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16. Abstract
The objective of this study is to address the use and performance of homemade and containerized patching maintenance mixtures for repairs in cold and wet weather. The Texas Department of Transportation (TxDOT) reported problems relating to the durability, workability, and shelf life of homemade patching mixtures under these conditions. TxDOT requires an improved mix design procedure to develop patching mixtures with a durability of at least 6 months that accounts for traffic volume.

Various failure mechanisms pertaining to the use of cold patch mixtures were identified and current mix design, materials, performance evaluation, and field application procedures were assessed. Based on results from screening experiments, a preliminary mixture design procedure was developed. A laboratory experiment was developed to evaluate the performance of patching materials by investigating the influence of pertinent material characteristics, including gradation, aggregate type, binder viscosity and content, compaction temperature, curing time, and use of admixture. The materials selected for homemade mix design in the laboratory are consistent with those used by the Lubbock district in its homemade mix design. The Cold Patch Slump Test (CPST), a slump-based laboratory workability test, was developed to quantify workability for cold patch materials. It is an inexpensive and quick test and shows correlation between laboratory and field values. The Hamburg Wheel Tracking Device (HWTD) was used for stability testing on cold patch mix, which was first cured and then compacted at elevated temperatures. Indirect Tensile Strength (ITS) and stripping tests will be conducted on the homemade mixes.

The initial field evaluation included six containerized medium-curing products, three homemade mixes made by district maintenance yards in the Lubbock district, and one commercially produced stockpile mix in Lufkin. The study area for the field evaluations is the Lubbock and Lufkin districts of TxDOT. The results of the field evaluation are still being collected and will be reported in the coming year.

A preliminary evaluation of the effectiveness of various cold patching mix containers was also conducted and guidelines for further durability testing in the laboratory were developed.

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Development of Mix Design and Testing Procedures for Cold Patching Mixtures

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Also appreciated is the involvement and support of the manufacturers of the cold patch materials for donating the products used for testing in this research project (in alphabetical order): Asphalt Patch, Perma Patch, Proline, QPR, Stayput, Unique Paving Materials (UPM). Special thanks also go to Valero Marketing for donating asphalt binder and Vulcan Materials and RE Janes for donating aggregates. 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 and Problem Statement

Patching potholes in asphalt pavements is an important maintenance operation for highway agencies because this activity is expensive and time-consuming. In areas with cold and wet winters, the pavement break-up makes the patching activity even more important. Potholes require immediate attention by maintenance crews to minimize further pavement damage and reduce the opportunity for vehicle damage and potential accidents. The two factors that usually cause potholes are water and traffic. When a combination of the two occurs, the integrity of the pavement can be compromised. This fact can easily be proved by comparing the number of potholes created during the rainy season to the number of potholes created during the dry season in a given area.

The creation of a pothole usually follows a general pattern wherein water finds a way into the base of the pavement (usually through a crack). Traffic loading can cause the base or subgrade to soften and finally to wash away (pumping). As the fines continue to be pumped out, the pavement surface loses support and the asphalt will begin to break up. If the pothole remains unrepaired, the distressed area can increase in size, making repairs more difficult and costly. Although less common, potholes are also caused by fatigue and/or low-temperature cracking. As potholes usually occur on roads with high traffic volume, the need for a speedy repair is essential.

Repairs during winter months are done primarily with cold patching mixtures because most hot-mix asphalt plants are not operational during this time of year. These mixtures are typically used to make temporary repairs until proper maintenance can be done. Depending on the extent of repair, maintenance crews may use stockpiled or containerized cold patch mixes. Some Texas Department of Transportation (TxDOT) districts make their own stockpiled cold patch mix and others purchase stockpile mixes by the ton from third party suppliers. These mixes can be stored in stockpiles for a period of up to 6 months, and containerized mixes have a reported shelf life of 12 months. The poor performance of homemade and some containerized mixes in cold and wet weather is a major concern for TxDOT. In addition, there are high expenses associated with the purchase and use of large quantities of containerized mixes.

Several American Society for Testing and Materials (ASTM) standards try to define the properties of cold patching mixes (ASTM D6704-01, "Standard Test Method for Determining the Workability of Asphalt Cold Mix Patching Material," and ASTM D4215-96 [2002], "Standard Specification for Cold-Mixed, Cold-Laid Bituminous Paving Mixtures"). These standards measure properties such as workability and viscosity/aggregate gradation, respectively. The problem with these standards is they do not necessarily identify poorly performing mixes. As a result, there is a need for developing a set of tests that can predict the field performance of cold mixes and a need for mix design guidelines.

Asphalt paving technologists all over the nation continuously strive to improve the quality of these materials; however, the expectations placed on patching materials often exceed the technology (Estakhri et al., 1999). It is desirable for patching materials to be both workable (ease with which mixture can be placed in field) and stable (ability to stay in place under load) in all seasons. To increase workability, an adequate amount of soft binder can be used. If the binder is too soft, however, the mixture can face instability problems in summer. Certain aggregates, such as sands and uncrushed gravels, can improve mixture workability but can also lead to pushing and shoving under traffic (Estakhri et al., 1999). Because the binder is the part of a bituminous mixture susceptible to temperature, it is the source of winter workability problems. A higher binder content mix could result in a cohesive unworkable mass in winter. Thus, a lower binder content could give better winter workability but at the cost of mixture cohesion (stability) and raveling resistance.

The primary problems with these mixtures can be poor cold weather workability in stockpile and on road, moisture susceptibility as highlighted by raveling and stripping, poor stability in deep patches, and overall inconsistent behavior during mix preparation and application according to standard specifications and guidelines (Estakhri and Button, 1995). These shortcomings have resulted in the use of unsuitable maintenance mixtures that are incapable of being used in cold weather. Such mixes, if left in an unprotected stockpile for more than a few weeks, result in 2 to 6 in. of hard crust formation. This hard crust makes workability difficult both in the stockpile and in the field. Short stockpile life is one major issue that needs attention because it is common practice to store cold mixes for up to 6 months. The scenario worsens because standard laboratory sample preparation may not produce specimens with properties comparable to similar mixes compacted in field. Methods were developed to assure the quality of cold-applied asphalt stabilized maintenance mixtures but no significant laboratory versus field relationships were observed (Estakhri and Button, 1995).

TxDOT purchases cold-laid bituminous patching mixtures under several Departmental Material Specifications (DMS 9000 series). Specifically, DMS-9202, "Asphaltic Concrete Patching Material (Stockpile Storage)," and DMS-9203, "Asphaltic Concrete Patching Material (Containerized)," will be evaluated based on the results of laboratory testing performed by researchers. One particular rapid-curing mixture used by TxDOT performs well under wet and cold conditions but is expensive and workability performance is variable. Medium-curing patching mixes fail to meet the existing specification criteria due to binder penetration, volatiles boiling range, and gradation. However, these criteria are not solely performance-related. Also, preliminary investigations using wheel-tracking tests to evaluate the rutting performances of both rapid- and medium-curing mixtures have not led to a better solution.

1.2 Objectives

This research study has five major objectives:

- to identify failure mechanisms and review current homemade mix designs, materials, performance evaluation, and field application procedures to establish design needs and criteria;
- to develop a preliminary mix design procedure for homemade mixes;
- to perform laboratory tests on homemade patching mixes to evaluate their workability and long-term durability;
- to evaluate the performance of various containerized patching mixtures in the field; and
- to conduct a preliminary study on effectiveness of various containers with time.

1.3 Research Scope

The containerized patching mixtures evaluated in the field in this study include (in alphabetical order) Asphalt Patch, Perma Patch, Proline, QPR, Stayput, and UPM Winter. The study areas for the field evaluations are the Lubbock and Lufkin districts. Both medium- and low-volume road sections from these districts are chosen to capture the impact of traffic on the patches. Current homemade mixes from these two districts are also included in the field evaluations. The Lubbock district experiences cold, dry winters, whereas Lufkin has warm, wet weather. Hence, the field performance evaluations in both regions help researchers address some of the critical performance related issues. The materials selected for homemade mix design in the laboratory are consistent with those used by the districts in their homemade mix design.

The preliminary homemade mix design procedure and specifications, field patching protocol, performance testing, and field testing of containerized mixes has potential for statewide implementation and for prequalification of patching materials at TxDOT materials and testing laboratories.

1.4 Report Organization

The results of this research study are presented in Chapters 2 through 7. Chapter 2 contains the literature review and describes previous studies and work done on performance evaluation of containerized patching materials. Chapter 3 contains the experimental design and the various factors involved in mix design. Chapter 4 presents the laboratory test results. Chapter 5 presents the field assessment of containerized patching mixture performance and includes the Field Patching Protocol, "Patch Condition Survey Manual," and condition monitoring results of patches. Chapter 6 includes the preliminary evaluation of effectiveness of various containers, and Chapter 7 provides conclusions and recommendations for further research.

2. Literature Review

2.1 Failure Symptoms and Mechanisms

There are several problems with the patching mixtures currently used. These deficiencies are reflected in unsatisfactory performance or failure, which may be initiated in the stockpile, during handling and placement, or in service. Some types of inadequate performance and their probable causes were found in the literature and are listed in Table 2.1 (Anderson, Thomas et al., 1988; Estakhri and Button, 1995). The most commonly encountered mixture deficiencies at the stockpile are poor workability and stripping (Evans, Mojab et al., 1992) with binder drainage being a problem with certain types of mixtures (Anderson, Thomas et al., 1988). Curing characteristics of the binder are also very important in the stockpile. Although some *skinning* or *crusting* may be expected in the stockpile, it should not be so pronounced that the mix is lumpy or hard to work. To avoid this, the viscosity-temperature characteristics of the binder must permit the mixture to be worked throughout the range of temperatures encountered during handling and placement. To reduce stripping, pavement striping paint can be sprayed on the stockpile surface. Past research has shown that spraying paint was the most effective treatment for hot-mix cold-laid (HMCL) mixtures in the laboratory evaluation; however, field evaluation of this treatment was inconclusive (Estakhri and Button, 1995).

During transport and placement, the primary concern is workability. Workability is gained by using an adequate amount of relatively soft binder. Immediately after compaction, before the binder cures, the mix must be stable and not susceptible to pushing or shoving. This immediate stability is obtained primarily through careful attention to aggregate properties and gradation. Mixture properties designed to improve workability may worsen the stability; therefore, these two characteristics must be carefully balanced.

The most frequently encountered in-service failures are pushing or shoving, raveling, and dishing. Dishing is compaction under traffic that leaves a depression in the repaired surface; it is a result of improper compaction or installation techniques. Other failure mechanisms may include freeze-thaw deterioration, poor skid resistance, and lack of adhesion to the side or bottom of the pothole.

Table 2.1 Problems and Failure Mechanisms in Cold-Mix Patching Materials

Problem or Symptom of Failure	Probable Causes—Failure Mechanisms
In Stockpile	
Hard to work	Binder too stiff; too many fines in aggregate, dirty aggregate; mix too coarse or too fine
Binder drains to bottom of pile	Binder too soft; stockpiled or mixed at high temperature
Loss of coating in stockpile	Stripping; inadequate coating during mixing; cold or wet aggregate
Lumps—premature hardening	Binder cures prematurely
Mix too stiff in cold weather	Binder too stiff for climate; temperature susceptibility of binder too great; too many fines in aggregate, dirty aggregate; mix too coarse or fine
During Placement	
Too hard to shovel	Binder too stiff; too many fines, dirty aggregate; mix too coarse or too fine
Softens excessively upon heating (when used with hot box)	Binder too soft
Hard to compact (appears "tender" during compaction)	Insufficient mix stability; too much binder; insufficient voids in mineral aggregate; poor aggregate interlock; binder too soft
Hard to compact (appears stiff during compaction)	Binder too stiff; excess fines; improper gradation; harsh-mix—aggregate surface texture and shape
In Service	
Pushing, shoving	Poor compaction; binder too soft; too much binder; tack material contaminates mix; binder highly temperature susceptible, causes mix to soften in hot weather; in-service curing rate too slow; moisture damage-stripping; poor aggregate interlock; insufficient voids in mineral aggregate
Dishing	Poor compaction; mixture compacts under traffic
Raveling	Poor compaction; binder too soft; poor cohesion in mix; poor aggregate interlock; moisture damage—stripping; absorption of binder by aggregate; excessive fines, dirty aggregate; aggregate gradation too fine or too coarse
Freeze-thaw deterioration	Mix too permeable; poor cohesion in mix; moisture damage-stripping
Poor skid resistance	Excessive binder; aggregate not skid resistant; gradation too dense
Shrinkage or lack of adhesion to sides of hole	Poor adhesion; no tack used, or mix not self-tacking; poor hole preparation
Note: In some instances items appear as both symptoms and causes. It is difficult to separate the symptoms from the causes in some cases.	

2.2 Factors Affecting Mix Design

Mixture design factors that should be considered for conventional cold-applied asphalt maintenance materials are summarized in Table 2.2 (Anderson, Thomas et al., 1988; Estakhri and Button, 1995). These are factors that affect any asphalt mixture, but here they are applied for cold bituminous mixtures.

Table 2.2 Design Considerations for Cold Bituminous Mixes

Design Considerations	Effect on Mixture
Binder consistency (before and after placement)	Too stiff may give poor coating during mixing; too stiff makes mix hard to shovel, compact; too soft causes drain-down in stockpile; too soft may cause stripping in stockpile; too soft may contribute to *tenderness* during compaction
Binder consistency (after placement)	Too soft accelerates stripping, moisture damage in service; too soft accelerates rutting, shoving; too soft may lead to bleeding, which causes poor skid resistance; must cure rapidly to develop cohesion; high temperature susceptibility causes softening and rutting in summer
Binder content	Maximize to improve workability; excess causes drain-down in stockpile; excess may lower skid resistance(bleeding); excess may cause shoving and rutting; insufficient yields poor cohesion and moisture susceptibility
Anti-stripping additive	Correct type and quantity may reduce moisture damage; some may affect workability
Aggregate shape and texture	Angular and rough aggregate gives good resistance to rutting and shoving but is hard to work; rounded and smooth gives good workability but poor resistance to rutting and shoving
Aggregate gradation	Reduced fines improves workability (2% max); excess fines can reduce *stickiness* of mix; coarse (> 25 mm) mixes are hard to shovel and spread; open-graded mixes can cure rapidly but allow water ingress; well-graded mixes are more stable; dirty aggregate may increase moisture damage; too dense a gradation will lead to bleeding or thin binder coating, and a dry mixture with poor durability; open or permeable mix may be poor in freeze-thaw resistance
Other additives	Short fibers increase cohesion, increase workability; polymers may increase mix toughness and cohesion

2.3 Desirable Performance Requirements

In most scenarios the failures of cold mixes are due to improper construction techniques (like *dump and run*, where material is dumped in a pothole on the run with little or no compaction). Failure can also result from a lack of desirable properties in stockpile patching mixtures. These properties, as described in Herrin, 1979, and Roberts, Kandhal et al., 1996, are as follows:

2.3.1 Stability

A patching mixture should be stable after placement and compaction to resist vertical and horizontal displacement under traffic loads, particularly right after installation when the material is still uncured. Lack of stability causes dishing and shoving of the mixture.

2.3.2 Stickiness

Stickiness helps the mix to adhere to itself, the underlying pavement, and sides of the pothole. Maintenance crews often do not take time to clean and dry a hole thoroughly so that a proper tack coat can be applied. In such scenarios a stickier mix is helpful.

2.3.3 Resistance to water action

Stripping is the separation of asphalt binder from aggregate, usually in the presence of water. If a mix is susceptible to stripping, the cold patch mix can ravel, causing the patch to fail. When a water-susceptible mix is used to patch potholes that exist due to poor water drainage, the impact of stripping can be significant. Cold patch mixture should be designed to reduce or eliminate stripping.

2.3.4 Durability

This property describes the ability of a patching mixture to withstand external loading, especially its resistance to raveling under traffic loads. Raveling is the progressive loss of aggregate from the surface of a repair and is caused by inadequate cohesion among aggregate particles within the mix, in addition to stripping.

2.3.5 Skid resistance

This is the frictional resistance that the surface of the patch offers to skid. Adequate skid resistance is desirable for long, large patches. Poor skid resistance will result if the mix contains aggregates that can be easily polished or if excess asphalt binder causes flushing or bleeding at the surface of the patch.

2.3.6 Workability

The patching mixture must be adequately soft and pliable so that placement and compaction using common hand tools is reasonably easy, especially in winter. It should be free of any lumps that cannot be easily broken up. Mixtures with poor workability are hard to place and compact, and as a result, they can affect patch durability and stability.

2.3.7 Storageability

A stockpile patching mixture should remain workable when stored for a desired period of time (6 to 12 months). If the mixture does not have the right type of liquid asphalt binder, it can lose volatiles too rapidly and become harder with time. Covering the stockpile with tarps or polyethylene extends storage time. The mixture should not contain excess binder, which drains and settles at the bottom of the stockpile.

2.3.8 Freeze-thaw resistance

This is the ability of the patching mixture to withstand the weakening effect of cyclic thermal expansion and contraction forces resulting from freeze and thaw cycles. It undermines the durability of the mix.

2.4 Current Mix Design Challenges

It is difficult to design stockpile patching mixtures because there are opposing demands on the material for stockpiling and handling and for performance after placement in the pothole. Some of these opposing demands, as reported in Kandhal and Mellott, 1981, and Roberts, Kandhal et al., 1996, are as follows:

2.4.1 Aggregate gradation

For good mixture workability, it is desirable to have an open gradation, but after the mix is placed, a denser gradation is needed to provide stability and durability.

2.4.2 Aggregate shape

To obtain good workability, angular aggregate should be avoided. However, once the mix is in place, high angularity is desirable for better stability.

2.4.3 Binder viscosity

Lower binder viscosity is desirable for storage ability and workability, but after placement and compaction, higher viscosity is desired for cohesion and stability of the mixture.

2.4.4 Binder content

Greater residual binder content in the mixture is needed to increase film thickness on the aggregate for stickiness, cohesion, and durability, but this can lead to drain-down problems in stockpiles. High binder content can also produce an unstable mixture.

Using highly absorptive aggregates can pose problems. High moisture content in these aggregates can lead to stripping or drain-down problems in the stockpile (Kandhal and Mellott, 1981; Roberts, Kandhal et al., 1996). Selective absorption of the lighter fractions of the asphalt binder by aggregates leaves an asphalt film with undesirable characteristics and significantly different properties than that of the original asphalt binder.

It is not possible to use conventional methods of mix design generally used for hot-mix asphalt (HMA), such as Marshall and Hveem methods (Roberts, Kandhal et al., 1996). Not only are specimen preparation and testing difficult, but the desired design criteria is unknown for the stockpile patching mixtures. An inherent tradeoff between handling and durability properties is usually faced, as these properties are contradictory in the mix design (see Table 2.3; Kandhal and Mellott, 1981).

Table 2.3 Tradeoffs Between Handling and Durability Properties

Property	Parameter	Workability	Durability
Gradation	Open gradation	Good	Poor
	Dense gradation	Poor	Good
Aggregate Shape	Angular	Poor	Good
	Round	Good	Poor
Binder Viscosity	Low viscosity	Good (good storageability)	Poor
	High viscosity	Poor	Good
Aggregate Size	Larger gradation	Poor	Good with ideal conditions
	Finer mix	Good	Good if depth < 76 mm (3”)
Gradation	One size	Good (effective cure)	
Anti-strip			Good if compatible

2.5 Concepts for Improved Mix Design

In the past, use of larger aggregate size (12–19 mm or 1/2–3/4 in.) in the stockpile mixture has been suggested to obtain higher stability. Such a mixture can be successful if the patching technique is ideal (such as making edges vertical, cleaning, applying tack coat, and compacting adequately). Because ideal patching techniques are not always used, mixtures with larger aggregates tend to ravel prematurely under traffic, resulting in failure of the patch. Another concept is to disregard the stability and make the mixture finer and more workable so that it is more tolerant to abuse during the placement and performance under traffic. For larger or deeper holes, the mixture should be compacted in layers (Kandhal and Mellott, 1981; Roberts, Kandhal et al., 1996).

The cohesive and adhesive properties of a mix are mainly dependent upon the composition of the mortar (asphalt binder and fines). The presence of excess fines or dust (material passing sieve No. 200 or 0.075 mm) in the mixture results in a mortar that is lean, less tacky, and friable. The absence of excessive fines causes mixtures to be very tacky and sticky; therefore, tack-coating of the pothole may not be required. Many conventional stockpile patching mixtures do not perform satisfactorily because of excessive fines. Such mixes are dull and friable, and lack cohesive and adhesive qualities (Kandhal and Mellott, 1981; Roberts, Kandhal et al., 1996).

In Strategic Highway Research Program (SHRP) Report H-348 (Wilson and Romine, 1993b), a cohesion test is recommended to quantify the cohesion of cold mixes. Although this test does not guarantee success of a mix, it indicates potential for poor performance of a mix. To perform the test, 1,200-gram samples of a mix are cooled to 4 °C (39.2 °F). The mix sample is compacted using the Marshall mold and hammer. Five blows of the Marshall hammer are applied to each side of the specimen. After compaction the weight is recorded and the specimen is placed along the bottom edge of a 305 mm diameter sieve (245.4 mm openings), while both the sieve and the sample are standing on end. A cover is placed on the sieve while still on end, and the sieve is rolled back and forth twenty times. With the sample still inside, the sieve is laid against the edge of a table, allowing room for sample pieces to fall through the sieve openings (for 10 seconds). The remaining material is weighed and reported as percentage retained. A minimum retention value of 60 percent is recommended.

In light of the mix design challenges and concepts for improved design described in Kandhal and Mellott, 1981, and Roberts, Kandhal et al., 1996, the characteristics that appear desirable for a satisfactory stockpile patching mixture are as follows:

2.5.1 Finer and predominantly one-size gradation

A gradation used successfully by a state DOT is given in Table 2.4. Ideally, two sizes of patching mixtures, a base-size (about 19 mm or ¾ in.) aggregate mixture to fill deeper holes and a small-size (about 6 mm or ¼ in.) aggregate mixture to fill shallow holes, should be available. Because it is convenient for the maintenance crew to handle only one patching mixture, a mixture with an intermediate aggregate size may be appropriate. A uniform gradation consisting of 100 percent passing the 9.5 mm (3/8 in.) sieve has the following advantages:

- The mix is pliable and workable.
- Due to increased surface area that results from higher voids in mineral aggregate, binder can be incorporated into the mix to improve durability.
- The mix remains pliable for a longer period of time and continues to get compacted under traffic.

Table 2.4 Recommended Composition of Stockpile Patching Mixture

Sieve Size	Percent Passing
9.5 mm (3/8 in.)	100
4.75 mm (No. 4)	85–100
2.36 mm (No. 8)	10–40
1.18 mm (No. 16)	0–10
0.075 mm (No. 200)	0–2
Residual asphalt content	4.5*

*For aggregates that do not absorb more than 1% water by weight.

2.5.2 Clean aggregate

It is essential to keep the dust content (minus 200 fraction) in the mixture to a minimum to impart tackiness. This will improve the cohesive and adhesive properties of the mixture. The workability of the mix is improved significantly if the minus 200 fraction in the mix is limited to a maximum of 2 percent.

2.5.3 Angular aggregate shape

Angular aggregate shape is desirable for higher stability. If a finer and predominantly one-size gradation is used, the effect of aggregate angularity on the workability of the mix may be minimized. Angular crushed stone aggregate is an appropriate material.

2.5.4 Low aggregate absorption

Highly absorptive aggregates should be avoided. The aggregate water absorption should be limited to less than 1 percent.

2.5.5 Proper binder type

The liquid asphalt binder selected for stockpile patching material must satisfy two conditions. First, it should have relatively low viscosity at low temperatures so the mix remains workable when cold. Second, it should not lose volatiles at a fast rate, which would cause the mix to become unworkable in the stockpile.

Binders for stockpiled patching mixtures consist of both cutbacks and emulsions. Cutbacks include MC-250, MC-400, MC-800, SC-250, and SC-800 grades. The low-viscosity grade (250 cSt) is preferred for longer stockpile life and when the mixture is used during winter. The high-viscosity grade (800 cSt) is usually used during the fall and spring. Both medium-setting and slow-setting emulsions are used.

2.5.6 Adequate binder content

The literature indicates that at least 4.5 percent residual bituminous binder is required in a stockpile patching mixture made from an aggregate whose water absorption is less than 1 percent. If the aggregate's water absorption is greater than 1 percent, the residual binder content should be increased a similar amount. Thus, an aggregate that has 1.5 percent water absorption should have 5.0 percent minimum residual bituminous binder. The factor limiting the maximum amount of the bituminous binder is drainage in the stockpile just after manufacture. The drainage can be minimized or eliminated by using lower mix temperature and limiting the stockpile height to 1.2 m (4 ft) during the first 48 hours (Kandhal and Mellott, 1981).

2.5.7 Proper type and amount of anti-stripping agent

The anti-stripping agent is an essential part of the formulation of the stockpile mixture. A mixture should retain its coating in the stockpile under adverse weather conditions, during handling, and in the pothole after placement. A stockpile patching mixture is more pervious than dense-graded HMA and thus more susceptible to severe weather and traffic effects. It has to survive in the poor conditions (poor base, inadequate drainage, and deteriorated adjacent pavement) that led to the pothole creation. Rain or melting snow provides water, and the pneumatic tires of the vehicles provide wear. This combination can cause the asphalt binder to debond from the aggregate. If sufficient debonding occurs by this action, the traffic will cause the aggregate particles to ravel.

There are many commercially available anti-stripping agents in the market for use with the medium-curing (MC) cutback asphalts. Extensive testing has shown there is no single additive that works with all aggregate types (Kandhal and Mellott, 1981). Thus, it is essential that the type of anti-stripping agent and its rate of application be selected after testing with the specific aggregate used in the mix.

2.6 Previous Studies

Several studies have been conducted on cold mix, pothole patching, winter patching, and other related topics. Stability of the mix was often determined. However, aging in the stockpile and workability of aged and unaged mixes were scarcely included as a part of study. Only a few studies discussed aging of material in stockpiles and problems with placing, compacting, and performance of the aged mix. Resilient modulus tests, tensile strength measurements, and extracted binder tests were conducted to evaluate aging characteristics of mixes (Estakhri and Button, 1995). Resilient modulus tests indicated that LRA (limestone rock asphalt) and specialty mixtures are less stiff at low temperatures than are HMCL materials. However, there is no significant indication of a similar trend in stiffness among the two mixtures after 6 months of stockpile aging. Tensile strength tests indicated no serious detrimental effects as a result of 6 months of aging. Also, viscosity and penetration of extracted binder indicated significant aging in some HMCL materials but no significant changes in the specialty mixtures.

The penetrometer test (Kandhal and Mellott, 1981) was one of the first attempts to quantify workability of bituminous maintenance mixtures. The mix is compacted using two blows of a Marshall hammer in a Marshall mold at ambient temperatures. A concrete penetrometer (Soil Test CT-421) is used to measure the maximum force required to penetrate the surface of the molded mix. A subjective rating of good, fair, or poor is associated with the mix. The mix is cooled to -6.7 °C (20 °F) and its ability to be broken apart with a spatula having a blade length of approximately 203 mm (8 in.) is assessed. Higher penetrometer readings were noted as the subjective workability declined.

Unconfined compressive strength and triaxial tests with conditioned mixes have been proposed as laboratory workability tests (Estakhri and Button, 1995). Although these methods simulated aging characteristics of mix in stockpiles, correlations to field measurements were inconclusive. Several modifications have been tried on the SHRP workability test (Anderson, Thomas et al., 1988) but with no significant correlations with respect to field workability.

The major objectives of the Federal Highway Administration (FHWA) study (Rissel, 1986) were to determine the type of defects on high-volume roads that require repair and can be repaired by patch-type methods; and to identify current patching methods that are efficient and produce effective, safe, and relatively permanent repairs on high-volume roads. The investigation of patching methods considered materials, equipment, and techniques.

The researchers visited thirty sites in nine states (including Texas) and gathered information from state transportation departments, cities, and toll authorities. The authors indicate that one of the more successful patching procedures for bituminous pavement involved the use of several different makes of equipment to heat the pavement in situ. It was also observed that many patches were placed after severe deterioration had occurred, thus requiring considerable repair effort.

The research revealed the interest in using engineering fabrics to control reflective cracking when patching bituminous concrete prior to overlaying. The authors found these materials to have good potential for improving the longevity of patches.

The primary purpose of the Pennsylvania Transportation Institute (PTI) study (Anderson, Thomas et al., 1988) was to develop and test an improved cold-mix, stockpiled patching material for the repair of asphalt pavements during cold, wet weather conditions. The failure mechanisms were identified, and performance requirements were developed. These performance requirements were used to develop a series of experimental binders. The binders were evaluated in the laboratory, and five experimental binders were recommended for field trials. A total of 410 repairs were made with the PennDOT control mixture and different experimental mixtures. Some conclusions of this study were:

- The principal mechanisms responsible for the early failure of stockpiled cold mix are the drainage of the binder from the aggregate, poor workability, stripping, inadequate stability under traffic, and inadequate self-tacking of the mix.
- A clean, crushed aggregate with less than 2 percent passing the No. 200 sieve and a maximum particle size of 13 mm (1/2 in.) is needed for a successful cold-mix stockpile.

- Experimental mixtures using the latex-modified cutback binder did not perform as well as their companion controls.

The Pennsylvania Department of Transportation (PennDOT) workability test using the 8-in. spatula was extended by judging the subjective workability in the laboratory at -7 °C (20 °F), -1 °C (30 °F), and 4 °C (40 °F). Three levels of workability were identified: *strong pass*, *pass*, and *fail*. The workability increased as the binder content in the mix increased. However, for a couple of mixes an opposite trend was observed. It was concluded that binder content plays an important role in assessing mix workability.

The SHRP H-106 study was probably one of the most extensive pavement maintenance experiments to date (Evans, Mojab et al., 1992; Wilson and Romine, 1993a; Wilson and Romine, 1993b; Wilson, 1998). At eight locations located throughout the U.S. and Canada, 1,250 patches were placed. The patches in Greenville, Texas, on FM 1570 and in Las Vegas, New Mexico, were important because the climates there are typical of the wet and dry climates in Texas. It is notable that most other types of patching materials had high survival rates after more than 1 year of service (> 67 percent), while the local Texas material had only a 20 percent survival rate after only 5 weeks, and there were no patches that lasted a year. The SHRP study on development of materials for pothole repair included a series of tests of the materials evaluated. The laboratory testing was an attempt to identify and measure pertinent material characteristics that could be used to predict the performance of the materials in the field. The tests performed on the materials were intended to characterize properties of the mixture as well as the aggregate and the binder. Most of the tests performed were originally developed for hot-mix asphalt materials. Because of the different properties of the cold mixes, the materials were *aged* in an oven to simulate field conditions prior to testing. A complete list of the tests performed follows:

- resilient modulus at 25 °C and three frequencies;
- Marshall stability and flow, ASTM D 1559;
- sieve analysis, ASTM D 136;
- binder content, ASTM D 2172;
- penetration (recovered binder only), ASTM D 5;
- ductility (recovered binder only), ASTM D 113;
- softening point (recovered binder only), ASTM D 36;
- viscosity (recovered binder only), ASTM D 2171;
- workability (Anderson, Thomas et al., 1988);
- maximum and bulk specific gravity, ASTM D 2041 and D 2726;
- water susceptibility, ASTM D 1664.

The SHRP study measured workability of freshly produced maintenance mixtures using the Pennsylvania Transportation Institute (PTI) method (Anderson, Thomas et al., 1988), which is essentially resistance to penetration by a modified CL-70 Soiltest Pocket Penetrometer, inserted into the side of a container of uncompacted mixture. The penetrometer was modified by attaching a 9.5 mm by 75 mm extension to the penetrometer foot. The test consists of a workability box, a pocket penetrometer (like Soiltest CL 700-A), and a penetrometer adapter. The workability box measures 102 mm on all sides and has a 10 mm hole in the center of one side panel. Three samples of approximately 2,500 grams each are cooled to 4 °C. Each cooled sample is placed loosely in the workability box and the penetrometer with adapter is pushed through the hole to record the maximum resistance as an indicator of workability. Average of the resistance values from the three samples gives values between 0 and 5. The acceptance criteria defined values less than 3 as acceptable, between 3 and 4 as marginal, and above 4 as unacceptable.

The laboratory procedure described above utilized a 9.5 mm (3/8 in.)diameter probe developed by PTI. When this attachment was compared directly to a blade attachment developed by SHRP researchers, the reading of the blade attachment was approximately five times larger. The circular probe seemed to work better for stiffer mixes because the smaller cross section presents less resistance. The blade attachment seemed to work for softer mixes because the length of the blade in contact with the mix produces more resistance.

The final report from this study, titled "Long-Term Monitoring of Pavement Maintenance Materials Test Sites" (Wilson, 1998), makes the following observations and recommendations:

- The throw-and-roll technique is more cost-effective than the semi-permanent procedure is in most situations when quality materials are used.
- Correlations between laboratory characteristics and field performance have been difficult to identify.
- Proprietary or high-performance mixes are usually four times more expensive than normal stockpile mixes. However, the overall cost of patching operations per cubic foot is five times less expensive when using high-performance mixes instead of common cold patching mixtures. This is due to longer service life.

Some prominent recommendations of the study were as follows.

- Use high-productivity throw-and-roll operations in adverse weather.
- Perform testing to ensure compatibility of aggregate and binder when producing a cold-mix pothole patching material.
- Use the best available materials for repatching.

There are many proprietary cold patching brands on the market. These mixtures are usually tailor-made under strictly controlled conditions with one stone type. Their quality is difficult to assess when reading the literature on the packaging, as all of them claim that they are the best-suited for the job. The only way to evaluate these proprietary products is by laboratory testing in conjunction with a long-term field study. The certainty of high survival life and thus lower future repair costs must be assured when considering the use of these commercially produced, high-performance cold patch products. They are more expensive than locally produced cold mixes are.

Modified binders are usually used in proprietary mixes and can radically change the properties of a binder. Polymers are visco-elastic, being elastic at operational temperatures, but flowing when heated. The use of polymers enhances the properties of a binder in many ways. The most important are:

- increasing viscosity,
- raising the softening point,
- decreasing thermal susceptibility,
- increasing elasticity,
- increasing cohesion or internal strength, and
- increasing low-temperature tensile strength and flexibility.

In the Virginia Transportation Research Council study (Prowell and Franklin, 1995), thirteen proprietary cold-mix patching materials were evaluated for performance. Two test sections were placed to measure material performance and a third to evaluate workability. Laboratory tests were conducted on coating, stripping, boiling, drain-down, workability, and adhesion.

Workability was examined using two methods. The first method was the SHRP workability test (Evans, Mojab et al., 1992), in which a sample is loosely placed in a 102 mm cubical box with a 10 mm hole centered on one side. A soil penetrometer with a round nose adapter 10 mm in diameter is pressed through the hole in the material. The value from the penetrometer was recorded as the workability reading. However, Kandhal and Mellott (1981) suggested the use of a spatula test for workability. Because several of the materials that fell in the marginal range had poor workability ratings in field, it was thought that the acceptable criterion should be a penetration number less than 3.0. Subjective rankings of workability by maintenance personnel showed workability to be independent of temperature. Some results of this study were:

- An evaluation system and a performance model were developed to rank potential cold mixes. In order to compare the overall performance of each product, a performance rating equation was developed. The equation combined the ratings for bleeding, dishing, edge disintegration, pushing and shoving, raveling, and workability. Survivability and stability (pushing and shoving) were identified as the most important properties for a good cold mix.
- Laboratory tests alone were insufficient to screen potential cold mixes, although they provide a valuable tool for design and quality control that help in improving the material quality.
- Solvent extractions may not be accurate for determining residual binder contents for cold mix.

The Texas Transportation Institute (TTI) study (Estakhri and Button, 1995) included laboratory and field evaluation of samples of maintenance mixture samples from across Texas. The following test procedures were used to evaluate the aging characteristics of the mixtures: (1) resilient modulus as a function of temperature, (2) indirect tensile strength, and (3) extracted asphalt cement properties. Two laboratory aging procedures were evaluated for their ability to predict workability of stockpiled maintenance mixture after 6 months of stockpile aging. One of the procedures (Procedure A) appeared to provide reasonable approximation of 6 months of field aging.

Workability of stockpiled field materials was subjectively evaluated and compared to laboratory measurements aimed at quantifying workability. Two modifications to the SHRP workability test and the use of the Superpave gyratory compactor for workability assessment were implemented. The workability values using the SHRP test fell below 1 for most of the mixes, with some as high as 2. As a result, modifications in the SHRP test were sought to better distinguish between the levels of workability of the different mixes. In the first modification, the hole located in the center of a side panel of the box was moved to the bottom third portion of the side panel. This modification resulted in slightly higher workability ratings for most mixtures, but the test still could not distinguish well among the levels of workability of the different mixes. Most of mixtures had workability values below 1 and some as high as 3. A second modification was made whereby the workability box was eliminated and standard size coffee cans were used to speed up the testing process. The material was placed loosely in the coffee can and stored at

4°C overnight to allow for consolidation prior to testing. Comparisons of the laboratory workability measurements to the field measurements indicated no clear relationship between them. Tex-530-C (boiling stripping test) was found to predict the stripping potential of maintenance mixtures, while Tex-531-C (modified Lottman test) did not. Two test procedures were evaluated regarding their potential to quantify the workability of hot-mix cold-laid (HMCL) asphalt maintenance mixtures: (1) a triaxial compression test, and (2) an unconfined compression test. Test results indicated that both procedures provide a relatively good measure of workability.

The Texas triaxial test (Tex-117-E) was modified to evaluate workability of hot-mix cold-laid (HMCL) maintenance mixtures by Estakhri and Button (Estakhri and Button, 1995). Different confining stresses were applied and corresponding Mohr circles were drawn. The Mohr failure envelope was then plotted for the different mixtures. A failure envelope acceptance region was defined for both oven-aged and unaged HMCL mixtures. An alternative unconfined compressive strength test was also proposed as a measure of workability. Both the modified triaxial test and the unconfined compression tests were implemented for evaluation of HMCL paving mixtures (Estakhri et al., 1999).

The TTI study titled "Evaluation of Texas DOT Item 334, Hot-Mix, Cold-Laid Asphalt Concrete Paving Mixtures" (Estakhri et al., 1999) focused on identifying simple and meaningful laboratory tests and acceptance criteria for HMCL patching materials that ensure reasonable stockpile life and field performance. As a part of the study, a survey of TxDOT districts was conducted to identify the problems that are faced with maintenance mixtures. It was found that HMCL (Item 334) is used by many districts for blade-on/level-up maintenance. Some districts reported inconsistent behavior due to problems like stripping, pushing in hot weather, un-workability in winter, and excessive stickiness in summer (owing to too much diesel content in the binder).

The laboratory results indicated that the mixtures produced with crushed limestone had higher Hveem stability than did those produced with crushed gravel. The SHRP cohesion test indicated that mixtures designed at 95 percent density had better cohesion with 89 to 95 percent retention value, whereas mixtures designed at 92 percent density had lower cohesion with 75 to 88 percent retention value, and mixtures designed at 89 percent density had even lower cohesion with 10 to 39 percent retention value. The SHRP workability test indicated no conclusive trends among the different mixtures. It was concluded that the mixture density could be lowered to 92 percent to improve winter workability without sacrificing mixture properties.

According to an American Society for Testing and Materials (ASTM) standard, workability of asphalt cold mix patching material was defined as the average maximum resistance to penetration by a designated penetrometer into a compacted asphalt cold mix that is confined in a designated box (ASTM D6704-01, "Standard Test Method for Determining the Workability of Asphalt Cold Mix Patching Material"). This standard is applicable for stockpiled and containerized material subjected to different climatic conditions. About 2 kg of material is placed in a box 165 mm × 165 mm × 50 mm and compacted by two blows of a compaction hammer according to ASTM D 5581. The compacted specimen would have a height of 48 to 50 mm. The compacted material and box is placed at -10±1 °C for a minimum of 12 hours but no longer than 24 hours. A penetration blade (130 mm × 50 mm × 3 mm) is attached to the adapter at the bottom of a proving ring of a Marshall apparatus with the blade parallel to the front of the machine. The box with compacted material is transferred from the freezer to the loading jack under the blade on the support stand. The motor is turned on, and the upward movement of the jack head continues. The highest dial reading is noted during 30 seconds of penetration. A similar procedure is adopted for two more specimens, and the average reading is designated as workability of the mix.

An Oregon Department of Transportation (ODOT) study titled "Asphalt Concrete Patching Material Evaluation" (Berlin and Hunt, 2001) evaluated the laboratory and field performance of several proprietary pothole patching materials. Existing potholes were identified, and potholes were manufactured on both open- and dense-graded pavements. The authors observed a low incidence of failures after 6 months of monitoring. It was recommended that gradation with fraction passing sieve No. 200 or 0.075 mm should be less than 5 percent.

2.7 Current Mix Design in TxDOT Districts

This section is divided into two subsections focusing on the mix design procedures adopted in the TxDOT districts of Lubbock and Lufkin.

2.7.1 Lubbock District

The Lubbock district makes its own homemade cold patch material to repair potholes throughout the year. Each maintenance section has a different homemade mix design.

Aggregate

The district has used aggregate from at least two quarries. The local R. E. Janes Quarry produces a low-cost Grade 5 crushed river gravel aggregate - minimum 70 percent retained on No. 4 sieve with one or more mechanically induced crushed faces). The Vulcan quarry in Brownwood produces Grade 5 crushed limestone aggregate minimum 85 percent retained on No. 4 sieve with two or more mechanically induced crushed faces according to Tex-460-A, Part I). The crushed limestone aggregate is more expensive due in part to higher transportation costs. Lubbock uses the crushed limestone patching material on higher-volume roads and the crushed river gravel material on low-volume roads. The TxDOT specification (1993) as determined by test method Tex-460-A, Part I for a Grade 5 aggregate is noted in Table A.1. The Grade 5 crushed river gravel from the R. E. Janes Quarry does not meet the crushed faces requirements according to Tex-460-A, Part I. It is impractical for this quarry to produce an aggregate with a higher percentage of particles with one or more crushed faces retained on sieve No. 4 because the size of the raw quarried river gravel aggregate is too small.

Regardless of the aggregate source, Lubbock's main difficulty has been the use of homemade patching materials in the winter season, particularly under wet conditions. Neither of the homemade mixtures holds up well when the base material is wet, and the patch does not last very long. The Lubbock district has used a rapid curing product containerized in a bucket and was satisfied with the performance. However, they feel this product is too expensive to be used on a routine basis or over large areas.

Binder

Lubbock uses a rapid-curing cutback liquid asphalt binder product designated RC-250. The principal distillate used to obtain the requisite viscosity in the product is naphtha. Lubbock adds diesel or kerosene to the RC-250 to thin the binder. Approximately 9:1 to 16:1 RC-250 to diesel by volume is used in the homemade mixtures prepared by the different maintenance sections.

Candidate Containerized Patching Materials

Six containerized patching materials were selected for the field performance evaluation. These are (in alphabetical order) Asphalt Patch, Perma Patch, Proline, QPR, Stayput, and UPM Winter. These proprietary patching materials were chosen because they offered a range of material characteristics that affect cold bituminous mixture design. For reporting purposes, these proprietary cold patch products were randomly assigned a letter designation A through F and are hereinafter labeled PCPA, PCPB…PCPF.

Gradation

The gradation curves for the homemade mixes from several maintenance sections in Lubbock and the six containerized patching materials are shown in Figure 2.1. The gradation in Littlefield had a high percentage of fines, with up to 9.1 percent fraction passing the sieve No. 200 or 0.075 mm. On the other hand, the gradation in Muleshoe and Bovina were dense. For the containerized mixes, PCPC represented a fine gradation, PCPE represented a dense gradation, and PCPD represented an open gradation. The containerized mixes have fines passing sieve No. 200 or 0.075 mm between 1.5 and 4.8 percent for PCPD and PCPB, respectively.

For the homemade mixes, gradation consisting of 100 percent passing the 22.225 mm or 7/8-in. sieve size was found. For the containerized mixes this sieve size was 9.5 mm or 3/8 inch.

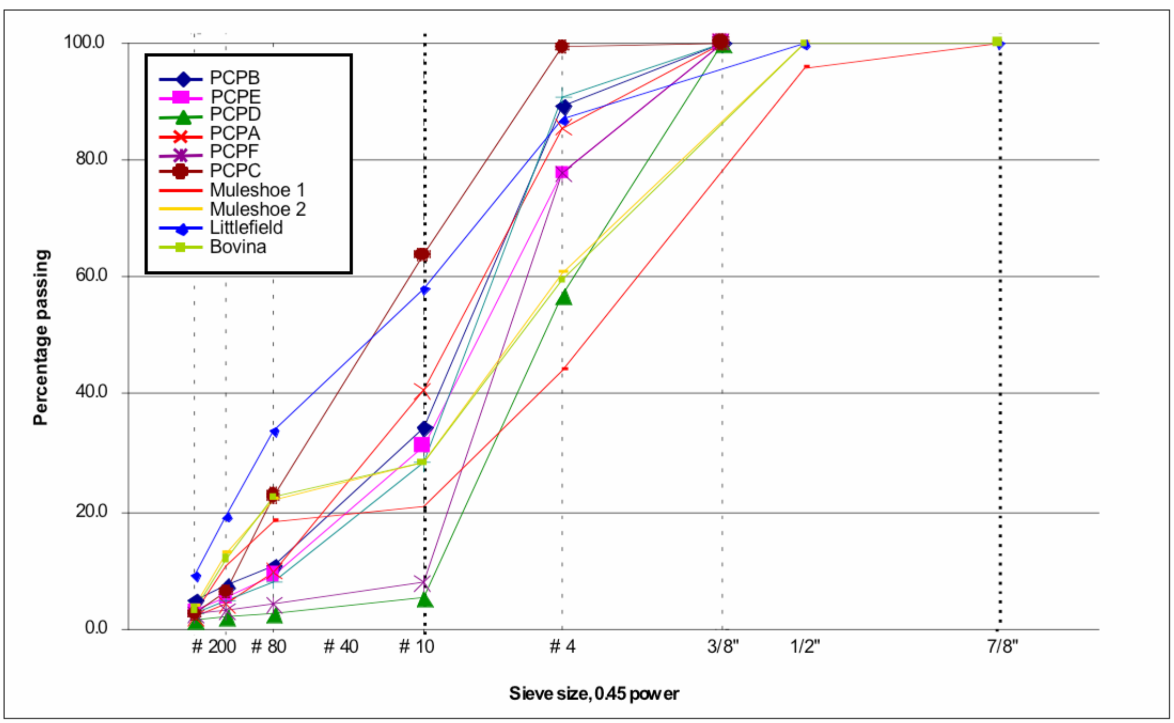

Figure 2.1 Gradation Curves for Containerized and Homemade Mixtures

Mix Proportions

A heavy mix with Grade 4–7 aggregate is used by the Lubbock district for deep patches, whereas a light mix with Grade 5 aggregate is used for shallow patching. The patches installed in summer with homemade mix survive very well, but patches installed in winter using the same material do not perform well.

The proportions of the various components in homemade mix designs from different maintenance sections in Lubbock are as follows:

Homemade Mix Designs from Muleshoe

Light mix (shallow patching)	Heavy mix (deeper patching)
81.8% Grade 5	27.3% Grade 4 or 7
18.2% Sand	54.5% Grade 5
4.75% RC-250	18.2% Sand
0.3% diesel (only winter)	4.75% RC-250
Summer—5% RC-250	0.3% diesel (only winter)
	Summer—5% RC-250

Note: Proportioning by weight.

Homemade Mix Design from Delwin Newton

36 CY Grade 5	(48.7%-50.7%)
18 CY Screenings	(24.3%-25.4%)
12–15 CY blow sand	(16.9%-20.3%)
900 gallons RC-250	(6%-6.3%)
100 gallons diesel	(0.7%)

Note: Proportioning by volume.
CY—cubic yards

Homemade Mix Designs from Jesse Meza

Batch mix		Blade mix	
36 CY Grade 5	(50.8%)	18 CY Grade 4	(25.4%)
12 CY Screenings	(16.9%)	18 CY Grade 5	(25.4%)
18 CY dry blow sand	(25.4%)	12 CY Screenings	(16.9%)
870 gallons RC-250	(6%)	18 CY dry blow sand	(25.4%)
80 gallons kerosene	(0.55%)	870 gallons RC-250	(6%)
50 gallons diesel	(0.35%)	80 gallons kerosene	(0.55%)
		50 gallons diesel	(0.35%)

Note: Proportioning by volume.
CY—cubic yards

Mixing Procedure

The different aggregates used in the mix are proportioned by the truckload. The mixing procedure used in Lubbock is to windrow the aggregate components and mix them using a maintainer. The binder is heated to about 71.1 °C to 85 °C (160 °F to 185 °F). The liquid binder is added, and the material is mixed with the maintainer. After mixing is complete, the patching material is placed into a stockpile. The stockpile has a reported shelf life of about 45 to 60 days.

Potential problems with mix design

Some potential problems with the current mix design are:

- The use of RC-250 may cause rapid curing of the cold mix, which leads to decreased workability and short stockpile life.
- The influence of different aggregate types and shapes needs further evaluation through laboratory testing and monitoring of field performance. The use of angular aggregate, like Grade 5 crushed limestone, increases stability, while the use of rounded aggregate, like Grade 5 crushed river gravel, increases workability.
- The binder content in the homemade mixes in Muleshoe is as low as 3.2 percent.
- The aggregate proportion passing sieve No. 200 or 0.075 mm is variable in the mix designs of different maintenance sections. It varied from 2.3 percent in Muleshoe to 9.1 percent in Littlefield.
- No anti-stripping agent is currently added to the Lubbock homemade mix. Because there are reports of patch failures due to stripping in the mix, the use of anti-stripping agents will be investigated during laboratory tests.
- The mix manufacturing procedure may not produce a uniform cold mix. Methods for improving the field production process of homemade cold mix will be investigated in the future.

2.7.2 Lufkin District

The Lufkin district does not manufacture homemade mix. They either import LRA (limestone rock asphalt) or purchase their stockpile mix from a commercial cold patch mix manufacturer. Most of the commercial cold patch mixes are proprietary mixes and use medium- or slow-curing cutback binder with diesel as the primary distillate.

The same six containerized patching materials used in Lubbock were used for the field performance evaluation in Lufkin to evaluate the effectiveness of these mixes in warm, wet weather.

2.8 Performance Testing Procedures

As described in the section on previous studies conducted, there were a multitude of tests conducted evaluating the performance of containerized cold bituminous mixtures in the laboratory. Based on previous work by the researchers on containerized patching materials, the laboratory investigations in this study will include:

- gradation analysis and aggregate screening;
- binder testing, including Tex-210F, "Extraction of Bituminous Mixtures," Tex 529-C, "Kinematic viscosity at 140 °F," Tex 514-C, "Specific Gravity by Hydrometer," Tex 515-C, "Distillation of Cut-Back Asphalts," and Tex 502-C, "Penetration of Distillation Residue at 77 °F";
- curing analysis for stability and workability assessment of mixtures;
- Superpave gyratory compaction and volumetric analysis to identify appropriate density requirements for specimens, depending on design traffic volumes and field compaction; and
- development of a slump-based workability test to identify a quantifiable measure for workability of cold patching mixtures.

The Cold Patch Slump Test (CPST) developed by researchers incorporates critical parameters that affect workability and is simple and efficiently run. A subjective laboratory workability test was developed. In this test the objective workability is compared to the laboratory and field subjective workability ratings. The work due to shear force that is necessary to prepare Superpave gyratory specimens during compaction and the slope of the percent maximum theoretical density versus number of gyrations compaction curves are also being assessed as indicators of mix workability.

The use of the Hamburg Wheel Tracking Device (HWTD) to assess the rutting performance of the compacted specimens. The testing is conducted under wet conditions in order to simulate the wet weather that is encountered in the field.

Indirect tensile strength (ITS) testing to assess the cohesiveness of patching materials.

The TxDOT boiling stripping test (Tex-530-C) to evaluate the stripping potential of the various cold patching mixtures.

2.9 Field Maintenance Procedures

The Lubbock district uses two different methods for patching potholes, permanent and semi-permanent. The field patching protocol developed for this study was based on a combination of TxDOT's Function Code 241—"Potholes, Semi-Permanent Repair" (Code Chart 12) and the cold patch manufacturers' recommendations. TxDOT's Function Code 241 is specifically for repairs with an area of less than one square yard and is described in Appendix B.

Function Code 241 generally satisfies the minimum recommendations of all the cold patch manufacturers. It should be noted that none of the manufacturers recommend the use of a tack coat for their products. Two vendors recommend making some effort to compact the base/subbase/subgrade to obtain good support for the patching material.

Because one cubic foot requires three 50-lb bags, patching will be done only on potholes from 1 to 2.5 ft in diameter and 2 to 5 in. deep (depending on the diameter). A nuclear density gage (NDG) was used for density measurements on all patches in the Lubbock district. Dynamic cone penetrometer (DCP) tests were conducted on select potholes in both the Lubbock and Lufkin districts.

The field study also includes the development of a field trial patch installation form, “Patch Condition Survey Manual,” and condition monitoring of patches over a 6-month period from the date of installation.

3. Development of Mixture Design Procedure

3.1 Experimental Design

A homemade cold patch experimental design was prepared for the development of a cold patch mix design procedure. The procedure considers six variables for a mixed factorial experiment with 1×3-level and 5×2-level design matrix. Table 3.1 shows the factors considered and the levels at which these are evaluated. The technical memorandum elucidating the experimental design is provided in Appendix C. A brief description of the factor levels follows:

Table 3.1. Experimental Design Matrix

Factor	Low	Center	High
Gradation	Dense	Open	Fine
Aggregate shape	Rounded	-	Angular
Binder viscosity	Low	-	High
Binder content	Low	-	High
Compaction temperature	50 °F	-	77 °F
Curing time	0 hours	-	96 hours

3.1.1 Gradation

Four different aggregate stockpiles have been collected for use in the laboratory production of homemade cold patch mixes. Each stockpile represents a component of the aggregate blend used in the Lubbock district to produce their homemade mixtures. The field sand was supplied by the Lubbock district. The Grade 5 crushed river gravel and crushed river gravel screenings were collected from the R. E. Janes Quarry near Lubbock. The Grade 5 crushed limestone was collected from the Vulcan Quarry in Brownwood. The target gradations for fine-, dense-, and open-graded mixes were based on the gradation curves for the various containerized mixes that were studied in previous work and the gradations of several homemade mixes made by the Lubbock district. The gradation of each stockpile was determined and blended in different proportions to obtain the target gradations.

Figure 3.1 shows the gradation curves of the aggregate stockpiles and the target fine, dense, and open gradations used in the homemade mix design. These target gradations are subject to modification on the basis of further laboratory tests. Also, the maximum aggregate size of all mixes is limited to 9.5 mm or 3/8 inch.

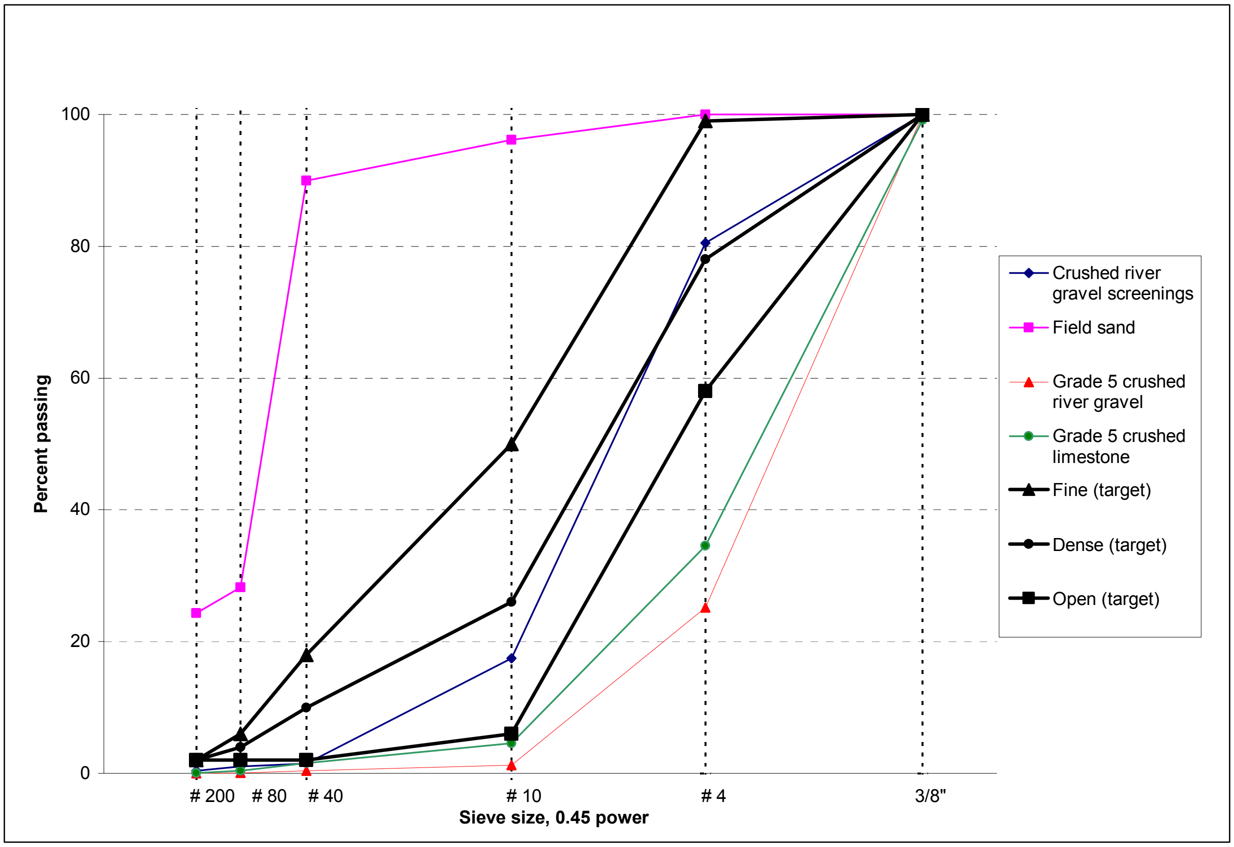

Figure 3.1 Gradation Curves of Aggregate Stockpiles and Target Gradations

3.1.2 Aggregate Shape

The two levels of aggregate shape incorporated in the experiment are rounded and angular. All aggregate blends will be produced using field sand from Lubbock and crushed river gravel screenings from the R. E. Janes Quarry. The *rounded* blends contain Grade 5 crushed river gravel aggregate from R. E. Janes, and the *angular* blends contain Grade 5 crushed limestone from the Vulcan Quarry.

3.1.3 Binder Viscosity

The binder selected for the experimental design is MC-250 produced by Valero Marketing, a medium-curing kerosene-based cutback with a kinematic viscosity of 250 to 500 cSt. This binder was chosen because the Lubbock homemade mixes using the rapid-curing RC-250 binder were observed by the researchers to be fully cured when the field trials of containerized mixes were performed. Also, commercially produced cold patch is typically made with either medium-curing or slow-curing cutback asphalt. The MC-250 binder is prepared by mixing about 30 percent PDA (pure asphalt) with a viscosity of 9,781 poise and 70 percent MC-30 binder. The final mix has approximately 67 percent residual binder by volume.

The homemade cold patch mixtures contain MC-250 with and without diesel to form the low- and high-viscosity levels, respectively. In the Lubbock district it is normal to add about 9:1 MC-250 to diesel by volume.

3.1.4 Binder Content

The residual binder content used in the screening experiments ranges from 3.5 percent to 5.0 percent, simulating the low and high binder content levels. However, on the basis of results from screening experiments it was decided that further laboratory testing be modified from an experimental design to a mix design process. Therefore, residual binder contents of 3.5 percent, 4.0 percent, 4.5 percent, and 5.0 percent will be used.

3.1.5 Compaction Temperature

The experimental design calls for compaction temperature levels of 10 °C (50 °F) and 25 °C (77 °F). During the screening experiments compactions were conducted at temperatures as low as 1.7 °C (35 °F) to simulate cold field temperatures. However, low-temperature compaction leads to Superpave gyratory specimens with high air voids, between 11 and 14 percent, adversely affecting the Hamburg stability results. A decision was made to compact at higher temperatures, similar to those used in hot-mix preparation, to reduce the air voids in the compacted specimens. The materials compacted at 100 °C (212 °F) resulted in air voids less than 10 percent at 200 gyrations in the Superpave gyratory compactor.

3.1.6 Curing Time

All mixes were cured prior to compaction to simulate aging in field. In the screening experiments, specimens were compacted after 0, 24, 48, 72, and 96 hours curing. Some mixes were cured at 25 °C (77 °F) and others were cured at an elevated temperature of 60 °C (140 °F). Materials compacted after short curing times and/or at lower curing temperatures produced unstable specimens, which either collapsed right after extrusion from the mold or instantly failed under the HWTD. It was determined that curing time and temperature for the materials be fixed at 96 hours and 60 °C (140 °F) for preparation of samples for HWTD testing.

3.1.7 Admixture

The effect of admixtures is critical to this experiment. In the screening experiments, a small fraction of mixes were prepared without an anti-stripping agent or admixture. These mixes failed very quickly due to stripping under the HWTD. Thereafter 1 percent lime by weight was added in all the mixes and will be added to all future mixes.

3.2 Preliminary Mixture Design Procedure

The preliminary mixture design process is depicted in Figure 3.2. Laboratory cold patch mixtures are prepared as follows. The aggregates are first heated at 110±5 °C (230±9 °F) for 24 hours to dry. Then they are allowed to cool to room temperature prior to mixing. Depending upon the gradation, a calculated amount of each aggregate stockpile is placed in a mixer and an appropriate amount of lime is added to the dry aggregates. The lime/dry aggregate blend is mixed for a few minutes until the aggregate is coated with lime. The binder is heated to 72 °C ($\approx$160 °F) according to the Lubbock homemade mix design procedure, and a measured amount is added to the aggregate blend and mixed until uniform. The mixing process usually takes about 5 to 10 minutes depending upon the amount of mix prepared.

The mixture design process is being updated as the screening experiments continue. Originally, ninety-six different mixes were included in the experimental design. After the screening results were obtained, the experimental design was modified to include the preparation, testing, and evaluation of approximately fifty mixes. The optimal mix design in terms of stability and workability will be developed.

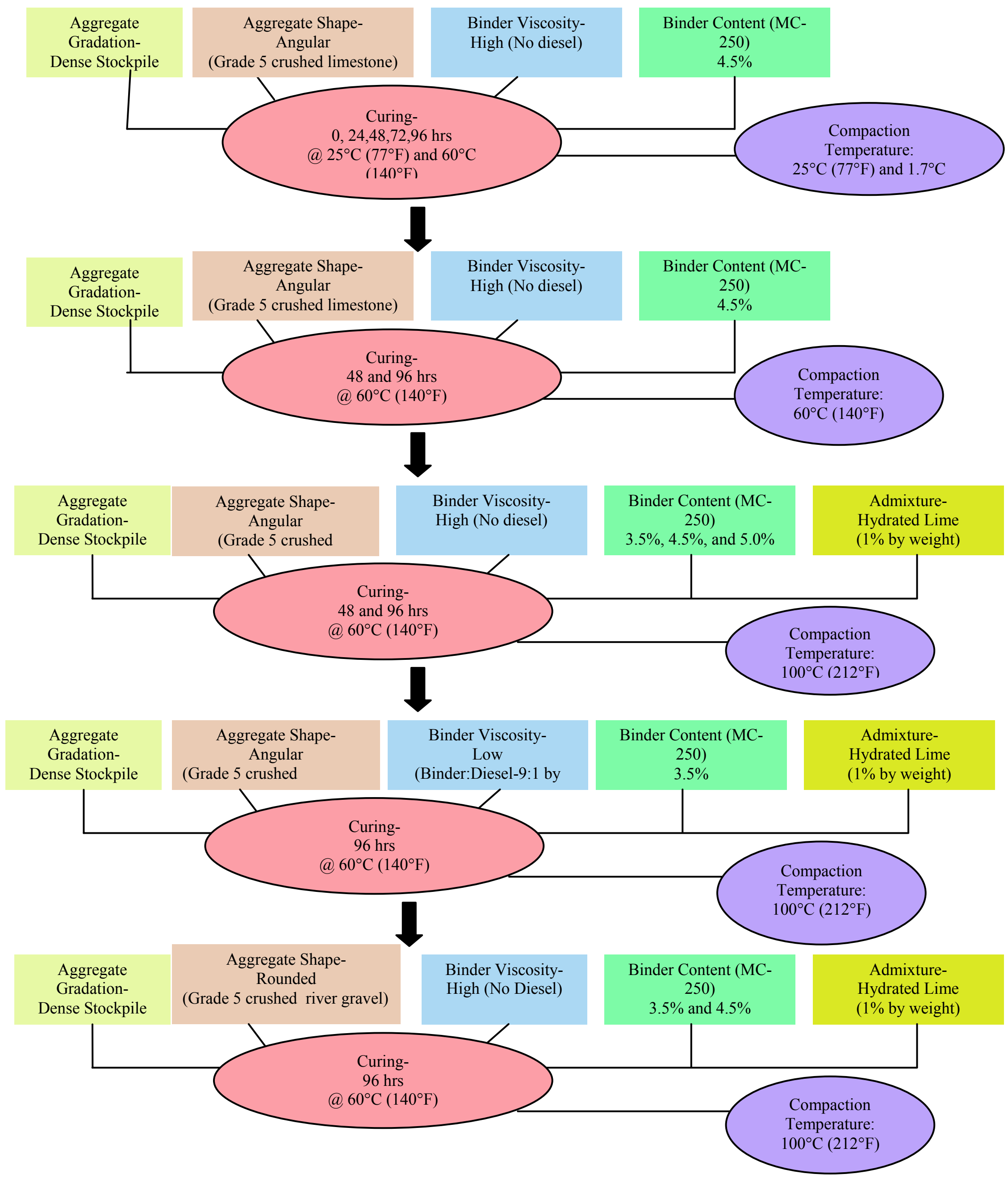

Figure 3.2 Preliminary Homemade Mix Design Process

4. Laboratory Testing of Patching Materials

This chapter describes the laboratory work carried out to fulfill the experimental design to develop a cold patch mix design for TxDOT. A screening experiment was performed first to establish laboratory procedures for the experimental design to follow. The principal result of the screening test was a shift from the original experimental design to a mix design procedure.

4.1 Gradation Analyses and Aggregate Screening

A dense-graded blend of aggregates was used for the screening experiments of the cold patch mixtures. Different aggregate shapes were used for mix preparation, including Grade 5 angular crushed limestone and Grade 5 rounded crushed river gravel. Crushed river gravel screenings and field sand were obtained from the Lubbock district for all the mixes. The gradation curves for the aggregate blends using the two Grade 5 aggregate types are shown in Figure 4.1. The proportions of the different aggregates were calculated and the blend was prepared from the aggregate stockpiles. A separate aggregate blend was prepared by sieving a portion of each stockpile and blending according to aggregate fractions retained on the different sieves. The sieve analysis results from Tex-210F, “Extraction of Bituminous Mixtures,” are shown in Figure 4.2. The tests reveal that there was no discernible difference between the aggregate gradations blended from aggregate stockpiles and the sieved aggregate fractions. Thus, it was decided that the aggregate blend for the remaining mixes would be prepared from the stockpiles.

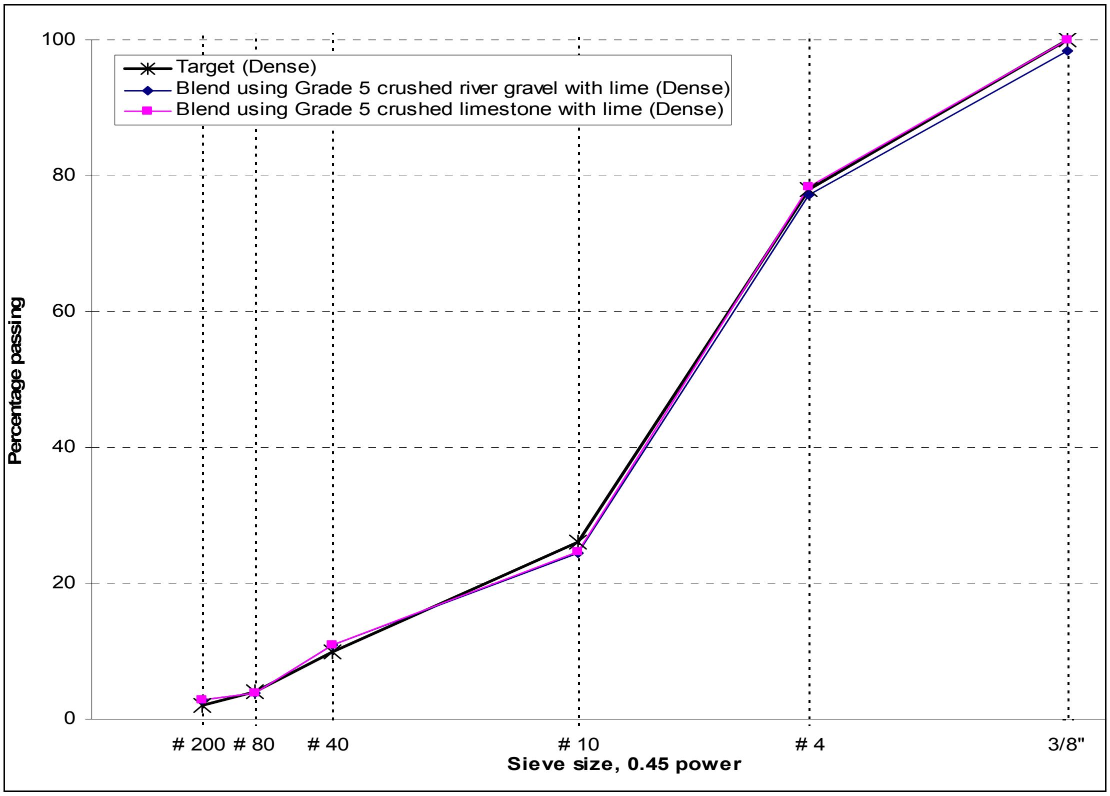

Figure 4.1 Blend Gradation Curves

We observe from Figure 4.1 that there is no distinct change in the blend gradation when we use different aggregate shapes. The proportions of the different aggregates in preparation of the blends are tabulated in Table 4.1. There is 8 percent by weight of Grade 5 crushed river gravel and 9 percent by weight of Grade 5 crushed limestone in the respective aggregate blends. Most of the aggregate in both blends is crushed river gravel screenings.

Table 4.1 Aggregate Proportions for Dense-Graded Blends

Angular aggregate blend	**Rounded aggregate blend**
Crushed river gravel screenings: 80%	Crushed river gravel screenings: 81%
Field sand : 10%	Field sand : 10%
Grade 5 crushed limestone : 9%	Grade 5 crushed river gravel : 8%
Hydrated lime : 1%	Hydrated lime : 1%

4.2 Binder Testing

According to the vacuum extraction method, the asphalt content loss in a mix designed with 4.5 percent residual or 6.5 percent MC-250 binder by total sample weight was 5.6 percent by total sample weight for the stockpile mix and 5.5 percent by total sample weight for the fractions mix.

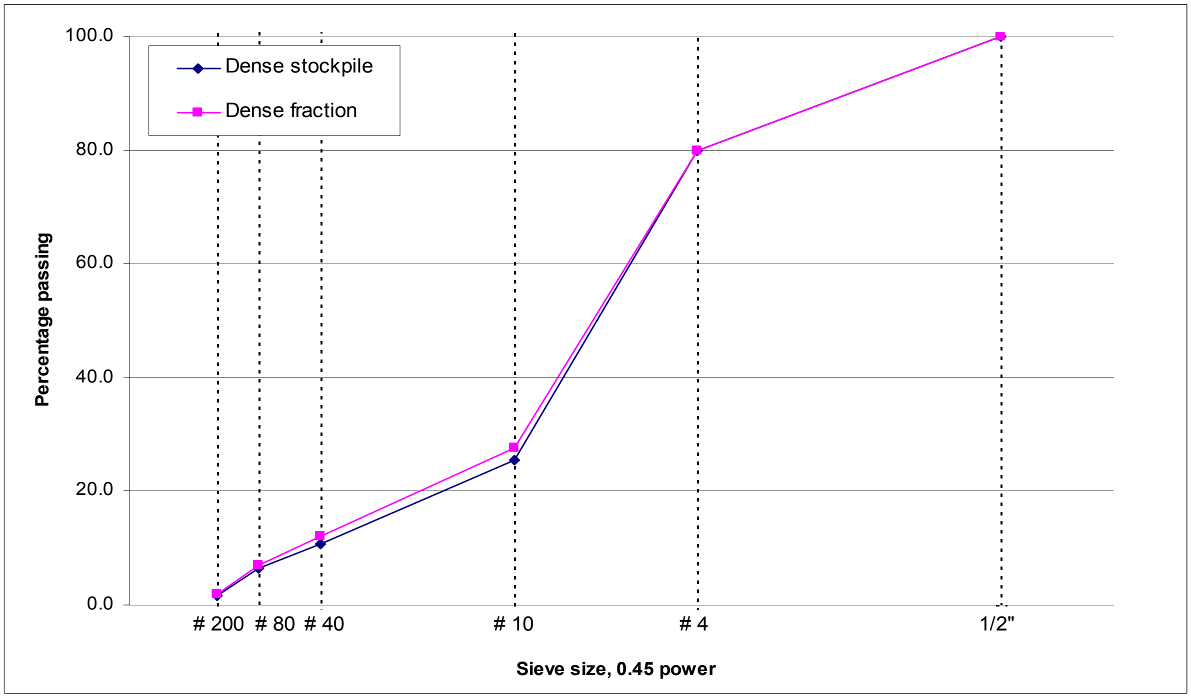

Figure 4.2 Gradation Curves from Tex-210F Test

Asphalt binder tests on the MC-250 resulted in the binder meeting all the TxDOT specifications. The various tests and their results are tabulated in Table 4.2.

Table 4.2 Specification Test Results for MC-250 Binder

Test No.	Test Name	Result	Units	Min	Max
Tex 529-C	Kinematic Viscosity at 140 °F	273.82	cSt	250	500
Tex 514-C	Specific Gravity by Hydrometer	0.962	At 60 °F		
Tex 515-C	Distillation of Cut-Back Asphalts				
	Residue by Volume	72.92	%	67	
	Portion of Total Distillate to 437 °F	0	%		10
	Portion of Total Distillate to 500 °F	41.07	%	15	55
	Portion of Total Distillate to 600 °F	80.36	%	60	87
Tex 502-C	Penetration of Distillation Residue at 77 °F	141	p.u.	120	250

4.3 Curing Analysis

Curing analysis is essential because curing affects the workability of the mix considerably. With regard to workability, during the screening experiments the mixes were cured at 25 °C (77 °F) and at elevated temperature of 60 °C (140 °F). The workability of the mix cured at 60 °C (140 °F) reduced drastically with curing time because most of the volatiles escape from the binder at high temperatures. In order to simulate the workability of a mix in the stockpile and during placement, the mix was cured at 25 °C (77 °F) and the workability was measured using the CPST at 0, 24, and 72 hours. In order to simulate the stability of the mix in service, it was decided from the screening experiments to cure the mixes at 60 °C (140 °F) for 96 hours and then increase the mix temperature to 100 °C (212 °F) to compact the specimens for HWTD tests.

4.4 Superpave Gyratory Compaction Results

Superpave gyratory compaction is designed for hot-mix asphalt. When this device is used to compact cured and uncured cold patch mixes, both the cured and uncured materials could not be compacted to achieve final air voids of less than 10 percent. The compaction curves for compactions done on different mixes with a standard vertical stress of 600kPa and gyratory angle of 1.25 ° are shown in Figure 4.3.

In the figure the residual MC-250 content and the curing times represent the different compaction curves. All the curves represent mixes that were compacted at 60 °C (140 °F) except the curves corresponding to 3.5 percent and 5.0 percent residual binder contents, which represent mixes that were compacted at 100 °C (212 °F). All the mixes have dense gradation with angular Grade 5 crushed limestone aggregate and include hydrated lime. The numbers against the mixes represent the different replicates of the same mix.

Preliminary investigations indicate that for cold patching mixes it is desirable to achieve compaction densities of at least 90 percent for durability. The compaction curves indicate that almost all the compacted specimens have air voids between 11 and 14 percent. When the curing time is increased to 96 hours, we observe that the 3.5 percent, 4.0 percent, 4.5 percent, and 5.0 percent residual binder mixes begin to approach final air voids of less than 10 percent at 200 gyrations, as indicated in Figure 4.3. Compaction was terminated at 200 gyrations or a final specimen height of 63 mm, whichever occurred first. An appropriate amount of material was used for preparation of the specimens in order to achieve both termination conditions simultaneously. The tolerance limit for heights of compacted specimens for Hamburg stability testing is 62±2 mm (Tex-242-F, "Hamburg Wheel-Tracking Test"). Because many specimens did not undergo 200 gyrations, this criterion was lowered to 60 mm to help ensure that all the specimens were subjected to the same compaction effort of 200 gyrations.

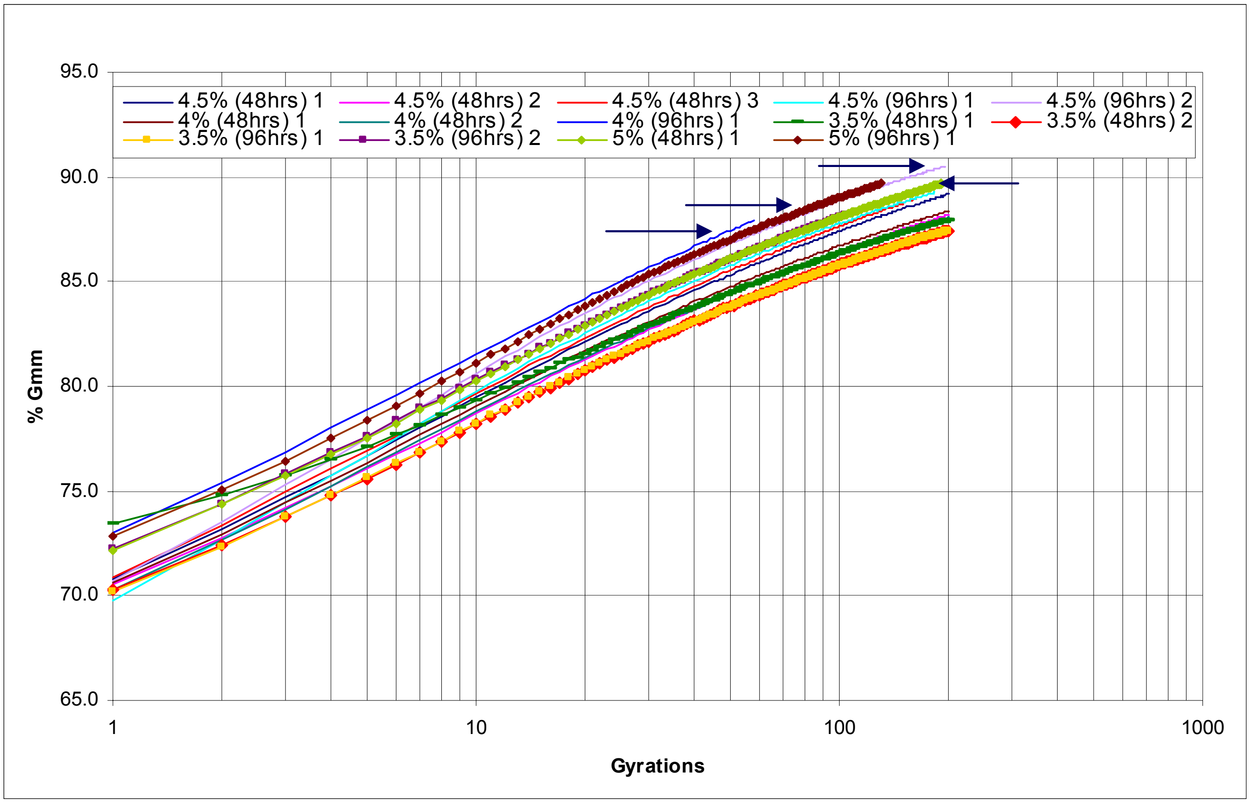

Figure 4.3 Compaction Curves for Different Homemade Mixes

4.5 Workability Assessments

4.5.1 Introduction

Workability is defined as the ability of a mixture to be handled and the ease with which it can be placed in field. It is an essential performance-related property, especially for maintenance mixtures. Cold patching materials are principally used for temporary repairs during cold or wet weather, and the repairs are usually expected to last up to 6 months, depending upon availability of hot-mix materials, and usually result in storage of maintenance mixtures in stockpiles.

Workability of the mixture prior to placement in field and over time in a stockpile is a critical issue in ascertaining the efficacy of the mix. If the mix is overly stiff, it is extremely difficult to work with and may result in improper compaction, resulting in poor in situ performance in the field. On the other hand, a mix that is very workable could result in poor stability under traffic loads resulting in pushing or shoving. The stiffness or workability of a mix is influenced by a number of factors, including the binder content of the mix and the temperature at which it is placed in the field. A mix with a high binder content placed at elevated temperatures would be relatively more workable and vice versa. Another concern specifically for stockpiled mixtures is the evaporation of the volatiles in the binder and the drain-down phenomenon. Both can result in a stiffer mix, thereby reducing the mix workability. Other factors affecting workability include aggregate gradation and cohesiveness between the binder and aggregate.

This section focuses on the development of a laboratory test to evaluate workability of bituminous maintenance mixtures. Emphasis is placed on the parameters that affect mix workability and an effort is made to work towards identifying workability indicators from the test, in terms of the mix properties. In the past, several laboratory workability tests have been proposed, but almost all of them have suffered in correlating results with field workability or are cumbersome to conduct in the laboratory. To deal with these issues, researchers developed a test called the Cold Patch Slump Test (CPST) for evaluating workability. The test is simple to perform in the laboratory, is less time-consuming, and generates repeatable results.

The CPST apparatus, procedure, and the experimental design are discussed. Slump tests using the CPST procedure were performed on six commercially available cold patch mixtures. In addition, the objective measure of workability using the CPST is related to subjective assessments of workability both in the laboratory and in the field. Results of the testing are reported and discussed.

4.5.2 Current Workability Tests

In the development of a workability test for cold mix, a number of different tests used to evaluate workability of different materials were investigated. This section describes workability tests used to assess hot-mix asphalt, and concrete. Test procedures are outlined briefly and shortcomings of these tests with regards to testing of cold patching mixtures are identified. Tests on bituminous cold patching mixtures are described in Chapter 2, only the shortcomings of these tests with regards to testing of cold patching mixtures are discussed here.

Bituminous maintenance mixtures

The penetrometer test (Kandhal and Mellott, 1981) indicated higher penetrometer readings as the subjective workability declined. The data were inconsistent and a vane-shear device to measure maximum torque was proposed.

The Pennsylvania Transportation Institute (PTI) study (Anderson, Thomas et al., 1988) extended the PennDOT workability test by judging the subjective workability in the laboratory. The workability increased as the binder content in the mix increased. However, for a couple of mixes, an opposite trend was observed. The subjective workability in the field was evaluated on the basis of the ease of breaking of crust and placement in the pothole. Similar levels of workability as in the laboratory were chosen, but no correlation with laboratory workability was investigated.

The Strategic Highway Research Program (SHRP) workability test (Wilson and Romine, 1993b) was devised to quantify workability and develop an acceptance testing procedure for cold patching materials. Several of the mixes reported workability values of less than 3 in the acceptable region. Thus it was difficult to distinguish among the different mixes in terms of workability.

During the study evaluating performance of bituminous maintenance mixtures (Estakhri and Button, 1995), after modifications to the SHRP workability test, greater differences in workability values among different mixtures were noted. Correlation with field ratings of workability was not good. The Texas gyratory compactor was also used to quantify workability. The number of revolutions of the mold required to achieve specified pressures for compaction (Tex-206-F) was noted. The underlying idea was that a mix requiring fewer gyrations was more workable. Correlations between laboratory workability from either of the tests and field evaluations of workability were not good. Thus, no conclusive relationship was established between the quantitative laboratory measurements of workability and the subjective field ratings of workability.

Both the modified triaxial test and the unconfined compression tests were implemented for evaluation of HMCL paving mixtures (Estakhri et al., 1999). The apparatuses for both tests require expensive equipment and cannot be readily conducted both in the laboratory and in field.

According to an American Society for Testing and Materials (ASTM) standard, workability of asphalt cold mix patching material was defined as the average maximum resistance to penetration by a designated penetrometer into a compacted asphalt cold mix that is confined in a designated box (ASTM D6704-01, "Standard Test Method for Determining the Workability of Asphalt Cold Mix Patching Material"). Precision and bias for this test are currently under investigation.

Hot-mix asphalt (HMA) mixtures

The idea of a workability meter, measuring the torque required to rotate a paddle immersed in a HMA sample at a constant rotational speed, was developed in the 1970s (Marvillet and Bougalt, 1979). Workability was defined as the resistance moment (torque) produced by the mix against the blade rotation. Thus, workability is inversely proportional to the torque required to rotate the paddle within the HMA sample. The initial concept for workability device was developed by Instrotek in 1998. It utilized a Hobart mixer and an amp meter. The mix was placed within the Hobart mixing bowl and a dough hook was used to push the HMA within the bowl. The amperage required to keep the dough hook traveling at a constant speed, while pushing the mix within the bowl, was measured. This amperage was later converted to torque. Modifications to the original workability device were made to identify the change in workability due to changes in mix characteristics (Gudimettla et al., 2003).

It was concluded that the workability of HMA was affected by the aggregate type. Mixes prepared with cubical, angular granite were less workable (generating more torque at a given temperature) than were mixes prepared with semi-angular crushed gravel. The workability of HMA was affected by the nominal maximum aggregate size (NMAS) of the gradation. As NMAS increased for a given aggregate type, gradation shape, and binder type, workability decreased. Gradation shape did not have a significant effect on workability. Binder type significantly affected the workability of mixes. There was a relationship between workability and temperature that showed increased workability at higher temperatures.

A workability device was deemed inapplicable for cold patch workability for two reasons. First, cold mix maintenance mixtures are much stiffer in nature than HMA mixtures are and may generate high torque values or even damage existing equipment. Second, such cumbersome equipment is expensive and cannot be installed readily in the field, and the test is time consuming.

Concrete

A two-point workability device was developed to assess workability of soft-to-fluid fresh concrete (Tattersol and Banfill, 1999). In the two-point workability device, the torque required to rotate an impeller at a constant speed while submerged in the concrete is measured. The impeller, or paddle, is rotated at various speeds and the corresponding values of torque are noted. The concept is similar to the workability device for HMA mixtures. It was not considered for cold patch workability because it is an expensive and time-intensive test.

The vibrating slope apparatus (VSA) was developed originally by the U.S. Federal Highway Administration (FHWA) for measuring the workability of low-slump concrete. A modified energy-based approach, the International Center for Aggregates Research (ICAR) flow energy method measures the minimum vibration energy to initiate concrete flow and the rate of flow at a given energy (Koehler et al., 2004). The energy-based approach was developed to characterize the workability of dry-consistency concrete. Dry-consistency concretes do not readily flow under their own weight without vibration and behave more like solids than liquids. The chute angle of the apparatus was related to shear stress and the mass flow rate was related to the shear rate. The parameters determined from the test were the energy to initiate flow and the flow rate at a particular energy. The ICAR flow energy method was able to distinguish among different levels of workability. Also, it could distinguish among different mixtures having the same slump. However, a few problems suggested include the size of the apparatus and control over the displacement amplitude, which could lead to large variations in energy values. The ICAR flow energy method parameters also need to be related to the field placement conditions.

The VSA apparatus was explored for workability of cold patching mixtures, because these are also dry and stiff. However, cold patching mixtures are more cohesive than concrete due to the presence of binder. Besides, flow due to vibration does not simulate the flow of the material or workability in field, for cold patching materials. A laboratory test involving compaction of material prior to flow assessment was considered more appropriate to judge the cohesiveness of the mixture. Both the cohesiveness and the aggregate interlock influence the mixture workability or flow capability.

The modified slump test was developed for measuring yield stress and plastic viscosity for fresh concrete (Ferraris and Larrard, 1998). The plastic viscosity parameter is related to the time required for the upper surface of concrete to slump 100 mm using a standard slump cone. The test is limited to concretes with slump of 120 to 260 mm. The validity of the test is required before being used as field quality control test. The test is simple to set up and operate and can be conducted reasonably quickly. Given these factors, it was explored further for evaluating the workability of cold patch as described in the following section.

4.5.3 The Cold Patch Slump Test (CPST)

Motivation

A quick method applied at the Flexible Pavements Branch of TxDOT in Austin to assess workability of patching materials includes dumping a cold patch mixture, stored in 5-gallon buckets, onto a flat surface and noting the time it takes for the mixture (which takes the shape of its container after dumping) to collapse under its own weight. This approach is similar to the slump test used extensively for Portland cement concrete. A similar test using a standard slump cone was investigated. Cold patch material was placed in the cone and rodded as specified for concrete, but it was found that the patching material would flow readily at ambient temperatures and it was impractical to measure the slump height. Based on the findings from these initial slump tests, an alternate Cold Patch Slump Test (CPST) was developed. The objective was to develop a test to assess workability in cold weather, when the maintenance mixtures are typically applied in field. Factors identified for consideration included degree of compaction, test temperature, and conditioning period. Different levels of compaction were used to assess the cohesiveness and the aggregate interlock of the mixture, and the inverse of the time to slump under its own weight was identified as a quantifiable measure of workability. More time to slump would indicate less workability of the mix and vice versa. The following is a description of the apparatus and test procedure as developed.

Apparatus

Cylindrical specimens are prepared in polyvinyl chloride (PVC) tubes measuring 4 inches in diameter and 10 inches in height. PVC end caps with a diameter of 4 in. are placed on one end of the tubes. A non-stick coating spray is sprayed on the inside of the mold as a bond breaker. Required tools include a steel chute for pouring the material in the mold, utensils for transferring, and a scale (ASTM D4753-02, "Standard Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing") for weighing. A standard Marshall Hammer (ASTM D1559-89, "Test Method for Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus") is used for the compaction and a standard measuring tape is used for determining the height of the compacted specimen. The conditioning of the specimens is done in a temperature control chamber, capable of maintaining temperatures from 0 °C (32 °F) to 23.9 °C (75 °F). Researchers used the specimen extractor on a Superpave gyratory compactor to extrude the compacted specimens from the mold.

In addition to the slump test described above, the procedure as developed involves the subjective rating of the cold patch. A wooden containment unit 24 in. × 24 in. with a cylindrical cavity 16 inches in diameter and ¾ inch in height was built for this subjective assessment in the laboratory. The volume of the cylindrical cavity was sized to equal the volume of a compacted specimen. The container height of ¾ in. is twice the maximum aggregate size of 3/8 inch. The specimen is placed in the cavity and allowed to slump. After slump, a standard 8-in.-long and 1¼-in.-wide spatula is used to work the specimen and fill the cavity. The apparatus for the CPST is shown in Figure 4.4.

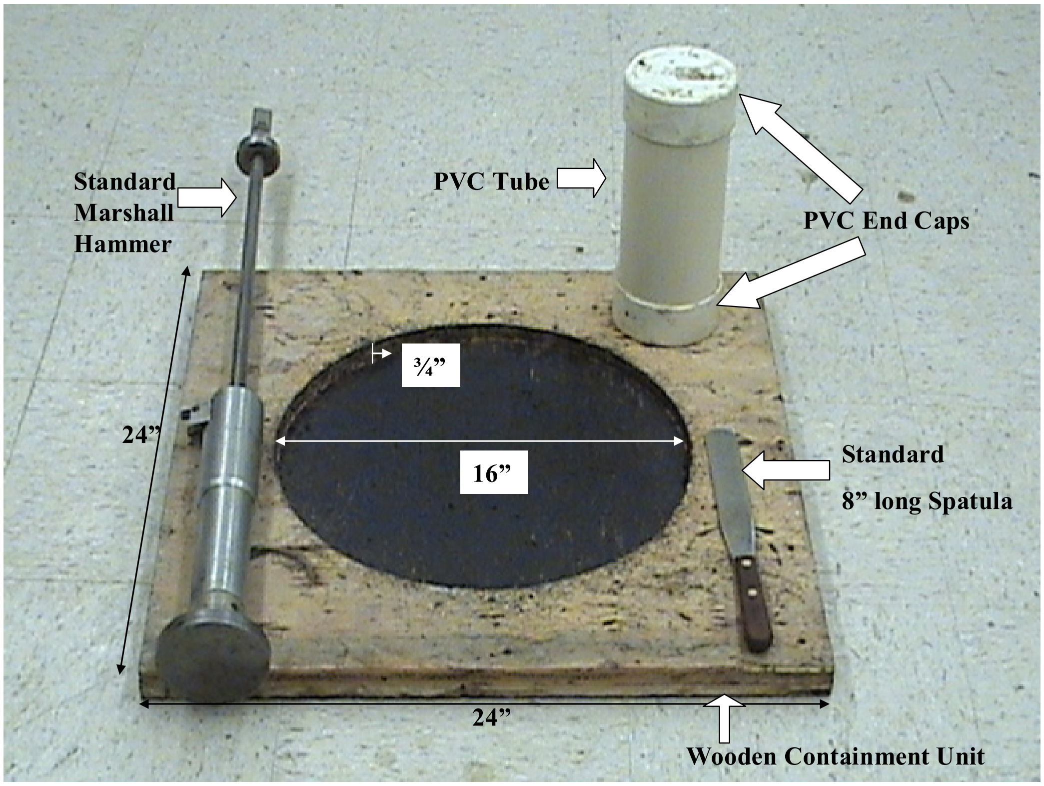

Figure 4.4 Apparatus for the CPST

Procedure

A mass of material necessary to prepare 4-in. (diameter) by 8-in. (height, ±½ in.) compacted specimens is used. A PVC cap is fitted to the bottom end of the tube and the inside of the mold is sprayed with a non-stick coating. A steel chute is used to prevent material loss during transfer of the material from the measuring scale to the mold. The specimen is compacted in two lifts to ensure proper compaction, with half of the material compacted in the first lift. For each lift, the material in the mold is leveled with a spatula and then the specimen is pre-compacted for 10 seconds by resting a Marshall hammer on top of the material. Thereafter, a specified number of blows of the hammer are applied. During compaction, special care is taken to keep the Marshall hammer vertical to ensure that the surface of the specimen remains level. To ensure a level top surface, a metallic disc 4 inches in diameter is placed on top of the second lift of material and the hammer is placed on top of the disc. The disc is removed after compaction.

All the specimens are prepared at a room temperature of about 25 ° C (77 ° F). The material is also at room temperature and is taken directly from sealed bags of patching materials. The final specimen dimensions are 4 inches in diameter and 8±½ inches in height. These dimensions provide an aspect ratio close to 1, so the specimen does not fail due to toppling. After preparation, the specimen is sealed by placing a second PVC cap on the open end of the PVC tube and placed in a temperature control chamber at a specified temperature for 24 hours. After 24 hours the specimen is extracted from the mold, using the extractor on a Superpave gyratory compactor. The extracted specimen is placed in the cylindrical cavity of the wooden containment unit and the time for the specimen to slump is recorded. The specimen is tested at room temperature and the temperature rise is recorded every 2 to 5 minutes, depending on the time taken to slump.

Once the specimen has failed (slumped), a rater fills the cavity with the material using a standard 8-in. long spatula. The time required to fill the cavity is noted as one measure of (objective) workability. The rater also provides a subjective rating of the material workability based on a scale of 1 to 5, where 1 means the material is easiest to work and 5 means the material is hardest to work.

Development of the experimental design

The experimental design for workability consists of three variables, namely, material type, compaction effort, and conditioning temperature. The material type has a total of six levels based on the six different containerized cold patching materials evaluated as a part of this study. Compaction effort is defined on the basis of the number of blows per lift of the standard Marshall hammer. Conditioning temperature has three levels, 1.7 °C (35 °F), 12.8 °C (55 °F), and 23.9 °C (75 °F), thereby covering the typical temperature range of cold mix patching material when placed in the field.

Initially as a part of a pilot experiment, each of the six materials were tested after conditioning at the different temperature levels. Compaction effort was varied with levels of zero, one, five, ten, and twenty blows per lift. Zero blows per lift represents only 10 seconds of static load of Marshall Hammer on top of each lift. A fixed mass of the material for each type was taken initially, and depending upon the final specimen height attained an estimate of bulk specific gravity was calculated and the appropriate amount of material required to attain an 8-in. final specimen height was calculated.

On the basis of the results from pilot experiments, it was decided that compaction effort should be limited to five and ten blows per lift. There was too much variability in slump times for specimens compacted with less than five blows per lift, and slump time increased considerably (up to 2 hours) if more than ten blows per lift were applied. After the failure of each specimen, a subjective assessment was made by a rater and the time to fill the containment unit was noted.

Upon completion of the above experiment, another pilot experiment was initiated to assess the use of weights placed on the specimens to accelerate the testing by reducing the time to slump. Slotted metal weights of 0.9 kg (2 lb), 2.26 kg (5 lb), and 4.53 kg (10 lb), 4 inches in diameter, were placed on top of the specimens to reduce the time to slump for different materials. Containerized materials PCPA, PCPC, and PCPD were chosen because they represent the low (few seconds), medium (few minutes), and high (few hours) times to slump under their own weight. Specimens were prepared at ten blows per lift and conditioned at 35 °F.

During the period of February 2005 to April 2005, all six materials were installed in the field under cold (39 °F to 47 °F), intermediate (49 °F to 63 °F), and warm (66 °F to 81 °F), material temperatures. The subjective workability ratings obtained from field workers are compared later with the laboratory workability measures under similar temperatures of 35 °F, 55 °F, and 75 °F, respectively.

4.5.4 Results and Discussion

Figure 4.5 shows the gradation curves of the different materials used in the experiment. PCPC has a fine gradation, PCPD and PCPF are open-graded, and the other materials are dense-graded. The residual binder content in PCPB, PCPE and PCPA, is between 4.5 percent and 4.7 percent. PCPD and PCPF have residual binder contents of 3.5 percent and 5 percent, respectively. All the materials have a percentage of fines, passing sieve No. 200 or 0.075 mm, between 1.5 percent and 4.8 percent.

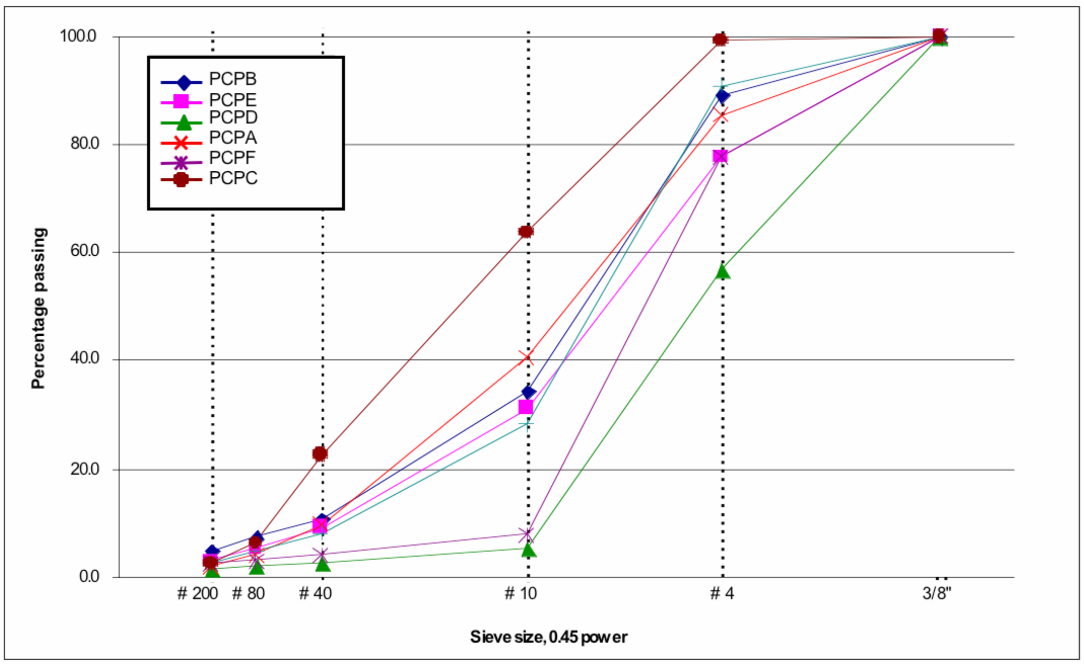

Figure 4.5 Gradation Curves for Various Containerized Materials

Laboratory workability assessments using the CPST were performed for compaction efforts of five and ten blows per lift. Figure 4.6 compares the objective measure of workability determined as the time for the prepared cylinder to slump under its own weight with the objective measure of the time it takes to fill the containment unit after the material has slumped. All six containerized materials were tested, with some replicates, at the three different temperature levels. PCPC, PCPE, and PCPF show increases in time to fill containment unit with increases in time to slump at different temperature levels. PCPD, PCPA, and PCPB do not show uniform increases in time to fill containment unit with increases in time to slump at different temperature levels due to the fact that, although they have high slump times, they are relatively easy to work in the containment unit. Thus, effort put in by the rater, different aggregate type, and gradation results in variation in the time to fill the containment unit.

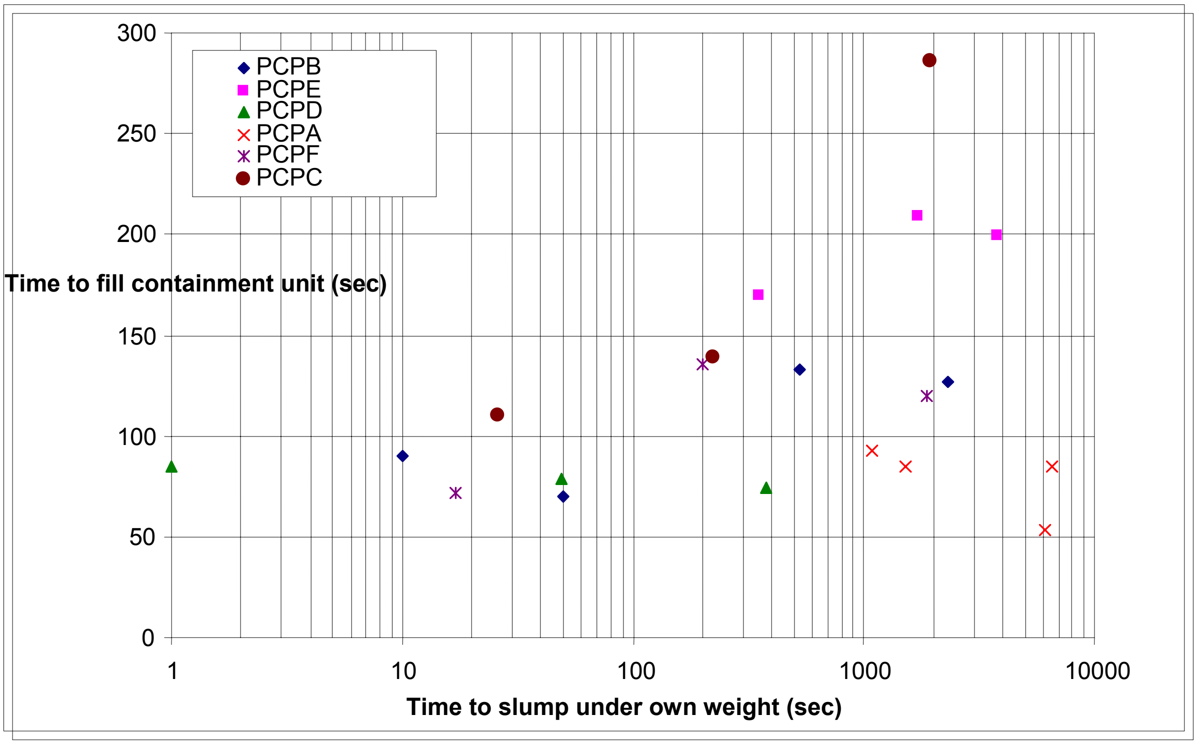

Figure 4.6 Laboratory Workability Assessments at Ten Blows per Lift

Figure 4.7 shows the variation between the slump time and the subjective rating assigned by the rater after filling the containment unit. All six containerized materials were tested, with some replicates, at the three different temperature levels. There is a uniform rise in rating with slump time at the different conditioning temperatures.

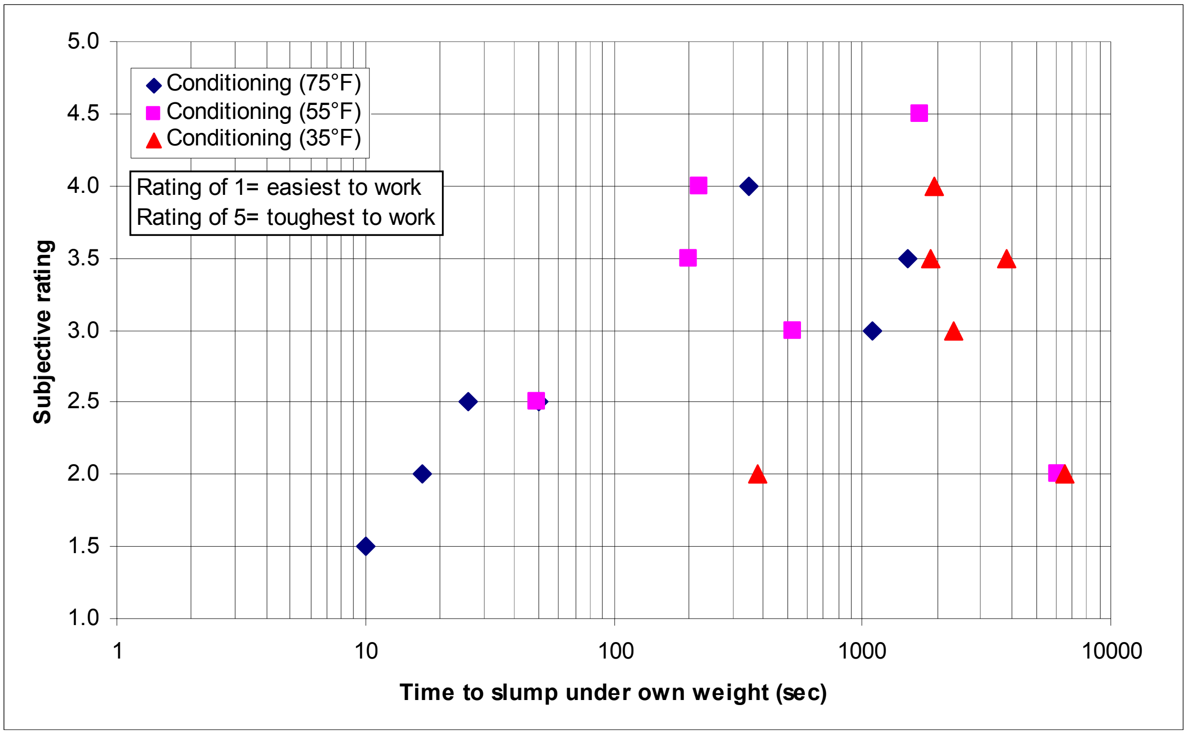

Figure 4.7 Laboratory Workability Assessments at Ten Blows per Lift

Figure 4.8 describes the variation of the objective measure of the time it takes to fill the containment unit with the subjective rating assigned by the rater. All six containerized materials were tested, with some replicates, at the three different temperature levels. The r-squared values for 55 °F and 35 °F are 0.89 and 0.72, respectively. This suggests a positive linear correlation between the two workability measures in the laboratory.

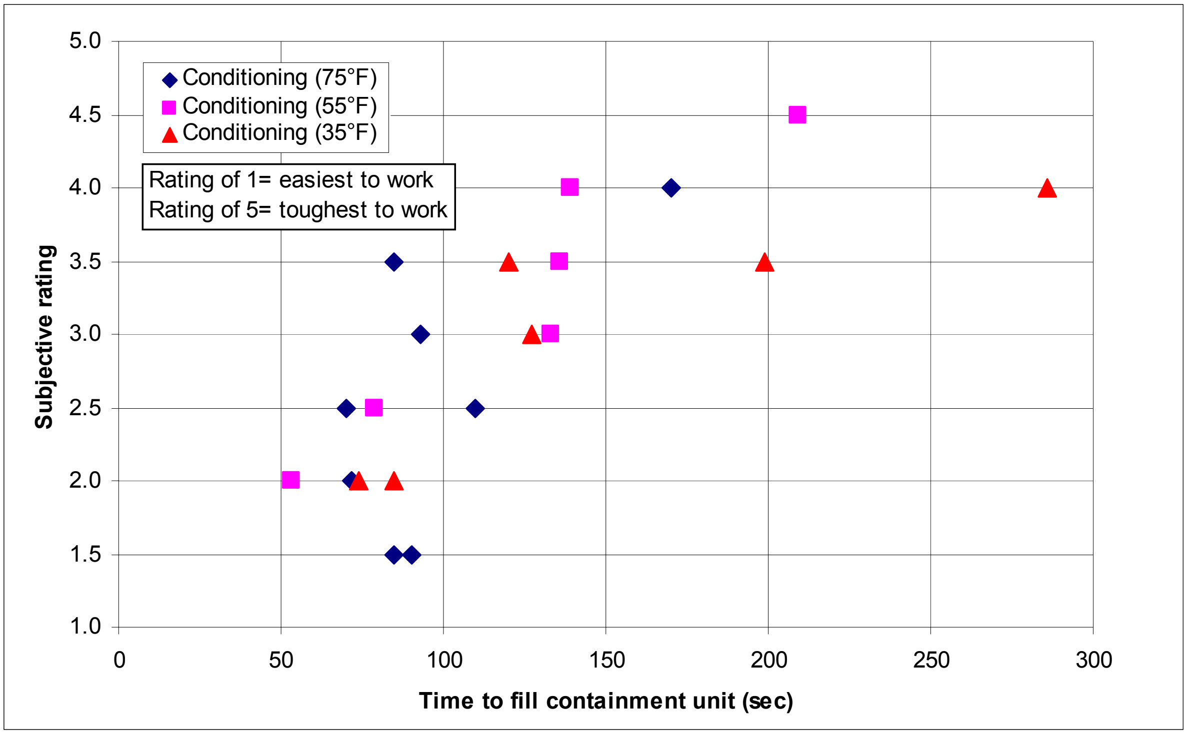

Figure 4.8 Laboratory Workability Assessments at Ten Blows per Lift

The inverse of the slump time suggests a quantifiable measure of workability. A material taking a long time to fail in slump will have less workability. Figure 4.9 describes the variation of the inverse of the time to slump under its own weight versus the conditioning temperature of the specimens. As the conditioning temperature rises a material should have increased workability as shown in Figure 4.9. PCPD has the highest workability, and PCPA the lowest. The r-squared values range from 0.8 to 0.89 for the different materials, suggesting a positive linear correlation between the workability measure and temperature.

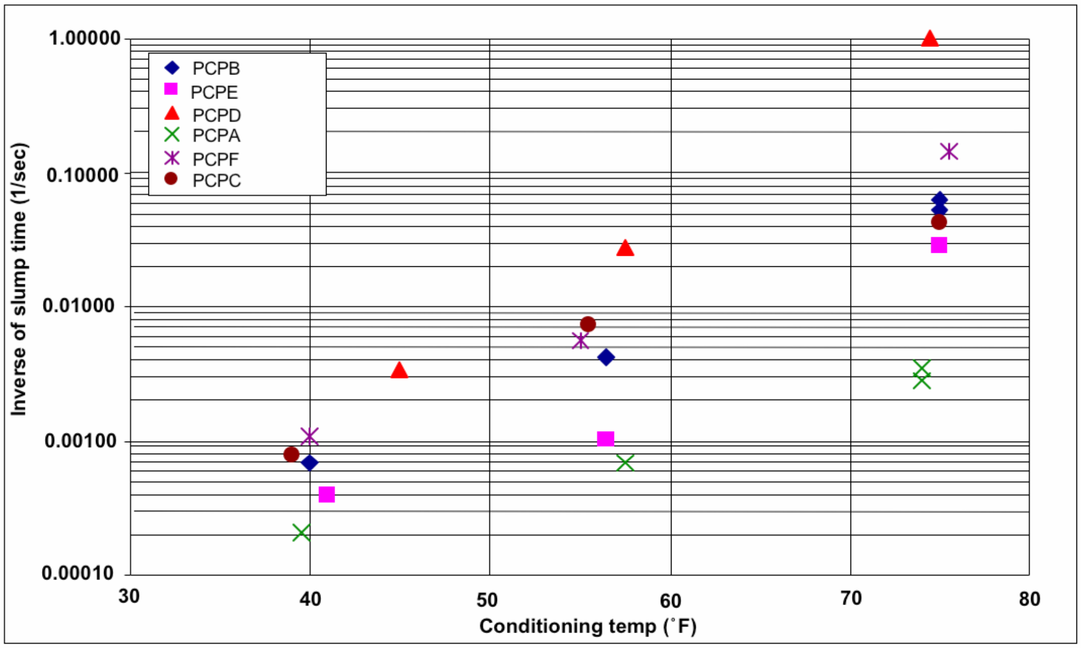

Figure 4.9 Workability Change with Conditioning Temperature at Five Blows per Lift

Correlation between subjective field measures of workability and the workability measures in the laboratory are essential for the validation of the laboratory tests. Figure 4.10 describes the variation of the subjective rating in field with the time to slump. When material temperatures are cold (39 °F to 47 °F in field and 35 °F in laboratory), there is a positive linear correlation with r-squared value of 0.69 (barring one point with high slump time and high field workability). The field subjective ratings depend on the crew person installing the patches and can be highly variable among different installers.

The subjective rating in the field and the time to fill the containment unit, according to Figure 4.11, suggest that at intermediate material temperatures (49 °F to 63 °F in field and 55 °F in laboratory) there is a positive linear correlation with r-squared value of 0.89.

The subjective ratings both in laboratory and field are on a similar scale of 1 to 5, with 1 being the easiest to work and 5 being the toughest to work. Figure 4.12 describes the variation of the field subjective rating with the laboratory subjective rating. At cold material temperatures the r-squared value is 0.77, and at intermediate material temperatures it is 0.88. Considering the fact that the patching materials are usually installed in cold weather, there is evidence to suggest that there is a positive linear correlation between laboratory and field workability.

A pilot experiment with weights on top of the specimens to accelerate the slump time was conducted. Figure 4.13 describes the variation of the weights placed on the specimens with the time to slump. It reveals a negative exponential correlation, with time decreasing as heavier weights are placed on the specimens. The r-squared value ranges between 0.932 to 0.943 for PCPC and PCPA, respectively. PCPA has the highest slump times among all the materials, PCPD has the lowest, and PCPC represents all other materials, which have similar slump times and fall in between.

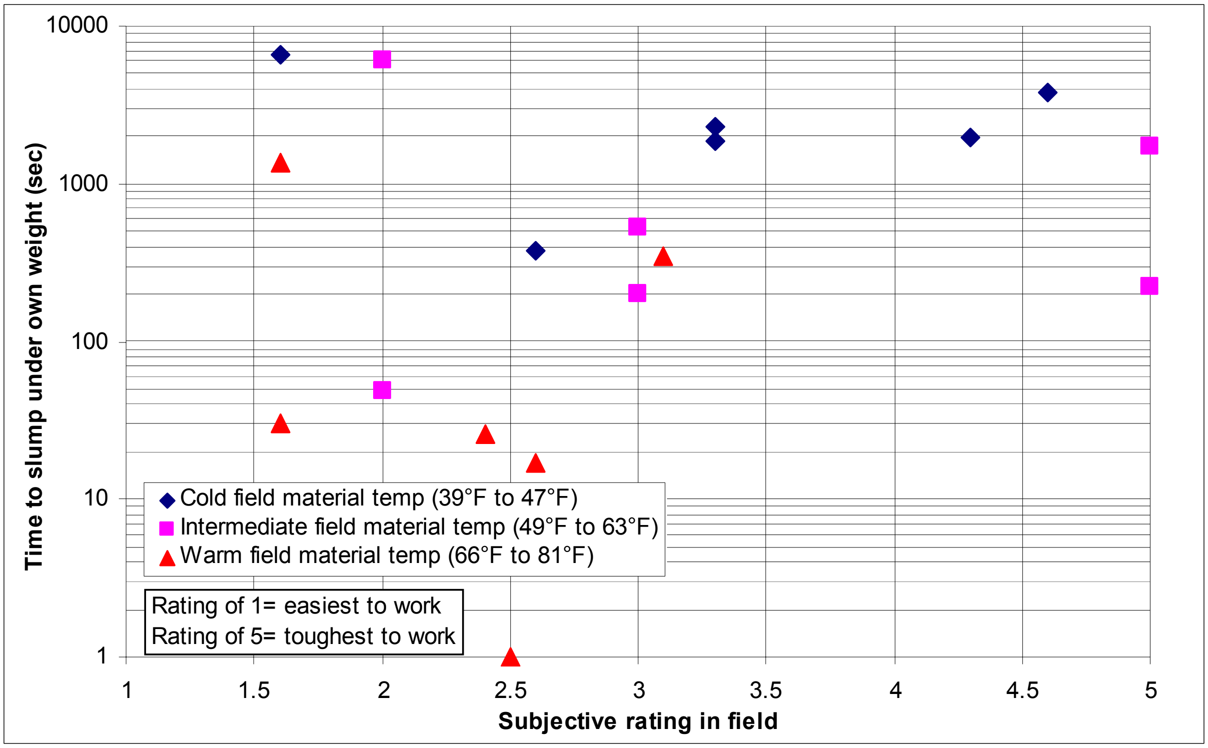

Figure 4.10 Workability Assessments in Field and Laboratory

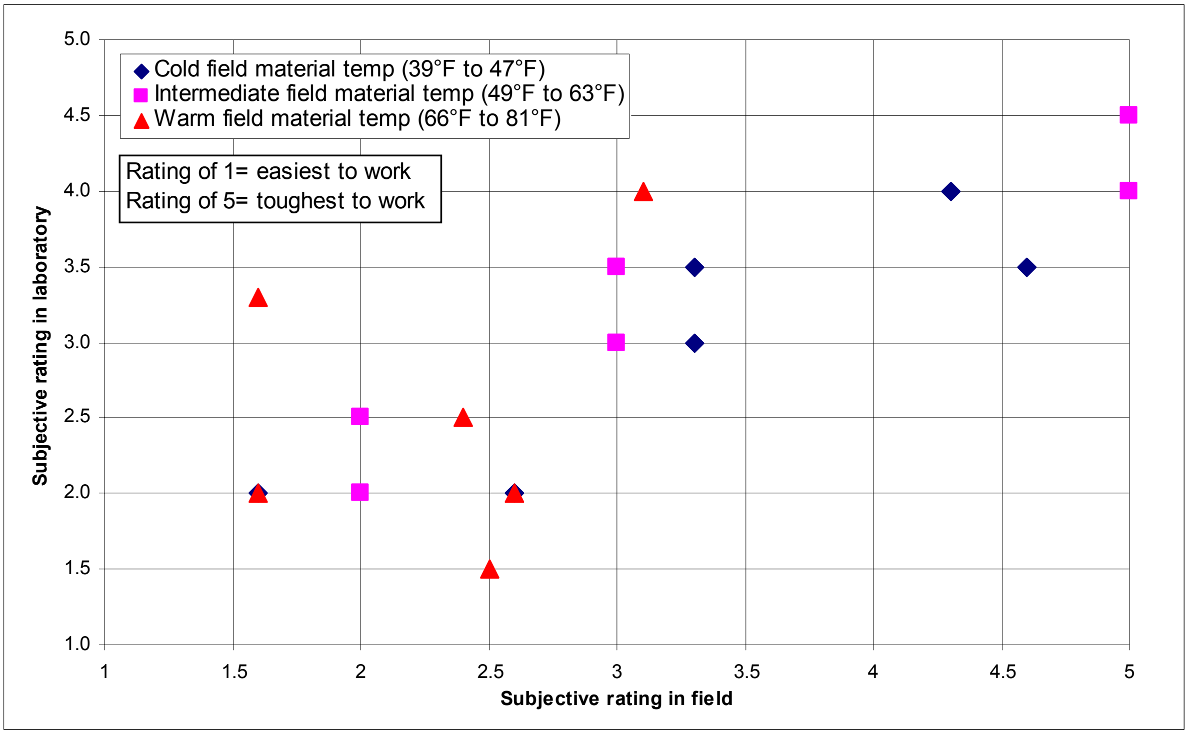

Figure 4.11 Workability Assessments in Field and Laboratory

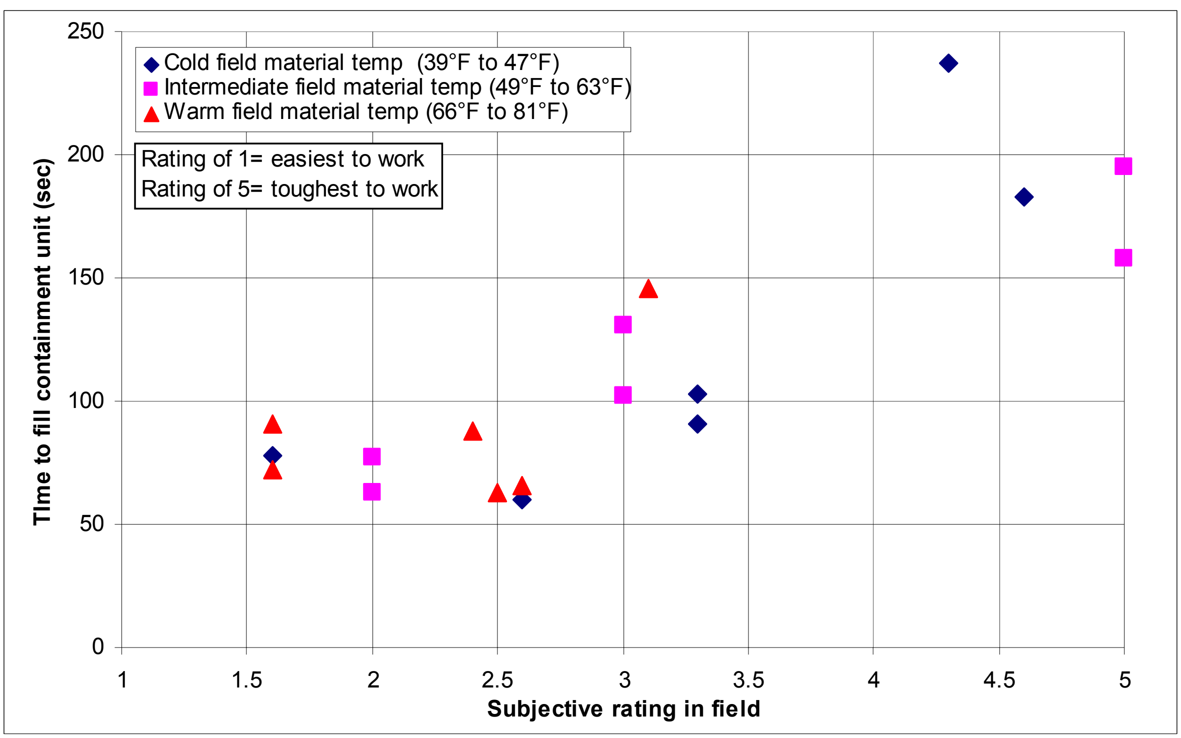

Figure 4.12 Subjective Workability Assessments in the Field and Laboratory

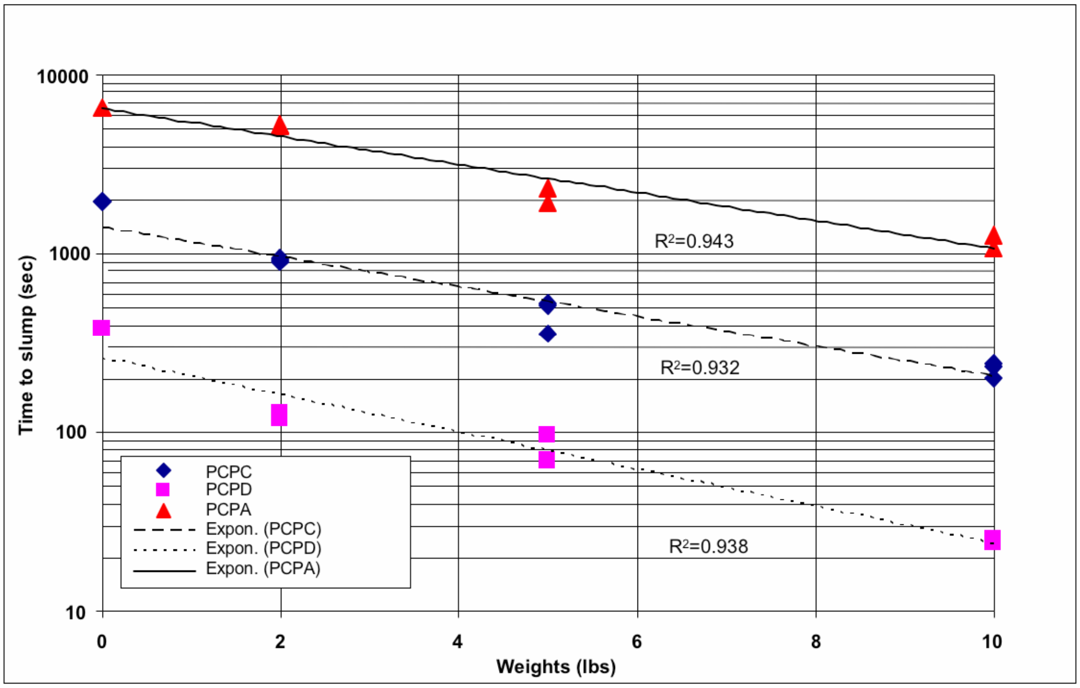

Figure 4.13 Slump Times for Different Materials with Weights on Top

Based upon initial results the researchers decided that for the homemade mixes the CPST is to be conducted with a compaction effort of ten blows per lift and specimen conditioning at 1.7°C (35 °F) for 24 hours. Tests are being conducted for mixes cured at 25 °C (77 °F) for 0, 24, and 72 hours in order to simulate the aging characteristics of the mix in the stockpile. Some preliminary results are presented in Figure 4.14. The figure shows the variation of the inverse of slump time with the time of curing of the mixes. We observe that the workability indicator (i.e., the inverse of slump time) decreases as mixes are cured for longer periods of time. Also, the workability for the mix with 5 percent residual MC-250 binder content is higher than the mix with 4.5 percent, at both curing times. Both mixes were prepared with a dense gradation using Grade 5 crushed limestone angular aggregate. Lime was added in both mixes to inhibit stripping.

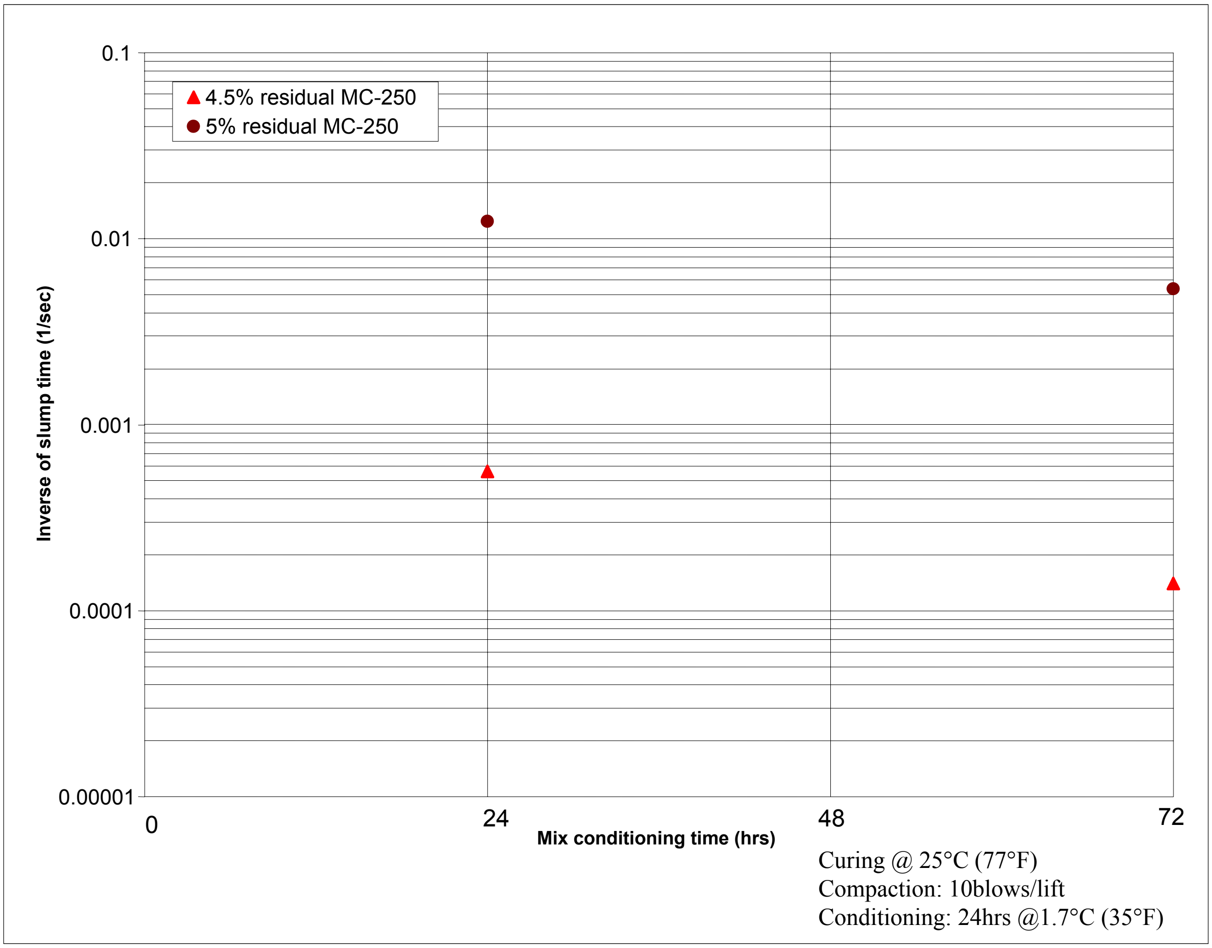

Figure 4.14 Preliminary Laboratory Workability Assessments for Homemade Mixes

The slope of gyratory compaction curves and the work done due to shear during compaction are also being explored as potential measures of workability. The shear stress curves for material cured at 60 °C (140 °F) and compacted at 100 °C (212 °F) were indistinguishable among the different mixes. At high compaction temperatures (135 °C) the aggregate contributes greatly to the mixture strength, while the asphalt binder contributes little (Anderson et al., 2002). Mix workability is dependent upon both the aggregate structure and the asphalt binder. Because the material was cured at 60 °C (140 °F) for 96 hours and compactions were done at 100 °C (212 °F), the mix was mostly cured with few volatiles left in the binder, as opposed to compaction of uncured cold patch at low temperatures. As a result, the development of shear stress was dominated by the aggregates. It was decided by the researchers to conduct Superpave gyratory compactions at 1.7 °C (35 °F) after conducting the CPST on material that is 0, 24, and 72 hours cured at 25 °C (77 °F) and then study the shear stress curves generated. Running the CPST at ten blows per lift and conditioned at 1.7 °C (35 °F) followed by the low-temperature gyratory compactions for shear stress curves will provide a means to compare the different workability indicators, under the worst possible temperature condition. Once shear stress curves sensitive to both aggregate structure and binder are generated, the area under the curve can be used as an indicator of work done due to shear, a potential indicator of mix workability.

4.6 Wheel Tracking Tests

Based on results of a previous study conducted by the researchers, it was decided that the Pine Rotary Asphalt Wheel Tester (RAWT) be discontinued for stability testing in this study. Furthermore, the researchers determined that the HWTD stability testing was too harsh for uncured cold patching mixes. The cold patch specimens have higher air voids and thus are less dense after Superpave compaction as compared to hot-mix specimens. The HWTD was designed for use on hot-mix asphalt, which is compacted uncured (e.g., while hot) and then allowed to cure (cool) before being subjected to the Hamburg. Therefore, for the purposes of this study it was decided to use the HWTD for stability testing after the cold patch is first cured and then compacted at elevated temperatures similar to hot mix. It is essential for the cold patch specimens to have air voids close to 10 percent, so that they are dense enough for stability testing under the HWTD. The specimens having air voids in the range of 11 to 14 percent, even with anti-stripping agent in the mix, failed partly due to stripping. For future tests, all the mixes will undergo a uniform number of gyrations (200) during Superpave compaction, keeping in mind that the final specimen height must fall between 60 mm and 64 mm.

The results of a previous study indicated that patching mixtures evaluated under the HWTD were particularly unstable when tested uncured or at temperatures greater than 25 °C (77 °F) regardless of the curing time. Based on screening experiments, it was decided that all mixes be cured at 60 °C (140 °F) for 96 hours, compacted at 100 °C (212 °F), and tested wet (under water) at 25 °C (77 °F) for rutting performance under the HWTD. The termination points for the HWTD were 20,000 cycles or 12 mm rut depth, whichever was attained earlier.

Some preliminary results of the wheel tracking tests are shown in Figure 4.15. It plots the number of cycles of the wheel tracking device versus the rut depth measured on the specimens. The different mixes are identified by the residual binder content and the curing times of the mixes at 60 °C (140 °F). All the mixes were dense-graded with angular Grade 5 crushed limestone aggregate. Lime was added to all the mixes to inhibit stripping. Mixes showed better rutting performance when cured for longer periods of time. Among the different mixes, 4.0 percent residual binder mix showed better rutting performance than 4.5 percent residual binder mix. The 4.0 percent residual binder mix lasted approximately 11,000 cycles, which is extremely desirable in terms of stability.

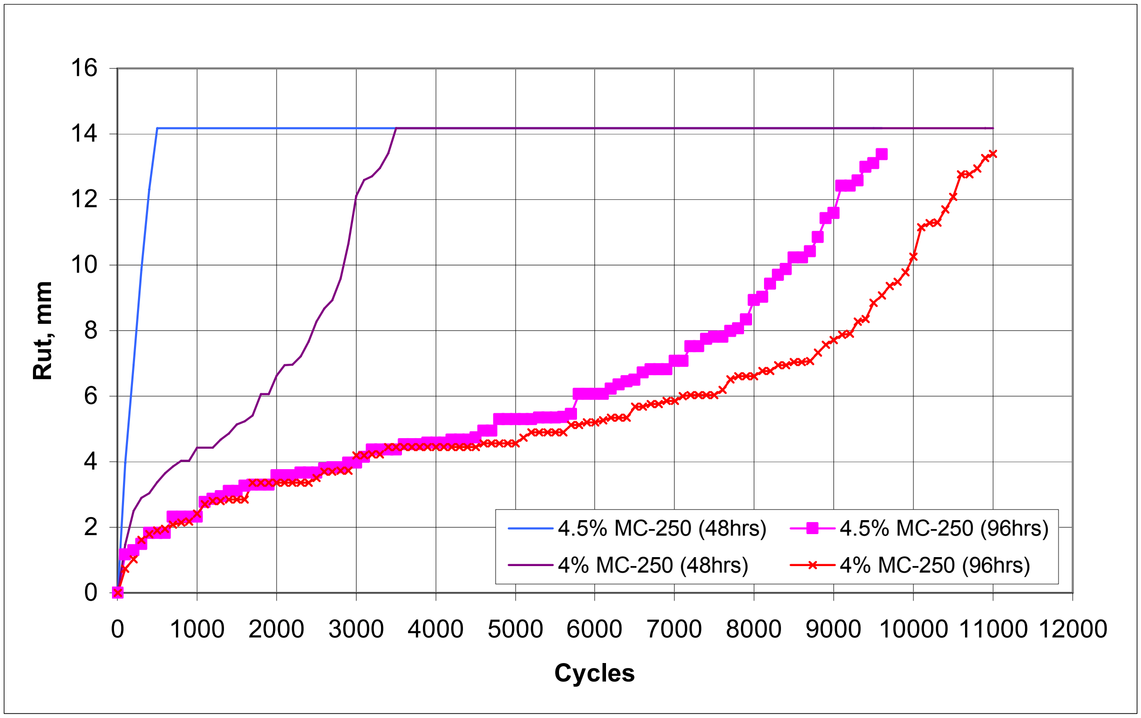

Figure 4.15 Preliminary Hamburg Stability Results for Homemade Mixes

4.7 Indirect Tensile Strength Testing

Based on the results of a previous study conducted by the researchers, it was observed that indirect tensile strength (ITS) tests on rapid- and medium-curing mixes at 25 °C (77 °F) at different curing times indicated a relative increase in the tensile strength of the respective mixes with curing. ITS tests on the cured homemade mixes will be conducted in this study to assess the cohesiveness of the mixes.

4.8 Stripping Tests

Estakhri and Button (1995) observed that Tex-530-C, "TxDOT Boiling Stripping Test," reasonably predicts the potential for maintenance mixtures to strip in the stockpile. In this study, the Tex-530-C test will be conducted to ascertain the benefit of this additive (hydrated lime) to the durability and survivability of homemade cold patch.

5. Field Evaluation of Patching Mixture Performance

One of this project's objectives was to perform a field evaluation of containerized cold patch and homemade cold patching mixes developed as part of Task 2. The main objective for researchers was to rate the performance of patching material in the field, to be followed by a critical evaluation of mix design and performance testing procedures. This initial field evaluation included six containerized medium-curing products, three homemade mixes, and one commercially produced stockpile mix. Promising homemade mixes developed for this research project will be tested in a second field evaluation in fiscal year 2006.

The field evaluation included the installation of the six containerized patching materials in the Lubbock and Lufkin districts. The patches were installed in roads with low and moderate traffic volumes in temperatures that ranged from 40 to 85 ^{o}F. Fifty-six patches were installed in Lubbock by three different maintenance yards, including Muleshoe, Bovina, and Littlefield. The installation occurred in February 2005. Each maintenance yard provided a homemade patching mix, which was installed in addition to the six containerized mixes. The Lubbock district represents an environmental zone that is cold and dry. Twenty-eight of the patches were installed with the warm material (65 to 75 ^{o}F), and twenty-eight were installed with cold material (40 to 50 ^{o}F). Twenty-eight patches were also installed in Lufkin, which is an environmental zone that is considered to be warm and wet. The installation occurred in April 2005, so all the patches were installed with warm material (77 to 93 ^{o}F). The district provided a commercially produced patching mixture from a local stockpile instead of a homemade mix.

Researchers developed several standard procedures and protocols to ensure the patches were installed uniformly and would not be subjected to significantly different roadway conditions. The criteria developed included pothole selection, the patching process, installation protocol, data collection protocol, and patch condition survey procedures.

5.1 Development of Field Patching Process

5.1.1 Pothole Selection

It was important to control the size of the potholes created. The pothole had to be of a size large enough that the patching material would carry the full weight of a truck tire but not so large that there would not be enough patching material to complete the experimental matrix. In the Lubbock district, eight potholes were filled with each material, and twenty bags of each material were available. This meant that the average patch could take no more than two-and-a-half bags to fill. Based on these criteria, potholes with the following dimensions were created for the field trials:

- Minimum diameter—1 ft
- Maximum diameter—2.5 ft (depending on depth)

The selection of road sections was also included in the pothole selection process. To be considered, the section of road had to provide at least seven patching opportunities so that one patch of each material was installed in a given pavement structure. The researchers inspected several roads in the Lubbock district that were selected by district staff as candidate roads for the field trials. Approximately 100 lane miles of road were inspected, and the researchers found a total of eight potholes. Only four or five satisfied the pothole selection requirements mentioned above. The technical memorandum summarizing these findings is in Appendix D. Each district was responsible for ensuring that there was no significant rehabilitation scheduled on the section of road for an 8-month period following the field installation.

5.1.2 Patch Preparation

Because of the lack of closely spaced open potholes, all the potholes for this field evaluation had to be manufactured by removing material from a previously patched pothole or by creating a new pothole in a heavily distressed pavement. To make the potholes, district staff provided traffic control, while the patches and potholes were prepared for patching. Existing patching material was removed to create the potholes and then they were filled with water as described in the patching protocol. After 1 hour, the patching crew swept the water and loose debris out of the holes and immediately installed the patching material. The selection of patching mix used to fill a pothole was made at random by the researchers. The same field procedures were used in both the Lubbock and Lufkin districts.

5.1.3 Patching Protocol

The patching protocol is based on a combination of TxDOT's Function Code 241—"Potholes, Semi-Permanent Repair" (Code Chart 12)—and the cold patch manufacturers' recommendations. TxDOT's Function Code 241 addresses repairs with an area of less than 1 square yard and is described in Appendix B. Function Code 241 generally satisfies the minimum recommendations of all the cold patch manufacturers, although none of the manufacturers recommend the use of a tack coat for their products. Two vendors recommend making some effort to compact the base/subbase/subgrade to ensure adequate support for the patching material. As a result, the following patching protocol was developed and implemented:

- Prior to patching, existing potholes will be filled with water to the pavement surface and allowed to stand for one hour or until the water soaks into the base. An existing patch will be removed with hand tools or an electric jackhammer to create a pothole and water will be added as described above. In no case will water be added if the temperature is below 0 °C (32 °F).
- Hand tools will be used to remove loose pavement, debris, and excess water from the pothole.
- When patching with the control material (district-supplied homemade mix), the crew will follow standard procedures for their material, including the application of tack coat. A tack coat will not be applied for the containerized materials.
- The hole will be backfilled with patching material in two-in. lifts. Hand tools will be used to level the patch and a truck tire will be used to compact each lift. The truck will make four passes (forward and backward equaling two passes) to compact each lift. Additional passes will be allowed if the patch is large or until the entire surface receives at least one pass of the truck tire.

The patching protocol was followed strictly and supervised by CTR staff for the field installations in both Lubbock and Lufkin districts.

5.2 Test Sites and Materials Used

5.2.1 Lubbock District

Field trials in the Lubbock district consisted of installing six different containerized patching materials that were chosen based on the results of a previous study. In addition, a Lubbock district homemade cold patch mix was installed as the control material. All the patches were installed in February 2005. Eight patches were made with each material for a total of fifty-six patches. Twenty-eight patches were installed on low-volume roads and twenty-eight on moderate volume roads. Of the eight potholes filled with each material, four were filled with cold material and four were filled with warmed material. Warming the material was accomplished by leaving the materials indoors the night before and transporting the materials inside heated vehicles. Table 5.1 provides an overview of the Lubbock field trial patching matrix.

Table 5.1 Field Trial Patching Matrix for Lubbock District

Cold Patching Materials	**Road Classification by Traffic**			
	Low Volume		**Moderate Volume**	
	Ambient	Warm	Ambient	Warm
Homemade	2	2	2	2
PCPA	2	2	2	2
PCPB	2	2	2	2
PCPC	2	2	2	2
PCPD	2	2	2	2
PCPE	2	2	2	2
PCPF	2	2	2	2

The highest volume road that required maintenance in the Lubbock district was US 60 at Bovina, which carries approximately 6,200 vehicles per day. This road provided the most traffic of all the road sections in both districts and is the only road where new potholes were created because there were no existing patches or potholes. This road had severe block cracking, so small areas of pavement outlined by block cracks were removed to make the potholes. Twenty-eight patches were installed in Bovina with fourteen using cold material, 3.9 °C to 13.3 °C (39 °F to 56 °F), and fourteen using warm material, 15.5 °C to 26.7 °C (60 °F to 80 °F). The air temperature during installation was 7.8 °C (46 °F).

Fourteen patches were installed on FM 746; a low-volume road close to Muleshoe, Texas, with warm material, 15.5 °C to 26.7 °C (60 °F to 80 °F). The air temperature was 8.9 °C to 10 °C (48 °F to 50 °F).

The remaining fourteen patches were installed on FM 1055; a low-volume road near Littlefield, Texas. These patches were installed with cold material, 3.9 °C to 13.3 °C (39 °F to 56 °F). The air temperature was 6.1 °C to 9.4 °C (43 °F to 49 °F).

5.2.2 Lufkin District

Field trials in the Lufkin district consisted of installing the same six containerized patching materials used in Lubbock. In addition, Lufkin supplied cold patch material from a stockpile made by an independent contractor. Four patches were filled with each material for a total of twenty-eight patches. Fourteen patches were installed on FM 1087, a low-volume road, and fourteen on SH 204, a moderate-volume road. All the potholes were filled with warm material—20.5 °C to 29.4 °C (69 °F to 85 °F). The air temperature during installation was 27.2 °C (81 °F). Table 5.2 provides an overview of the Lufkin field trial patching matrix. All of these patches were installed in April 2005.

Table 5.2 Field Trial Patching Matrix for Lufkin District

Cold Patching Materials	Road Classification by Traffic	
	Low Volume	Moderate Volume
	Ambient	Ambient
Homemade	2	2
PCPA	2	2
PCPB	2	2
PCPC	2	2
PCPD	2	2
PCPE	2	2
PCPF	2	2

5.3 Data Collection Protocol

A data collection form was developed containing the detailed installation records for all the patches. Nuclear density gauge and DCP test results were recorded separately. Figures 5.1a and 5.1b show the data collection form used during field installations of cold patching material.

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: ____________

Photograph No. (s) _________________
Pothole: _______________
Patch: _________________

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

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Figure 5.1a Data Collection Form Used during Field Installation of Cold Patching Materials

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: _________________

1st Measurement: ______________

2nd Measurement (after turning gauge 180 °): ________________

Subjective workability from crew (Circle One)

1 = unworkable

2

3

4

5 = highly workable

Special installation notes and comments: ____

____

____

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Figure 5.1b Data Collection Form Used During Field Installation of Cold Patching Materials

5.4 Condition Survey Protocol

The "Patch Condition Survey Manual" was developed specifically for cold patching mixes based on the "Pavement Surface Condition Rating Manual" (Northwest Pavement Management Systems Users Group and Kay, 1992). The "Patch Condition Survey Manual" is presented in Appendix E. It contains the various patch and pavement distresses and their severity levels. On the basis of the "Patch Condition Survey Manual," a condition survey data collection form was developed that was used to monitor the condition of the patches 1, 3, and 6 months after installation. Figure 5.2 shows the condition survey form used for monitoring the condition of the patches. The "Patch Condition Survey Manual" and condition survey data collection form were modified slightly after the first condition survey in Lubbock to change severe dishing depth from ¼ in. to ¾ in. or greater.

Condition Survey Form for Field Trial of Cold Patching Mix (2005)
Project 0-4872

Rater: ___________________________ Date: __________ Time: ______________
Patch No. __________

Patch location: GPS Coordinates Lat: ____________ Long: ____________
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:	None	Slight/Moderate	Severe
Adjacent Pavement Distress			
Rutting:	None	Slight/Moderate	Severe
Cracks:			
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: ____
____
____

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Figure 5.2. Condition Survey Form for Cold Patching Materials

5.5 Field Performance Evaluation

5.5.1 Lubbock District

The three follow-up condition surveys have been performed in the Lubbock district. The one-month survey was performed in March 2005, the three-month survey in June 2005, and the six-month survey in August 2005. A detailed Excel spreadsheet database was developed and has been populated with the installation and condition monitoring data. The researchers observed that during the 3-month condition survey in June, fourteen patches in Bovina had been covered by a pavement level-up maintenance action. During the 6-month condition survey it was noted that the remaining fourteen patches had also been covered as a result of another level-up procedure.

5.5.2 Lufkin District

Installation of twenty-eight patches in the Lufkin district took place in April 2005. Since then, the 1-month and 3-month condition surveys have been performed in May and July 2005, respectively. The 6-month condition survey is scheduled to take place in October 2005. The Excel spreadsheet database has been populated with the condition data.

5.5.3 Field Performance Results

After the final condition survey is completed in October 2005, the data will be evaluated to determine if enough patches remain to assess the performance of the patching materials. Of the total eighty-four patches installed in both districts, approximately thirty-two to thirty-four were covered or have received some type of maintenance treatment. Some pictures of the installation process and from the condition surveys are included in Appendix F.

6. Preliminary Evaluation of Cold Patching Mix Containers

6.1 Packaging of Containerized Patching Materials

The objective of this task is to determine the costs and benefits of various containers in terms of effectiveness and performance. This task will be conducted in the second year of the project. In this section, a preliminary evaluation of the packaging of the containerized patching materials is presented.

In contrast to rapid-curing patching materials in buckets, medium-curing containerized mixes are bagged, although the quality of the packaging varies. One manufacturer uses paper bags with plastic lining on the inside. On the other hand, some suppliers use fiber-reinforced plastic bags.

An important aspect in terms of durability of the containers is the packing of the bags on pallets. One pallet in particular was neatly stacked and double wrapped, first with plastic sheets and then with plastic shrink wrap. This extra care helped prolong the survivability of the bags resting on the pallet over a period of 6 months. On other pallets, bags would be punctured when the bottom layer of bags crept over the edge of the pallet. The costs and benefits of special handling and reheating procedures during application of the stockpiled mixtures (if feasible) will also be evaluated during the second year of the project.

6.2 Performance Evaluation of Containers

The durability of the packing materials is also being investigated in terms of resistance to damage with handling. In this regard, an experimental program is being planned to evaluate the puncture resistance of the bags. Drop tests will be performed to determine if there are differences in the resistance of the bags to damage from stresses encountered during typical handling activities.

7. Summary and Conclusions

Based on the findings and results presented in Chapters 1 through 6, several conclusions and recommendations are discussed below.

7.1 Literature Review

The following conclusions were identified from previous studies:

- The deficiencies in cold patching mixtures are reflected in unsatisfactory performance or failure, which may be initiated in the stockpile during handling and placement or in service.
- The most commonly encountered mixture deficiencies at the stockpile are poor workability and stripping with binder drain-down. Curing characteristics of the binder are also very important during stockpiling.
- One study indicated that spraying pavement striping paint on the stockpile surface helps reduce stripping and was the most effective treatment for HMCL mixtures in the laboratory evaluation.
- During transport and placement the primary concern is workability.
- Immediately after compaction, before the binder cures, the mix must be stable and not susceptible to pushing or shoving.
- The most frequently encountered in-service failures are pushing or shoving, raveling, and dishing.
- Mixture properties designed to improve workability may worsen the stability; therefore, these two characteristics must be carefully balanced.
- Because ideal patching techniques are not always used, mixtures with larger aggregates (12–19 mm or 1/2–3/4 in.) tend to ravel prematurely under traffic, resulting in failure of the patch.
- For larger or deeper holes the mixture should be compacted in layers.
- The SHRP cohesion test is recommended to quantify the cohesion of cold mixes. Although this test does not guarantee the success of a mix, it indicates potential for poor performance of a mix.
- A uniform gradation, consisting of 100 percent passing the 9.5 mm (3/8 in.) sieve, is recommended because the resulting mix is pliable, workable, and durable.
- The workability of the mix is improved significantly if the minus 200 fraction in the mix is limited to a maximum of 2 percent.
- Angular-crushed stone aggregate is an appropriate material for higher stability.
- Binders for stockpiled patching mixtures consist of both cutbacks and emulsions. The low-viscosity grade (250 cSt) cutback binder is preferred for longer stockpile life and when the mixture is used during winter. The high-viscosity grade (800 cSt) cutback binder is usually used during the fall and spring.
- The literature indicates that at least 4.5 percent residual bituminous binder is required in a stockpile patching mixture made from an aggregate whose water absorption is less than 1 percent. If the aggregate's water absorption is greater than 1 percent, the residual binder content should be increased by a similar amount.
- The use of anti-stripping agent is critical. Extensive testing has shown that there is no single additive that works with all aggregate types. Thus, it is essential that the type

of anti-stripping agent and its rate of application be selected after testing with the specific aggregate used in the mix.

- In one study, researchers conducted the resilient modulus tests, tensile strength measurements, and extracted binder tests to evaluate aging characteristics of mixes. Resilient modulus tests indicated that LRA (limestone rock asphalt) and specialty mixtures are less stiff at low temperatures than HMCL materials are; however, there is no significant indication of a similar trend in stiffness among the two mixtures after 6 months of stockpile aging.
- Unconfined compressive strength and triaxial tests with conditioned mixes have been proposed as laboratory workability tests. Although these methods simulated aging characteristics of mix in stockpiles, correlations to field measurements were inconclusive. Several modifications have been tried on the SHRP workability test, but with no significant correlations with respect to field workability.
- A research study revealed the interest in using engineering fabrics to control reflective cracking when patching bituminous concrete prior to overlaying.
- A study suggested that experimental mixtures using the latex-modified cutback binder did not perform as well as their companion controls.
- The SHRP H-106 study (Evans, Mojab et al., 1992; Wilson and Romine, 1993a; Wilson and Romine, 1993b; Wilson, 1998) indicated that the throw-and-roll technique is more cost-effective than the semi-permanent procedure is in most situations, when using quality materials.
- Proprietary or high-performance mixes are usually four times more expensive than normal stockpile mixes are. However, the overall cost of patching operations per cubic foot is five times less expensive when using high-performance mixes instead of common cold patching mixtures.
- A TTI study (Estakhri et al., 1999) indicated that the mixtures produced with crushed limestone had higher Hveem stability than those produced with crushed gravel. It was also concluded that the mixture density could be lowered to 92 percent to improve winter workability without sacrificing mixture properties.

Conclusions from the mix design procedures adopted in the Lubbock district are:

- The Lubbock district makes its own homemade cold patch material to repair potholes throughout the year. Each maintenance section has slightly different homemade mix designs.
- The R. E. Janes Quarry near Lubbock produces a low cost Grade 5 crushed river gravel aggregate with 70 percent (minimum) retained on No. 4 sieve with one or more mechanically induced crushed faces). The Vulcan Quarry in Brownwood produces Grade 5 crushed limestone aggregate with 85 percent (minimum) retained on No. 4 sieve with two or more mechanically induced crushed faces).
- The Grade 5 crushed river gravel from the R. E. Janes Quarry does not meet the crushed faces requirements according to Tex-460-A, Part I.
- Crushed limestone aggregate is used by some maintenance yards to make homemade mix for patching on higher-volume roads and the crushed river gravel aggregate is used to make homemade mix for use on low-volume roads.
- Lubbock's has experienced difficulty using their homemade patching materials in the winter season, particularly under wet conditions. Discussions with Lubbock district

personnel indicate that the homemade mix may be highly susceptible to stripping. They have used a rapid curing containerized product and were satisfied with the performance, but the product is too expensive to be used on a routine basis or over large areas.

- Lubbock adds diesel or kerosene to RC-250 to thin the binder used for their homemade mixes. Approximately 9:1 to 16:1 RC-250 to diesel by volume is added to the binder.
- The gradation of the homemade mix from the Littlefield maintenance yard had a high percentage of fines with a 9.1 percent fraction passing the sieve No. 200 or 0.075 mm. The gradation in Muleshoe and Bovina produced 2 to 3.5 percent fines and was a denser mix overall.
- For the homemade mixes, gradation consisting of 100 percent passing the 22.225 mm or 7/8-inch sieve size was found.
- A heavy mix with Grade 4–7 aggregate is used by the Lubbock district for deep patches, whereas a light mix with Grade 5 aggregate is used for shallow patching.
- TxDOT personnel in Lubbock report that the patches installed in summer with homemade mix survive very well but patches installed in winter using the same material do not perform well.
- The use of RC-250 may cause rapid curing of the cold mix, which leads to decreased workability and short stockpile life.
- During field trials to install containerized mixes, homemade patching material was installed as a control material. Researchers noted that the material appeared fully cured. Workability was not an issue because the patching truck used a conveyor belt that broke up the homemade material when it came out of the truck. The holes that were patched with this material were primed with RC-250, and in some cases RC-250 was added to rejuvenate the homemade mix.
- The residual binder content in the homemade mixes in Muleshoe was measured as low as 3.2 percent.
- No anti-stripping agent is currently added to the Lubbock homemade mix.
- The mixing procedure used in Lubbock is to windrow the aggregate components and mix them using a maintainer. The binder, heated to about 71.1 °C to 85 °C (160 °F to 185 °F), is added and the material is mixed with the maintainer before being stockpiled.

Conclusions from discussions with the TxDOT district in Lufkin regarding the use of cold patching materials are as follows:

- The Lufkin district does not manufacture homemade mix. They either import LRA (limestone rock asphalt) or purchase their stockpile mix from a commercial cold patch mix manufacturer.
- The same six containerized patching materials used in Lubbock were selected for the field performance evaluation in Lufkin to evaluate the effectiveness of these mixes in warm, wet weather.

Based on previous laboratory work on containerized patching materials, some important laboratory investigations adopted for this study include:

- gradation analysis and aggregate screening;
- binder analysis and testing;
- curing analysis for stability and workability assessment of mixtures;
- Superpave gyratory compaction and volumetric analysis to identify appropriate density requirements for specimens, depending on design traffic volumes and field compaction;
- development of a slump-based workability test to identify a quantifiable measure for workability of cold patching mixtures;
- the use of the Hamburg Wheel Tracking Device (HWTD) to assess the rutting performance and stability of the compacted specimens;
- indirect tensile strength (ITS) testing to assess the cohesiveness of patching materials; and
- the TxDOT boiling stripping test (Tex-530-C) to evaluate the stripping potential of the various cold patching mixtures.

The current field maintenance procedures in the Lubbock district were identified. The following information was collected:

- TxDOT uses two different methods for patching potholes, permanent and semi-permanent.
- The field patching protocol developed for this study was based on a combination of TxDOT's Function Code 241—"Potholes, Semi-Permanent Repair" (Code Chart 12)—and the cold patch manufacturers' recommendations.
- Function Code 241 generally satisfies the minimum recommendations of all the cold patch manufacturers.

7.2 Development of Mixture Design Procedure

On the basis of screening experiments, a preliminary homemade mixture design procedure was developed in the laboratory and the following conclusions were realized:

- The target gradations for fine, dense, and open-graded mixes were based on the gradation curves of containerized mixes and the gradations of several homemade mixes made by the Lubbock district.
- The maximum aggregate size of all mixes is limited to 9.5 mm or 3/8 inch.
- The *rounded* blends contain Grade 5 crushed river gravel aggregate from R. E. Janes and the *angular* blends contain Grade 5 crushed limestone from the Vulcan Quarry in Brownwood.
- The binder selected for the experimental design is MC-250, a medium-curing kerosene-based cutback with a kinematic viscosity of 250 to 500 cSt. This binder was produced and supplied by Valero Marketing.
- Based on screening experiments, residual binder contents of 3.5 percent, 4.0 percent, 4.5 percent, and 5.0 percent will be used for further laboratory testing toward development of a cold patch mix design.
- Low-temperature compaction leads to Superpave gyratory specimens with high air voids, between 11 and 14 percent, adversely affecting the Hamburg stability results.

A decision was made to compact at higher temperatures, similar to those used in hot-mix preparation, to reduce the air voids. The materials compacted at 100 °C (212 °F) resulted in air voids less than 10 percent at 200 gyrations in the Superpave gyratory compactor.

- Materials compacted after short curing times or at lower curing temperatures produced unstable specimens that either collapsed right after compaction or instantly failed under the HWTD. After several screening experiments researchers determined that the cold patch should be cured for 96 hours at 60 °C (140 °F) to prepare the material for compaction. During compaction, the material temperature was elevated to 100 °C (212 °F) for preparation of samples for HWTD testing.
- Based on screening results, it was decided that 1 percent lime by weight will be added to all future mixes.
- A standard mixer was used for preparing the mix, which usually took about 5 to 10 minutes, depending upon the amount of mix prepared.
- Based on screening results, the experimental mix design was modified to include the preparation, testing, and evaluation of approximately fifty mixes. The optimal mix design in terms of stability and workability will be developed.

7.3 Laboratory Testing of Patching Materials

Several laboratory tests were undertaken and developed as part of the screening experiments to fulfill the experimental mix design for developing a preliminary cold patch mix design procedure. Based on the screening experiments, the following conclusions were noted:

- A dense-graded blend of aggregates was used for the screening experiments. The results from Tex-210-F, "Extraction of Bituminous Mixtures," revealed that there was no discernible difference in the gradations of the aggregate blends prepared from the stockpile versus the aggregate blends prepared from the fractions retained on the different sieves. So a gradation blended from stockpile aggregates will be used for the remaining mixes.
- There was 8 percent by weight of Grade 5 crushed river gravel and 9 percent by weight of Grade 5 crushed limestone in the respective dense aggregate blends. Most of the aggregate in both the blends is crushed river gravel screenings.
- The percentage passing the sieve No. 200 or 0.075 mm was less than 2 percent for both the aggregate blends.
- Asphalt binder tests on the MC-250 resulted in the binder meeting all the TxDOT specifications.
- In order to simulate the stability of the mix in service, it was decided following the screening experiments to cure the mixes at 60 °C (140 °F) for 96 hours and then increase the mix temperature to 100 °C (212 °F) for gyratory specimen compaction for HWTD tests.
- The Superpave gyratory compactor was designed for hot-mix asphalt. When this device was used for compaction of cured and uncured cold patch mixes, both the cured and uncured materials could not be compacted to achieve final air voids of less than 10 percent.

- When the curing time is increased to 96 hours we observe that the 3.5 percent, 4.0 percent, 4.5 percent, and 5.0 percent residual binder mixes begin to approach final air voids of less than 10 percent at 200 gyrations.
- The tolerance limit for heights of compacted specimens for Hamburg stability testing is 62±2 mm. Because many specimens did not undergo 200 gyrations, this criterion was lowered to 60 mm to help ensure that all the specimens were subjected to the same compaction effort of 200 gyrations without exceeding the allowable limits of specimen thickness.
- A TTI study by Estakhri and Button (1995) indicates that Tex-530-C, "TxDOT Boiling Stripping Test," reasonably predicts the potential for maintenance mixtures to strip in the stockpile. Tex-530-C will be conducted for assessing the benefit of using anti-stripping agent (lime) in the mixes.
- Based on the results of a previous unpublished study, it was observed that indirect tensile strength (ITS) tests on rapid- and medium-curing mixes at 25 °C (77 °F), at different curing times, indicated an increase in tensile strength of the respective mixes with curing. ITS tests will be conducted on cured homemade mixes to assess mix cohesiveness.

Some conclusions and findings from the Cold Patch Slump Test (CPST), a slump-based workability test developed in this study, are discussed below. The CPST is an inexpensive, quick, and simple test procedure used to quantify workability of bituminous maintenance mixtures in the laboratory. The application of a slump-based test, where the material is compacted and conditioned at temperatures to simulate those encountered in the field, is used to predict the ease of placing cold patching material in the field. The inverse of the slump time indicates a measure of workability, and the results demonstrate a uniform increase in workability with material temperature. The variation of slump time with subjective ratings in the laboratory shows a positive linear correlation. However, the deviations are a result of different aggregate gradations and inherent variability that result from subjective ratings. The laboratory workability measures and the subjective rating in the field show positive linear correlation in cold (39 °F to 47 °F) and intermediate (49 °F to 63 °F) temperatures.

Initial experiments were conducted using six different containerized patching materials under different compaction efforts and conditioning temperatures. PCPD—with an open gradation, 3.5 percent residual binder, and 1.5 percent fines—took the least time to slump at 35 °F and is the most workable at cold temperatures. PCPA—with a dense gradation with 4.6 percent residual binder—took the most time to slump at 35 °F. There is strong negative exponential correlation between the weights placed on specimens and the time to slump, indicating that the next task would be to select an appropriate weight based on prior results and to test all the specimens with that weight on top in order to reduce the slump time. Tests are underway with the specimens placed on surfaces with different coefficients of friction in order to estimate the effect of lateral frictional force on slump time.

The temperature of the material taking the longest time to slump rose to just 10 °F. This suggests that the material does not slump entirely as a result of higher temperatures. The slump of the specimen is a combination of shear and normal stress acting on the failure plane. Intrinsic material properties like cohesion and internal friction influence the workability of the material. The stress calculations on the specimens undergoing slump will help in estimating the impact of these parameters on the workability of the material. These parameters incorporate variables like binder content and aggregate gradation, which affect the workability of maintenance mixtures. The slope of gyratory compaction curves and the work done due to shear during compaction are also being explored as potential measures of workability.

The use of multiple raters for subjective workability measures on all materials will help eliminate experimental bias, which might have occurred with the single rater used in this experiment. Further tests on cured materials will help characterize the workability of cold patching materials taken from stockpiles.

Conclusions from the CPST conducted on homemade mixes are as follows:

- Based on initial results, the CPST is to be conducted with a compaction effort of ten blows per lift and specimen conditioning at 1.7 °C (35 °F) for 24 hours.
- Tests are being conducted for mixes cured at 25 °C (77 °F) for 0, 24, and 72 hours in order to evaluate the aging characteristics of the mix in the stockpile.
- We observe that the workability indicator (i.e., inverse of slump time) decreases as mixes are cured for longer periods of time. Also, the workability for the mix with 5 percent residual MC-250 binder content is higher than that for the mix with 4.5 percent, at different curing times.

Output of shear stress from the Superpave gyratory compactor was evaluated as a possible measuring stick of workability and the following results were observed:

- It was observed that the shear stress curves for material cured at 60 °C (140 °F) and compacted at 100 °C (212 °F) were indistinguishable between among the different mixes.
- Since the material was cured at 60 °C (140 °F) for 96 hours and compactions were done at 100 °C (212 °F), the mix was mostly cured with few volatiles left in the binder, as opposed to compaction of uncured cold patch at low temperatures. As a result, the development of shear stress was dominated by the aggregates.
- It was decided by the researchers to conduct Superpave gyratory compactions are to be conducted at 1.7 °C (35 °F) after conducting the CPST on material which that is cured for 0, 24, and 72 hours at 25 °C (77 °F), and then study the shear stress curves, sensitive to both aggregate structure and binder will be studied.

The HWTD was used for assessing the long-term durability of the homemade mixes. Based on the study, the following conclusions were realized:

- Based on a previous study it was decided that the Pine Rotary Asphalt Wheel Tester (RAWT) be discontinued for stability testing in this study.
- The HWTD stability testing was too harsh for uncured cold patching mixes.
- The HWTD was designed for use on hot-mix asphalt, which is compacted uncured (i.e., while hot) and then allowed to cure (cool) before being subjected to the Hamburg. Therefore, for the purposes of this study, the HWTD was used for stability testing after the cold patch was first cured and then compacted at elevated temperatures similar to hot mix.
- It is essential for the cold patch specimens to have air voids close to 10 percent, so that they are dense enough for stability testing under the HWTD.
- The specimens having air voids in the range of 11 to 14 percent, even with anti-stripping agent in the mix, failed partly due to stripping.

- All the cold patch mixes should undergo a uniform number (200) of gyrations so that they all receive the same compaction effort.
- All mixes are to be cured at 60 °C (140 °F) for 96 hours, compacted at 100 °C (212 °F), and tested wet (under water) at 25 °C (77 °F) for rutting performance in the HWTD.
- Mixes showed better rutting performance when cured for longer periods of time.
- The 4.0 percent residual binder mix showed better rutting performance than the 4.5 percent residual binder mix did. It lasted approximately 11,000 cycles, which is extremely desirable in terms of stability.

7.4 Field Evaluation of Patching Mixture Performance

- This initial field evaluation included six containerized medium-curing products, three homemade mixes made by maintenance yards in the Lubbock district, and one commercially produced stockpile mix in Lufkin.
- The Lubbock district represents a cold and dry environment and the Lufkin district represents a warm and wet environmental zone.
- On the basis of a previous laboratory study, six containerized patching materials were selected for the field performance evaluation. These are (in alphabetical order) Asphalt Patch, Perma Patch, Proline, QPR, Stayput, and UPM Winter.
- Fifty-six patches were installed in Lubbock by three different maintenance yards, including Muleshoe, Bovina, and Littlefield. The installation occurred in February 2005. Twenty-eight of the patches were installed with the warm material (65 to 75^{o}F) and twenty-eight were installed with cold material (40 to 50^{o}F).
- Twenty-eight patches were installed in the Lufkin district. The installation occurred in April 2005, so all the patches were installed with warm material (77 to 93^{o}F).
- The patches were installed in roads with low and moderate traffic volumes.
- Because one cubic foot requires three 50-lb bags, patching will be done only on potholes from 1 to 2.5 ft in diameter, and depending on the diameter, the depth of the pothole will be limited to 2 to 5 inches.
- The patching protocol was developed based on a combination of TxDOT's Function Code 241—"Potholes, Semi-Permanent Repair" (Code Chart 12)—and the cold patch manufacturers' recommendations.
- Due to the lack of closely spaced open potholes, all the potholes for this field evaluation were manufactured by removing material from a previously patched pothole or by creating a new pothole in a heavily distressed pavement.
- A data collection form was developed, one which contains the detailed installation records for all the patches. Nuclear density gauge and DCP test results were recorded separately.
- A "Patch Condition Survey Manual" was prepared and a condition survey data collection form was developed which was used to monitor the condition of the patches 1, 3, and 6 months after installation.
- In the Lubbock district, the 1-month survey was performed in March 2005, the 3-month survey in June 2005, and the 6-month survey in August 2005. In the Lufkin district, the 1-month and 3-month condition surveys were performed in May and July 2005, respectively, and the 6-month condition survey is scheduled for October 2005.

- After the final condition survey is completed in October 2005, the data will be evaluated to assess the performance of the patching materials.
- Of the total eighty-four patches installed in both districts, approximately thirty-two to thirty-four, in the Lubbock district, were covered or have received some type of maintenance treatment.

7.5 Preliminary Evaluation of Cold Patching Mix Containers

The objective of this task is to determine the costs and benefits of various containers in terms of effectiveness and performance. This task will be conducted in the second year of the project. Some observations and plans for this task are provided as follows:

- Medium-curing containerized mixes used for the project are, in general, bagged, although the quality of the packaging varies.
- One manufacturer uses paper bags with plastic lining on the inside. Some other manufacturers use fiber-reinforced plastic bags.
- Many bags were damaged in transit, due in part to the palletizing process. One pallet in particular was neatly stacked on the pallet and double wrapped first with plastic sheets and then with plastic shrink wrap, which protected the bags from damage during shipping and in storage.
- On other pallets, bags would be punctured when the bottom layer of bags crept over the edge of the pallet.
- To assess the durability of the bags, an experimental program is being planned whereby a device may be used to measure the puncture resistance of the different bags.
- Drop tests will be performed to determine if there are differences in the resistance of the bags to damage from stresses encountered during typical handling activities.

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Appendix A: TxDOT Specification as per Tex-460-A, Part I for Grade 5 Aggregate (1993)

Table A.1 Specification for Grade 5 Aggregate

Sieve Size	Percent Retained
½”	0
3/8”	0–5
No. 4 sieve	40–85
No. 10 sieve	98–100
No. 20 sieve	99–100

Appendix B: TxDOT's Function Code 241

TxDOT's Function Code 241—"Potholes, Semi-Permanent Repair" (Code Chart 12)

TxDOT's Function Code 241 is specifically for repairs with an area of less than 1 square yard and reads as follows:

> Function 241 should be used for all activities associated with the repair of potholes as a temporary corrective measure. Work item associated with semi-permanent portholes repairs could include using hand tools to remove loose pavement from the hole, sweeping debris from the hole, applying a tack coat, backfilling the hole with patching material, using hand tools to level the patch and using hand tools or power equipment to compact the patch.

Appendix C: Technical Memorandum No. 1 (Experimental Design)

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EXPERIMENTAL DESIGN

1. Experimental design

The following is an outline of the experimental program designed for the development of a mix design procedure homemade (stockpiled) cold mix.

1.1. Factors

A mixed factorial experiment with 1 x 3–level and 5 x 2–level factors is proposed. Table 1 shows the factors to be considered and the different levels at which these should be evaluated. A brief description and motivation for each of the factors follows:

Table C.1 Experimental Design Matrix

Factor/Level	Low	Center	High
Gradation	Dense	Open	Fine
Aggregate shape	Rounded	—	Angular
Binder viscosity	Low	—	High
Binder content	Low	—	High
Compaction Temperature	50 °F	—	77 °F
Curing Time	0 hours	—	96 hours

<u>Gradation</u>

Given that the focus of the project is on the mix design of patching mixes, it was deemed necessary to consider at least three different mix gradations. Research has shown that gradation has a significant influence on both the workability and durability of patching mixes. Figure 1 shows the proposed gradations to be evaluated. These constitute the low, middle, and high *levels* used for containerized patching mixtures evaluated as part of preliminary investigations. The maximum aggregate size of all mixes will be limited to 3/8 in.

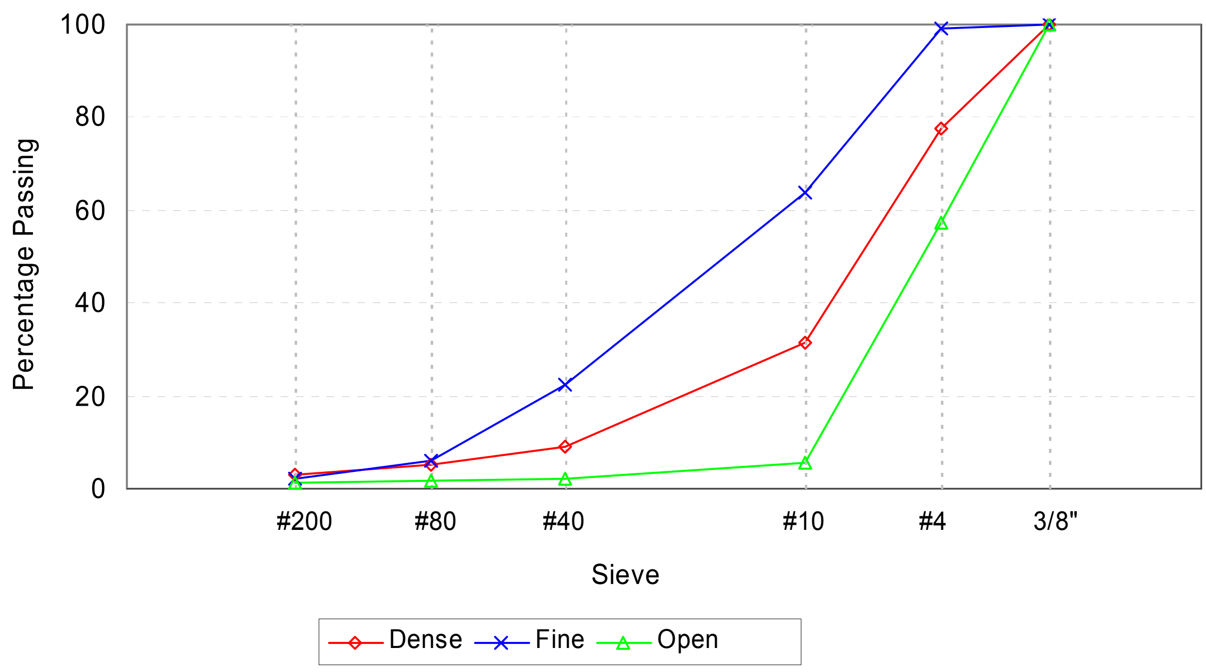

Figure C1. Proposed Gradation Levels

Aggregate shape

This factor has a significant influence on workability and stability. Aggregate shape is related to aggregate type. River gravels are naturally rounded and afford more workability compared to crushed limestone aggregates. By blending rounded and crushed aggregates it is possible to manipulate the workability of the mix; thus center points may be tested. It is proposed that the aggregates commonly used in the Lubbock district be used for the experiment. Two different aggregate types are required.

Binder viscosity

This factor will be influenced by the type and amount of additive used for the patching mix. It is proposed that diesel cutback be used for all the mixes but that the viscosity of the binder be varied by the amount of cutback used. Two levels of viscosity will be chosen based on a review of current practices in the industry. It is also proposed that an anti-stripping agent (e.g., lime) be used for all the mixes.

Binder content

It is proposed that two levels of residual binder content be evaluated to investigate its influence on the workability and durability of the patching mixes.

Compaction temperature

Two levels of compaction temperature should be considered. These are the temperatures at which the patching materials will be compacted in the field during winter maintenance. Typically the mixes will be compacted at the lower temperature, but the researchers would like to investigate the benefits of heating the mixes before compaction as well.

Curing Time

Curing time has a significant influence on workability. It is proposed that mixes be tested without curing and after 96 hours be cured at 140 °F.

1.2. Responses

The experiment is designed to consider a number of mix responses. Primary responses include stability, workability, durability, and cohesion. Other performance requirements to be satisfied include stripping and drainage resistance of stockpiled material.

Stability

For patching mix stability it is proposed that the response variable to be investigated be Hamburg wheel test rutting. Hamburg tests will be done using the standard TxDOT equipment, wet at a temperature of 77 °F. The rutting of the specimens after the application of 100 and 1,000 cycles will be monitored. The project statement calls for a mix design procedure that accounts for traffic. Including this factor will allow the influence of traffic volume to be taken into account. The low (100 cycles) and high (1,000 cycles) levels as stated in Table 1 are based on typical low and high Hamburg cycle values from preliminary research on containerized patching mixes.

Workability
A suitable workability test for patching mixes will be evaluated as part of the study. It is proposed that workability be investigated using the modified slump test. Other measures of workability to be tested include the slope of the gyratory compaction curve and subjective ratings.

Durability
This will be evaluated in terms of mix density. Preliminary investigations indicate that it is desirable to achieve compaction densities of at least 90 percent.

Cohesion
This factor will be evaluated in terms of indirect tensile strength.

1.3. Testing

All testing will be replicated at least once and center points may be considered for the 2-level factors. The experiment was designed using the SAS statistical analysis software. The final design is shown as an appendix. All testing will be replicated at least once. Center points will be considered for 2-level factors.

2. Factorial Experiment

RUN	GRAD	AGGS	VISC	CONT	TEMP	CURE
1	Dense	Rounded	Low	Low	50	0
2	Open	Rounded	Low	Low	50	0
3	Fine	Rounded	Low	Low	50	0
4	Dense	Rounded	Low	Low	50	96
5	Open	Rounded	Low	Low	50	96
6	Fine	Rounded	Low	Low	50	96
7	Dense	Rounded	Low	Low	77	0
8	Open	Rounded	Low	Low	77	0
9	Fine	Rounded	Low	Low	77	0
10	Dense	Rounded	Low	Low	77	96
11	Open	Rounded	Low	Low	77	96
12	Fine	Rounded	Low	Low	77	96
13	Dense	Rounded	Low	High	50	0
14	Open	Rounded	Low	High	50	0
15	Fine	Rounded	Low	High	50	0
16	Dense	Rounded	Low	High	50	96
17	Open	Rounded	Low	High	50	96
18	Fine	Rounded	Low	High	50	96
19	Dense	Rounded	Low	High	77	0
20	Open	Rounded	Low	High	77	0
21	Fine	Rounded	Low	High	77	0
22	Dense	Rounded	Low	High	77	96
23	Open	Rounded	Low	High	77	96
24	Fine	Rounded	Low	High	77	96
25	Dense	Rounded	High	Low	50	0
26	Open	Rounded	High	Low	50	0
27	Fine	Rounded	High	Low	50	0
28	Dense	Rounded	High	Low	50	96
29	Open	Rounded	High	Low	50	96
30	Fine	Rounded	High	Low	50	96
31	Dense	Rounded	High	Low	77	0
32	Open	Rounded	High	Low	77	0
33	Fine	Rounded	High	Low	77	0
34	Dense	Rounded	High	Low	77	96
35	Open	Rounded	High	Low	77	96
36	Fine	Rounded	High	Low	77	96
37	Dense	Rounded	High	High	50	0
38	Open	Rounded	High	High	50	0
39	Fine	Rounded	High	High	50	0
40	Dense	Rounded	High	High	50	96

RUN	GRAD	AGGS	VISC	CONT	TEMP	CURE
41	Open	Rounded	High	High	50	96
42	Fine	Rounded	High	High	50	96
43	Dense	Rounded	High	High	77	0
44	Open	Rounded	High	High	77	0
45	Fine	Rounded	High	High	77	0
46	Dense	Rounded	High	High	77	96
47	Open	Rounded	High	High	77	96
48	Fine	Rounded	High	High	77	96
49	Dense	Angular	Low	Low	50	0
50	Open	Angular	Low	Low	50	0
51	Fine	Angular	Low	Low	50	0
52	Dense	Angular	Low	Low	50	96
53	Open	Angular	Low	Low	50	96
54	Fine	Angular	Low	Low	50	96
55	Dense	Angular	Low	Low	77	0
56	Open	Angular	Low	Low	77	0
57	Fine	Angular	Low	Low	77	0
58	Dense	Angular	Low	Low	77	96
59	Open	Angular	Low	Low	77	96
60	Fine	Angular	Low	Low	77	96
61	Dense	Angular	Low	High	50	0
62	Open	Angular	Low	High	50	0
63	Fine	Angular	Low	High	50	0
64	Dense	Angular	Low	High	50	96
65	Open	Angular	Low	High	50	96
66	Fine	Angular	Low	High	50	96
67	Dense	Angular	Low	High	77	0
68	Open	Angular	Low	High	77	0
69	Fine	Angular	Low	High	77	0
70	Dense	Angular	Low	High	77	96
71	Open	Angular	Low	High	77	96
72	Fine	Angular	Low	High	77	96
73	Dense	Angular	High	Low	50	0
74	Open	Angular	High	Low	50	0
75	Fine	Angular	High	Low	50	0
76	Dense	Angular	High	Low	50	96
77	Open	Angular	High	Low	50	96
78	Fine	Angular	High	Low	50	96
79	Dense	Angular	High	Low	77	0
80	Open	Angular	High	Low	77	0
81	Fine	Angular	High	Low	77	0
82	Dense	Angular	High	Low	77	96
83	Open	Angular	High	Low	77	96
84	Fine	Angular	High	Low	77	96

RUN	GRAD	AGGS	VISC	CONT	TEMP	CURE
85	Dense	Angular	High	High	50	0
86	Open	Angular	High	High	50	0
87	Fine	Angular	High	High	50	0
88	Dense	Angular	High	High	50	96
89	Open	Angular	High	High	50	96
90	Fine	Angular	High	High	50	96
91	Dense	Angular	High	High	77	0
92	Open	Angular	High	High	77	0
93	Fine	Angular	High	High	77	0
94	Dense	Angular	High	High	77	96
95	Open	Angular	High	High	77	96
96	Fine	Angular	High	High	77	96