3	5	3	5	3
5	Special handling requirements	4	3	5	5	5	5	5	5	5
5	Other (i.e., environmental impact)	1	1	1	1	1	1	5	1	1
25	Patch life (performance)	4	5	2	2	2	5	2	1	3
100	**Totals**	**330**		**325**	**345**	**290**	**405**	**305**		**345**

* Bag durability was rated 4.5 for the UPM Winter mixture and 1.5 for the UPM Summer mixture. The average was used in this table. It should be noted that the UPM Winter and UPM Summer mixtures used the same bag. One explanation for the different rates is that because the UPM Winter material was more workable than the UPM Summer material, it helped the bag to be more impact resistant.

9. Summary and Conclusions

This chapter presents recommendations for a homemade mixture design procedure based on the literature review and testing results. It is important to note that this design procedure was developed specifically for the cold and wet weather conditions similar to those experienced in the Lubbock District. However, this procedure may serve as a framework for use in other districts and other weather conditions. Modifications must be made based on literature, experience, material testing, and specific environment and project demands. In addition, this chapter also suggests recommendations for performance-based specifications based on the results from this research study.

9.1 Homemade Mixture Design Procedure

9.1.1 Aggregate Type

The type of aggregate used in the design of homemade cold patching mixtures should be chosen based on material availability in the area of the project. Materials may include crushed rock or crushed gravel. Good quality materials should be used at all times, when price permits, to support the integrity of the mixtures. Leftover materials from construction projects may also be beneficial, such as the pre-coated Grade 4 that was used in Bovina.

Either crushed rock (100 percent crushed faces) or crushed gravel (high percentage of crushed faces) may be used in the design. Crushed aggregates generally provide higher stability while crushed gravels tend to increase mixture workability. CPST results presented in this study indicate that the workability of mixtures prepared with crushed gravels is less susceptible to increasing curing time than that of a mixture prepared with crushed rock.

9.1.2 Gradation

Different gradations may be used in the design of cold patching mixtures. Field and laboratory observations showed that open gradations demonstrated desirable strength and tend to be very workable. Recommendations on the range of aggregate proportions were developed as part of this study and are summarized in Table 9.1. Actual target aggregate proportions will vary slightly from area to area. These proportions should be based on material availability, sieve analysis, and desired mixture properties. Local experience with locally available material may, in some cases, override the recommendations in Table 9.1.

Table 9.1: Cold Patching Aggregate Proportions

Sieve Size	Percent Passing
3/8 in (9.5 mm)	95-100
No. 4 (4.75 mm)	40-85
No. 8 (2.36 mm)	15-40
No. 16 (1.18 mm)	6-25
No. 200 (0.075 mm)	1-6

9.1.3 Binder Viscosity and Curing Rate

Both cutback and emulsified asphalts of different grades can be used in the design of cold patching mixtures. Binder selection is one of the most important decisions in the homemade mixture design procedure. Asphalt type and grade should be carefully selected based on desired mixture properties. The scope of this research project only included the use of cutback asphalts. Specifically, MC-250 was identified as encompassing desired characteristics. The use of polymer modification was outside the scope of this research study.

As a general rule, the most viscous grade that can be adequately worked during mixing and installation should be used. Open graded mixtures often require a more viscous binder than dense graded mixtures. Those mixtures with a high percentage of fines, on the other hand, require less viscous binder in order to mix.

Special consideration must be given to the ambient temperature, or season, in the selection of the binder viscosity. This is particularly important for stockpiled patching mixtures. At lower temperatures the binder becomes more viscous, resulting in an unworkable mass. To ensure mixture workability, the viscosity of the binder chosen should be relatively low at the lower temperatures. The lower viscosity grades also provide a longer stockpile life. In the particular case of homemade mixtures, MC-250 is preferred if the mixture is to be used 2 or more weeks after mixing. On the other hand, if mixtures are to be used immediately, or within 2 weeks, RC-250 is preferred. This recommendation depends on local environmental and storage conditions and may differ from district to district.

Factors that affect the curing rate include asphalt type, quantity, grade, wind, rain, and ambient temperature. For example, material at lower temperatures and higher humidity will experience a low curing rate. The rate at which volatiles evaporate from the mixture must be controlled. Otherwise, the stockpile will cure prematurely and become unworkable.

9.1.4 Binder Content

The MC-250 residual binder content for use with the recommended target gradation range should be between 3.0 and 4.0 percent. Lower binder contents are preferred if the mixture is to be used quickly. However, if the mixture is to be used at a slow rate, higher binder contents are preferred. CPST and TST should be performed to identify the optimal binder content within this range for varying aggregate shapes and gradations. In addition, MMLS3 testing may be performed to validate the optimal binder content.

9.1.5 Admixtures

Although the use of diesel was considered as part of this study, no added benefit was observed as a result of its use. In fact, mixtures prepared with diesel displayed excessive workability, which limited its use in the field. Therefore, the use of diesel should be avoided and only be considered when the mixtures become “too dry” due to long stockpile life and exposure to the environment. Diesel may wash out the binder, leaving the aggregate exposed to the environment, increasing the potential for stripping and decreasing durability.

The use of hydrated lime is recommended to inhibit stripping. A percentage of lime, by weight, of 1 to 3 percent should be considered. Optimal lime content can be identified through TST. Yet, the percentage of lime added to the mixture will also be somewhat dictated by cost implications. For the conditions and materials evaluated in this research, 2 percent lime seems to be satisfactory.

9.2 Recommendations for Performance-Based Specifications

Performance-based specifications are intended to identify those homemade and containerized cold patching mixtures that will perform adequately in the field. These specifications were developed with a focus on stability and workability. All recommendations are based on testing results from CPST, TST, and MMLS3.

9.2.1 Cold Patch Slump Test (CPST)

The CPST should be performed on homemade and containerized cold patching mixtures as a measure of mixture workability. The procedure for the CPST is outlined in detail in Appendix A. All specimens should be prepared with a compaction effort of ten blows of the Marshall hammer per lift and prepared and tested at room temperature (77˚F). The time to fill should be graphed versus the logarithmic time to slump under own weight (as in Figure 4.2). Any mixtures in the unworkable quadrant should be deemed unacceptable. This will generally include any mixture with a time to fill greater than 150 seconds.

9.2.2 Texas Stability Test (TST)

The TST should be performed on cold patching mixtures as an indicator of mixture stability. The TST procedure developed as part of this study is included in Appendix B. Specimens should be cured and tested at various times and temperatures to adequately capture the effects of aging and temperature susceptibility. This is particularly important if the mixture will be stockpiled for several weeks or if the expected ambient temperature at time of installation is highly variable. Corrected stability values should be graphed as a function of temperature to indicate the susceptibility of the material stability to temperature (as in Figure 4.15). As in the case of hot asphalt mixes, high temperature susceptibility is undesirable. In addition, too much or too little stability may adversely affect other material characteristics, resulting in poor patch performance. As a general guideline, mixtures with corrected stability values above 3,500 pounds and below 500 pounds at lower temperatures should be rejected.

9.2.3 Model Mobile Load Simulator (MMLS3)

Proposed mixtures meeting the minimum requirements for CPST and TST should be further validated under the MMLS3. This test measures the mixture's resistance to deformation under a moving wheel load and serves as a general indicator of relative patch performance. Procedures for MMLS3 testing are outlined in detail in Appendix D. All patch installations should be protected from rain and tested at 24 hours after installation, which is the critical time in the life of the patch. The material temperature during testing should be kept constant. For the purposes of this research, material temperatures in the range of 60˚F to 70˚F were considered acceptable for comparative purposes. Since TxDOT currently approves IRR, all materials displaying good performance relative to IRR should be deemed acceptable for use in the field. The average number of wheel passes to failure for IRR was seventy-six. Recall that failure is defined as a rut depth greater than 3/8 inch. Therefore, any material failing before the application of seventy-five wheel passes under the MMLS3 will be deemed unacceptable for use in the field.

9.3 Conclusions

Many of the protocols developed as part of this study provide the framework for future work in the area of cold patching mixtures. Standardized testing methods will facilitate data comparison and validation. The homemade mixture design developed herein provides useful guidelines for those maintenance areas mixing and utilizing homemade mixtures. Minor modifications might have to be made for areas in hot and dry weather as the homemade mixture design procedure was developed based on areas with cold and wet weather. When such modifications must be made, material performance must be ascertained through CPST, TST, and MMLS3.

The recommendations for performance-based specifications provide guidelines for rejection or approval of homemade and containerized mixtures. Those mixtures designed locally in the maintenance yards can be easily tested prior to a full scale installation throughout the district to ensure that the material will perform adequately in the field. In addition, any containerized mixture previously not approved for use by TxDOT can also be evaluated. Until now, only one containerized material, IRR, has been approved for use by the state due largely to the lack of such specifications. An increase in the number of approved containerized materials will provide, among other things, a more competitive price. In conjunction, the homemade mixture design procedure and performance-based specifications should ensure the material characteristics necessary for adequate patch performance in the field. This, in turn, will reduce the failure rates of cold patching mixtures and make it a more cost effective maintenance operation.

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Appendix A: Cold Patch Slump Test (CPST) Procedure

Overview

This method outlines the specimen preparation and testing procedure used to establish the workability of cold patching mixtures. Objective and subjective measures of workability are attained through measurement of time to fill containment unit and time to slump under own weight.

Apparatus

The following apparatus is required to perform the Cold Patch Slump Test.

- Scale – accurate to 0.5 gram
- Non-stick coating spray
- Steel chute
- Metallic disk – 4 in. diameter
- Measuring tape
- Temperature gun – accurate to 0.5˚F
- Timer – accurate to 1 sec.
- Standard Marshall hammer
- Standard spatula with 8 in. blade
- 24 in. x 24 in. wooden containment unit with a cylindrical cavity 16 in. diameter by ¾ in.
- Polyvinyl chloride (PVC) tube – 4 in. diameter by 10 in. height
- Two PVC end caps per tube – 4 in. diameter
- Conditioning chamber, capable of maintaining 35˚F ± 5˚F
- Conditioning chamber, capable of maintaining 55˚F ± 5˚F
- Superpave gyratory compactor extractor

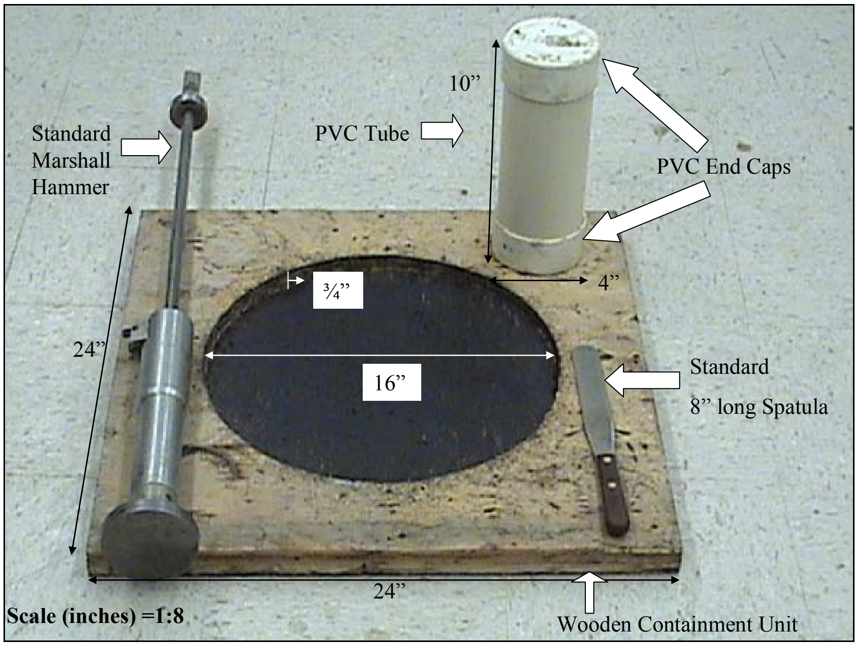

Figure A1 CPST Apparatus (Chatterjee et al., 2006)

Procedure

Use the following procedures in Table A1 and A2 to prepare and test the CPST specimens, respectively.

Table A1 Procedure for Preparation of CPST Specimens

Step	Action
1	Fit a PVC cap to the bottom end of the PVC tube.
2	Spray the inside of the mold with non-stick coating spray.
3	Weigh 1400 g of material to be used for the first lift of the specimen.
4	Use the steel chute to place the material into the mold.
5	Level material with spatula.
6	Pre-compact lift for 10 sec. by resting the Marshall hammer over the material.
7	Compact the first lift with 10 blows of the Marshall hammer. Keep the Marshall hammer level to ensure a level specimen surface.
8	Weigh 1400 g of material to be used for the second lift of the specimen.
9	Use the steel chute to place the material in the mold. Measure height to ensure this is enough material to form a specimen with a height of 8 in. ($\pm$0.5 in.)
10	Level material with spatula and place 4-in. metallic disk on top.
11	Pre-compact material for 10 sec. by resting the Marshall hammer over the material.
12	Compact the second lift with 10 blows of the Marshall hammer. Keep the Marshall hammer level to ensure a level specimen surface.
13	Remove the metallic disc from the top of the specimen.
14	Place the second PVC cap on the top of the mold.
15	Repeat Steps 1 thru 14 to prepare three specimens of each material to be tested.

Table A2 Procedure for Conditioning and Testing of CPST Specimens

Step	Action
1	Place one specimen of each material in the temperature control chambers at 35˚F and 55˚F for 24 hours. Store the third specimen at room temperature.
2	After conditioning, remove the specimen from the temperature control chamber. Measure and record the specimen temperature.
3	Use the extractor on a Superpave gyratory compactor to extrude the specimen from the mold.
4	Place the specimen in the cylindrical cavity of the wooden containment unit.
5	Measure and record the time to slump in sec.
6	Place the slumped material back into the mold following the specimen preparation procedures outlined in Table A1.
7	Recondition the specimen to the temperature in Step 1 by placing in the adequate control chamber for 24 hours.
8	Repeat Steps 2 through 4.
9	Have a rater work the material into the cavity of the wooden containment unit using the 8-inch spatula.
10	Measure and record the time to fill in sec.
11	Ask the rater to provide a subjective rating of the material workability based on a scale of 1 to 5. • 1=Very workable • 5=Not workable
12	Repeat steps 2 thru 8 for all other prepared specimens.

Analysis

Time to fill values should be validated through comparison with subjective ratings. These values should exhibit a linear correlation. Time to fill and logarithmic time to slump should be graphed as a function of conditioning temperature to determine their susceptibility to conditioning temperature. Time to fill should also be graphed as a function of logarithmic time to slump to determine if the materials are workable, workable and cohesive, or unworkable.

Appendix B: Texas Stability Test (TST) Procedure

Overview

This method outlines the testing procedure used to determine the stability of cold patching mixtures.

Apparatus

The following apparatus is required to perform the Texas Stability Test.

- Texas Gyratory Compactor
- Scale – accurate to 0.5 gram
- Non-stick coating spray
- Paper gaskets
- Steel chute
- Large bent spoon
- Plastic wrap
- Calipers
- Temperature gun – accurate to 0.5˚F
- Conditioning chamber, capable of maintaining 35˚F ± 5˚F
- Conditioning chamber, capable of maintaining 50˚F ± 5˚F
- Marshall stability apparatus

Procedure

Use the procedure outlined in Table B1 to prepare and test specimens with the TST.

Table B1 Procedure for Preparation and Testing of TST Specimens

Step	Action
1	Weigh 950 g of material to be used for specimen preparation.
2	Prepare specimens with the Texas Gyratory Compactor (TGC) as described in part I of Tex-206-f.
3	Prepare 18 specimens of each material to be tested.
4	Cure the 18 specimens for 0, 168, and 336 hours as follows: • Immediately wrap six 0-hr specimens in plastic wrap. • Store six 168-hr specimens at room temperature for 168 hours (7 days). • Store six 336-hr specimens at room temperature for 336 hours (14 days).
5	Immediately after specimen preparation, condition the six 0-hr specimens as follows: • Place two specimens in a conditioning chamber at 35˚F for 48 hours (2 days). • Place two specimens in a conditioning chamber at 50˚F for 48 hours (2 days). • Store two specimens at room temperature for 48 hours (2 days).
6	After the 2 day conditioning, test the six 0-hr specimens with the Marshall Stability apparatus as follows: • Measure and record the specimen temperature (˚F), weight (g), height (mm), and initial height and diameter (mm) prior to testing. • Place specimen on Marshall Stability breaking head. • Subject specimen to a compressive load under the Marshall frame of 2 in. /min. until failure. • Measure and record the final height and diameter (mm) and maximum load applied (lbs).
7	After curing for 168 hrs, condition and test the six 168-hr specimens by following Steps 5 and 6.
8	After curing for 336 hrs, condition and test the six 336-hr specimens by following Steps 5 and 6.

Calculations

The total load value applied had to be corrected to account for variations in specimen thickness. The corrected load value should be calculated with Equation A1.

$$CS = \left(\frac{50.8}{H_t} \right)^{1.64} \times L \tag{A1}$$

Where the variables are defined as follows:

CS = Corrected stability value (lbs)

H_t = Specimen height (mm)

L = Load applied (lbs)

Analysis

The corrected load values should be graphed as a function of temperature to illustrate the effects of temperature on material stability. This graph will indicate which materials have too little or too much stability.

Appendix C: Drop Testing Procedure and Data Collection Forms

Overview

This method outlines the testing procedure used to evaluate the impact resistance of cold patch containers (bags) to free falls.

Apparatus

The following apparatus is required to perform the Drop Test.

- Drop Test apparatus – as illustrated in Figure C1
- Forklift
- Large mallet
- Temperature gun – accurate to 0.5˚F
- Measuring Tape

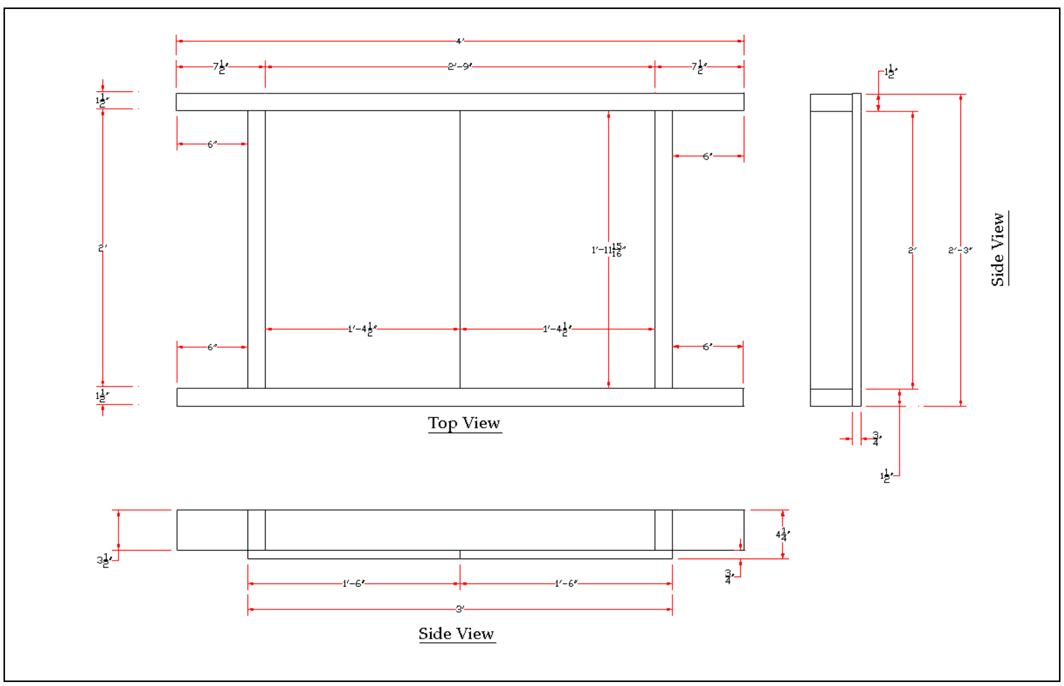

Figure C1 Drop Test Apparatus Design

Procedure

Use the procedure outlined in Table C1 to evaluate the impact resistance of cold patch bag with the drop test.

Table 9.2: Table C1 Drop Testing Procedure

Step	Action
1	Identify a horizontal impact surface of concrete, stone, or steel.
2	Place forklift over the impact surface.
3	Place drop test apparatus over the forklift so that the trap doors are able to open and move freely.
4	Record all the pertinent bag information requested in the Drop Test Specimen Information Sheet in Figure C2. • Material type • Temperature (˚F) • Bagged material weight (lbs) • Bag description • Bag condition
5	Identify and label all faces of the container according to ASTM standards.
6	Place bag in the cavity of the drop test apparatus so that Face 1 faces the impact surface. Ensure the load is distributed evenly on the apparatus.
7	Raise the drop test apparatus to a height of 5 ft.
8	Use the large mallet to tap the trap door release mechanism and drop the bag. The face tested should be parallel to the impact surface throughout the drop.
9	Inspect the bag for any damage and record any observations in the Drop Test Results Sheet in Figure C3.
10	Repeat Steps 6 through 9 for Faces 2 through 6.
11	If necessary, repeat Steps 6 through 10.
12	Terminate testing when the bag has an opening larger than 3 inches.
13	Repeat this procedure with at least two bags of each material being tested.

Analysis

The total number of drops to failure should be reported to determine if the bag is adequate for impact resistance purposes.

DROP TEST SPECIMEN INFORMATION SHEET

Date:________________ Time:________________

Bag Number:_________

Material Type: Asphalt Patch

Perma Patch

Proline

QPR

Stayput

UPM

Approx. Material Age:___________

Material Temperature:___________

Material Weight:________________

Bag Description

Bag Material:____

Bag Construction:____

Bag Condition

Visible Damage:____

____

Page 1 of 2

Figure C2 Drop Testing Data Collection Form (Page 1 of 2)

<u>DROP TEST RESULTS SHEET</u>

Bag Number:______________

Drop Progression

Face of Impact:____________ Use of Hazard: Y N

Visible Damage:____

Face of Impact:____________ Use of Hazard: Y N

Visible Damage:____

Face of Impact:____________ Use of Hazard: Y N

Visible Damage:____

Face of Impact:____________ Use of Hazard: Y N

Visible Damage:____

Face of Impact:____________ Use of Hazard: Y N

Visible Damage:____

Face of Impact:____________ Use of Hazard: Y N

Visible Damage:____

Page 2 of 2

Figure C3 Drop Testing Data Collection Form (Page 2 of 2)

Appendix D: MMLS3 Testing Procedure and Data Collection Form

Overview

This method outlines the Model Mobile Load Simulator testing procedure used to evaluate the resistance to deformation of cold patching materials. This method can also be used as a measure of expected relative field performance.

Apparatus

The following apparatus is required to perform MMLS3 testing.

- Model Mobile Load Simulator (MMLS3)
- Pothole installation site
- Concrete saw
- Shovel and pick
- Broom
- Hydraulic cement concrete
- Insulated shed construction
- 6 in. square compaction hammer
- Vibratory plate compactor
- Level
- Temperature gun – accurate to 0.5˚F
- Ruler, or other straight edge
- Measuring tape

Procedure

The procedure outlined in Table D1 describes site preparation and material installation. The MMLS3 testing procedure is presented in Table D2.

Table D1 MMLS3 Procedure for Site Preparation and Material Installation

Step	Action
1	Identify or construct a pavement structure for material installation and testing of the mixtures under the MMLS3.
2	Use a pavement saw to cut four potholes into the pavement structure. • Length = 12 in. • Width = 12 in. • Depth = 6 in. • Horizontal spacing = Half the length of the MMLS3 apparatus • Vertical spacing = Greater than the length of the MMLS3 apparatus
3	Remove the cut pavement material and sweep away any debris.
4	Use hydraulic cement concrete to fill the bottom 2 in. of all potholes.
5	Place insulated shed over fabricated potholes.
6	For material installation, ensure the pothole is clean of debris.
7	Place about 2 in. of material into the pothole for the first lift.
8	Compact the first lift with the 6 in. square compaction hammer by applying 5 blows to each corner and the middle of the pothole area.
9	Place about 5 in. of material into the pothole for the second lift so that 3 in. of material form a mound over the pothole area.
10	Compact the second lift with one pass of the vibratory plate compactor by holding it in place over the material installation for 5 sec.
11	Remove any excess material on the sides of the pothole with the edge of the shovel.
12	Compact the second lift a second time with the vibratory plate compactor by holding it in place over the material installation for 5 sec.
13	If necessary, remove any excess material on the sides of the pothole with the edge of the shovel.
14	Compact the second lift a third time with the vibratory plate compactor by holding it in place over the material installation for 5 sec.
15	The initial mound height relative to the adjacent pavement area should be greater than 0, but less than 1/2 in. Otherwise, remove material and follow Steps 6 through 14.
16	Repeat Steps 6 through 15 for the three other patch installations.
17	Sweep the area around the four patches in preparations for MMLS3 testing.

Table D2 MMLS3 Testing Procedure

Step	Action
1	Carefully position the MMLS3 over the patch installation to be tested.
2	Lower the MMLS3 machine over the patch so that the wheel path will run directly over the center of the material installation during testing. Do not lower the MMLS3 with a wheel directly over the patch.
3	Use the level to make sure the machine is level relative to the pavement slope.
4	Check the spring gap size in the loading frame. This spring gap should be between 1/4 and 1/2 in. If necessary, lower or raise the MMLS3 to attain an adequate spring gap.
5	Measure and record the pertinent information in the MMLS3 Data Collection Form in Figure D1. • Material type • Initial mound height (in.) • Ambient temperature (˚F) • Pavement temperature (˚F) • Patch temperature (˚F)
6	Connect the MMLS to a power source.
7	Set the MMLS frequency to 10.
8	Begin testing by applying 4 wheel passes to the patch installation.
9	Place the straight edge over the material mound and use the measuring tape to measure the rut depth (R_t) and shove height (R_s) illustrated in Figure D1. Record these on the MMLS3 Data Collection Form.
10	Calculate the rut depth due to densification (R_d) according to Equations D1 and D2. Record this value on the MMLS3 Data Collection Form.
11	Repeat Steps 8 through 10 following the total number of wheel passes prescribed in the MMLS3 Data Collection Form.
12	Terminate testing when rut depth due to densification (R_d) is greater than 3/8 in.
13	Unplug the MMLS3 from the power source.
14	Raise the MMLS3 over the patch installation.
15	Repeat Steps 1 through 10 for the three remaining patch installations.

Calculations

The following equations and definitions should be used in conjunction with the MMLS3 testing procedure.

$$R_s = S_h - S_0 \quad \text{(D1)}$$

$$R_d = R_t - R_s \quad \text{(D2)}$$

Where the variables are defined as follows:

R_s = Rut due to Shoving
S_h = Shove Height
S_0 = Initial Mound Height
R_d = Rut due to Densification
R_t = Total Rut Depth

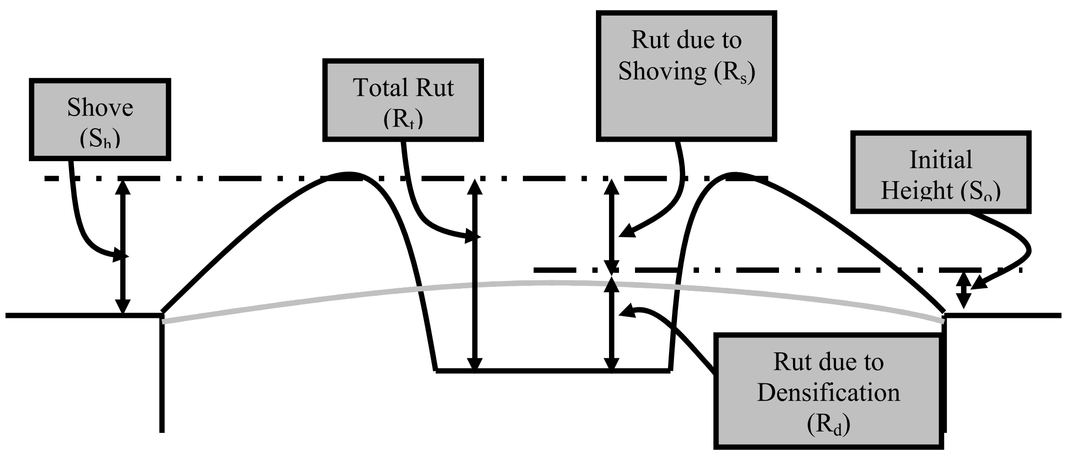

Figure D1 MMLS3 Measured and Calculated Values

Analysis

The rut depth due to densification should be graphed as a function of the logarithmic total number of wheel passes applied to determine if the material is acceptable for use in the field.

Model Mobile Load Simulator (MMLS3) Data Collection Form

Date: ______________ Time: ______________
Patch ID: ___________ Ambient Temp: _____
Material Type: ____________ Pvmt. Temp: ________
Initial Mound Height: ______ Patch Temp: ________

Total Passes	Measured Rut Depth	Measured Shove Height	Rut Depth Due to Densification
4			
8			
12			
16			
24			
32			
40			
48			
64			
80			
96			
112			
144			
176			
208			
240			
304			
368			
432			
496			
624			
752			
880			
1008			

Comments:____
____

Figure D2 MMLS3 Testing Data Collection Form

Appendix E: Initial Data Collection Forms

Data Collection Form for Field Trial of Cold Patching Mix (2005)
Project 0-4872

Date: __________ Researchers: _____________________ Time: _______

Equipment List: ____

Pothole No. ________________

Road: ________________
Milepost: _____________
Direction: _____________
Lane: _________________
County Maint. Section__________ Crewmen_____________

Offset from Centerline to nearest pothole edge: __________
Cut/Fill section: __________________

GPS Coordinates: Lat__________ Long __________

Manufactured pothole (Check One) [ ] Yes
[ ] No

Pothole Dimensions
Length: _____________
Width: ______________
Depth: ______________

Width of lane: ______________

Patch Condition: ____

Pavement distress types (Choose all that apply)

Cracking: ________ Raveling: ________ Rutting: ________
Bleeding: _____ _ Pushing/Shoving: ________

Page 1 of 2

Figure E1 Initial Data Collection Form (Page 1 of 2)

Photograph No. (s) ________________
Pothole: ______________
Patch: ________________

Water swept from pothole (Check One) [ ] Yes (water did not drain)
[ ] No

Weather conditions:
Air Temperature: ________
Pavement Surface Temperature: _____________
Rainfall: ________________

Time for pothole preparation (not creation): ___________

Material Type used for patching: ____________________
No. of bags used to patch the hole (to neared ½ bag): __________
Temperature of patching material prior to use: __________________

Time for material placement: _______________________

Time for compaction and no. of passes (forward and backward is one pass): ____

DCP Test performed (Check one) [ ] Yes [ ] No
(DCP results recorded on a separate sheet)

Density of patch by NDG:
Operator (Phone)_____________________________
Calibration provided by District: ________________
1^{st} Measurement: _____________
2^{nd} Measurement (after turning gauge 180°): _______________

Subjective workability from crew (Circle One)
1 = unworkable
2
3
4
5 = highly workable

Special installation notes and comments: __________________________________

Page 2 of 2

Figure E2 Initial Data Collection Form (Page 2 of 2)

Appendix F: Patch Condition Survey Manual and Form

Patch Condition Survey Manual for Condition Survey Form for Field Trial of Cold Patching Mix (2005)

Patch Distress Condition and their Severity Levels

Raveling:
Slight/Moderate—The aggregate or binder has worn away, and the surface texture is slight to moderately rough and pitted. Loose particles may be present, and fine aggregate is partially missing from the surface. Patch appears slightly aged and slightly rough.
Severe—The aggregate and binder have worn away significantly, and the surface texture is deeply pitted and very rough. Fine aggregate is essentially missing from the surface, and pitting extends to a depth approaching one half the coarse aggregate sizes.

Bleeding:
Slight/Moderate—Slight to significant quantities of the surface aggregate have been covered with asphalt. However, much of the coarse surface aggregate is exposed, even in areas that show bleeding.
Severe—Most of the aggregate is covered by asphalt in the affected pavement region. The area appears wet and sticky in hot weather.

Dishing (consolidation):
Slight/Moderate—Patch consolidation is less than ¾ of an inch.
Severe—Patch consolidation is greater than ¾ of an inch.

Edge Disintegration:
Slight/Moderate—Edge patching extent > 25 percent of the length of the segment.
Severe—Edge raveling or edge lane less than 10 ft extent > 25 percent of the length of the segment.

Pushing/Shoving:
Slight/Moderate—Patch material vertical displacement < ½ of an inch and does not require maintenance.
Severe—Patch material vertical displacement > ½ of an inch and requires maintenance.

Figure F1 Patch Condition Survey Manual—Patch (Chatterjee et al., 2006)

Patch Condition Survey Manual for Condition Survey Form for Field Trial of Cold Patching Mix (2005)

Adjacent Pavement Distress Condition and their Severity Levels

Rutting:
Slight/Moderate—Average rut depth in the wheel path for a pavement segment is ¼ to ¾ of an inch.
Severe—Average rut depth in the wheel path for a pavement segment is > ¾ of an inch.

Longitudinal and Transverse Cracks:
Slight/Moderate—The cracks have little or no spalling, but they are greater than ¼ of an inch wide. There may be a few randomly spaced low-severity connecting cracks near the main crack or at the corners of intersecting cracks.
Severe—Cracks are spalled and there may be several randomly spaced cracks near the main crack or at the corners of intersecting cracks. Pieces are visibly missing along the crack, or the two sides of the crack do not match.

Alligator Cracks:
Slight/Moderate—Cracking is completely interconnected and has fully developed an alligator pattern. None to slight spalling appears at the edges of cracks. The pieces formed by the cracking may be predominantly large (12 inches or more in the longest dimension). The cracks may be greater than ¼ of an inch wide, but the pavement pieces are still in place.
Severe—The pattern of cracking is well developed, with predominantly small pieces (less than 12 inch in the longest dimension). Spalling is very apparent at the crack. Individual pieces may be loosened and may rock under traffic. Pieces may be missing. Pumping of fines up through the cracks may be evident.

Block Cracks:
Slight/Moderate—Block size 5 ft x 5 ft or larger; crack size larger than ¼ of an inch.
Severe—Block size 2 ft x 2 ft to 4 ft x 4 ft; spalled cracking.

Figure F2 Patch Condition Survey Manual—Pavement (Chatterjee et al., 2006)

Condition Survey Form for Field Trial of Cold Patching Mix (2005)
District Evaluation

District: ___________________________ Date: __________ Time: ___________
Maintenance Section: ______________________

Patch location: County _____________________________________
Highway ____________________________________
Reference Marker ______________________________
In wheelpath? Yes [ ] No [ ]
Distance from center stripe of road: __________________

Material Type used for patching: ______________
Time after patching (weeks): _________________

Pavement Structure (Choose): ACP Surface Treatment Other _______________

Traffic Volume
Low [ ] <1000 vehicles/day
High [ ] >1000 vehicles/day

Patch condition: In-place ( ) Failed ( ) Re-patched ( )

Distress condition (Choose all that apply)

Patch Distress			
Raveling:	None	Slight/Moderate	Severe
Bleeding:	None	Slight/Moderate	Severe
Dishing (consolidation):	None	Slight/Moderate	Severe
Edge Disintegration:	None	Slight/Moderate	Severe
Pushing/Shoving (displacement):	None	Slight/Moderate	Severe
Adjacent Pavement Distress			
Rutting:	None	Slight/Moderate	Severe
Longitudinal	None	Slight/Moderate	Severe
Transverse	None	Slight/Moderate	Severe
Alligator	None	Slight/Moderate	Severe
Block	None	Slight/Moderate	Severe
Bleeding	None	Slight/Moderate	Severe
Raveling	None	Slight/Moderate	Severe

Special inspection notes and comments: ____

Figure F3 Condition Survey Form

Appendix G: Data Requirements (TxDOT)

- Material/mixture costs (Product cost/cost to compile stockpile (e.g., material, labor, equipment)
  - Containerized mixes = $/ton
  - Stockpile mixes = $/ton
  - Homemade mixes = Cost of material, labor and equipment
    - How many tons do you typically produce?
    - How much of each material is required?
    - What is the cost of the different materials?
    - What equipment do you use for the mixture?
    - What does the equipment cost ($/day)?
    - How long does it take to make the homemade mix?
    - How many people are required to make the mix?
    - What are their labor rates (per 8 hour day)?
- Shipping cost (e.g., transportation and delivery charges)
- Inventory costs/"Money" tied up in product storage (e.g., quantities stored, average usage rate, etc.)
  - How many months of the year do you need to use cold patching mixtures?.
  - How much mixture do you purchase during these months?
  - How many times during these months do you purchase mixture?
  - On average, how many tons of mixture do you use per day?
- Shelf life (Function of durability of container and testing material and cost of "unusable" material)
  - How much of the mixture that you typically purchase cannot be used?
- Patching method/ Productivity
  - What patching methods do you typically use to fill potholes in your district?

  For each patching method (throw and go, square and cut, semi-permanent procedure):
  - What is the average size of a pothole?
  - How long does it take to fill an average pothole?
  - How much material is needed to fill the average pothole?
  - What equipment (e.g., trucks, compressors, jackhammers, compaction devices, and spray-injection devices) is needed to fill an average pothole?
  - How many tons/day or number of potholes per day can be filled?
  - What is the size of the patching crew?
  - What are the labor rates (per 8 hour day) of the patching crew?
  - What does the equipment cost (dollars per day)?
- Other costs
  - Periodic turning of containers (e.g. labor costs)
  - Reheating of mixture (?)

Appendix H: Data Requirements (TxDOT General Warehouse)

- How many General Warehouses does TxDOT have?
- How much bagged or containerized cold mix is typically bought by a GW?
- What brands are typically bought by the GW serving Lubbock?
- What does each of these brands cost? Please indicate for bagged/bucket and stockpile differently?
- Where is the GW located that serves the Lubbock District?
- How much of this mix is typically transported to the Lubbock maintenance sections at a time? In other words, how big is the order?
- Who is responsible for transporting the mix to the Lubbock maintenance sections?

Table H.1 : Regional Supply Center Location and Districts Served

<table>
<tr><th>Regional Supply Center</th><th>Districts Served</th></tr>
<tr><td>Athens Regional Supply Center
Stock Account 29320
2400 N. E. Loop 317
Athens, Texas 75752
Telephone : (903) 675-4369
Fax: (903) 675-4040</td><td>• Atlanta
• Beaumont
• Bryan (except Brenham)
• Dallas
• Fort Worth
• Houston (Conroe & Humble only)
• Lufkin
• Paris
• Tyler
• Waco
• Wichita Falls (Montague & Cooke only)</td></tr>
<tr><td>Post Regional Supply Center
Stock Account 29330
709 South Broadway
Post, Texas 79356-3700
Telephone: (806) 495-3531
Fax: (806) 495-3707</td><td>• Abilene
• Amarillo
• Brownwood (except McCulloch, San Saba, Mills & Lampasas)
• Childress
• El Paso
• Lubbock
• Odessa
• San Angelo (except Sutton, Kimble, Edwards & Real Counties)
• Wichita Falls (except Montague & Cooke)</td></tr>
<tr><td>Seguin Regional Supply Center
Stock Account 29340
2024 Highway 46 North
Sequin, Texas 78155-2206
Telephone: (830) 379-3755
Fax: (830) 372-2129</td><td>• Austin
• Brownwood (McCulloch, San Saba, Mills & Lampasas only)
• Bryan (Brenham only)
• Corpus Christi
• Houston (All except Conroe & Humble)
• Laredo
• Pharr
• San Angelo (Sutton, Kimble, Edwards & Real Counties only)
• San Antonio
• Yoakum</td></tr>
<tr><td>Austin Regional Supply Center
Stock Account 29310
3500 Jackson Avenue
Austin, Texas 78701-2483
Telephone: (512) 465-7328
Fax: (512) 465-3730</td><td>Support for Division offices.</td></tr>
</table>

Appendix I: Data Requirements: Vendor

- Material/mixture costs
    - What will it cost the TxDOT Regional Supply Center in Post to purchase 22.5 tons of your product? If applicable, please specify for bags and drums/buckets separately?
    - How quickly can you fill an order for 22 tons of product?
- Shipping cost
    - Does the price quoted above include shipping cost (i.e., transportation and delivery charges) to the TxDOT Regional Supply Center in Post? If applicable, please specify for bags and drums/buckets separately?
    - Do you ship your bagged product (if applicable) by pallet? How many bags are typically loaded on a pallet?
- Inventory costs
    - Does your product have any specific storage requirements? If applicable, please specify for bags and drums/buckets separately?
    - Can it be purchased in bulk and stored outside (without bags/drums/buckets)?
    - Can it be stored outside when bagged?
    - Can it be stored outside when in drums/buckets?
- Shelf life
    - What is the average shelf life of your product if stored according to your recommendations? If applicable, please specify for bags and drums/buckets separately?
    - What is the average shelf life of your product when ***not*** stored according to your recommendations (e.g., in bulk outside)? If applicable, please specify for bags and drums/buckets separately?
- Patching method/ Productivity
    - What is the recommended patching method for your product?
- Other costs
    - Do you recycle the buckets/drums?
    - If there are concerns about the costs of the buckets, would you consider filling containers for TxDOT with your product? If yes, would this result in a reduction in the cost of your product? If so, by how much?
    - Are you aware of any concerns about the durability of the bags (if applicable) in which your product is sold? What are the bags made of? Are the bags made according to some standard/specification?
    - Are there any special requirements for handling (i.e., loading/unloading) the bagged product (if applicable)?
    - If ordered bags are damaged upon delivery, would you accept "returns" and refund TxDOT for the product in the damaged bags?