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16. Abstract

In this interim report, various cold-laid and hot-mix asphalt (HMA) mixes were designed and/or evaluated based on the balanced mix-design concept and the Texas Department Transportation (TxDOT) crack attenuated mix (CAM) special specification (SS) 3109 specification for their potential application as very thin overlay mixes. The research methodology incorporated extensive laboratory testing and field experiments including the Hamburg, overlay, and the ground penetration radar.

While exhibiting fairly satisfactory field performance, laboratory results indicated that the cold-laid maintenance mixes are potentially susceptible to moisture damage (stripping). In general, their laboratory performance under the wet Hamburg test and the overlay test was very poor. Their excellent laboratory performance under dry Hamburg testing at ambient temperature suggest that these cold-laid mixes are good for application in dry areas, but they may not perform well under wet conditions or if water infiltrates into the mix. More research is recommended with these mixes. With the HMA mixes, promising laboratory results have been obtained with fine-graded (⅜-inch nominal maximum aggregate size) mixes; predominantly composed of Type F rock and screenings and an asphalt-binder content of over 7 percent. Based on the TxDOT CAM SS 3109 specification, high quality clean Class A aggregates, such as granite, exhibited superior laboratory performance and are recommended. However, acceptable laboratory designs were also obtained with good quality sandstone and limestone materials. As described in this report, the initial field performance of these mixes has been very good and this will be further validated in Year 2 of this study. Draft specifications and guidelines for very thin HMA overlays will be submitted at a later stage after conducting field performance monitoring and evaluations of selected demonstration/implementation projects.

17. Key Words
Thin Overlay, Rutting, Cracking, Skid Resistance, Hamburg, Overlay, Ground Penetration Radar, Rolling Dynamic Deflectometer, Infra-red

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LIST OF NOTATIONS AND SYMBOLS

AASHTO	American Association of State Highway and Transportation Officials
ADT	Average daily traffic
BPT	British pendulum tester
CAM	Crack attenuating mix
DFT	Dynamic friction tester
DOT	Department of Transportation
ESAL	Equivalent single axle load
FWD	Falling weight deflectometer
GPR	Ground penetrating radar
HMA	Hot-mix asphalt
HMCL	Hot-mix cold-laid
HWTT	Hamburg wheel tracking test
JCP	Jointed concrete pavement
LRA	Limestone rock asphalt
MTD	Material transfer device
OAC	Optimum asphalt-binder content
OT	Overlay tester
PG	Performance grade
RAP	Reclaimed asphalt pavement
RBL	Rich-bottom layer
RDD	Rolling dynamic deflectometer
SS	Special specification
SMA	Stone mastic asphalt
STOA	Short-term oven aging
TTI	Texas Transportation Institute
TxDOT	Texas Department of Transportation

CHAPTER 1
INTRODUCTION

Quite often, the Texas Department of Transportation (TxDOT) engineers need an alternative cost-effective "very thin overlay" system between micro surfacing and a typical 1.5 to 2 inch thick overlay for routine maintenance and/or rehabilitation of existing pavements. For this project, a very thin overlay is defined as a new hot-mix asphalt (HMA) surface layer of less than or equal to 1 inch in thickness, often placed on a pavement with minor surface distresses and no major structural defects. Among other requirements and expectations, it is desired that such an alternative "very thin overlay" system be of acceptable structural and functional integrity, cost-effective, easy and quick to place, less disruptive during construction, and easy to maintain. Accordingly, some of the challenges of developing an economically, structurally, and functionally sound overlay system are considered to revolve around balancing the following competing requirements:

- provision of adequate rut and crack resistance;
- provision of adequate durability and skid resistance characteristics;
- provision of appropriate optimal mix-design procedures and development of mixes that are economical, easy, and quick to place;
- provision of appropriate cost-effective and efficient construction specifications for both mix placement and compaction; and
- good construction practices – quality control and assurance (QC/QA).

In Texas, the most commonly used surface mixes are the Item 340 Type C and D mixes (TxDOT, 2004a). However, because of the size of the largest aggregate, these mixes are often unsuitable for placement in layers less than 1 inch thick. Although 1.5 inch is specified as the minimum thickness, TxDOT Type D mixes are commonly placed in a 2 inch layer thickness. Consequently, there is a need to develop a new economical very thin overlay system that is easy and quick to construct, durable, and performs satisfactorily - both structurally and functionally.

RESEARCH OBJECTIVES

The overall objective of this project is to provide TxDOT with balanced design methodologies for very thin overlays that provide acceptable resistance to rutting, cracking, and wet weather skid resistance. To ensure durability and adequate performance, researchers envisage that the mixes should exhibit good stone-on-stone contact and contain premium high content asphalt-binders, and additives such as fibers and anti-stripping agents (e.g., lime). The complete deliverable package will include methods to design and evaluate the mixes specifically designed as very thin overlays. Test methods and criteria to evaluate and verify acceptable performance will also be provided. To achieve these objectives, various research activities, including the following, are being undertaken:

(1) Conducting an extensive literature review of existing mixes, associated specifications (including mix-design, construction, and maintenance), and performance histories of thin overlays in the USA and other countries worldwide.
(2) Develop aggregate specifications that ensure good durability and skid resistance properties of the thin overlay mixes.
(3) Develop mix design procedures and specifications for thin overlay mixes that ensure adequate resistance to both rutting and cracking under different traffic and environmental conditions.
(4) Develop construction specifications (draft) for thin overlays, including QC/QA protocols.
(5) Conduct demonstration and implementation projects using thin overlays and among others to evaluate their cost-effectiveness and skid-resistance characteristics.

The research methodology basically revolve around evaluating fine-graded HMA mixes based on the balanced mix-design concept and the TxDOT crack attenuating mix (CAM) special specification (SS) 3109 (TxDOT, 2004b). The balanced mix-design concept is discussed in Chapter 3 of this interim report. The work plan incorporates extensive laboratory testing and field experimentations with demonstration and implementation projects.

Specifically, the field experiments are tailored to validate the laboratory mix designs and aid in the development of prototype construction specifications and structural evaluations and performance monitoring guidelines of very thin overlays. As stated previously, the final deliverable product and key step in this research project is development of draft design guidelines and construction specifications for TxDOT consideration. The researchers hope that these draft guidelines and specifications will enable the various TxDOT districts to develop their own acceptable standard mixes for very thin overlays.

SCOPE OF WORK

Thus far, the following major tasks have been accomplished and are documented in this interim report:

(1) Literature search: This task focused on gathering data on materials, mix-designs, constructions specifications, and performance histories of existing thin overlay systems worldwide. However, this task is an ongoing, and the literature will continue to be updated as new data and information are acquired. Important findings of this task are summarized in Chapter 2 and Appendix A of this interim report.

(2) Laboratory evaluation of cold-laid maintenance mixes: Hot-mix cold-laid (HMCL) and limestone rock asphalt (LRA) mixes were evaluated with the Hamburg and overlay tests to assess their potential as candidate mixes for thin overlays. One HMCL mix and three LRA mixes were evaluated and are discussed in Chapter 5 of this interim report. These mixes were molded according to the TxDOT method Tex-205-F (TxDOT, 2007).

(3) Design, evaluation, and laboratory testing of fine-graded HMA mixes: Various fine-graded HMA mixes were designed, evaluated, and tested with the Hamburg and Overlay test to determine the optimum asphalt-binder content and evaluate laboratory performance (rutting and cracking resistance). In total, nine HMA mixes were designed and/or evaluated, and are discussed in Chapter 6 of this interim report.

(4) Skid resistance measurements: The primary objective of this task was to investigate the possible skid resistance problems of the HMCL, LRA, and HMA mixes designed/evaluated in Tasks 2 and 3 above. On an experimental basis only, the top of the Hamburg molded samples were tested with the British Pendulum tester (BPT) before the

Hamburg testing, both under dry and wet conditions. Skid resistance results are contained in Chapters 5 and 6.

(5) District visits and field performance evaluation: Various TxDOT districts, including Atlanta and Lufkin that already have thin overlay surfacings, were visited for on-site survey interviews, data (including mix designs) and materials (including ready-made plant mixes) collection, and performance monitoring. Photographs of surface distresses were also taken, and performance was evaluated including radar measurements. Other site visits include the National Center for Asphalt Technology (NCAT) test track in Alabama for visual performance surveys, performance data collection, and materials collection including plant mix.

(6) Demonstration projects: Some demonstration projects were constructed in the summer of 2007, and these are currently under performance monitoring. Texas Transportation Institute (TTI) researchers monitored and documented the construction operations of some of these demonstration/implementation projects. These demonstration projects are discussed in Chapter 7 of this interim report.

DESCRIPTION OF CONTENTS

This interim report consists of eight chapters including this introductory chapter (Chapter 1), which provides the research objectives, research methodology, work plans, and the scope of work. Chapter 2 summarizes documentation of the literature review of thin overlays and includes materials, mix designs, construction specifications, and performance data. Chapter 3 presents the experimental design and includes a discussion of the balanced mix-design concept, the proposed thin overlay mix-design procedure, materials, and HMA specimen fabrication procedures. The typical TxDOT Excel mix-design spreadsheets are also discussed in this chapter, including some proposed modifications.

Laboratory and field tests are discussed in Chapter 4. This chapter includes the Hamburg (rutting), overlay (cracking), British Pendulum (skid resistance), dynamic friction tester (DFT) (skid resistance), Ground penetration radar (GPR) (structural and forensic evaluation), rolling dynamic deflectometer (RRD) (structural evaluations), and infra-red (mat temperature measurements). The thin overlay mixes including hot-mix cold-laid, limestone rock asphalt, and HMA together with the laboratory and field test results are discussed in Chapters 5 and 6, respectively. Demonstration projects, including construction specifications and structural evaluations and performance monitoring issues, are discussed in Chapter 7. The report concludes in Chapter 8, with a summary of findings and recommendations. Ongoing and future planned works are also discussed in Chapter 8, including the deliverable products. Other important data, such as the literature search and detailed test results, are included in the appendices.

SUMMARY

In this introductory chapter, the background and research objectives were discussed. The research methodology, work plans, and scope of work were then described followed by a description of the contents of this interim report. Note that in this interim report, the symbol " is used interchangeably to represent inches as a dimensional unit, i.e., 1" = 1 inch ≅ 25 mm. Additionally, as some of the laboratory tests such as the Hamburg use standard metric (SI) units, some of the test results have consequently been reported in metric units, e.g., use of “mm” for the Hamburg test results.

CHAPTER 2
LITERATURE REVIEW

Researchers completed a literature search of electronic databases and documented publications on thin overlays. The data included materials, mix designs, construction details/specification, and performance histories. Site visits and meetings, including survey questionnaires, were also conducted for first-hand information to enrich the literature search and expand the knowledge base. The findings from the literature search are summarized in this chapter and Appendix A.

THIN HMA OVERLAY APPLICATION

Based on the literature definition, thin overlays are non-structural preventive maintenance (PM) HMA mixes used for the routine maintenance and rehabilitation of existing pavements. They are typically placed in thin lifts of about 1 inch thick. Thin overlay application is primarily used to preserve pavements exhibiting surface distresses such as raveling, aging, bleeding, minor cracking, minor disintegration, texture loss, skid resistance loss, etc.

Most literature state that thin HMA overlays should be used wherever pavement preservation (including functional, durability, and performance improvement) is the primary objective of the surface treatment. Thin HMA overlays enhance pavement performance and extend the service life including functional characteristics such as improved user serviceability (i.e., smoothness, comfort, and quite ride), skid resistance, noise reduction, water spray reduction, and conspicuity of road markings and glare/reflections (Gilbert et al., 2004). Overlays also contribute to the improvement of the pavement strength, including impermeability properties, thus minimizing moisture damage and oxidative aging from water and air infiltration, respectively. Overlays also improve the aesthetic appearance of the pavement surface (Cooley Jr. et al., 2002).

In summary, thin HMA overlays are considered as a cost-effective application of preserving and maintaining existing pavements, applicable to both flexible asphalt and rigid concrete pavements. Thin HMA overlay applications on bridge decks has also been reported in the literature and is widely practiced in Europe. According to Rosenberg (2000) and Nicholls et al. (2002), approximately 5 percent of the Danish bridges are paved with thin HMA surfacings.

Candidate Pavements for Thin Overlay Applications

Candidate pavements for thin overlays should be structurally sound with no major structural defects such as rutting (i.e., rutting ≤ 0.25 inch) or fatigue cracking; otherwise, a thicker overlay or reconstruction is recommended (Technical Bulletin, 2002). Rutting and cracks greater than 0.25 inch should be sealed, and any surface deformities greater than 0.5 inch should be filled up (but not over filled) prior to overlay placement. Equally, potholes should be patched up. Figure 2-1 shows an example of cracking (greater than 0.25 inch) requiring sealing prior to a thin overlay placement (Uhlmeyer, 2003).

Figure 2-1. Example of Cracking Greater than 0.25 inch – Seal Prior to Overlay.

Structural Evaluations and Design Considerations

As thin overlays are typically considered as non-structural layers, no structural design considerations were found in the literature, apart from the layer thickness meeting the 1.5 to 3 times NMAS requirement. NMAS is the nominal maximum aggregate size defined as one sieve size larger than the first sieve to retain more than 10 percent of the aggregate material.

MIX DESIGNS

In general, most literature indicate that fine-graded HMA mixes with ⅜" or No. 4 NMAS are ideal mixes for thin overlays. While meeting the lift thickness (*t*) to NMAS ratio requirements (i.e., $1.5 \leq t/NMAS \leq 3$), these fine mixes can be placed in a lift thickness less than 1 inch with reasonable workability.

Aggregates

The use of fine-graded (less coarse) aggregates improves workability, ride quality, and impermeability characteristics including durability in thin HMA overlays. According to Cooley Jr. et al. (2003), small NMAS mixes are less permeable than large NMAS mixes, if evaluated at the same air void (AV) level. Use of high quality aggregates (such as crushed gravel, granite, sandstone, etc.) with superb physical properties and creation of a good stone-on-stone contact in the mix matrix ensures good skid resistance, surface rutting resistance, and durability characteristics.

Different aggregate physical properties are specified depending on the mix-type, the designing agency, pavement location, environment, and the expected traffic level. Some of the requirements found from the literature reviewed include but are not limited to the following (MDOT, 2005; Gilbert et al., 2004):

- a minimum crushed faces count of 50 percent,
- a minimum angular index of 2.5,
- a maximum Los Angeles (LA) abrasion loss value of 40,
- a flakiness index less than 18,
- a minimum stone polish value of 50,
- a minimum aggregate crushing value of 20, and
- a maximum water absorption value of 1.5 percent.

These requirements are not exhaustive and are variable depending, among other things, on the designing agency and location. Good micro-texture from rough and polish resistant aggregates also ensures good skid resistance characteristics.

According to the literature, the aggregate gradation can be dense, single sized, open, or gap graded but with seemingly NMAS no greater than ½". For the gap-graded mixes, the gap ensures adequate voids in the mineral aggregate (VMA) and stone-on-stone contact. The stone-on-stone contact matrix creates an efficient load transfer mechanism for improved rutting resistance. On average, the limits for the aggregate percent passing the No. 4 sieve are about 70 to 100 percent. For the aggregate percent passing the No. 200 sieve, an average maximum limit of 12 percent was found in the literature; this limit helps in addressing stability and durability issues (Cooley Jr. et al., 2002). For the other sieve sizes, the literature indicated a very wide variation, and the number of sieve sizes was inconsistent, depending among other factors on the mix type and design method. Table 2-1 is a comparative listing of some of the aggregate gradations found in the literature. Appendix A contains more details on some of these aggregate gradations.

Table 2-1. Comparative Listing of Aggregate Gradations Based on Literature Review.

Sieve Size	**Aggregate % Passing Limits**							
	Texas CAM	⅜" Superpave	⅜" SMA	Ohio Smoothseal Type A	Ohio Smoothseal Type B	Michigan	Georgia	Maryland
½"	100	100	100	100	100	100	100	100
⅜"	98-100	90-100	90-100	100	95-100	99-100	90-100	100
No. 4	70-90	32-90	26-100	95-100	85-95	75-95	75-95	80-100
No. 8	40-65	32-90	20-65	90-100	53-63	55-75	60-65	36-76
No. 16	20-45	-	13-36	80-100	37-47	-	-	-
No. 30	10-30	-	12-28	60-90	25-35	25-45	-	-
No. 50	10-20	-	12-22	30-65	9-19	-	20-50	-
No. 100	-	-	-	10-30	-	-	-	-
No. 200	2-10	2-10	8-15	3-10	3-8	3-8	4-12	2-12

Asphalt Binder and Other Additives

High polymer modified (e.g., latex rubber, styrene-butadiene-styrene [SBS], etc.) asphalt-binder contents are typically used to enhance workability, stability, performance, and durability characteristics. The commonly used asphalt-binder contents typically range from about 6 to 8.5 percent, with PG 76-22S as the asphalt-binder type of preference. Unmodified asphalt binders such as PG 64-22 or PG 70-22 are also reportedly used, but mostly for low to medium traffic highways. For South Africa and other European countries, use of 40/50 and 60/70 penetration grade binders was found in the literature (Pretorius et al., 2004; Nicholls et al., 2002a). Additives such as anti-aging and anti-stripping agents, including hydrated lime (about 0.3 to 1.5 percent), may be used to enhance durability. Other additives, such as silicon dioxide or natural sand, may also be added to improve the frictional characteristics and skid resistance properties.

Mix-Design Methods and Specifications

Worldwide, thin HMA overlays are typically developed as proprietary products designed for specialized applications with limited standardized methods. In fact, there are hardly any thin HMA overlay specifications that have been widely accepted for general applications or use as reference guidelines. Consequently, different or special mix-design methods, including the Superpave and Marshall, are used for designing these mixes. Different agencies seem to have different preferences or have developed their own mix designs. However, for most of the countries outside of the United States, the Marshall appears to be the most commonly used mix-design method. Few, if any, of these mix-design methods utilize a balanced mix-design approach, in particular for rutting and cracking resistance.

Table 2-2 provides a summary of the currently available thin overlay specifications and/or guidelines found in the literature, both inside and outside of the United States (Cooley Jr. et al., 2002; Cooley Jr. and Brown, 2003; MnDOT, 2005; Xie et al., 2005). See also Appendix A for more details on some of these mixes.

Table 2-2. Summary of Thin HMA Overlay Specifications/Guidelines

Agency	Overlay Type/Name	Mix-Design Method
(a) In the US		
(1) Arizona	Asphalt Rubber (AR)	1) Type AC-ACFC: Superpave (open-grade @ 15% AV) 2) Type AR-AC: Superpave (gap-graded @ 3% AV)
(2) Georgia	Superpave No. 4 NMAS-like HMA	Superpave – 50 gyrations @ N_{design}, 4% AV
(3) Ohio	Smoothseal	1) Type A – Recipe 2) Type B – Marshall
(4) Maryland	No. 4 NMAS-like HMA	Superpave – @ 4% AV
(5) Michigan	Ultra-thin HMA	Marshall - @ 4.5 to 5.0% AV and VMA≥15.5%
(6) NCAT (Alabama)	1) SMA (No. 4 or ⅜″ NMAS) 2) Superpave No. 4 NMAS-like HMA	1) Superpave 2) Superpave - @ 4% AV and VMA≥16%
(b) Outside of the US		
(1) Australia	Ultra-Thin Open-Graded Asphalt (UTOGA) SMA	Marshall ≅ 15% AV
(2) Europe (France, Germany, plus others)	SMA	
(3) New Zealand	SMA	
(4) South Africa	Ultra Thin Friction Course (UTFC)	Marshall – open to gap graded HMA
(5) UK	SMA	
(c) Proprietary		
(1) NovaChip	Typically ⅜″ NMAS HMA	Gap-graded, ≥ 5% binder content
(2) Micro-surfacing	-	Often cold-laid

Laboratory Test Methods

As most of the mix-design methods for thin HMA overlays are proprietary, no standardized laboratory test methods or criteria for characterizing performance properties, such as rutting and cracking resistance, were found in the literature reviewed. Various agencies rely on typical tests used for conventional HMA mixes or have adopted their own test methods.

NCAT, for instance, uses the Asphalt Pavement Analyzer (APA) for rutting and stability characterization, standard permeameter for permeability tests, and the American Association of State Highway and Transportation Officials (AASHTO) T 305-97 for drain-down tests (for SMAs) (Cooley Jr. and Brown, 2003; Xie et al., 2005). The South African tests include the model mobile load simulator (MMLS) rutting test and the pendulum friction test for skid resistance (Pretorius et al., 2004).

The Australians incorporate the Cantabro tests for durability and binder film thickness (at least 10 microns [µm]). In the UK, tests such as indirect tensile stiffness modulus and dynamic creep are also often used. However, concerns have being raised regarding the considerable difference between the standardized specimen dimensions and the thin overlay thickness (Nicholls et al., 2002). Caution should be exercised when analyzing and interpreting the results.

Summarized, most of the literature reviewed indicates that the following mix-design attributes improve thin HMA overlay performance and durability:

- use of high modified (polymer) asphalt-binder content (i.e., about 6 to 8.5 percent) to improve cracking resistance and durability characteristics. Polymer modified binders such as PG 76-22S, are also less temperature susceptible.
- use of high quality fine (such as granite or crushed gravel), preferably gap-graded aggregates with a good interlock and stone-on-stone contact matrix for improved rutting resistance and durability properties.
- hard, durable, non-polishing, and well macro-textured low absorptive aggregates for improved skid resistance and surface texture.
- high VMA and low AV (i.e., high compaction target density of around 98 percent) in the mix-design matrix. Low AV minimizes water and air ingress, consequently minimizing the potential for moisture damage and binder oxidative aging. On top of promoting stone-on-stone contact, high VMA also decreases mix permeability.
- increased asphalt-binder film thickness for improved durability and cracking resistance properties. Most literature recommends at least 10 to 12 µm.
- use of additives such as lime (about 0.3 to 1.5 percent) and silicon dioxide to improve moisture damage and skid resistance, respectively.

POTENTIAL THIN OVERLAY HMA MIX TYPES

Based on the literature review, HMA mixes that are commonly used and/or can be used for thin overlay applications are basically the No. 4 and/or ⅜″ NMAS HMA mixes. As listed in Table 2-1, some of these HMA mixes include Superpave, SMA, Smoothseal, ultra-thin HMA, ultra thin friction course, NovaChip^{RM}, micro-surfacing (cold-asphalt, Ralumac, micro-asphalt, Reditex, Permitex, etc), asphalt rubber, etc. Details of these mixes can be found elsewhere (Cooley Jr. et al., 2002; Cooley Jr. and Brown, 2003; MnDOT, 2005; Xie et al., 2005). These mixes are placeable in lift thickness of about 0.625 to 1.5 inch with reported service lives of 8 to 15 years.

Other thin HMA overlay mixes used in Australia and the UK are the dense graded ½" NMAS mixes often designed with polymer modified asphalt binder and placed to a thickness of about 0.8 to 1.6 inch. Their reported service life is about 10 to 15 years. Others include thin asphalt concrete (TAC) with generic names such as masterflex, thin pave, etc, typically for about 0.6 to 1.2 inch thick placement with service lives of up to 15 years (Nicholls et al., 2002; Yeo, 1997). However, these mixes are predominantly used for texture and skid resistance improvements. Denmark also extensively utilizes thin HMA overlays for surfacing and waterproofing steel and concrete bridges, with service lives of 10 to 15 years (Rosenberg, 2000; Nicholls et al., 2002).

TxDOT Surfacing Mixes

In Texas, the most commonly used surface HMA mixes are the Item 340 Type C and D mixes (TxDOT, 2004a). These are basically dense-graded mixes with about ½" NMAS. However, because of the size of the largest aggregate size, these HMA mixes are often unsuitable for placement in thin layers less than 1 inch thick. In fact, the minimum recommended placement thickness is 1.5 inch (TxDOT, 2004a). Consequently, various districts are exploring alternative prototype HMA mixes for their PM treatments as thin overlays.

However, TxDOT does have a fine Type F SMA mix in their specification. This mix could be a candidate for thin overlays (TxDOT, 2004a). Australia, UK, and Europe have successfully placed about ½" NMAS SMA mixes, about 0.5 to 1.5 inch thick overlays, with reasonable field performance results for at least 15 years (Nicholls et al., 2002).

The German experience, where SMA was first developed, indicates a service life of up to 18 years for thin SMA overlays (Belin, 1998). New Zealand has also successfully utilized thin SMA surfacings (about 0.5 to 1.2 inch thick) with expected service lives of at least 15 years, typically for providing texture and skid resistance under high stress environments (Watters, 2006).

Currently, neither TxDOT nor the districts have standardized design, construction, or performance evaluation guidelines specifically for the very thin HMA overlay mixes.

CONSTRUCTION

This section discusses the construction aspect as reviewed from the literature. The discussion includes mix production, pavement surface preparation, placement and compaction, and QC/QA procedures. Traffic is also discussed.

Mix Production

In general, due to the potential of thin HMA overlay mixes cooling more rapidly than conventional mixes, the production and mix temperature should be high enough to facilitate field compaction but without causing binder drain-off during transit and/or placement. Typically, high temperatures are required for mixes with modified asphalt-binders, i.e., about 350 °F (maximum) production and about 290 °F (minimum) placement. According to the literature, uniform mix production, uniform mix temperature, uniform mix delivery to site, uniform head of material in front of screed, and uniform compaction are some of the key aspects to ensure the success and adequate placement of thin HMA overlays. Because of stickiness, handling and raking should be minimized where modified asphalt binders are used.

Pavement Surface Preparation

In general, all other surface preparatory and placement procedures should follow typical practices. The pavement surface must be clean, cracks greater than 0.25 inch be patched up or sealed, and all surface deformities filled up where necessary. The pavement surface temperature should be at least 50 °F and rising.

The air temperature should at least be 42 °F and rising at the time of placement (Rodney, 2007). Where applicable, tack coat or other appropriate bonding material should be applied on the pavement surface prior to overlay HMA mix placement.

Placement and Compaction

Rolling compaction should follow immediately behind the paver in a continuous operation with minimal stoppages. For satisfactory results, the literature recommends at least 2 and 1 for the first (breakdown) compaction and finishing rolling, respectively, with steel drum static rollers (about 10 to 15 ton). Use of vibratory rollers should be minimized unless where it is necessary. For thinner mats, such as thin HMA overlays, vibrations may often fracture the constituent aggregate particles or cause the HMA to shove (and become less dense) due to the drums bouncing as the pavement increases in density. Thus, extreme caution and control of the compaction variables (vibration amplitude, frequency, etc.) must be exercised when in vibratory mode for thin HMA overlays. On the other hand, use of pneumatic rollers may often result in HMA pickup (mix sticking to the tires), especially where modified asphalt binders are used. The target placement thickness should generally range between 1.5 times the NMAS and 3 times the NMAS, i.e., $1.5 \leq t/NMAS \leq 3$.

Quality Control and Quality Assurance

However, although at least one QC/QA test per day for gradation, asphalt-binder content, and AV is suggested, no specific criteria or elaborate guidelines (QC/QA) were found in the literature reviewed. The literature, however, suggests that the Australians and some European countries exercise very good construction and QC/QA practices for their thin HMA surfacings. In general, QC/QA procedures and test protocols for thin HMA overlays should be tight to ensure satisfactory performance. However, because of the thin layer thicknesses, density measurements for these mixes are often considered unnecessary. It is worth noting that conventional portable field density-measuring devices such as the nuclear density gauge or the pavement quality indicator (PQI) have been reported to give pessimistic results on thin HMA overlays due to the influence of the underlying layers of the existing pavement structure. In Europe, greater emphasis is instead placed on texture and skid resistance evaluations (Nicholls et al., 2002).

Opening to Traffic

Thin HMA overlays are generally open for all season placement, even at night provided weather conditions permit satisfactory compaction. While most overlays can be readily opened to traffic, the literature recommends doing so, for some overlay mixes, when they have cooled to below 150 °F after placement. This cooling is necessary to avoid deformation or glazing under traffic.

DISTRESSES AND PERFORMANCE EVALUATIONS

Commonly observed thin overlay distresses, including performance evaluation methods, are discussed in this section.

Common Overlay Distresses

Provided it is well designed, well constructed, and placed on a structurally sufficient pavement structure, the expected service life of thin HMA overlays range from about 8 to 15 years. Thus far, reported distresses include bleeding, reflective cracking, fatting, texture loss, and decrease in skid resistance. The Australian literature suggests that surface cracking (including reflective) and roughness are the most predominant and severe distress modes. In the UK, most of the observed performance inadequacies are considered to be significantly related to the existing pavement condition and construction practices (workmanship and QA/QC) (Nicholls et al., 2002).

Performance Evaluation Methods

Various performance evaluation methods/criteria found in the literature include visual surveys, pavement surface profile indexes, surface rutting, sand patch texture depth measurement, pavement friction tester, hydraulic conductivity (spray), surface crack detection (Australia), etc. These methods appear to vary from mix type to mix type and agency to agency, even for the same mix type. Pavement surface roughness and skid resistance were by far found to be the most commonly evaluated field distresses for performance evaluation. In fact, overlay performance in most of the European countries is measured with respect to texture and/or skid resistance loss. Although comparatively costly, most of the literature indicates that SMAs have historically exhibited superior performance.

SERVICE LIFE AND ECONOMICS

As far as economics are concerned, utilizing a thinner lift thickness generally allows for more project length to be covered with the same tonnage of mix, thus being very cost-effective. Their construction time is shorter, and they are readily open to traffic, thus reducing user delay costs. Thin HMA overlays also provide a very economical use for leftover manufactured screening stockpiles. On a cost comparison basis, thin HMA overlays are on average about 11 to 40 percent cheaper than other conventional surface treatments (Gilbert et al., 2004).

REPORTED CONCERNS OF THIN HMA OVERLAYS

On top of the proprietary nature of the existing design methods, the other major disadvantage associated with most of the thin HMA overlay mixes discussed is the requirement of specially trained, reliable, and quality contractors. Also, specialized construction equipment may be required. Additionally, thin overlays in most cases, offer very marginal structural benefits and are applicable to only structurally sound existing pavements with minor surface distresses.

SUMMARY

Although different HMA mix types/names and design characteristics are used, the majority of the thin overlay HMA mixes essentially revolve around the ⅜″ or No. 4 NMAS HMA mixes. Different or special (agency-specific) mix-design methods that are volumetric-based including the Superpave and Marshall, are used for designing these mixes. However, hardly any of these mix-design methods incorporate a balanced mix-design approach, in particular for rutting and cracking resistance.

In general, most of the literature reviewed indicates that the following mix-design attributes improve thin HMA overlay performance irrespective of the design method used, high quality gap-graded fine aggregates, use of modified binders (e.g., PG 76-22S) with relatively high asphalt-binder contents (6.0 to 8.5 percent) and increased binder film thickness (≥ 10 µm).

With respect to construction and placement, rolling compaction should follow immediately after the paver in a continuous operation with minimal stoppages, with at least two rolling passes of steel drum static rollers. Uniformity and consistency with respect to both the mix and temperature are imperative. The overlay thickness should at least be 1.5 times the

NMAS but not more than 3 times the NMAS. The reported typical service life of thin HMA overlays is about 8 to 15 years.

However, because thin HMA overlay surfacing is a relatively new PM application, the literature reviewed indicated that there are limited standardized design, structural evaluation, construction, QA/QC, performance evaluation, and maintenance guidelines/specifications for thin HMA overlays, particularly in the US. Those that are available are agency or state-specific and not very elaborate. Most agencies use their own proprietary or modified prototype specifications. Additionally, no standardized laboratory tests are mentioned in the literature for characterizing the rutting and cracking resistance of thin overlay HMA mixes. In fact, the literature reviewed so far indicates that hardly any of these thin HMA overlays are specifically designed to offer structural functions such as rutting and/or cracking resistance.

Other countries like Australia, Europe (e.g., France, Denmark, Germany, and the UK), South Africa, and New Zealand, where thin surfacings are extensively used, have over the years developed or adopted their own specifications. However, these specifications are applicable only to their conditions, and their thin HMA overlay applications are predominantly used for texture and skid resistance restoration and bridge deck surfacings. Nonetheless, these specifications will serve as a reference source for developing the Texas thin HMA overlay specifications.

CHAPTER 3
EXPERIMENTAL DESIGN

This chapter discusses the experimental design program and includes the balanced mix-design concept and the proposed thin overlay HMA mix-design procedure. Suggested modifications to the typical TxDOT Excel mix-design spreadsheets are also presented. The HMA specimen fabrication process is discussed. A summary is then provided to conclude the chapter.

THE BALANCED HMA MIX-DESIGN CONCEPT

In TxDOT Project 0-5123, "Development of an Advanced Overlay Design System Incorporating Both Rutting and Reflection Cracking Requirements," Zhou et al. (2007) investigated the concept of a balanced mix-design for ensuring adequate rutting and cracking resistance for HMA mixes. Together with the TxDOT CAM SS 3109 specification (TxDOT, 2004b), this is the procedure adopted in this project for thin overlay HMA mixes. As this project incorporates both laboratory and field (i.e., field demonstration projects) studies, it will also provide a framework for further laboratory and field validation of the proposed balanced HMA mix design concept. Note also that this project provides an opportunity to experiment and validate the balanced mix-design concept on fine-graded HMA mixes, which were out side the scope of the study conducted by Zhou et al. (2007).

The current TxDOT HMA mix-design process uses the volumetric design method (volumetric requirements) to select the optimum asphalt-binder content (OAC) and the Hamburg Wheel Tracking Test (HWTT) to ensure rutting and moisture resistance of the proposed HMA mix. The Hamburg test for rutting resistance characterization is part of the mix-design process and OAC selection criterion, whereas the overlay test is not. Instead, the mixes are only checked for cracking resistance with the overlay tester after the mix-design process is complete. Thus far, only SMA mixes have been able to satisfactorily pass the Hamburg test with subsequent verification in the overlay test. Although it has a history of superior performance, SMA is generally not very competitively priced, in particular the upfront construction costs. SMA costs at least 25 percent more than most conventional HMA mixes.

In general, the Superpave process determines OAC based on volumetric requirements only. Other empirical HMA mix design methods, such as the Hubbard-Field, Marshall, and Hveem, utilize volumetric properties and stability (rutting resistance) to determine OAC (Zhou et al., 2007). Clearly, most of these methods do not sufficiently address other performance-related distresses such as cracking, which is most prevalent in today's HMA pavements, particularly in the United States. Additionally, few, if any, incorporate a balanced mix-design approach for simultaneously checking the mix rutting and cracking resistance. By contrast, the proposed balanced HMA mix-design method in TxDOT Project 0-5123 is based on meeting both rutting and cracking requirements. In this approach, the HWTT is utilized to evaluate the rutting potential and moisture damage susceptibility (stripping potential) while the Overlay Tester (OT) is used to evaluate cracking (reflection) resistance of the mix. Figure 3-1 illustrates this concept schematically.

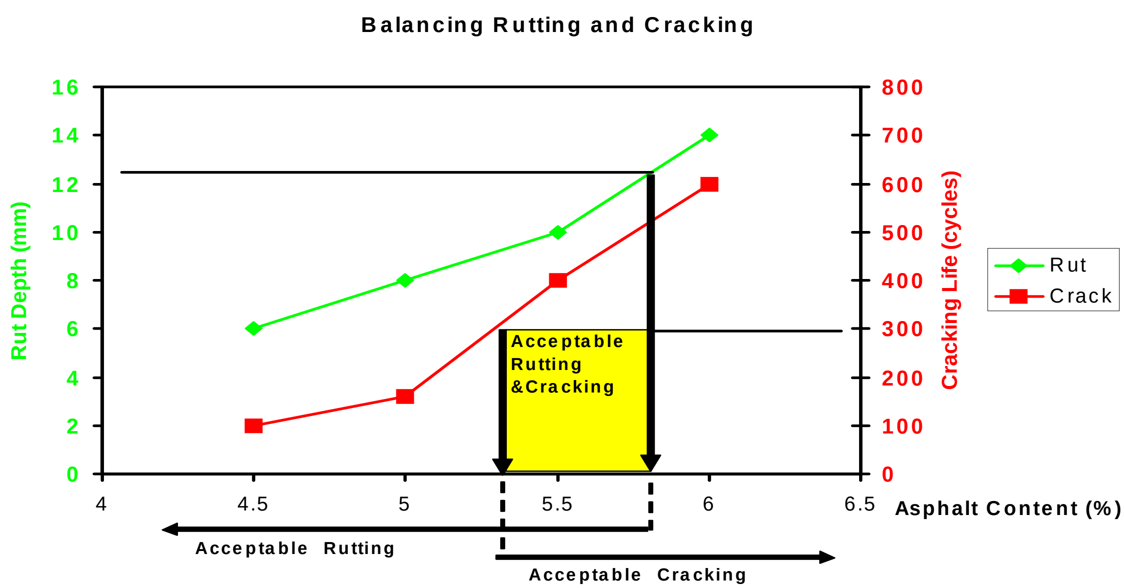

Figure 3-1 The Balanced Mix Design Concept (Zhou et al., 2007).

In Figure 3-1, the green line represents the HWTT rut depth for different asphalt binder contents. Rut depths below 12.5 mm (0.5 inch) are considered acceptable, i.e., $Rut_{HWTT} \leq 12.5$ mm. The red line shows the performance in the OT (cracking resistance), in this case, for dense-graded HMA mixes that last over 300 load cycles to failure at 93 percent stress reduction and are judged as acceptable, i.e., $N_{OT} \geq 300$. Chapter 4 discusses both the HWTT and OT tests.

Figure 3-1 clearly shows the concept of a balanced HMA mix design for rutting and cracking resistance. As the asphalt-binder content increases, the rutting resistance decreases, but the cracking resistance improves. Conversely, the opposite result would be expected if the asphalt-binder content is decreased. A balanced design includes an asphalt-binder content in which the HMA mix passes both the rutting ($Rut_{HWTT} \leq 12.5$ mm) and cracking ($N_{OT} \geq 300$) requirements. As found in TxDOT Project 0-5123, which is based on extensive laboratory evaluation of various dense-graded, Superpave, and SMA mixes, a balanced design is possible for most HMA mixes as long as quality aggregates are used (Zhou et al., 2007).

Window of Acceptable OAC and Binder PG Grade

Zhou et al. (2007) observed that the window of acceptable asphalt-binder contents was found to be relatively narrow for the lower PG binder grades, such as PG 64-22 binders. Adding additional asphalt binder often causes the mixes to rut excessively. The window for higher PG binder grades, such as PG 76-22, was found to be substantially wider as these binders are relatively less temperature sensitive and not highly rut susceptible. On this basis, researchers in this project opted to predominantly experiment with the PG 76-22 binder.

Rutting and Cracking Failure Criteria

For the purpose of this project and in consistency with the TxDOT CAM SS 3109 specification (TxDOT, 2004b), the traditional adopted OT failure criterion of 300 load cycles (i.e., $N_{OT} \geq 300$) for the surface dense-graded HMA mixes was conservatively revised to 750 load cycles for the thin overlay HMA mixes (i.e., $N_{OT} \geq 750$) . This stringent requirement was viewed as necessary to ensure sufficient cracking resistance, as one of the primary purposes of the thin overlays would be to seal underlying cracks and/or minimize crack propagation. Therefore, it is only appropriate that these thin overlay HMA mixes have sufficient cracking resistance. Being the surface layer also means that these mixes would be subjected to the harshest environmental conditions such as oxidative aging, which has a tendency to reduce the HMA cracking resistance.

Inevitably, and as will be seen later in this interim report, this stringent requirement (i.e., $N_{OT} \geq 750$) calls for a high asphalt-binder content that is essential for the mix's improved cracking resistance and durability characteristics. In summary, these researchers proposed the following HWTT and OT failure criteria for thin overlay HMA mixes:

- Hamburg: Rut $Depth_{HWTT} \leq 12.5$ mm (0.5 inch) under wet conditions at 122 °F.
- Overlay: Number of load cycles to failure ≥ 750 (i.e., $N_{OT} \geq 750$) at 93 percent stress reduction at 77 °F; this failure criterion is also consistent with the TxDOT CAM SS 3109 specification (TxDOT, 2004b).

THE PROPOSED THIN OVERLAY HMA MIX-DESIGN PROCEDURE

Within the framework of the balanced HMA mix-design concept and the TxDOT CAM SS 3109 specification (TxDOT, 2004b), the mix-design process and OAC selection criterion for thin overlay HMA mixes were formulated as follows;

Step 1: Aggregate Sourcing and Material-Property Characteristics

- Review locally available aggregate sources. Typically, only fine-graded Type F rock (98 – 100 percent passing the ⅜" sieve) and screenings materials will be used.
- Recommend Class A aggregate (e.g., granite or crushed gravel for Texas materials)
- or Class B aggregates with low soundness value (TxDOT, 2007).
- High quality clean (preferably no dust) fine-graded aggregates with good skid resistance are desired.
- Perform wet sieve analysis prior to any aggregate batching.

Step 2: Mold HMA Specimens at 50 Gyrations and 98 Percent Target Density to Determine the OAC

- Use at least four trial asphalt-binder contents (6.5, 7.0, 7.5, 8.0, 8.5 percent are preferred).
- For each proposed trial asphalt-binder content, determine the Rice density.

- For each trial asphalt-binder content, gyratory mold at least two HMA specimens of 6 inch diameter by 5 inch in height.
- Measure the HMA specimen density; target = 98 percent, to determine the OAC.
- Cut the molded samples to test in HWTT and OT tests for rutting and cracking resistance characterization.
- Select the OAC as the asphalt-binder content simultaneously meeting both the Hamburg rutting and overlay cracking criteria, i.e., Rut $Depth_{HWTT} \leq 12.5$ mm at 122 °F and $N_{OT} \geq 750$ cycles at room temperature for 93 percent stress reduction. A window of acceptable OAC will usually be determined.
- Preferably draw a graph, as shown in Figure 3-1, to indicate the window of acceptable OAC.

Step 3: OAC Verification (as per TxDOT-Recommended Mix Verification Procedures)

- Gyratory mold at least two separate HMA specimens at the balanced OAC and 93±0.5 percent density (as per TxDOT-recommended mix verification procedures).
- Run the HWTT and OT tests to verify the balanced OAC.
- Select the balanced OAC as the design OAC, or otherwise select a different OAC within the window of the acceptable balanced OAC determined from Step 2 till the balanced OAC is verified at 93±0.5 percent density (or 7±0.5 percent AV).

For the HWTT and OT tests, the specimens are typically cut from the same gyratory molded sample, to ensure some level of reasonably acceptable consistency in the mix homogeneity and air void uniformity for the test specimens. Figure 3-2 shows how the samples were gyratory molded and cut to produce HWTT and OT test specimens, respectively.

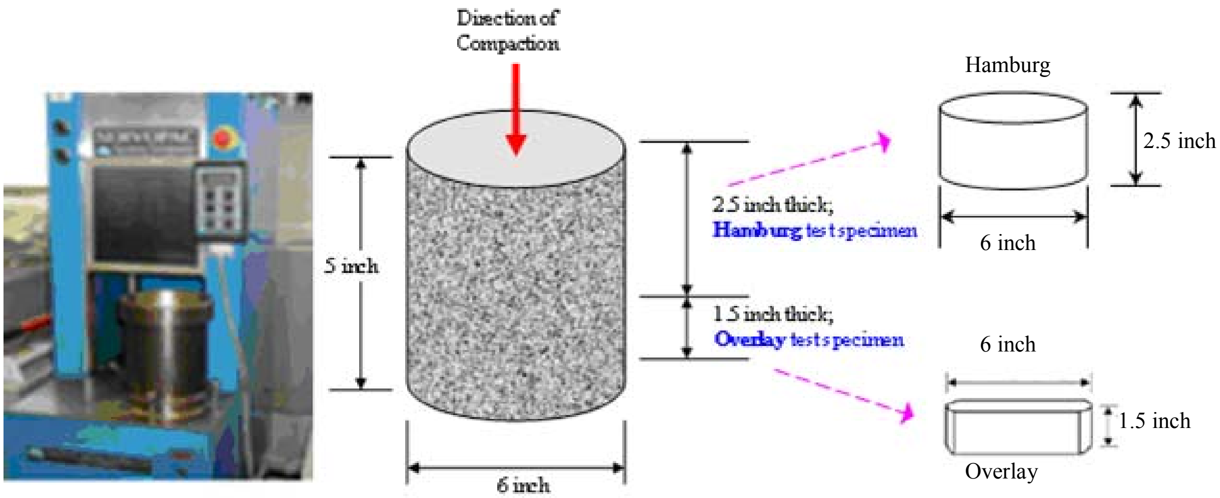

Figure 3-2. Gyratory Molding and Sawing of the HWTT and OT Specimens.

One of the critical aspects during specimen sawing is to have parallel and smooth end surfaces for the OT test specimens. In particular, smooth end surfaces are necessary to allow for proper visual monitoring of the crack development during OT testing.

Note that during OAC verification, the samples are molded to 93 percent density and subjected to performance testing with both the Hamburg (Tex-Method 242F; TxDOT, 2007) and overlay tester (≥750 cycles as measured by Tex-Method 248-F; TxDOT, 2007). The use of 93 percent density is somewhat controversial and is under evaluation in this project. This compaction is supposed to indicate the compaction level routinely achieved in the field; 93 percent is adequate and appropriate for traditional HMA mixes. However, monitoring of construction projects has reported that the CAM type mixes are traditionally placed at around 96 percent density. The molding of laboratory performance test samples at 93 versus 96 percent density, in particular with respect to passing the HWTT-OT criteria, during OAC verification is thus being reviewed in this project and is discussed in the subsequent chapters of this interim report.

PROPOSED MODIFICATIONS TO THE TYPICAL TxDOT EXCEL MIX-DESIGN SPREADSHEET

In the view of the proposed thin overlay HMA mix-design procedure, the modifications discussed in this section were made to the typical TxDOT Excel mix-design spreadsheets.

[Appendix B](#) provides a full comparative overview of a typical TxDOT Excel mix-design spreadsheet and the modified Excel mix-design sheet for overlay HMA mixes.

Mix-Volumetrics "Summary" Sheet

(1) A table for the Hamburg and overlay test results corresponding to all the trial asphalt-binder contents has been added, as shown in Figure 3-3. All other mix-design tests such as stability, static creep, and indirect tension tests, are considered unnecessary for thin HMA overlays in lieu of the Hamburg and overlay tests for rutting- and cracking-resistance, respectively, and were therefore removed.

	Static Creep		
Hveem Stability (%)	Creep Stiffness (psi)	Perm. Strain X1000 (in/in)	Slope of SS Curve X 10^9 (in/in/Sec)

Overlay Test	Hamburg Test	
Overlay Tester Cycles (Min. 750)	Number Cycles	Rut Depth (mm) (max. 12.5 mm)

Figure 3-3. Table of OT and HWTT Test Results for OAC Determination.

(2) A table of both the Hamburg and overlay test results for verifying the selected OAC at 93 percent density has been added. The table is for verification of the selected OAC consistent with the TxDOT mix-design verification procedures (TxDOT, 2007), and is shown in Figure 3-4.

OAC Verification @ 93% Density

		Hamburg Test	
OAC	Overlay Tester Cycles (Min. 750)	Number Cycles	Rut Depth (mm) (Max. 12.5 mm)

Figure 3-4. Table of OT-HWTT Test Results for OAC Verification at 93 Percent Density.

(3) Selection of the OAC is based on the window of acceptable OAC determined from simultaneous Hamburg rutting and overlay crack resistance testing, which is subsequently verified at 93% density as illustrated in Figure 3-4.

Mix-Volumetric "Charts" Sheet

Since OAC selection is based on rutting and cracking resistance under the Hamburg and overlay tests, respectively, researchers modified the mix-volumetrics "charts" sheet to reflect these properties. Property charts such as creep and Hveem stability, have been deleted, since they will not be part of the proposed thin overlay HMA mix-design process. See Figure 3-5 for the proposed charts. The typical TxDOT mix-volumetrics "charts" are shown in Figure 3-6.

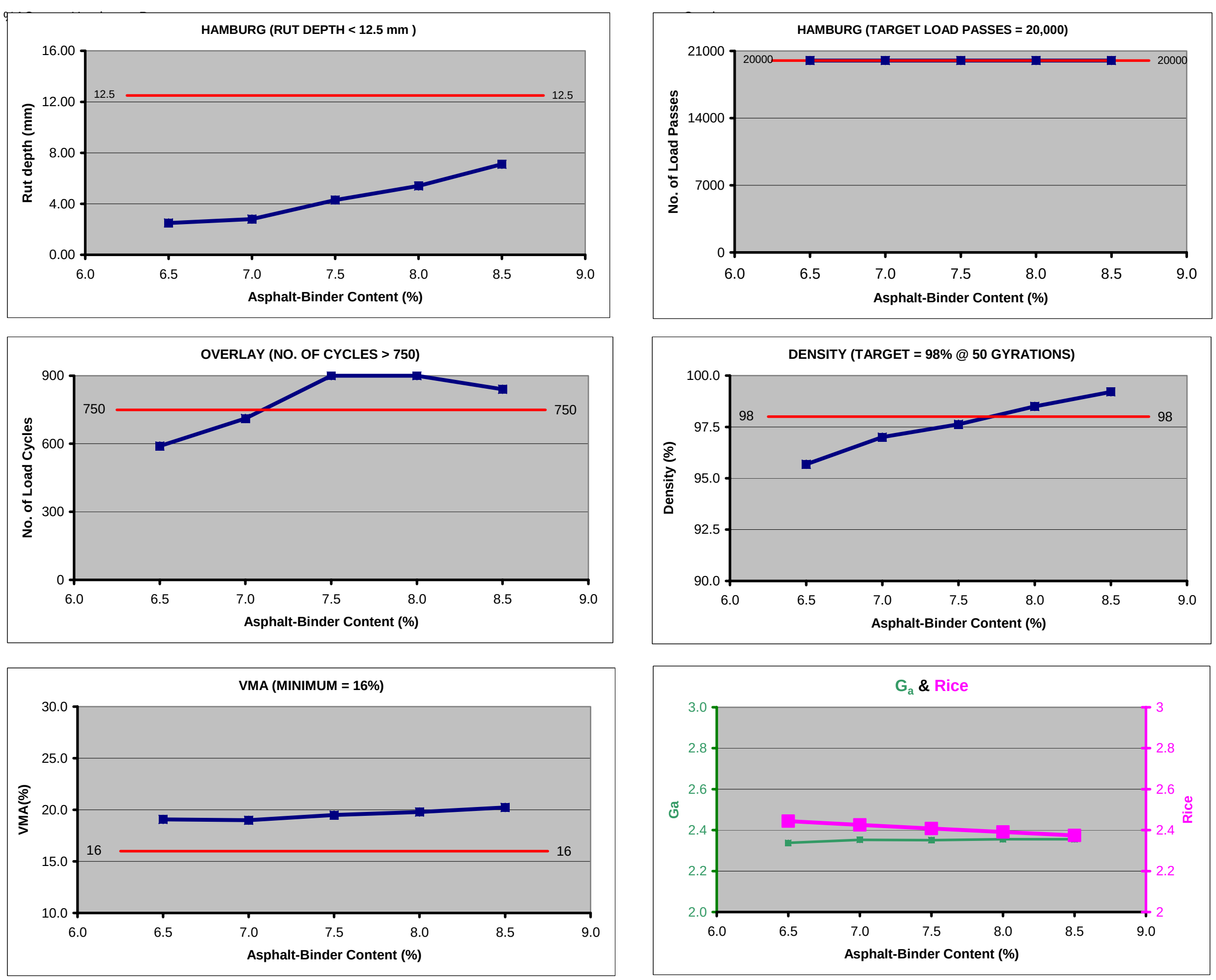

Figure 3-5. Example of the Proposed Mix-Volumetric Charts for Thin Overlay HMA Mix-Design.

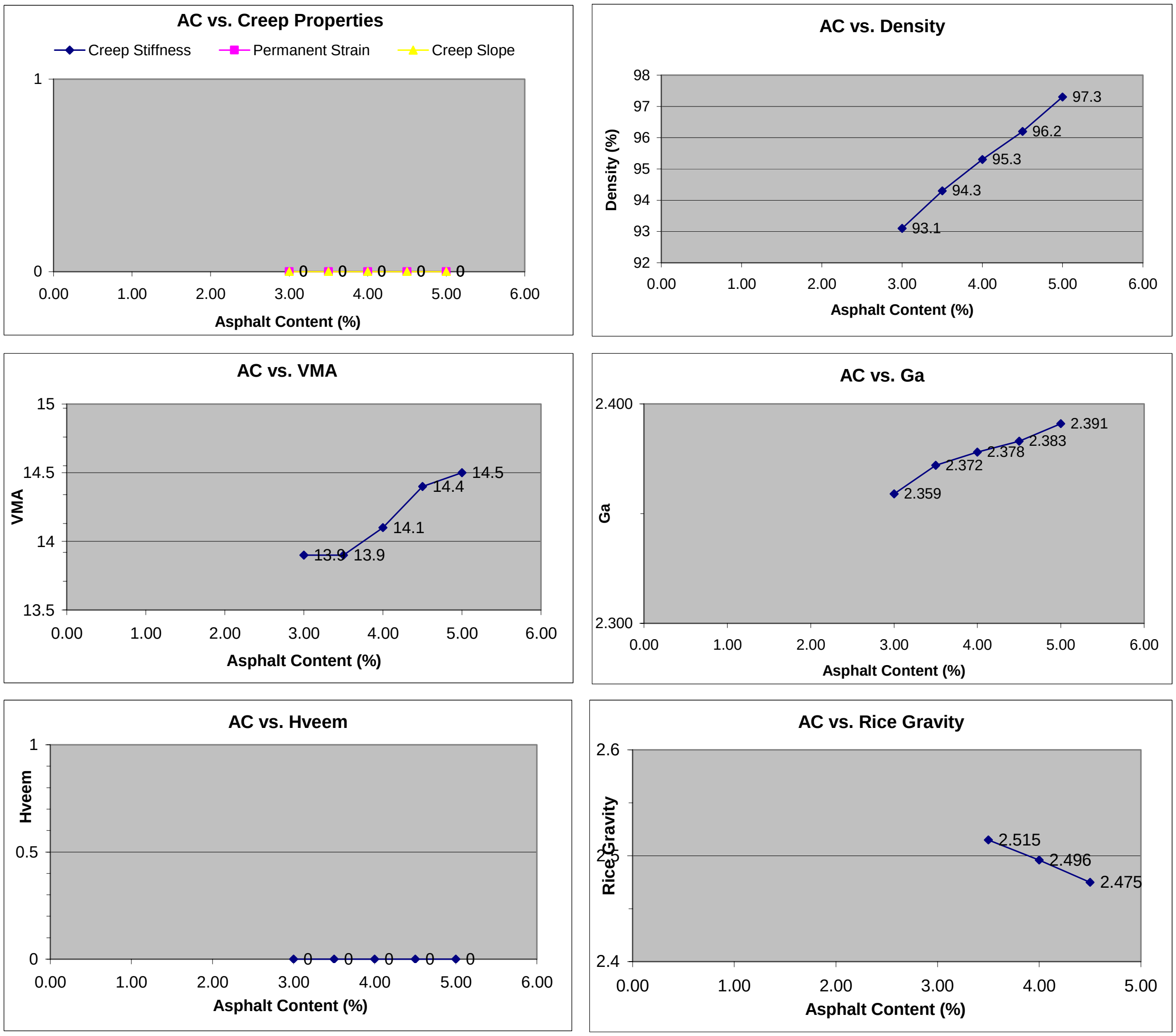

Figure 3-6. Example of the Mix-Volumetric Charts in a Typical TxDOT Excel Mix-Design Sheet.

MATERIALS AND THIN OVERLAY HMA MIXES

The proposed procedure developed in this project is in line with the TxDOT CAM SS 3109 specification "Crack Attenuating Mix" developed by Darlene Goehl in the Bryan District (TxDOT, 2004b). This specification has been used on several jobs, and it is currently under review for potential statewide application.

To ensure durability and satisfactory performance, stiff high PG asphalt-binder grades (mostly PG 76-22S modified with about 5 percent SBS) were utilized. As pointed out previously, stiff high PG asphalt binders are relatively less temperature sensitive and, therefore, not very rut susceptible. Recent studies have also shown that mixes designed with polymer-modified asphalt binders are relatively less susceptible to oxidative aging and therefore not as prone to age-related decline in cracking resistance over time (Walubita and Epps Martin, 2007; Wisneski et al., 1996). High asphalt-binder content around 7 percent was utilized for improved cracking resistance and durability properties.

Mix-Design Characteristics

All the HMA mixes were ⅜" NMAS with high quality fine-graded aggregates based predominantly on the TxDOT CAM SS 3109 specification (TxDOT, 2004a, b). The CAM SS 3109 specification includes using good quality clean aggregates with measured LA Abrasion and magnesium soundness values of less than 30 and 20 percent, respectively. The mixes used were essentially Type F HMA mixes, consisting of Type F rock and screenings. On average, the limits for the aggregate percent passing the No. 4 sieve were about 70 percent to 90 percent; larger NMAS mixes are unsuitable and often difficult for placement in layer lifts less than 1 inch thick. For the aggregate percent passing the No. 200 sieve, the maximum specification limit was 10 percent (basically ranging from 2 to 10 percent), which helps in addressing stability and durability issues (Cooley Jr. et al., 2002). Lime, on the order of about 1.0 to 1.5 percent, was also added in some instances to improve the moisture damage resistance properties of the mixes. To ensure good stone-on-stone contact, improved rutting resistance, and better impermeability characteristics, a high VMA (at least 16 percent) is desired (TxDOT, 2004b).

Rutting Resistance and Fine-Graded Thin Overlay HMA Mixes

Note that even with the fine-graded mixes such as with ⅜" NMAS aggregates (which are easily place-able in thinner layer lifts) it is possible to attain sufficient rutting resistance in the field. As pointed out by Newcomb et al. (2006), some of the HMA mix property characteristics to ensure sufficient rutting resistance are the internal friction provided by the aggregate interlock and the cohesiveness or stiffness of the asphalt-binder. Therefore, it is not so important that a mix contains larger or coarse aggregates as it is to having a good aggregate interlock and stone-on-stone contact. Kandhal et al. (2002) have in fact shown that fine-graded mixes, with good aggregate interlock and stone-on-stone contact, may provide as much resistance to rutting as coarse-graded mixes.

On the same basis, it is also arguable that sufficient field rutting resistance can be attained with a 1 inch thick HMA layer provided there is good aggregate interlock and stone-on-stone contact within the HMA mix matrix. The use of stiff PG graded asphalt-binders that are relatively less temperature sensitive also adds on to the rutting resistance characteristics of the mix. In any event, the exposure to the harshest environmental conditions and high temperatures (which also fluctuate considerably) often dictate for the use of stiffer polymer modified asphalt-binders for surfacing mixes such as overlays.

Durability Considerations

To ensure sufficient asphalt-binder film thickness (T_F) that is essential for adequate cracking resistance and durability, 10 microns (µm) was arbitrarily used as the reference benchmark (i.e., $T_F \geq 10$ µm) based on recommendations from the literature (Pretorius et al., 2004; see Chapter 2). In this project, T_F was calculated as expressed in Equation 3-1 below:

$$T_F = 1000\left(\frac{V_{asp}}{SA \times W}\right) \qquad \text{(Equation 3-1)}$$

where:

T_F = average binder film thickness in microns,

V_{asp} = effective binder volume in liters,

SA = aggregate surface area in m^2/kg, and

W = aggregate weight in kg.

According to Roberts et al. (1996), asphalt-binder film thickness is generally correlated with performance/durability and that thin asphalt-binder films are often more susceptible to oxidation (than thicker asphalt-binder films) due to the ease of air infiltration into the compacted mix. Rapid asphalt-binder oxidation often results in a more brittle mix and, consequently, a decreased resistance to cracking, which is undesirable. Having sufficient asphalt-binder film thickness is therefore very critical, especially for thin surfacing mixes such as overlays that would be directly exposed to the harshest environmental conditions.

HMA SPECIMEN FABRICATION

The basic HMA specimen fabrication procedure involved aggregate batching, binder-aggregate mixing, curing, short-term oven aging, compaction, sawing and coring, and finally volumetric analysis to determine the specimen air void content. These processes were conducted consistent with the TxDOT standard specifications (TxDOT, 2007). Prior to any aggregate batching, however, researchers conducted a wet sieve analysis consistent with the TxDOT test procedure Tex-200-F (TxDOT, 2007). This process was necessary to properly account for the dust portions and any deleterious materials in the aggregate gradation and blend characteristics. Table 3-1 contains a list of the binder-aggregate mixing and compaction temperatures as utilized in this project (TxDOT, 2007).

Table 3-1. HMA Mixing and Compaction Temperatures.

Process	Temperature (°F)	
	PG 70-22	PG 76-22
Aggregate pre-heating (≥ 12 hrs [overnight])	300 (149 °C)	325 (163 °C)
Asphalt binder pre-heating (≅30 min)	300 (149 °C)	325 (163 °C)
Binder-aggregate mixing	300 (149 °C)	325 (163 °C)
4 hrs short-oven aging	275 (135 °F)	1275 (135 °C)
Compaction	275 (135 °C)	300 (149 °C)

Shorten-Term Oven Aging

HMA short-term oven aging (STOA) lasted for 4 hrs at a temperature of 135 °C (275 °F), consistent with the AASHTO PP2 standard aging procedure for Superpave mixture performance testing (AASHTO, 1994). STOA simulates the time between HMA mixing, transportation, and placement up to the time of in situ compaction in the field. However, no STOA was conducted for the HMCL and LRA mixes - just curing, since these mixes are cold laid in the field.

HMCL and LRA Curing

Unlike the HMA mixes, the HMCL and LRA mixes required curing prior to molding/compacting. For convenience and to ensure complete water removal from the HMCL and LRA mixes that contained emulsion, the curing process was conducted over 12 hrs (i.e., overnight). Otherwise, the curing process was consistent with the TxDOT Tex-205-F test specification (TxDOT, 2007). According to Tex-205-F, the curing process is terminated only when a constant mix weight is obtained after successive heating at 140°F.

Molding and Compaction

All of the mixes including HMCL, LRA, and HMA were gyrated compacted to initial dimensions of 6 inch diameter by 5 inch in height using a standard Superpave Gyratory Compactor (SGC), shown previously in Figure 3-2. As was shown in Figure 3-2, for each gyratory molded sample, either at (a) 50 gyrations 98 percent density or (b) 93±0.5 percent density, one verlay and one Hamburg test specimens were cut, respectively. For each asphalt-binder content or target AV, two samples were molded for subsequent testing.

All HMCL and LRA mixes were molded/compacted at 140°F after curing at 140°F, without any short-term oven aging. The molding/compacting temperatures for the HMA mixes are listed in Table 3-1 and are consistent with the TxDOT (2007) specifications for PG asphalt-binders (Tex-205-F and Tex-241-F test specifications). The SGC compaction parameters included a 1.25° compaction angle and 600 kPa (87 psi) vertical pressure at a rate of 30 gyrations per minute. During the OAC determination process, the SGC compaction process was terminated based on the 50 gyrations count at a target batch mixing of 98 percent density. For the OAC verification process at 93±0.5 percent density, the SGC compaction process was terminated based on the 5 inch target specimen height and 7±0.5 percent AV.

Densities and AV measurements were conducted on all the test specimens prior to running the Hamburg and overlay tests. This procedure was also conducted according to the TxDOT standard test specifications for HMA density and AV measurements (TxDOT, 2007).

SUMMARY

In this project, the balanced mix-design concept, consistent with the TxDOT CAM SS 3109 specification, was utilized for selecting the OAC so as to ensure adequate rutting and cracking (reflection) resistance of very thin overlay HMA mixes. The Hamburg and overlay tests were used for both selecting the OAC and characterizing the rutting- and cracking-resistance, respectively. The proposed thin overlay HMA mix-design procedure incorporates the following three main steps:

- Step 1 – aggregate sourcing and material property characterization;
- Step 2 – HMA specimen molding at 50 gyrations 98 percent density and OAC determination through Hamburg and overlay testing, respectively; and
- Step 3 – OAC verification at 93±0.5 percent density through Hamburg and overlay testing, respectively.

The proposed HWTT and OT failure criteria for the very thin overlay HMA mixes are: Rut $\text{Depth}_{HWTT} \leq 12.5$ mm for the HWTT test and $N_{OT} \geq 750$ cycles for the OT test. These failure criteria are also consistent with the TxDOT CAM SS 3109.

The HMA specimen fabrication process is basically consistent with the TxDOT standard specifications, including the Tex-205-F test specification.

The candidate "very thin overlay" HMA mixes are essentially the ⅜" NMAS Type F mixes, consisting of high quality clean fine-graded Type F rock (i.e., 98-100 percent passing the ⅜"sieve) and screenings. Researchers recommend Class A aggregates (such as granite or crushed gravel) with low soundness value and good skid resistance characteristics. The preferred mix-design characteristics to ensure improved field performance and durability include use of stiff PG-graded asphalt-binder, such as PG 76-22S; high asphalt-binder content on the order of about 7 percent and above; high VMA (≥16 percent); and high asphalt-binder film thickness (≥ 10 μm).

CHAPTER 4
LABORATORY AND FIELD TESTING

This chapter provides a description of the tests that were conducted in this project. The laboratory tests are presented first, followed by field tests for structural and performance evaluations. A bullet-list of the tests is then presented to summarize the chapter.

LABORATORY TESTS

Researchers conducted the following laboratory tests for both OAC determination and material property characterization of the thin overlay HMA mixes: Hamburg, overlay, and the British Pendulum skid resistance. Other laboratory tests conducted include the aggregate water absorption and asphalt-binder extraction tests. These tests are summarily described in this section.

The Hamburg Wheel Tracking Test

As discussed in Chapter 3, rutting- and cracking-resistance characterization of the mixes based on the proposed balanced mix-design concept was accomplished using the HWTT and OT tests, respectively. HWTT is a test device used for characterizing the rutting resistance of HMA mixes in the laboratory including stripping susceptibility assessment (moisture damage potential). The loading configuration consists of a repetitive passing load of 158 lb-force (705 N) at a wheel speed of 52 passes per minute and a test temperature of 122 °F in a controlled water bath. HWTT test specimens are 2.5 inch thick by 6 inch diameter, with one trimmed edge. Figure 4-1 is the HWTT test device with a specimen set-up.

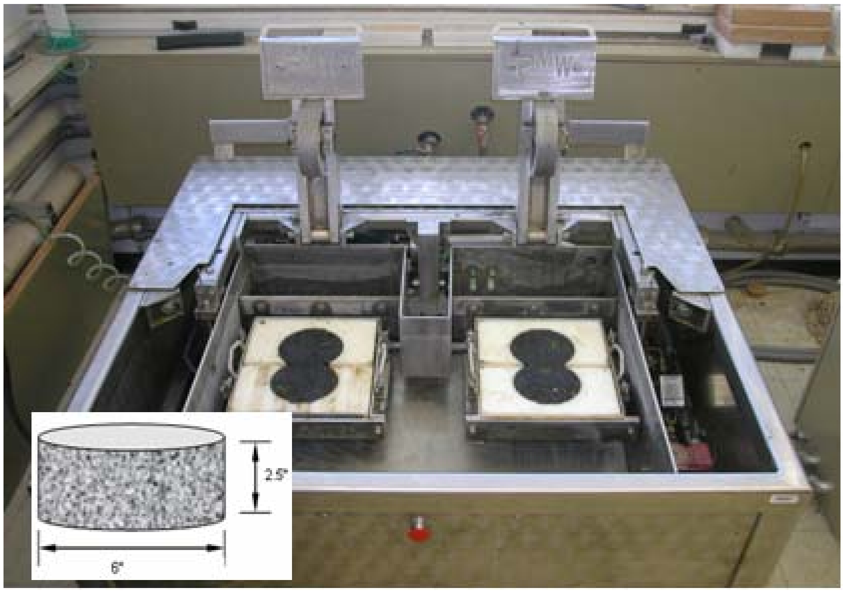

Figure 4-1. The Hamburg Test Device and Test Specimen.

In this project, HWTT testing was conducted consistent with the TxDOT Tex-242-F test specification (TxDOT, 2007). During HWTT testing, the measurable parameters include the applied load, temperature, number of load passes, and rutting. The HWTT terminal rutting failure criterion is 12.5 mm rut depth ($Rut_{HWTT} \leq 12.5$ mm [0.5"]) and is listed in Table 4-1 per PG asphalt binder type.

Table 4-1. Standard HWTT Terminal Rutting Failure Criteria.

Rut_{HWTT}	Number of Passes	Mix with Binder Type
≤ 12.5 mm (0.5")	10,000	PG 64-XX
≤ 12.5 mm (0.5")	15,000	PG 70-XX
≤ 12.5 mm (0.5")	20,000	PG 76-XX

For the thin overlay HMA mixes in this project that predominantly used PG 76-22, a maximum rut depth of 12.5 mm (≤ 12.5 mm) after 20,000 HWTT load passes was universally used as the failure criteria for acceptability (i.e., Rut $Depth_{HWTT} \leq 12.5$ mm after 20,000 load passes). Note that the HWTT results should generally be analyzed with respect to both the rut magnitude and the corresponding number of HWTT load passes. Full details of the HWTT testing can be found elsewhere (Zhou and Scullion, 2007).

The Overlay Tester

The overlay tester is a simple performance test used for characterizing the reflection cracking potential of HMA mixes in the laboratory at an ambient (room) temperature of 77 °F (25 °C). The test loading configuration consists of a cyclic triangular displacement-controlled waveform at a maximum horizontal displacement of 0.025 inch (0.63 mm) and a loading rate of 10 s per cycle (5 s loading and 5 s unloading). The OT test specimens are 6 inch total length, 3 inch wide, and 1.5 inch thick; they can be conveniently sawn by trimming a laboratory molded specimen, field-extracted core, or a field sawn slab. The OT test setup is shown in Figure 4-2; together with an example of a test specimen.

Figure 4-2. The Overlay Tester and Specimen Setup.

During OT testing, the measurable parameters include the applied load (stress), opening displacement (fixed at 0.025 inch), time, number of load cycles, and the test temperature. As discussed in Chapter 3, the OT terminal failure criterion was set at 750 load cycles for thin overlay mixes (i.e., $N_{OT} \geq 750$), at 93 percent stress reduction in the initial load. Note that the currently proposed failure criteria for typical Texas dense-graded mixes is 300 load cycles. Full details of the OT testing can be found elsewhere (Zhou and Scullion, 2007).

The British Pendulum Skid Resistance Tester

On an experimental basis only, the British Pendulum skid resistance tester was utilized to measure the surface wet skid resistance of the molded mixes in the laboratory. This measurement was achieved through testing under dry and wet conditions of the surface of the Hamburg test specimens prior to actual Hamburg testing. Figure 4-3 shows the British pendulum.

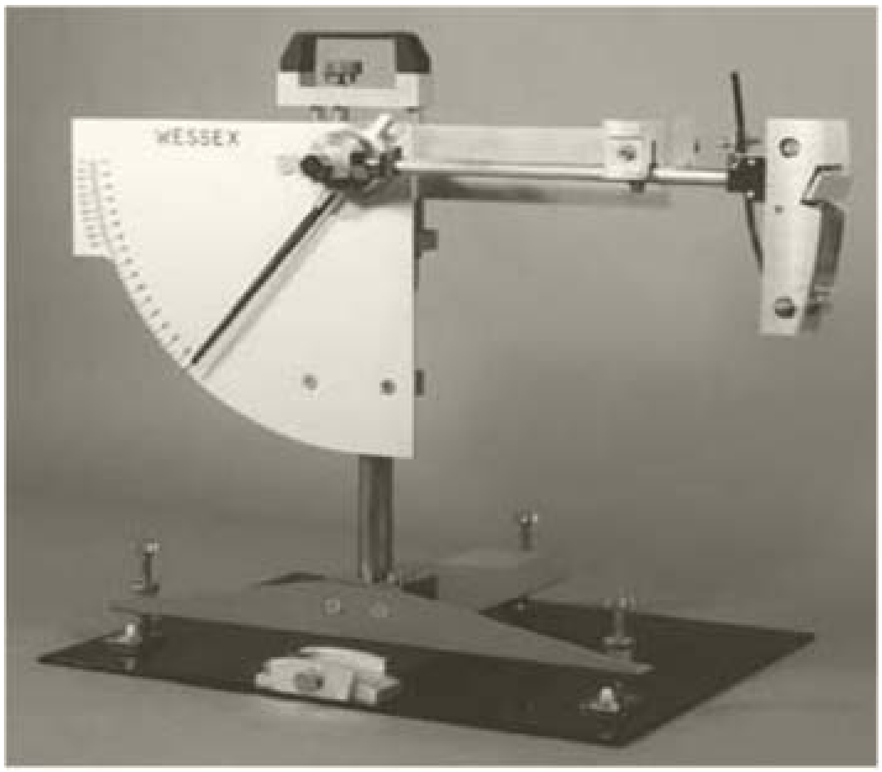

Figure 4-3. British Pendulum Skid Resistance Tester.

A skid resistance number (SN) of 34 was arbitrarily utilized as the reference benchmark (i.e., SN ≥ 34) based on the data from the literature. However, caution should be exercised in the interpretation of these SN results. The BPT was not properly calibrated and was not meant for skid resistance measurement of the Hamburg-type specimens. Additionally, 34 is not a standardized reference for laboratory Hamburg samples. Therefore, the SN results presented in Chapters 5 and 6 are open to subjectivity.

The Dynamic Friction Tester

In general, as will be seen in Chapters 5 and 6, experimentation with the BPT yielded pessimistic results and has since been discontinued. Recently, TTI purchased a dynamic friction tester through TxDOT Project 0-5627 "Aggregate Resistance to Polishing and Its Relationships to Skid Resistance." Figure 4-4 shows the TTI's newly acquired DFT device.

Figure 4-4. TTI's Newly Acquired Dynamic Friction Tester Device.

In the second phase of this project, researchers will be using this DFT device for wet skid resistance measurements. Details of the DFT can be found elsewhere (Saito et al., 1996; Nippo, 2007).

Aggregate Bulk Specific Gravity and Water Absorption Capacity

Other laboratory tests conducted included the aggregate bulk specific gravity and water absorption capacity of the aggregates. These tests were conducted with TxDOT test specifications Tex-201-F (TxDOT, 2007). Additionally, researchers conducted asphalt binder and aggregate extraction tests using the Troxler Ignition Oven (TxDOT, 2007). Test results are presented in Chapters 5, 6, and 7 of this interim report.

FIELD TESTS

Field tests included the ground penetration radar, rolling dynamic deflectometer, and infra-red (IR) mat temperature measurements. These field tests are discussed in this section, while test results are presented in Chapters 5 through 7. Visual surveys were also conducted and are discussed in Chapters 5 through 7.

Ground Penetrating Radar Measurements

For structural design considerations, TTI's 1-GHz air-coupled GPR was used for the non-destructive "structural" evaluations of the candidate thin overlay projects, such as the BU 59 business highway in downtown Lufkin. TTI's GPR has a maximum operable speed of 70 mph with a potential to capture pavement data up to a depth of 2 ft (Scullion, 2007). Figure 4-5 shows TTI's GPR system setup.

Figure 4-5. TTI's GPR System Setup.

TTI's GPR is typically utilized to characterize: (1) pavement layer densities (AV), (2) pavement layer thicknesses, and (3) presence of free moisture. The measurements are based on electromagnetic wave principles and dielectric characteristics (function of moisture content and density) of the pavement layer materials. Details of the GPR are documented elsewhere (Scullion, 2006, 2007). During this phase of the project, the GPR was primarily used for structural evaluations of the existing pavement sections' candidature for thin overlay surfacing.

Rolling Dynamic Deflectometer Measurements.

Like the GPR, researchers used the RDD for structural evaluations of the existing pavement sections' candidature for thin overlay surfacing and other structural design considerations. The RDD is a non-destructive testing device that is used to measure continuous deflection profiles along highway and airport pavements. It (the RDD) is an effective tool for identifying critical sections, cracks, or joints along a pavement test section that needs repair (Lee et al., 2004). It is also an effective tool for monitoring deterioration in pavement sections over time. A schematic diagram of the RDD is shown in Figure 4-6 (Lee et al., 2004).

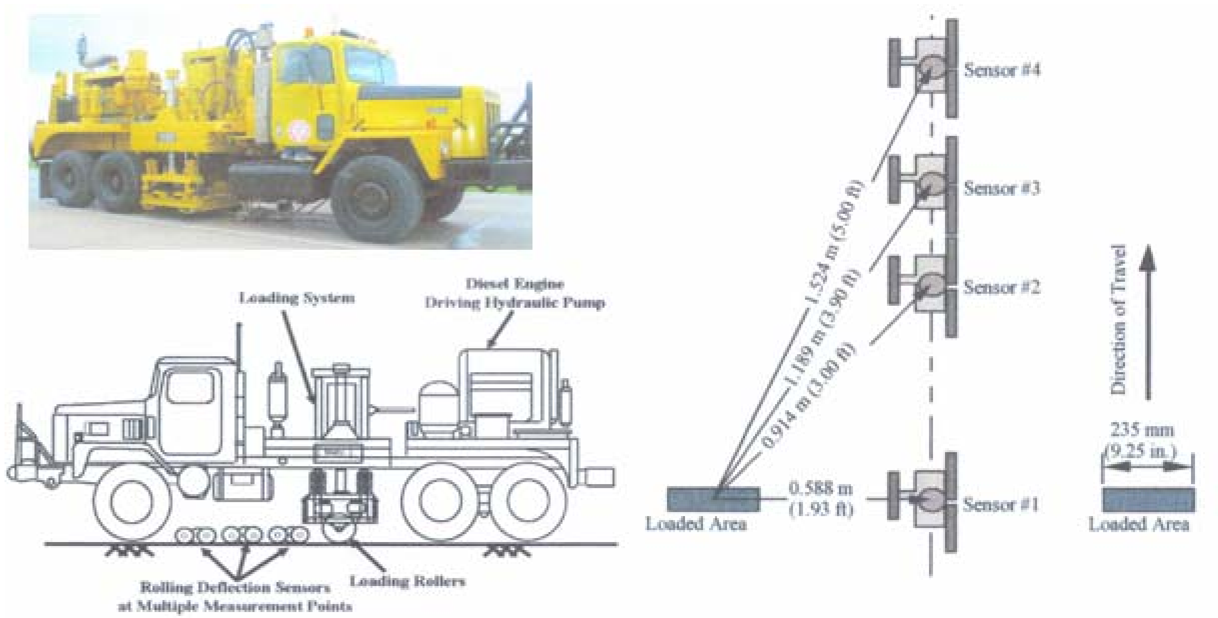

Figure 4-6. Schematic of the RDD Loading Configuration and Sensor Locations (Lee et al., 2004; Scullion, 2006).

During testing, the RDD places a cyclic load on the pavement as it rolls along at 1.5 mph. For pavement testing, the load is usually fixed at 10,000 lb with a frequency of 30 Hz. One innovative feature of the RDD is the four rolling geophones (see Figure 4-5), which continuously measure the movement of the pavement surface at different offsets from the load wheels (Scullion, 2006).

The RDD is the only known operational rolling deflection system that provides sufficient data to make project-level decisions on jointed concrete pavements (JCPs). In particular, the RDD is ideal for testing JCPs where it is important to assess both sub-slab support condition and load transfer efficiency (LTE) (Scullion, 2006). The current data acquisition system collects continuous pavement deflections; the operator typically summarizes the data into a 2-second window and calculates an average pavement deflection for that time interval. Under normal operating speed, this corresponds to an average deflection measurement for every 2 to 3 feet of pavement. The current RDD software also generates a strip map showing the location along the highway where the rolling deflection survey was conducted (Scullion, 2006). More details on the RDD system can be found elsewhere (Lee et al., 2004; Scullion, 2006). The following is the proposed RDD criteria based on the recommendations by Scullion (2006):

- **For load transfer efficiency** – instantaneous difference in deflection between sensors 1 and 3 when sensor 1 peaks, with RDD operating at the 10 kip load level; Good < 6 mils, Marginal = 6 – 8 mils, and Poor > 8 mils.

- **For center slab support** – mid-slab deflections on sensor 1; Good < 5 mils, Marginal = 5 – 7 mils, and Poor > 7 mils.

According to the mechanistic-empirical pavement design guide (MEPDG) (AASHTO, 2007), rehabilitation is recommended if the LTE falls below 80 percent. RDD structural evaluations of the existing jointed concrete pavement in Lufkin (BU 59) for thin overlay placement are discussed in Chapter 6 of this interim report.

Infra-Red Temperature Measurements

TTI used its infra-red monitoring system to measure mat temperatures during placement of the thin overlays, such as the Fort Worth – Pumphrey Street thin overlay project. The latest version of this system is shown in Figure 4-7.

Figure 4-7. TTI's Infra-Red System and Mat Temperature Measurements.

The TTI IR system is described in detail elsewhere (Sebesta and Scullion, 2002). It essentially consists of 10 infra-red sensors installed in a bar, which attach to the foot plate of a paver. Custom built software displays the mat temperatures in real time. For the CAM mixes with PG 76-22 binder, the minimum pavement surface and mix placement temperatures are around 60 and 280 °F, respectively (TxDOT, 2007). IR temperature measurements were conducted during placement of the thin overlay project on Pumphrey Street in Fort Worth, and results are presented and discussed in Chapter 7 of this interim report.

SUMMARY

The laboratory and field tests conducted during this phase of the project are bullet-listed below:

- Hamburg – for rutting resistance characterization (failure criterion: Rut Depth$_{HWTT}$ ≤ 12.5 mm at 122 °F after 20,000 load passes).
- Overlay – for cracking resistance characterization (failure criterion: Number of OT cycles ≥ 750 [i.e., NOT ≥ 750] at 77 °F for 93 percent stress reduction in the initial load).
- British skid resistance pendulum – for wet skid resistance (SN) measurements (reference bench mark: SN ≥ 34). In the next phase of the project, TTI's newly acquired dynamic friction tester device will be used for wet skid resistance measurements.
- GPR – for structural evaluations of the underlying pavement structure's candidature for thin overlay surfacing. GPR characterize (1) pavement layer densities (AV), (2) pavement layer thicknesses, and (3) presence of free moisture.

- RDD – for structural evaluation of the underlying pavement structure's candidature for thin overlay surfacing and other structural design considerations, in particular rigid jointed concrete pavements. RDD measures continuous deflection profiles for assessing, among others, sub-slab support conditions and load transfer efficiency. According to the MEPDG, rehabilitation is recommended if the LTE falls below 80 percent.
- Infra-Red – for mat temperature measurements during construction. For the CAM type mixes with PG 76-22 binder, the minimum mix placement temperature is 280 °F.

CHAPTER 5
COLD-LAID MAINTENANCE MIXES

Cold-laid maintenance mixes were evaluated with the Hamburg and overlay tests to assess their potential as candidate mixes for thin overlays. One HMCL mix and three LRA mixes were evaluated and are discussed in this chapter. A summary of the findings is then presented to wrap-up the chapter.

HOT-MIX COLD-LAID MIX (TxDOT SPEC. ITEM 334)

The HMCL mix evaluated was the plant-mix used in the Bryan District on the IH 45 ramps. More details on HMCL can be found in the TxDOT 2004 standard specification handbook as Item 334 (TxDOT, 2004a). Using a laboratory-determined Rice value of 2.578 from the plant-mix, Hamburg and overlay samples were molded at 7±0.5 percent AV and tested accordingly. The Hamburg and overlay test results are shown in Figures 5-1 and 5-2, respectively.

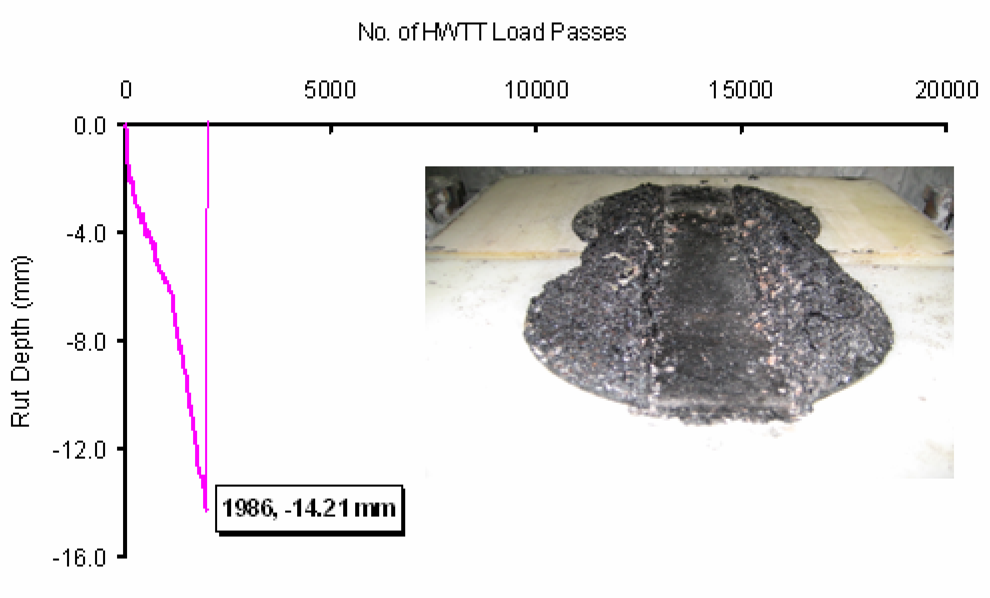

Figure 5-1. Hamburg Results for the Bryan HMCL Plant Mix.

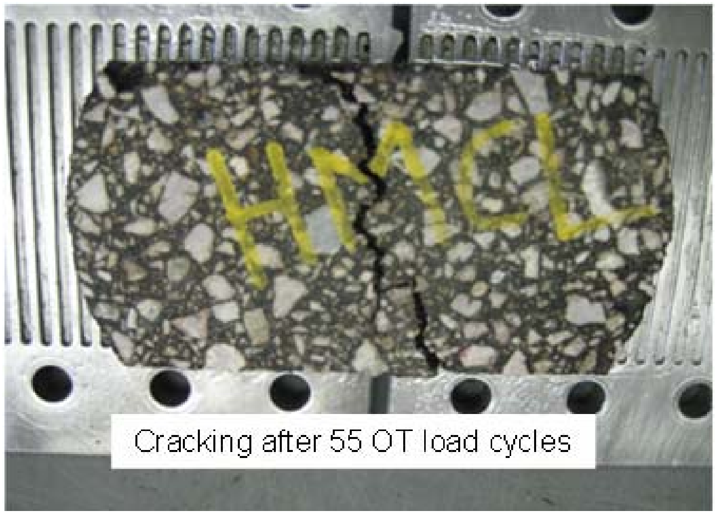

Figure 5-2. Overlay Results for the Bryan HMCL Plant Mix.

Clearly, there is poor performance both under the Hamburg and overlay tests, respectively, for this HMCL plant mix. The rut depth was already 14.21 mm just after 1986 HWTT load passes, with visual evidence of stripping. Compared against the 12.5 mm pass criterion after 20,000 HWTT load passes, these results suggest potential for rutting problems, especially at elevated temperatures. For a pass criterion of 750 OT load cycles, the marginal 55 OT load cycles indicate poor cracking resistance. Note that the actual measured average AV for these samples was 7.3 percent. If a SN of 34 is arbitrarily used as a reference benchmark, then the mix surface has sufficient skid resistance based on the British pendulum SN test values of 69 (dry) and 62 (wet). Based on these SN results, it is apparent that wetting caused a skid resistance drop of about 10 percent.

LIMESTONE ROCK ASPHALT MIXES (TxDOT SPEC. ITEM 330)

Three LRA mixes from the San Antonio District were evaluated and included both plant mix and field-extracted cores from different highway sections. Details about LRA mixes, including the types and grade classifications, are contained in the TxDOT 2004 standard specification handbook as Item 330 (TxDOT, 2004a). The mix volumetrics and laboratory test results are summarized in Tables 5-1 and 5-2, respectively. An analysis and discussion of each LRA mix is presented in the subsequent text. A visual performance evaluation of the LRA highways sections was also conducted, and the observations and findings are discussed in this chapter as well.

Table 5-1. LRA Mix Volumetrics.

Highway	LRA Mix Type*	Rice	AV (Core)	AV (Plant-Mix Specimen)
FM 140/SH 97 (Charlotte)	Type II Grade DS	2.354	6.4%	7.2%
US 83 (Uvalde)	Type I Grade CC	2.338	8.5%	6.6%
SH 2696 (Blanco)	Type II Grade DS	2.389	7.6%	7.3%

*Full details of the LRA mix type and grade classification are contained in the TxDOT 2004 standard specification handbook as Item 330, page 242 (TxDOT, 2004a)

Table 5-2. LRA Laboratory Test Results.

Highway	LRA Mix Type	Hamburg (mm)		Overlay		SN	
		Core	Plant Mix	Core	Plant Mix	Dry	Wet
FM 140/SH 97 (Charlotte)	Type II Grade DS	13.0 (2150)[a]	13.5 (1100)	75	144	60 (65)[b]	55 (54)
US 83 (Uvalde)	Type I Grade CC	12.7 (1050)	13.4 (2750)	272	26	65 (69)	53 (62)
SH 2696 (Blanco)	Type II Grade DS	14.0 (3200)	13.1 (6350)	73	3	66 (63)	61 (59)

[a]Hamburg: values in parentheses ( ) represent the number of HWTT load passes
[b]SN: values in parentheses ( ) represent the SN value measured from the plant-mix specimen

LRA Type II Grade DS - FM 140/SH 97 Intersection (Charlotte)

The LRA Type II Grade DS mix was used at the intersection of FM 140 and SH 97 downtown in the city of Charlotte, San Antonio, about half a mile long section. At the time of this interim report, the mix has been in service for over two years. Contrary to the poor laboratory performance shown in Table 5-2, field performance has been satisfactory at the time of inspection in spring 2007, without any major visual distresses observed. Being at an intersection, it was surprising that there was no evidence of rutting or shoving due to slow and/or braking traffic. Figure 5-3 shows the photographic view of the FM 140/SH 97 intersection, without any visual evidence of distresses after over two years of service.

Figure 5-3. LRA Type II Grade DS – FM 140/SH 97 Intersection (Charlotte) (2 Yrs Old).

While the laboratory molded plant-mix samples performed poorer under the wet Hamburg test at 122 °F, this LRA mix generally exhibited greater sensitivity to moisture with high potential for stripping. Even at room temperature (≅73 °F), the mix still performed poorly, accumulating 12.8 mm rutting just after 6300 HWTT load passes. In the absence of water at room temperature (≅73 °F), however, satisfactory laboratory performance was observed with only 1.8 mm rutting after 20,000 HWTT load passes. These results for both the field-extracted cores and samples molded from the plant mix are comparatively shown in Figures 5-4 and 5-5.

Figure 5-4. Hamburg Results (Cores) – FM 140/SH 97 Intersection (Charlotte).

Hot-wet condition at 122 °F (plant-mix);
13.0 mm rutting after 2150 HWTT load passes.

At 77 °F (plant-mix [lab-molded]) = 75 OT load cycles
(At 77 °F (cores) = 144 OT load cycles)

Figure 5-5. Hamburg and Overlay Results (Plant Mix) – FM 140/SH 97 Intersection (Charlotte).

Clearly, Figures 5-4 and 5-5 show very poor laboratory Hamburg performance under water, in particular at elevated temperatures. As evident in Figure 5-5, the Hamburg test was most severe for the laboratory-molded plant mix samples, also with severe stripping. Figure 5-4 shows that performance is superb under dry conditions in the absence of water. Based on these results, it is apparent that water may be reducing the LRA mix shear strength and thus accelerate failure and/or build-up of hydrostatic water pore pressure that may be breaking the mix internally.

The laboratory-cracking resistance was equally poor (less than 300 OT load cycles) for both the field-extracted cores and the plant-mix. The excellent field performance observations (Figure 5-3) supported by the dry Hamburg test suggests that as long as moisture does not get into the mix, satisfactory performance may be expected, particularly under dry and low-traffic conditions.

Like the HMCL mix, skid resistance results were satisfactory (Table 5-2) based on the minimum threshold SN value of 34. However, as stated in Chapter 4, these SN results are very pessimistic and subjective. Nonetheless, the effect of wetting is evident, with a decrease of about 13 percent in the SN after wetting the surface.

LRA Type I Grade CC – US 83 (Uvalde)

Except for the SN results (Table 5-2), this Type I Grade CC mix also exhibited poor laboratory performance, with visual evidence of moisture damage (stripping) particularly for the laboratory-molded plant-mix samples. These results are shown pictorially in Figure 5-6.

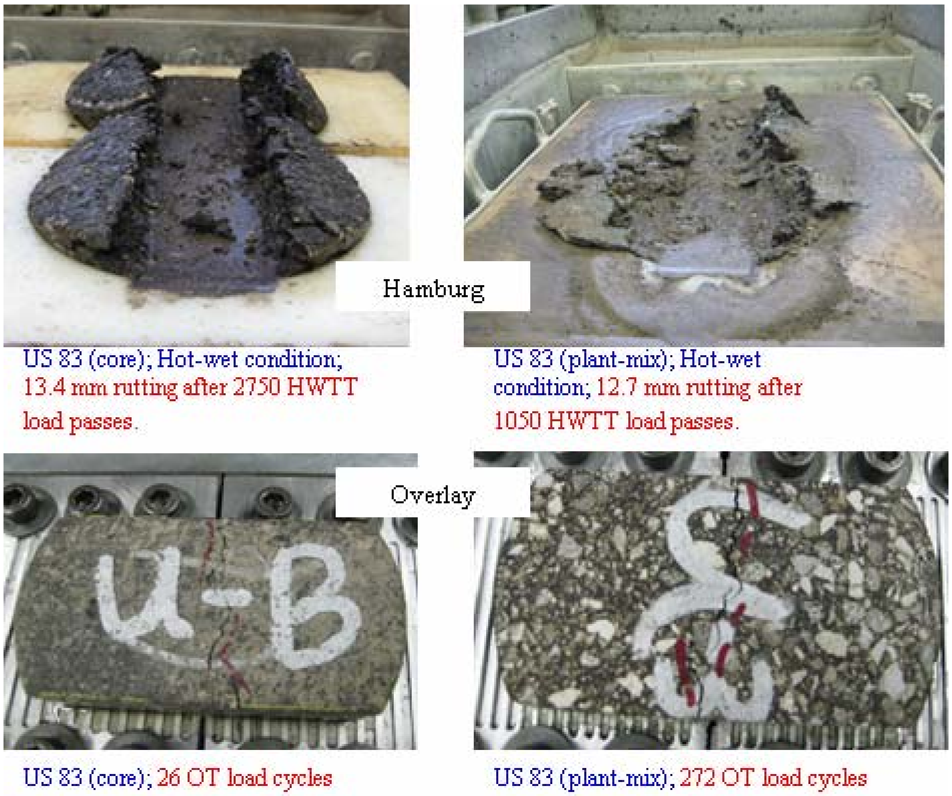

Figure 5-6. LRA Type I Grade CC Laboratory Results – US 83 (Uvalde).

As shown in Figure 5-7, both dry Hamburg testing of samples molded from the plant mix at room temperature and field visual observations on the US 83 section (where this mix has been used) indicated satisfactory performance. The US 83 section with the LRA Type I Grade CC surfacing has been in service for over four months at the time of the site visit in spring 2007. The dry Hamburg test results suggest that these mixes are good for application under dry conditions.

Hamburg dry condition at room (73 °F); 1.3 mm rutting after 20,000 HWTT load passes.

US 83 (Uvalde); LRA Type 1 Grade CC; After 4 months of service = satisfactory performance

Figure 5-7. Dry Hamburg Testing (Plant Mix) and Field Performance of US 83.

LRA Type II Grade DS – SH 2696 (Blanco)

Table 5-2 showed poor laboratory performance for this LRA mix, both under the Hamburg and overlay tests, except for skid resistance tests. Like all other LRA mixes, there was visual evidence of stripping under hot-wet conditions at 122 °F Hamburg testing. The measured rut depths were already over 12.5 mm just after 6350 HWTT load passes. Cracking resistance was equally poor, with the laboratory-molded plant-mix samples failing only after 3 OT load cycles while the field-extracted cores only sustained up to 73 OT load cycles.

However, both dry Hamburg tests at room temperature and field visual observations of the SH 2696 section (where this mix has been placed) after one year of service indicated satisfactory performance. These results are pictorially shown in Figure 5-8.

Hamburg dry condition at room (73 °F); 1.7 mm rutting after 20,000 HWTT load passes.

SH 2696 (Blanco); LRA Type 2 Grade DS; After 1 year of service = fairly satisfactory performance

Figure 5-8. Dry Hamburg Testing (Plant Mix) and Field Performance of SH 2696.

SUMMARY

Based on the laboratory Hamburg testing, both the HMCL and LRA mixes exhibit potential for moisture damage susceptibility and poor rutting resistance, particularly at elevated temperatures. The measured rut depths were already over 12.5 mm just after 6300 HWTT load passes, with visual evidence of stripping. Laboratory performance was satisfactory under dry Hamburg testing at room temperature, with rut depths less than 2 mm even after 20,000 HWTT load passes, suggesting that these cold-laid mixes are good for application in dry areas. However, these mixes may not perform well under wet conditions or if water infiltrates into the mix. Some of the probable causes for these mixes' poor laboratory performance under wet Hamburg testing were attributed to the following factors:

- Water may be reducing the mix's shear strength and thus accelerating failure.
- Building-up of hydrostatic water pore pressure may be breaking down the mix internally.

The mixes equally exhibited poor laboratory cracking resistance under the overlay test. All the mixes had OT load cycles to failure less than 300, while some sustained only 3 OT load cycles prior to crack failure. By contrast, the mixes appear to be performing well in the field; it is needless to point out that San Antonio is a relatively dry area with an average pavement surface temperature around 110 °F. The visual performance evaluation of the highway sections utilizing these cold-laid mixes was conducted in the spring of 2007. The potentially promising field observation results and the fact that the mixes performed excellently when subjected to dry Hamburg testing at room temperature could be a basis for further improving these maintenance mixes, in particular for application in dry areas and on low-volume roads. In general, these mixes have low energy costs and are more environmentally friendly. In comparison to hot-laid HMA mixes, their major advantages include: hot and cold weather paving, thus allowing for better optimization of paving resources; low temperature placement resulting in early opening to traffic; and reduced mix aging due to lower production temperatures. Benefits to contractors may include the ability to increase hauling distances between the plant and project, reduced plant emissions resulting in improved air quality, and cost savings because of reduced energy costs. More research is recommended on these mixes.

CHAPTER 6
FINE-GRADED HMA MIXES

Up to nine fine-graded HMA mixes were designed and/or evaluated in the laboratory using the balanced mix-design concept based on the Hamburg and overlay testing. These mixes, with some already in-service, are discussed in this chapter. A detailed discussion of each mix follows, including field structural evaluations, construction, and performance evaluations where applicable. A summary of the findings is then presented to conclude the chapter.

MATERIALS

This section of the chapter discusses the asphalt binders, aggregates, and other additives that were used. The discussion includes aggregate properties, blend proportions, and gradations.

Asphalt-Binders

As discussed in previous chapters, the target asphalt binder for Texas thin HMA overlays is polymer modified PG 76-22S that has relatively superior rheological properties, less temperature sensitivity, less rut susceptiblity, and reasonably good durability characteristics. These PG 76-22S asphalt-binders were predominantly sourced from Wright and Valero Asphalt in Texas. PG 70-22S (from Lion Asphalt) and PG 64-22 (from Valero Asphalt) were also used.

Aggregates Characteristic Properties

Consistent with the TxDOT CAM SS 3109 specification, high quality aggregates with a preferred surface aggregate classification (SAC) Class A and low soundness value are recommended for thin overlays mixes. Among other requirements, the aggregates should basically have no natural sand or reclaimed asphalt pavement (RAP) material (TxDOT, 2004b). Various aggregate types including limestone, granite, sandstone, and trap rock were utilized. Table 6-1 is a summary of the aggregate characteristic properties. Based on Table 6-1, it is clear that most of the aggregates were within the specification recommendations, except for the trap rock that exhibits potential for asphalt-binder absorption with the net effect of reducing the effective asphalt-binder content (high water absorption capacity [WAC] > 2 percent).

Table 6-1. Aggregate Characteristic Properties.

Item	Mix Type	Aggregate	SAC	RSSM (≤ 20%)	RSPV	RSLA (≤ 30%)	BSG	WAC (≤ 2%)	Source
Vulcan-Spicewood	TxDOT CAM	Limestone (⅜" NMAS)	B	6	21	21	2.79	1.73%	Vulcan Materials (Spicewood)
BU 59 – Lufkin	TxDOT CAM	Granite (⅜" NMAS)	A	3	24	8	2.70	1.89%	Martin Marietta (Snyder, OK)
Brownwood	TxDOT CAM	Limestone (⅜" NMAS)	B	8	20	24	2.72	1.94%	Vulcan Materials (Brownwood)
Jones Mill	TxDOT CAM	Granite (⅜" NMAS)	A	6	30	18	2.71	1.82%	Martin Marietta (Jones Mills)
Uvalde - Knippa	TxDOT Type D	Trap rock (⅜" NMAS)	A	8	26	15	3.10	2.60%	Vulcan Materials (Knippa)
FW – Pumphrey Street	TxDOT F	Granite (⅜" NMAS)	A	4	27	28	2.72	0.70%	Martin Marietta (Mill Creek
NCAT – Alabama	TxDOT Type D Class A	Granite (⅜" NMAS)	-*	-	-	-	-	-	Jones Mill (AR)
US 82 - Texakarna	TxDOT Type F Hybrid	Sandstone (⅜" NMAS)	A	14	32	32	2.62	1.40%	Martin Marietta (Apple-Sawyer;

*Data not available at the time of this interim report.

Legend:

CAM = Crack attenuating mixture

SAC = Surface classification for wet weather accident reduction program

RSSM = Rated source soundness magnesium

RSPV = Rated source polish value

RSLA = Rated source Los Angeles abrasion

BSG = Bulk specific gravity

WAC = Water absorption capacity

Aggregate Blend Proportions and Gradations

In general, fine-graded Type F or D rock with ⅜" NMAS and screenings were utilized, with about 1 percent lime in some instances, as an anti-stripping agent to minimize the effects of moisture damage. The addition of lime is particularly critical in HMA mixes that are very susceptible to moisture damage, i.e., stripping. The target gradation for the thin overlay HMA mixes presented in this interim report is that specified for the CAM mixes according to the special specification SS 3109 (TxDOT, 2004b). Table 6-2 shows the aggregate blend proportions and gradations.

Table 6-2 shows that with the exception of trap rock (Uvalde-Knippa), granite (NCAT-Alabama), and sandstone (US 82-Texarkana), all other aggregates met the CAM gradation specifications (TxDOT, 2004b). As discussed in subsequent text of this section, both the NCAT-Alabama and US 82-Texarkana mixes were originally designed by TxDOT not as CAM mixes, but as TxDOT Type D Class A Surfacing and TxDOT Type F – Hybrid mixes, respectively. These mixes were designed consistent with the following gradation specifications:

- NCAT-Alabama Type D Class A Surfacing = Typical TxDOT Type D gradation.
- US 82-Texarkana Type F Hybrid = ⅜" Superpave gradation.

Therefore, it was not unexpected that these mixes' aggregate gradations did not meet the CAM gradation specification on the No. 4 and No. 8 sieves, respectively. The Uvalde-Knippa trap rock, on the other hand, did not meet the CAM gradation specification primarily due to the coarseness and single-sized nature of the aggregates that are quarried as chip seal aggregates in Grades of 3 to 5 (i.e., Gr3, Gr4, and Gr5) and No. 4 NMAS screenings. Even 100 percent trap rock screenings could not be used as it failed to meet the CAM specification on the ⅜" and No. 200 sieves, respectively. However, the combined gradation of 22 percent Gr5 and 78 percent screenings meet the TxDOT Type D and ⅜" Superpave gradation specifications. The Uvalde-Knippa trap rock gradations for Gr3, Gr4, Gr5, and screenings after wet sieve analysis are shown in Figure 6-1. The combined Gr5 (22 percent) and screenings (78 percent) gradations are shown in Figures 6-2 and 6-3, together with the TxDOT Type D and ⅜" Superpave gradation specification limits.

Table 6-2. Aggregate Blending and Gradations.

Item	Vulcan-Spicewood	BU 59-Lufkin	Brownwood	Jones Mill	Uvalde - Knippa	FW – Pumphrey Street		NCAT – Alabama	US 82 – Texarkana	CAM Spec
Aggregate	Limestone	Granite	Limestone	Granite	Trap Rock	Granite		Granite	Sandstone	**SS 3109**
Blend/Sieve Size	50% F-rock + 50% screenings	30% ⅜" NMAS rock + 69% screenings + 1% lime	53% F-rock + 47% screenings	45% F-rock + 55% screenings	22% Gr5 + 78% screenings	55% F-rock + 45% screenings (+1% Akzo anti-stripping agent for Latex mix)		25% D-rock + 35% F-rock + 40% screenings	60% F-rock + 40% screenings	
¾"	100.0	100.0	100.0	100.0	100.0	100^{GCR}	100^{L}	100.0	100.0	***100***
½"	100.0	100.0	100.0	99.9	100.0	100.0	100.0	99.8	100.0	***100***
⅜"	100.0	100.0	99.9	98.0	97.3	98.6	99.6	98.1	100.0	***98 - 100***
No. 4	77.1	79.4	81.0	73.7	59.4	71.1	74.9	53.4	78.8	***70 - 90***
No. 8	42.5	47.6	41.3	51.6	37.7	42.7	42.4	-	39.5	***40 -65***
No. 10	-	-	-	-	-	-	-	35.6	-	***-***
No. 16	26.4	31.0	27.5	34.3	25.0	28.3	27.2	-	25.5	***20 - 45***
No. 30	17.2	20.1	20.8	23.3	18.1	19.4	17.6	-	19.9	***10 - 30***
No. 40	-	-	-	-	-	-	-	15.1	-	***-***
No. 50	12.6	12.2	17.3	16.5	13.7	13.1	11.6	-	17.3	***10 - 20***
No. 80	-	-	-	-	-	-	-	10.5	-	***-***
No. 200	9.6	4.2	10.0	8.5	8.3	3.2	4.0	5.7	8.1	***2 - 10***

GCR = aggregate gradation extractions from plant-mix with ground crumb rubber; ***L*** = aggregate gradation extractions from plant-mix with latex.

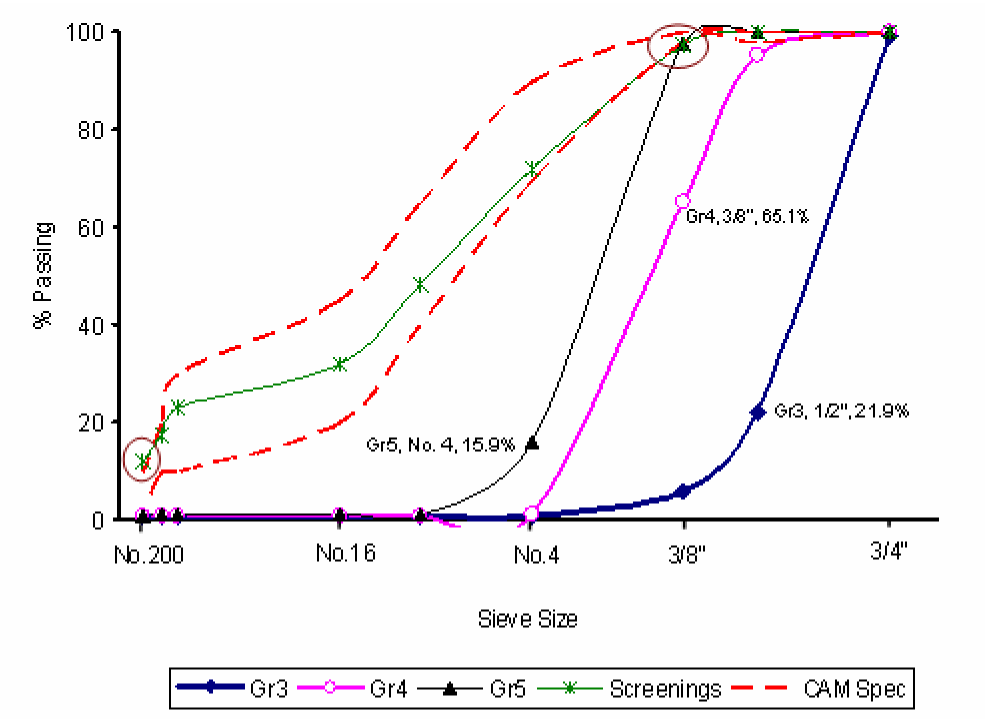

Figure 6-1. Gradations Characteristics of the Uvalde – Knippa Trap Rock (Gr3, Gr4, Gr5, and Screenings).

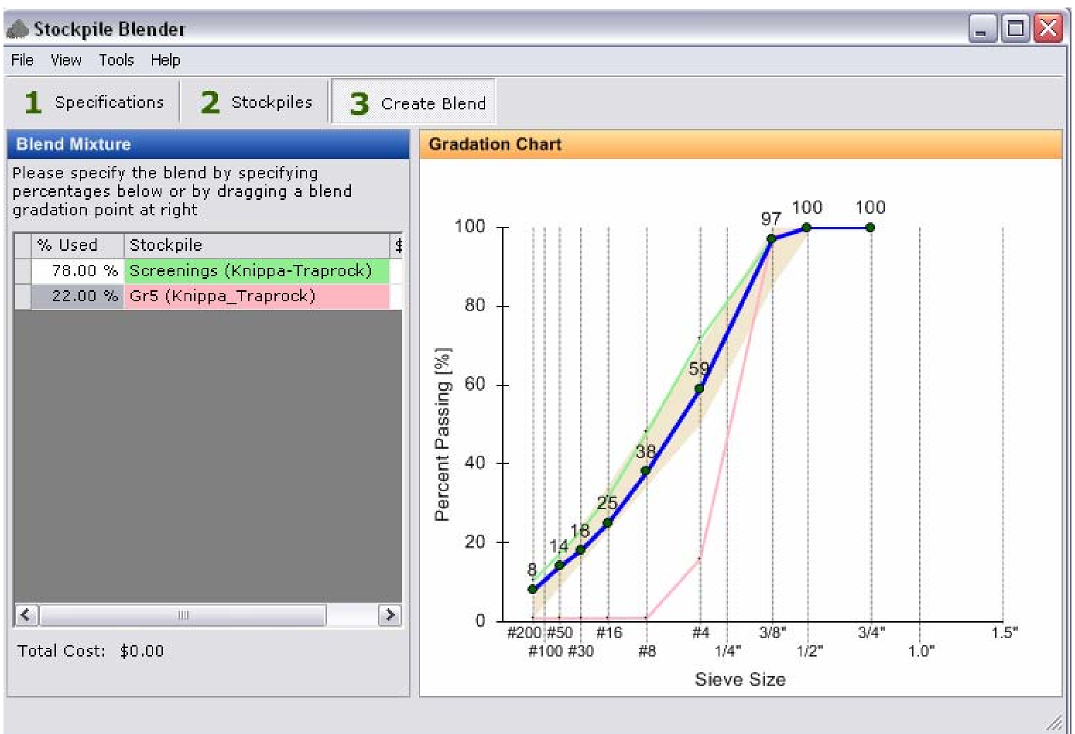

Figure 6-2. TxDOT Type D Gradation Blending of the Uvalde – Knippa Trap Rock Gr5 and Screenings.

Figure 6-3. ⅜" Superpave Gradation Blending of the Uvalde – Knippa Trap Rock Gr5 and Screenings.

Figures 6-2 and 6-3 indicate that there is considerably more flexibility in the blending of the trap rock Gr5 and screenings gradations to meet either the TxDOT Type D or ⅜" Superpave specification. The window of blending proportions is reasonably wide. Consequently, as the CAM gradation specification could not be met (even with 100 percent screenings), a trap rock Gr5 and screenings gradation combination similar to a TxDOT Type D gradation viz-v ⅜" Superpave gradation (which is also a ⅜" NMAS mix) was tried for the district consideration; see Table 6-2.

Based on these researchers' recommendations, however, the San Antonio District has supplied a new batch of sandstone aggregates composed of Type D rock, F rock, and screenings from Delta Pit for laboratory evaluation and mix design at TTI. The aggregate wet sieve analysis is complete, and the aggregate gradations are shown in Figure 6-4. Close to the trap rock screenings, which had about 8 percent washable dust content, the screenings from the Delta Pit had about 6 percent washable dust content.

Clearly, this new gradation design of 50 percent Type F rock and 50 percent screenings (Figure 6-5) satisfactorily meets the CAM SS 3109 specification. At least, the screenings are not as coarse as those shown in Figure 6-1 for the trap rock screenings. Even a design blend proportion of 45 percent Type F rock and 55 percent screenings would still be satisfactory.

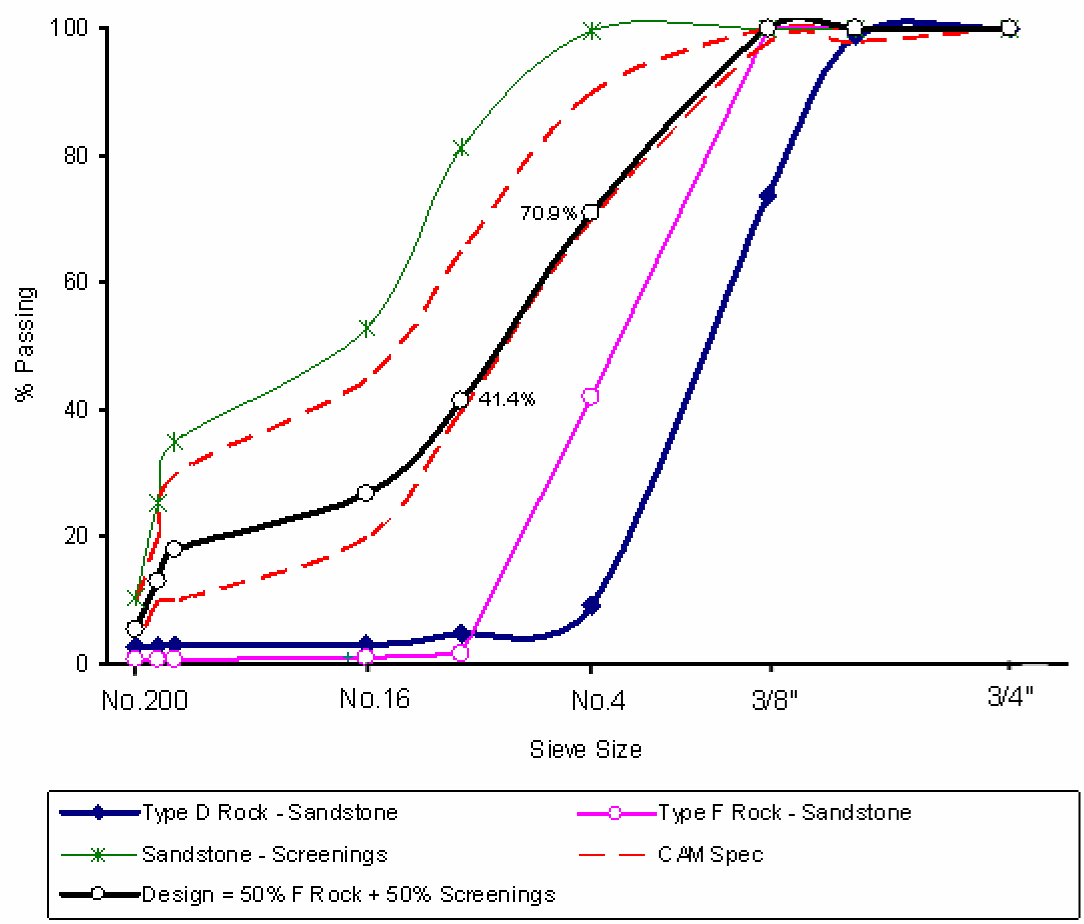

Figure 6-4. Aggregate Gradations for the Uvalde Sandstone Aggregates.

The laboratory-measured BSG and WAC for the Type F sandstone rock were 2.70 and 2 percent, respectively. Currently, the balanced mix design and OAC selection processes are in progress.

MIX DESIGN VOLUMETRICS AND LABORATORY TEST RESULTS

Table 6-3 summarizes the mix-design volumetrics and laboratory test results, followed by a detailed discussion of each mix. As evident in Table 6-3, almost all the mixes satisfied the proposed mix-design requirements for thin overlay HMA mixes (see Chapters 1 to 4). Note that all the asphalt-binder contents shown in Table 6-3 and all others discussed in this interim report are by weight of the aggregate.

Table 6-3. Mix-Design Volumetrics and Lab Test Results.

Item	Mix Type	Mix-Design Characteristics					Lab Test Results		
		Materials	Rice	VMA (≥ 16%)	AV (≅ 7±0.5%)	T_F (≥ 10 μm)	HWTT (≤ 12.5 mm)	OT (≥ 750)	BPT (SN ≥ 34)
Vulcan-Spicewood	TxDOT CAM	7.8% PG 76-22S + Limestone	2.418	23.9%	6.9%	13.68	11.2	750	41
BU 59 – Lufkin	TxDOT CAM	8.3% PG 76-22S + Granite	2.302	20.4%	7.0%	15.05	7.81	900+	44
Brownwood	TxDOT CAM	7.9% PG 76-22S + Limestone	2.417	20.3	6.8%	15.55	13.91 (after 16,215 passes)	900	-*
Jones Mill	TxDOT CAM	8.3% PG 76-22S + Granite	2.401	19.6%	6.8%	18.8	8.96	900+	-
Uvalde – Knippa	TxDOT Type D	7.7% PG 76-22S + Trap rock	2.623	22.5%	7.2%	17.3	11.8	850	-
FW – Pumphrey Street 01	TxDOT F – Crumb Rubber	6.6% 64-22 + 7% Crumb Rubber + 1% Akzo + Granite	2.398	-	7.6%	21.8	13.78 (after 3063 passes)	900+	-
FW – Pumphrey Street 02	TxDOT F – Latex	7.2% PG 64-22 + 3% Latex + Granite	2.394	-	7.5%	21.7	13.89 (after 4075 passes)	900+	-
NCAT - Alabama	TxDOT Type D Class A Surfacing	6.7% PG 76-22S + Granite	2.424	15.9%	6.9%	16.6	3.77	900+	53
US 82 - Texakarna	TxDOT Type F Hybrid	7.8% PG 70-22S + Sandstone	2.289	18.8%	6.8%	15.59	6.78	900+	40

*Data not available at the time of this interim report.

Legend: VMA = voids in mineral aggregate; AV = air voids; T_F = asphalt-binder film thickness; HWTT= Hamburg wheel tracking test for rutting resistance characterization (failure criterion ≤ 12.5 mm rut depth); OT = Overlay tester for cracking resistance characterization (failure criterion ≥ 750 load cycles at 93 percent stress reduction); SN = skid resistance number based on the British Pendulum Test (BPT) (utilized reference failure criterion was wet SN ≥ 34).

VULCAN – SPICEWOOD: TxDOT CAM DESIGN

This mix (7.8 percent PG 76-22S + limestone) was designed in the laboratory based on the balanced mix-design concept and the proposed thin overlay HMA mix-design procedure described in Chapter 3. As evident in Table 6-3, the mix was verified at 93±0.5 percent density, passing both the laboratory Hamburg and overlay test requirements. The Hamburg and overlay test results at various asphalt-binder contents, together with the window of acceptable OAC, are shown in Figure 6-5.

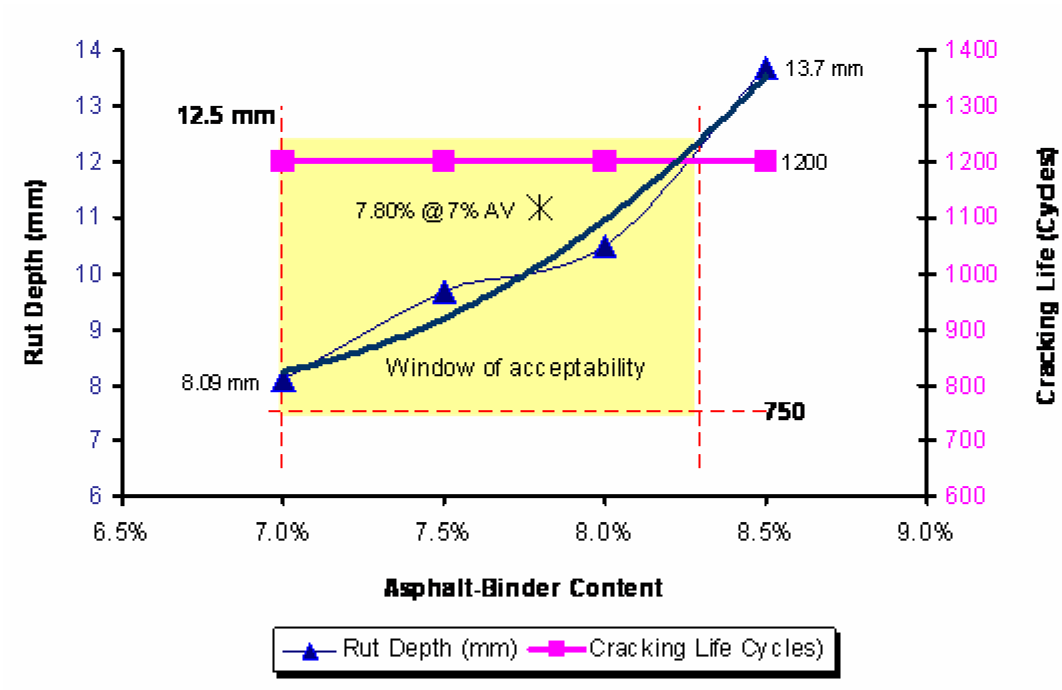

Figure 6-5. Lab Test Results for the Vulcan-Spicewood Limestone Mix.

From Figure 6-5, the window of acceptable OAC based on the 50 gyrations at 98 percent density (mix design) procedure ranges approximately from 7 to 8.3 percent. This range is reasonable for OAC selection flexibility. However, the TxDOT verification procedure at 93±0.5 percent density was only satisfactorily met at 7.8 percent OAC. So, 7.8 percent was selected as the design OAC for this mix. This mix is being considered for overlaying an approximately 1 mile section of US 281 in Marble Falls in the Austin District. This overlay will facilitate an opportunity to validate the mix-design as well as monitor the performance thereafter.

BU 59 – LUFKIN: TxDOT CAM DESIGN

As is evident in Table 6-3, this mix (8.3 percent PG 76-22S + granite) equally met all the balanced mix-design requirements and verification at 8.3 percent OAC. The mix will be placed in the fall of 2007 as a 1 inch overlay to rejuvenate an existing pavement downtown in Lufkin (Texas) on business highway BU 59. The existing underlying pavement structure is jointed concrete with approximately 3 to 4 inches of existing HMA. Load transfer measurements were undertaken, and the calculated LTE based on the RDD testing was judged as reasonable, i.e., greater than 80 percent. The existing surface cracks were considered to be largely caused by thermal movements of the slabs. Figure 6-6 shows an example of the measured RDD surface profiles, while Figure 6-7 is an example of transverse cracking observed on BU 59.

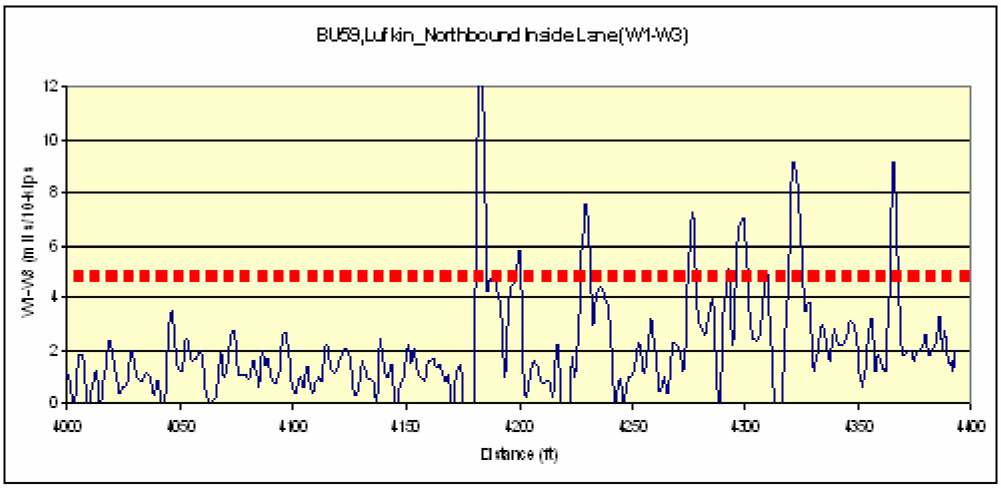

Figure 6-6. RDD Surface Profiles on BU 59 (Lufkin).

Figure 6-7. Example of Transverse Cracking on BU 59 (Lufkin).

Considering Scullion's (2006) proposed criteria discussed in Chapter 3 of this interim report, the approximately 5 mils average deflection in Figure 6-6 would be judged as good. Based on this proposed criteria, this level of LTE does not call for mandatory major rehabilitation activities, but it does indeed indicate the need for an overlay. As shown in Figure 6-8, GPR measurements also did not detect any other potential defects or major problems such as moisture entrapment.

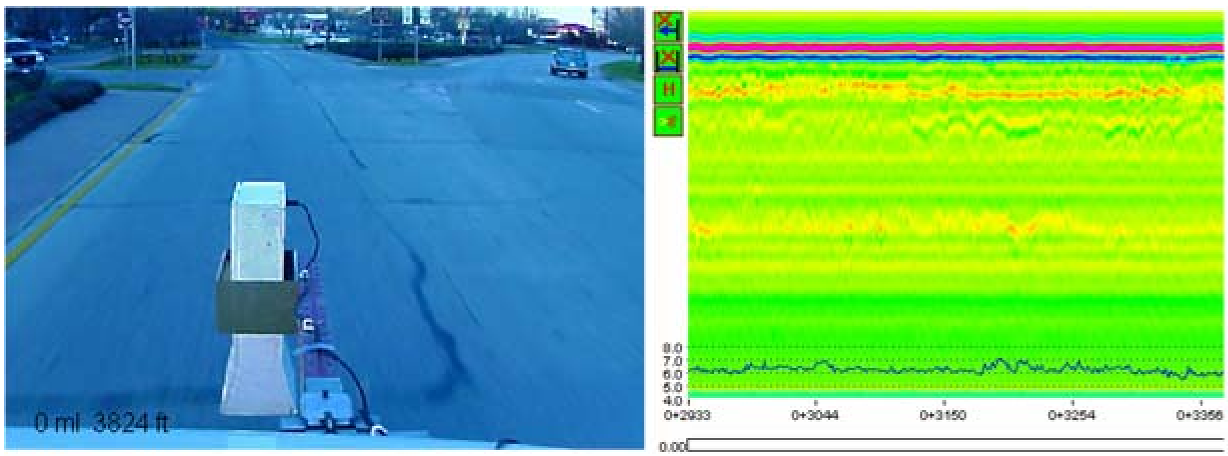

Figure 6-8. GPR Measurements on BU 59 (Lufkin).

As BU 59 is a high traffic volume city road, with a low traffic speed of around 30-40 mph, it will provide an ideal framework to validate the mix design. Because of the high volume and slow traffic, this mix will be a critically interesting project to watch for possible rutting and wheel path bleeding problems.

Although both the RDD and GPR did not indicate the need for major rehabilitation, this project will be very critical to this study for monitoring the probability of the cracks propagating through the new thin HMA overlay to the surface in the future. Numerous transverse cracks were visually observed on the existing pavement structure.

BROWNWOOD: TxDOT CAM DESIGN

Tables 6-2 and 6-3 show that the Brownwood limestone at 53 percent type F rock and 47 percent screenings satisfactorily met the CAM SS 3109 specification (TxDOT, 2004b). The Hamburg and overlay test results in Figure 6-9 below shows that the window of acceptable OAC for this mix is extremely very narrow, 7.8 to 7.95 percent. Based on these results, 7.9 percent was tried as the design OAC. Verification results at both 93±0.5 and 96±0.5 percent densities are shown in Table 6-4.

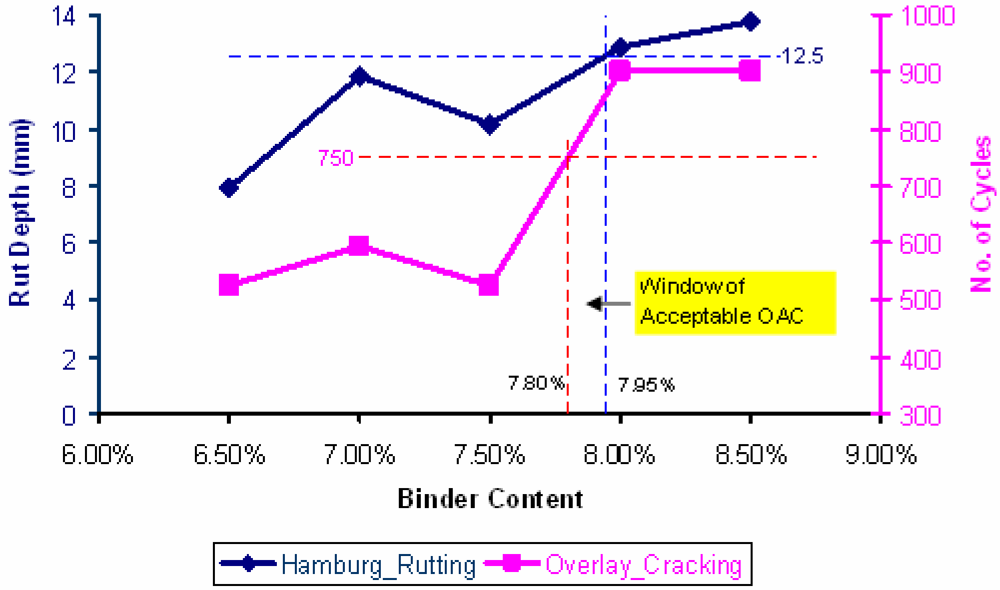

Figure 6-9. Lab Test Results and OAC Selection for the Brownwood Limestone Mix.

Table 6-4. OAC Verification Results at 93±0.5 Percent and 96±0.5 Percent Density – Brownwood Limestone.

OAC	Target AV	Specimen AV	Overlay Tester Cycles	Hamburg	
				Number of Load Passes	Rut Depth (mm)
7.9%	7±0.5%	6.8%	763	16,215	13.91
7.9%	4±0.5%	4.4%	900	20,000	11.78

According to Table 6-4, the 7.9 percent OAC fails at 93±0.5 percent density, but passes only at 96±0.5 percent density. In general, this mix exhibited greater difficulty in meeting the 98 percent target density at 50 gyrations during the mix design and OAC selection process. A density as low as 91.4 percent was in fact obtained for one of the trial asphalt-binder contents.

JONES MILL: TxDOT CAM DESIGN

This mix (8.3 percent PG 76-22S + granite) was also designed at TTI consistent with the mix design procedures discussed in Chapter 3 and in line with the TxDOT CAM SS 3109 specification (TxDOT, 2004b). The Hamburg-overlay laboratory test results and the window of acceptable OAC are shown in Figure 6-10.

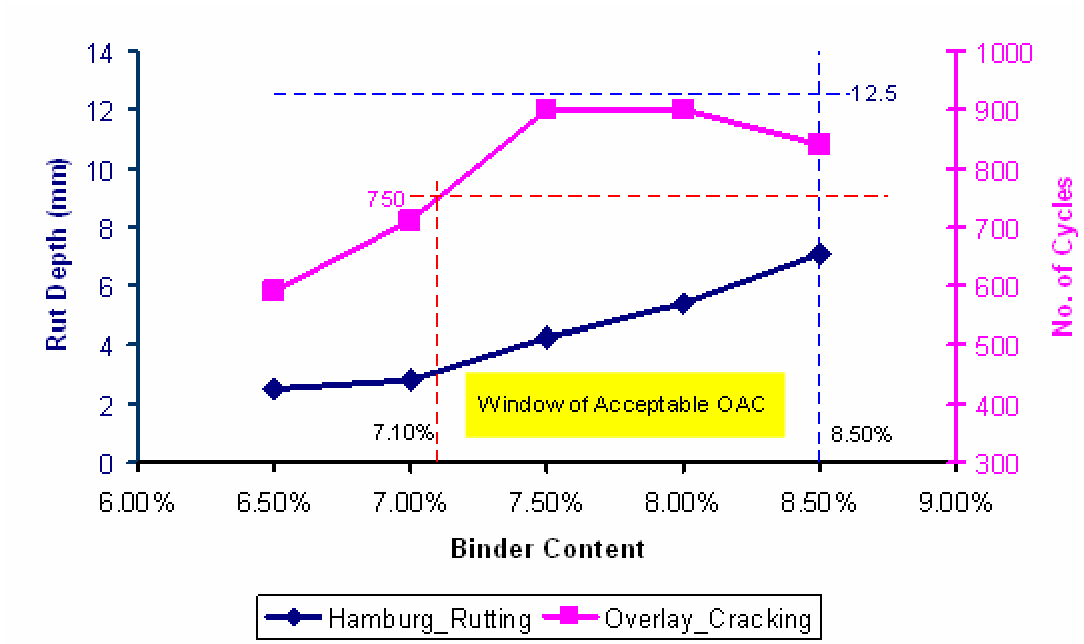

Figure 6-10. Lab Test Results and OAC Selection for the Jones Mill Granite Mix.

Based on Figure 6-10, the window of acceptable OAC is from 7.1 to 8.5 percent, which is considerably wide. Consequently, Hamburg and overlay performance tests for OAC verification were conducted at three asphalt-binder contents (7.5, 7.9, and 8.3 percent) to select the final design OAC. Table 6-5 shows the results for these tests. Another test was also conducted at 96±0.5 percent density for the OAC at 7.9 percent, and the results are shown in Table 6-6.

Table 6-5. OAC Verification Results 93±0.5 Percent Density – Jones Mill Granite.

OAC	Specimen AV	Overlay Tester Cycles	Hamburg	
			Number of Load Passes	Rut Depth (mm)
7.5%	7.6%	852	20,000	5.65

7.9%	6.9%	900+	20,000	8.13
8.3%	7.1%	900+	20,000	8.96

Table 6-6. OAC Verification Results at 96±0.5 Percent Density – Jones Mill Granite.

OAC	Specimen AV	Overlay Tester Cycles	Hamburg	
			Number of Load Passes	Rut Depth (mm)
7.9%	4.3%	900+	20,000	4.50

It is clear from both Tables 6-5 and 6-6 that all the selected OACs meet the verification requirements at both 93±0.5 and 96±0.5 percent target density. The final selected design OAC would be 8.3 percent for this mix. Evidently, this high OAC would also sufficiently allow room for construction variability and possible asphalt-binder absorption by the aggregates. In fact, this mix was found to be the best mix designed so far in this interim report.

UVALDE – KNIPPA: TxDOT TYPE D

From Figure 6-11 below, the window of acceptable OAC for this mix (PG 76-22S + trap rock) is 6.9 to 7.8 percent, a reasonably wide window of acceptable OAC. OAC verification tests were conducted at 6.9, 7.3, and 7.7 percent asphalt-binder contents, and the results are shown in Table 6-7.

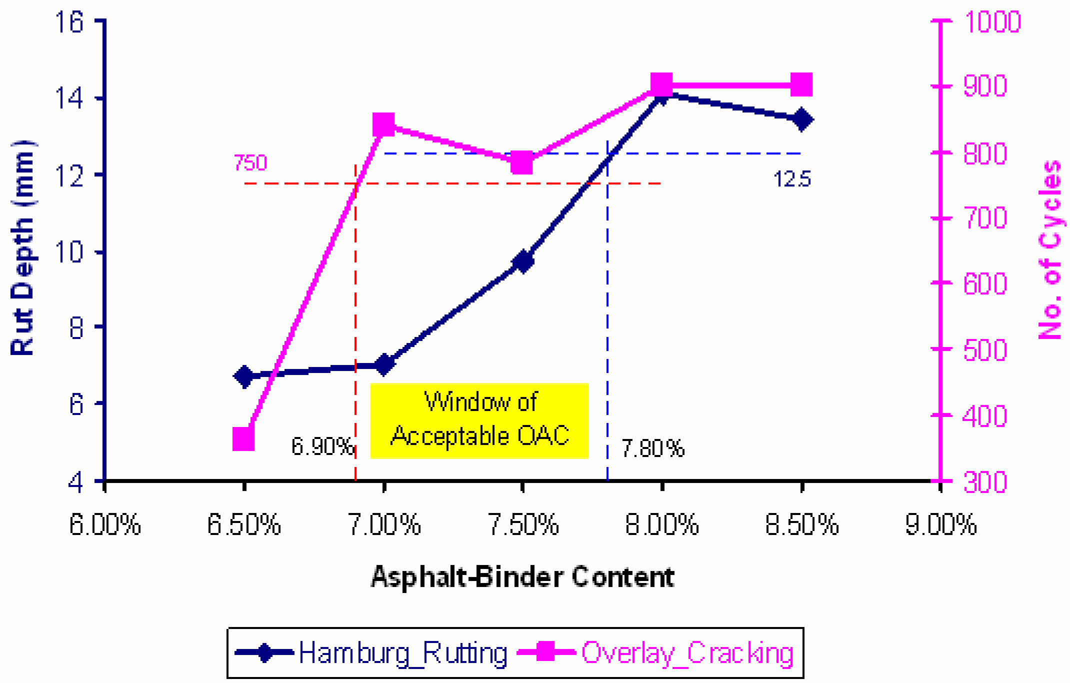

Figure 6-11. LabTest Results and OAC Selection for the Uvalde Trap Rock Mix.

Table 6-7. OAC Verification Results 93±0.5 Percent Density – Uvalde Trap Rock.

OAC	Specimen AV	Overlay Tester Cycles	Hamburg	
			Number of Load Passes	Rut Depth (mm)
6.9%	7.2%	590	20,000	10.8
7.3%	6.7%	763	20,000	10.5
7.7%	7.2%	815	20,000	11.8

Although 7.7 percent would be selected as the design OAC, both Tables 6-3 and 6-7 show that the mix barely passed the laboratory Hamburg requirements at this OAC level. Consequently, a supplementary verification test was performed at 96±0.5 percent density for the 7.7 percent OAC. The results are shown in Table 6-8.

Table 6-8. OAC Verification Results at 96±0.5% Density – Uvalde Trap Rock.

OAC	Specimen AV	Overlay Tester Cycles	Hamburg	
			Number of Load Passes	Rut Depth (mm)
7.7%	4.6%	900+	20,000	9.60

Although, the actual specimen AV deviated slightly by about +2.2 percent from the target 4±0.5 percent AV, Table 6-8 shows that both the Hamburg and overlay requirements were satisfactorily met for the 7.7 percent asphalt binder at 96±0.5 percent target density. Considering that these fine-graded overlay mixes are often placed at about 97 to 96 percent target density in the field, it would not hurt to consider 96±0.5 percent density as the alternative or secondary OAC verification criteria.

FW – PUMPHREY STREET: CRUMB RUBBER AND LATEX

These two mixes (6.6 percent 64-22 + 7 percent Crumb Rubber + 1 percent Akzo + granite and 7 percent PG 64-22 + 3 percent Latex + granite) were included in this project for evaluation purposes only and to aid both in the development of the mix design and construction specifications and performance evaluation guidelines for thin overlay HMA mixes. As per TxDOT Report FHWA/TX-07/5-5123-01-1 (Zhou and Scullion, 2007), these mixes were designed as typical TxDOT Type F mixes at 96.5 percent density as follows:

(a) TxDOT Type F mix with 7 percent ground crumb rubber
   - 6.8 percent PG 64-22 + 7 percent crumb rubber + SAC class A granite aggregates.
   - OAC selected based on the overlay test (> 1200 cycles) and Hamburg test (< 12.5 mm rut depth after 20,000 passes).

(b) TxDOT Type F mix with 3 percent latex
   - 6.8 percent PG 64-22 + 3 percent latex + 1 percent Akzo (anti-stripping agent) + SAC Class A granite aggregates.
   - OAC selected based on 3.5 percent design AV, overlay test (> 1200 cycles), and Hamburg test (< 12.5 mm after 20,000 passes).

The detailed mix-design report for these two mixes can be found elsewhere (Zhou and Scullion, 2007). Note that the test data presented in Tables 6-2 and 6-3 represent the plant mix hauled from the site at the time of construction, and hence, a difference in the mix-design characteristics from the initial design indicated above and those contained in the mix-design report by Zhou and Scullion (2007).

As shown in Table 6-3 and based on the plant mix samples molded at 93±0.5 percent target density in the TTI laboratory, both mixes performed satisfactorily in the overlay test but failed the Hamburg test. With modification additives, such as crumb rubber and latex, it was not unexpected that the mixes would pass the overlay test. Accordingly, another set of plant mix samples were gyratory molded at 96±0.5 percent density and tested in the Hamburg and overlay tests, respectively. These results are shown in Table 6-9.

Table 6-9. Test Results at 96±0.5 Percent Density - Crumb Rubber and Latex Mixes.

Mix	Asphalt Binder (Plant Mix)	Specimen AV	Overlay Tester Cycles	Hamburg	
				Number of Load Passes	Rut Depth (mm)
7% crumb rubber	6.6%	<u>4.7%</u>	900+	20,000	11.26
3% latex	7.2%	4.38%	900+	<u>17,890</u>	<u>13.47</u>

At 96±0.5 densities, both mixes still pass the overlay test, but only the crumb rubber mix passes the Hamburg test. The higher than design OAC (7.2 versus 6.8 percent) could be one of the contributing factors for the latex mix's poor laboratory performance in the Hamburg test. The results, however, do indicate that the addition of crumb rubber and latex does significantly improve the mix cracking resistance observed from the overlay testing in this project. Note that the modification with crumb rubber and latex is considered to make the PG 64-22 asphalt binder equivalent to PG 76-22 asphalt-binder, and hence treating these mixes like a PG 76-22 mix in the Hamburg test.

During laboratory work, researchers generally observed that the latex mix was comparatively more difficulty to work with. It is very sticky and not as workable as the crumb rubber mix, and so was the difficultness to attain the target density. The crumb rubber mix, on the other hand, had a tendency to expand just after compaction, prior to cooling. To minimize this expansion effect, the crumb rubber mix was allowed to cool off in the mold. Unlike most HMA mixes, which are often molded at a higher AV to achieve the target AV after cutting the samples, the molding AV was about 25 percent lower than the target AV level for the crumb rubber mix, e.g., mold at 5 percent AV to get a final AV content of 7 percent.

NCAT – ALABAMA: TxDOT TYPE D CLASS A SURFACING

This mix (6.7 percent PG 76-22S + granite) was incorporated in this project for evaluation and verification purposes only. The mix was initially designed by TxDOT for accelerated performance-evaluation studies at the NCAT test track in Alabama. The results of samples molded from the plant mix in Table 6-3 indicate that the mix satisfactorily met the mix-design verification requirements at 93±0.5 percent density. However, the VMA (15.9 percent) is just barely at the 16 percent threshold recommended for CAM mixes (TxDOT, 2004b).

Note that the results in Table 6-3 are for the Type D plant-mix that was hauled from NCAT and gyratory molded at 93±0.5 percent density at the TTI laboratory. This mix was placed in a 3 inch layer thickness as the surfacing layer resting directly on a 1 inch rich asphalt bottom layer (RBL). Figure 6-12 shows the construction stages and the finished HMA surface after 3 million load applications.

12 × 15 ft HMA slab after saw cutting (10/18/06)

1 inch thick CAM [RBL] mix after construction (10/19/06)

3 inch thick Type D surfacing mix (2007; after 3 million load applications)

Figure 6-12. Dense-Graded TxDOT Type D Surfacing Mix at NCAT (Alabama).

Based on the NCAT preliminary field performance data after 3 million equivalent single axle loads (ESALs) of trafficking, the following performance results were reported: average rut depth of about 9.1 mm, about 100 in/mile average IRI (international roughness index), and about 0.75 mm mean texture depth. Preliminary evidence suggests that the underlying RBL could be the source of this high rutting. However, elaborate investigative studies such as undercutting the pavement section are underway to ascertain the actual source of this rutting.

Nonetheless, construction could be another probable cause of this substantial field rutting. Although the extracted asphalt-binder content was higher than the design (i.e., 7.3 percent versus 5.7 percent design), the field-extracted cores nonetheless passed both the Hamburg (7.31 mm rut depth) and overlay (> 750 load cycles) tests, respectively. These results for field-extracted cores from the NCAT test track are summarized in Table 6-10.

Table 6-10. Laboratory Test Results for the NCAT Type D Field-Extracted Cores.

Laboratory Test	Result
Design OAC	5.7%
Extracted asphalt-binder content	7.3%
Hamburg (core AV =2.96%)	7.31 mm
Overlay (core AV = 2.94%)	900+

US 82 – TEXARKANA: TXDOT TYPE F HYBRID

This mix (7.8 percent PG 70-22S + sandstone) was initially designed by TxDOT as a Type F Hybrid mix with a gradation similar to a ⅜" NMAS Superpave mix. It was used in emergency work to overlay the severely raveling seal coat on the in-service business highway (US 82) in Texarkana. The overlay thickness was 1 inch, placed over an approximately 0.6 miles stretch of the four-lane business highway US 82 in 2004.

This mix was incorporated in this project for evaluation and verification purposes of both the balanced mix-design concept and the initial TxDOT mix-design. Based on the laboratory test results in Table 6-3, the mix design was satisfactorily verified at 93±0.5 percent density, with 7.8 percent PG 70-22S. As shown in Figure 6-13, satisfactory field performance has also been observed with this mix after over 2 years of service, with a measured field SN value of 36 (bald tire at 40 mph). No rutting or reflection cracking was found during the January 2007 field survey, and the TxDOT district is extremely happy with its performance to date.

Figure 6-13. TxDOT Type F Hybrid Overlay Mix on US 82 (Texarkana).

SUMMARY

The ⅜" NMAS HMA mixes with high polymer modified asphalt-binder content (≥ 7 percent) and high quality clean (no dust) fine aggregates, typically Type F rock and screenings, seem to be producing promising laboratory results for use as thin overlay HMA mixes. In particular, SAC Class A aggregate with low soundness value and good polish resistance (e.g., granite, sandstone, etc) that meets the TxDOT CAM SS 3109 specification is recommended. In general, the mixes with granite aggregates were observed to be of superior laboratory performance in terms of meeting both the balanced mix-design requirements and the TxDOT CAM SS 3109 specification (TxDOT, 2004b). The bullet-list below summarizes the findings/observations from this chapter:

- The granite mixes exhibited superior laboratory performance with a reasonably wider window of acceptable OAC in general. These mixes also satisfactorily met the TxDOT CAM SS 33109 specification.
- The limestone mixes were the most problematic, particularly in achieving the 98 percent target density at 50 gyrations during the balanced mix-design and OAC selection process. In some instances the mixes deviated as high as -8 percent from the target density. Additionally, even the window of acceptable OAC was considerably very narrow such as for the Brownwood limestone; 7.8 to 7.95 percent. Their relatively high water absorption capacity may be a contributing factor and suggestive of potential for problems in the field. In general, however, the design aggregate gradations were within the TxDOT CAM SS 3109 specification.
- The Uvalde trap rock Grade 5 and screenings could not meet the TxDOT CAM SS 3109 gradation specification predominantly due to the aggregate coarseness and having a single-sized gradation. The type of trap rock evaluated in this project was quarried as single-sized graded aggregates predominantly for chip seal or seal coat applications. Additionally, these aggregates were also observed to have high dust content (about 8 percent for the screenings) with potential for asphalt-binder absorption based on the relatively high water absorption capacity measured in the laboratory. This high water absorption capacity measured in the laboratory could be indicative of potential problems in the field, i.e., reduction of the effective asphalt-binder content. However, the new gradation design, with sandstone aggregates at 50 percent Type F rock and 50 percent screenings, satisfactorily meets the TxDOT CAM SS 3109 specification; the mix-design process is currently in progress.

- For the balanced design OAC selection, it is recommended as a rule of the thumb to pick the OAC preferably at the third-quarter point of the window of acceptable OAC. This OAC level reasonably allows for construction variability while satisfactorily meeting the Hamburg rutting and overlay cracking requirements.

Based on the fact that it was problematic for some mixes to meet the 98 percent target density at 50 gyrations during the balanced mix-design and OAC selection process, consideration should be given to review and/or increase the number of gyrations. A similar review should also be done for the OAC verification procedure.

While a limited number of mixes could not satisfy the OAC verification requirements at 93±0.5 density, it was apparent that satisfactory results were, in almost all cases, obtained at 96±0.5 density. Consequently, the molding of laboratory performance test samples at 93±0.5 percent versus 96±0.5 percent density during the OAC verification process need to be reviewed. Based on the results presented in this chapter and in consideration of some construction reports that indicate the CAM type mixes are traditionally placed at around 96 percent density, these researchers feel it is reasonable to consider 96±0.5 percent density as an alternative or secondary OAC verification process in the balanced mix-design method for thin overlay HMA mixes.

CHAPTER 7
DEMONSTRATION PROJECTS

Thus far, there are about five potential demonstration projects for the thin HMA overlay application:

- Lufkin on BU 59,
- Fort Worth on Pumphrey Street,
- San Antonio on US 90,
- San Antonio on IH 37, and
- Austin on US 281.

Specifically, the two districts of Lufkin (BU 59) and Fort Worth (Pumphrey street) have already received implementation funding to construct very thin (1 inch thick) overlay surfaces. Both sections are over JCP, so both will be a very severe test for the mixes designed with the criteria described in Chapter 3. Mix designs have already been completed for these two projects. Trial construction was conducted in summer 2007 for the BU 59 project in Lufkin, while construction of the Pumphrey Street project in Fort Worth was completed in early August 2007. Both of these projects are discussed in the subsequent sections of this chapter; however, the proposed San Antonio and Austin District projects are discussed first.

THE SAN ANTONIO DISTRICT – US 90 (UVALDE) AND IH 37

The San Antonio District has nominated US 90 (near Uvalde) and IH 37 as highway locations where the researchers can apply the balanced mix-design concept and monitor the construction process and performance thereafter. The mix-design process is currently ongoing. The researchers initially used the Uvalde trap rock from Knippa quarry, but as discussed in Chapter 6, this aggregate could not meet the CAM SS 3109 specification (TxDOT, 2004a). As was presented in Chapter 6, even the screenings were too coarse and predominantly single-sized to be used as the only aggregate blend, i.e., 100 percent screenings.

The Uvalde trap rock (grade 5 plus screenings), however, sufficiently meets the TxDOT Type D (or the ⅜" Superpave) gradation, and the mix design results have accordingly been forwarded to the District for their consideration. To meet the CAM SS 3109 requirements (TxDOT, 2004b), the researchers have recommended blending with (or completely using) aggregates from different quarry sources, in particular for the screenings. Needless to say that the mix-design results in Chapter 6 suggest that the Type D gradation may equally perform satisfactorily based on the mix meeting both the laboratory Hamburg and overlay test requirements.

In view of these researchers' recommendations, the San Antonio District has supplied a new batch of sandstone aggregates, Type D and F rocks, and screenings for laboratory evaluations and mix design. As pointed out in Chapter 6, the balanced mix-design and OAC selection processes are in progress with the new sandstone aggregates. As per the district's preference, the mix is being designed with PG 76-22S from Valero Asphalt.

THE AUSTIN DISTRICT – US 281 (MARBLE FALLS)

The Austin District is considering using the Vulcan-Spicewood limestone materials with PG 76-22S as an approximately 1 inch thick overlay on a 1 mile section of US 281 in Marble Falls. Based on the mix-design results in Chapter 6, this mix satisfactorily met the balanced mix-design requirements and the TxDOT CAM SS 3109 specification at 7.8 percent OAC (TxDOT, 2004a). GPR data have been collected on this site, and there are some concerns about the structural adequacy of the section. As can be seen in Figure 7-1, there is evidence of wheel path cracking on the pavement surface and low density spots on some sections.

The severest of these cracks, as can be seen in Figure 7-2, is indicative of weak spots and a probable source for water infiltration into the pavement. The high dielectric constant at this location, seen in Figure 7-1, is confirmation of low density and weak spots. These distresses are a cause for concern prior to thin overlay placement. Consequently, discussions are currently ongoing with Mr. Howard Lyons, the area engineer, for possible additional testing and structural evaluations including field coring, if need be. An interim recommendation would be to mill off these cracked and low density/weak sections prior to any thin overlay placement.

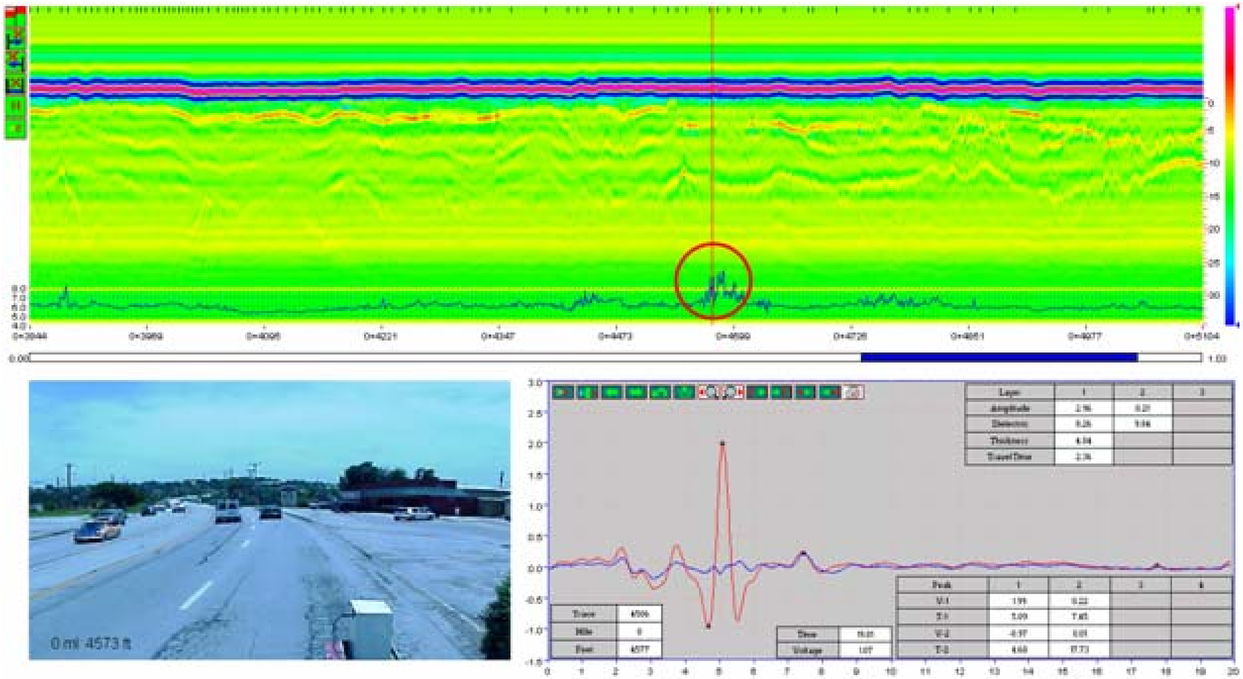

Figure 7-1. GPR Data on US 281 (Marble Falls) – Southbound Outside Lane.

Figure 7-2. Wheel Path Surface Cracking on US 281 (Marble Falls) – Southbound Lane.

THE LUFKIN DISTRICT – BU 59

In mid-August of 2007, the Lufkin District placed a short section of the CAM mix as a demonstration project just to try the mix for any possible construction problems. This CAM mix was designed by these researchers consistent with Chapter 3 of this interim report, and the mix-design results were presented in Chapter 6 as BU 59 – Lufkin (TxDOT CAM; 8.3 percent PG 76-22S + granite). The main project has been delayed to November 2007. The trial mix was plant molded at 325 °F; the haul distance was very short, and the air temperature at the time of placement was about 107 °F. It is reported that the construction crew had to leave the mix for a little while before compaction, as it was a little tender. However, no major construction problems were experienced.

Laboratory-molded densities were relatively high at 97 percent. No cores were taken at the time of construction. So far, the district is happy with both the mix design and the trial construction operation. TTI researchers will monitor and document the main construction process in November 2007.

Ready-made plant mix was taken from the trial construction site on August 15th, 2007, for sample molding and testing at the TTI laboratory. TTI conducted OAC/aggregate extractions, Hamburg, and overlay tests. The laboratory test results of the samples from the plant mix are shown in Table 7-1 and Figure 7-3.

Table 7-1. Laboratory Test Results of the CAM Plant Mix (BU 59 – Lufkin).

Laboratory Test	Result
Rice	2.341 (2.337)
Asphalt-binder content extraction	8.39% (8.2%)
Hamburg (specimen AV = 7.43%)	8.22 mm
Overlay (specimen AV = 7.16%)	900+

The numbers in parentheses in the results column of Table 7-1 represent tests conducted by the Lufkin TxDOT District laboratory. It is clear that the results are comparable.

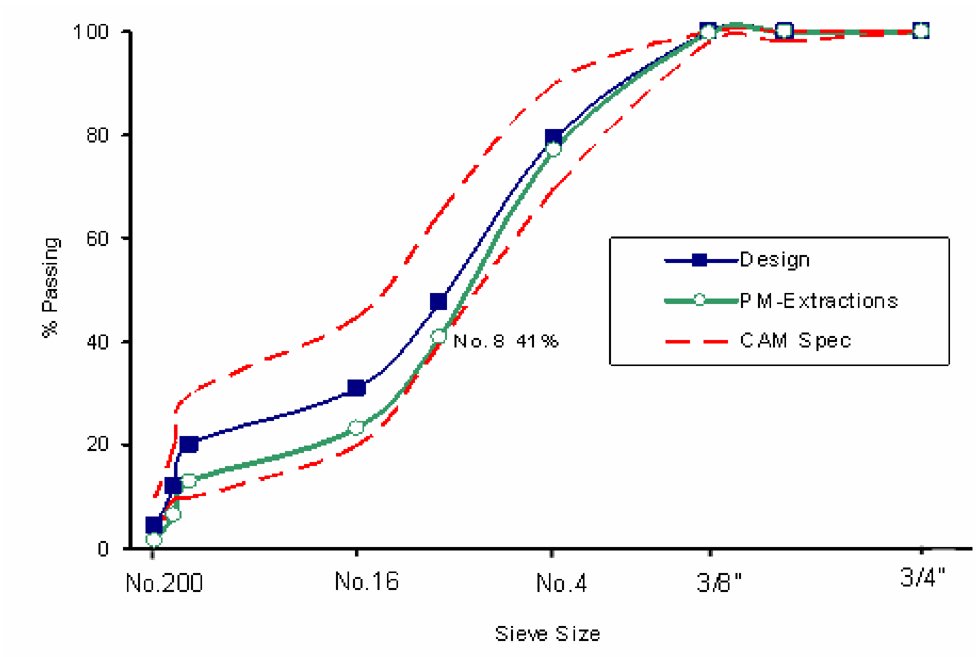

Figure 7-3. Aggregate Extractions from the CAM Plant Mix (BU 59 – Lufkin).

With some slight deviations from the design gradation and the CAM SS 3109 specification on the No. 50 and No. 200 sieves, Table 7-1 and Figure 7-3 show that the plant mix still satisfactorily met the balanced mix-design requirements (TxDOT, 2004b). Note that the Hamburg and overlay samples from the plant mix were laboratory molded to a target density of 93±0.5 percent, consistent with the TxDOT mix-design verification procedure (TxDOT, 2007).

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THE FORT WORTH DISTRICT – PUMPHREY STREET

The Fort Worth Pumphrey Street location, including the on/off ramps (to/from SH 183), was overlaid with an approximately 1 inch thick HMA overlay consisting of Type F mixes (PG 64-22 + granite), composed of crumb rubber (7 percent) in the inside lanes and latex (3 percent) in the outside lanes. The construction process occurred between July 30th and August 3rd, 2007. The plan view of the project site is shown in Figure 7-4. One of the objectives of this project is to compare the performance of the crumb rubber and latex mixes as an overlay on an old jointed concrete pavement.

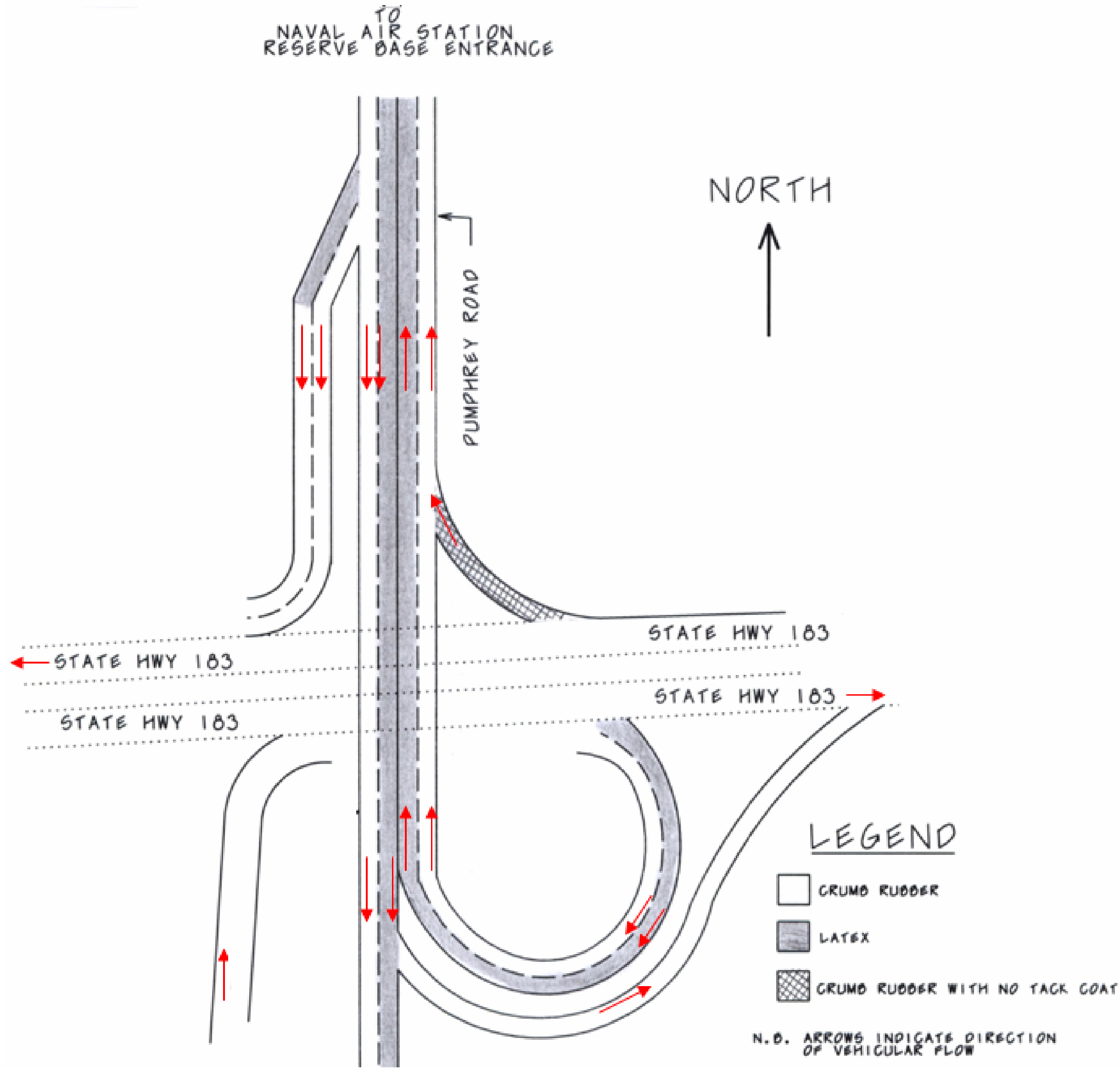

Figure 7-4. Plan View of the Pumphrey Street Project (Drawing not to Scale).

Although initially designed as a typical TxDOT Type F mix (Zhou and Scullion, 2007), both mixes based on the initial mix design satisfied both the balanced mix-design requirements and the CAM SS 3109 specification. However, samples molded from the plant mix and tested at the TTI laboratory did not pass the Hamburg test at 93±0.5 percent laboratory density; see Chapter 6. At 96±0.5 percent laboratory density, only the crumb rubber (plant mix) passed the Hamburg test. Conversely, these results may suggest potential for rutting, in particular at elevated temperatures; their field performance is yet to be observed in the planned monitoring program.

During the period between July 30th and August 3rd, 2007, TTI researchers monitored and documented the construction process of the crumb rubber mix. IR temperature measurements were also conducted and are included in the subsequent discussions. The mix placement (both the crumb rubber and latex) was undertaken by the Fort Worth Tarrant County construction crew, Precinct 4.

Pavement Surface Preparation

Typical pavement surface preparatory practices were followed. The pavement surface was bloomed and tack coated prior to HMA placement. However, as evident in Figure 7-4, one off ramp was not tack coated. This is an experiment to asses the potential of the crumb rubber to hold onto the existing pavement surface without any tack coat and, later on, asses if this has an effect on performance during the subsequent performance monitoring program.

HMA Placement and the Paving Process

The pavement surface temperature was about 106 °F, which meets the CAM SS 3109 recommendations (TxDOT, 2004b). According to the construction crew, the air temperature should at least be 42 °F and rising for construction operations such as the Pumphrey project. The air temperature was about 78 °F at the start of the construction operation, which satisfied the ≥42 °F recommendation.

No material transfer device was engaged in this construction operation. The trucks dumped the hot-mix directly into the paver. This operation is shown in Figure 7-5.

Figure 7-5. Paver Operation on the Pumphrey Street Project – Fort Worth.

Infra-Red Temperature Measurements

TTI conducted IR temperature measurements on this project during placement of the crumb rubber mix on the outside southbound lane, from the entrance towards SH 183. The IR set-up and measurement concepts were discussed in Chapter 4 of this interim report. The IR-measured mat surface temperature profiles are shown in Figure 7-6.

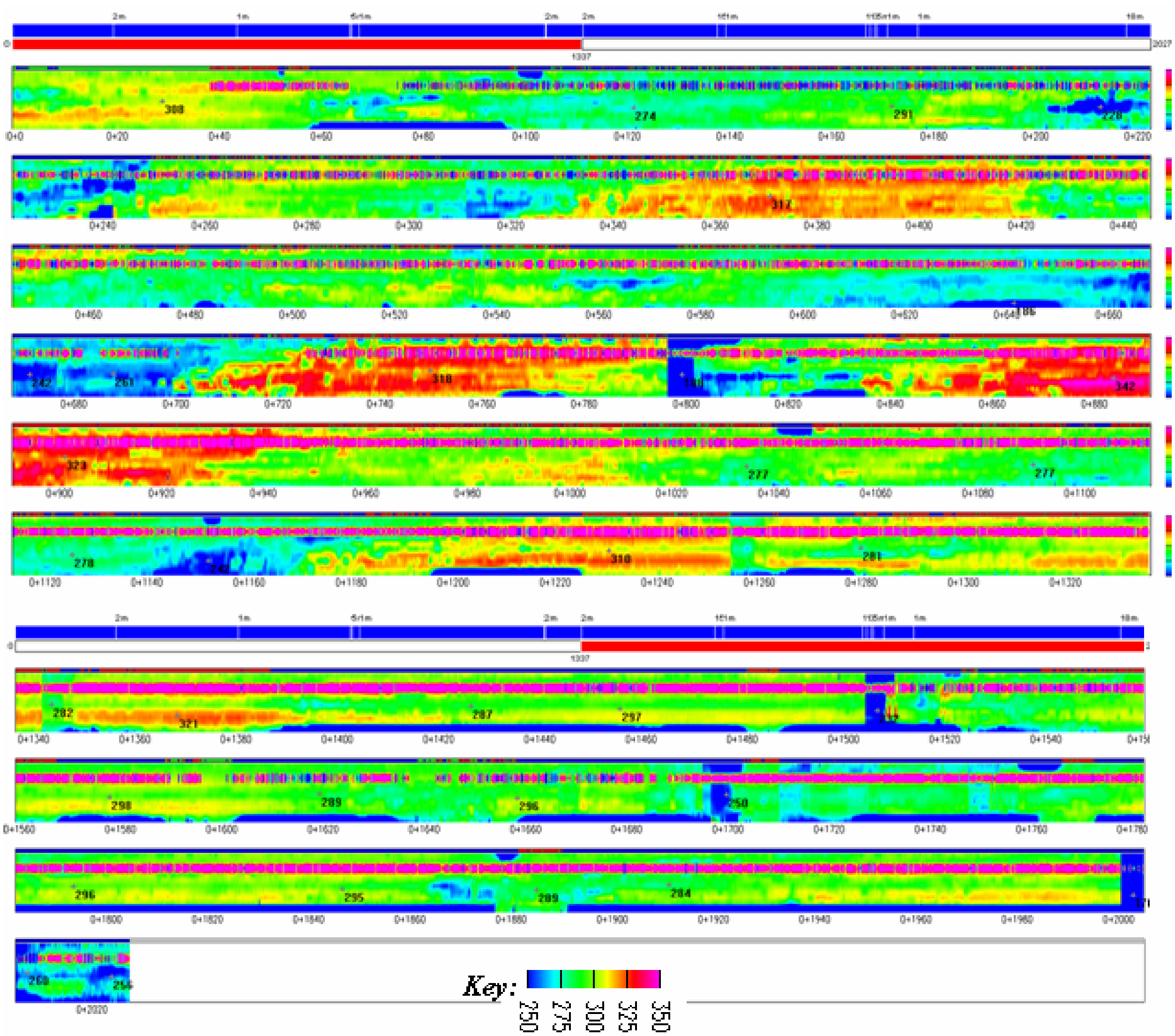

Figure 7-6. IR Thermal Profiles Measured on Pumphrey Street (Crumb Rubber Mix).

Figure 7-6 is the surface temperature profile for the full lane width for 2027 ft of new mat. The distance scale is under each plot. The key for the different colors is also shown in the bottom center of the figure. The detailed description of the thermal color coding is discussed subsequently.

In Figure 7-6, the red colors represent temperatures around 300 °F, whereas the blues are temperatures of around 220 °F. The green colors represent temperatures between 235 and 270 °F. The numbers on the plot are the actual temperatures at that location. The pink uniform horizontal line across each temperature bar profile is not to be considered as a reading or measurement. It is an indication of a loose connection or a dysfunctional IR sensor. In general, blue is the undesired IR thermal color reading, as it often indicates cold spots. For a target mat placement temperature of 300 °F with a tolerance of ±30 °F, the green and red IR thermal color readings would be considered as acceptable. Also, a consistently uniform IR thermal color reading, such as just green or red, indicates uniform mat temperature, which is desired. The blue strips at the edges indicate points where the IR sensors had gone over the side curb and are not to be considered in the thermal data analysis and interpretations.

As shown in Figure 7-6, the mat temperature was hardly uniform. There are some intermittent sections of green (about 290 °F) and red (about 318 °F) IR thermal color readings, which could be a cause for concern with respect to uniformity in the compaction operation. Additionally, there is also clear visual evidence of intermittent cold spots (bluish) of thermal segregation in the mat. These cold spots were predominantly caused by paver stops and most often coincided with the end of every truck load of HMA. In more than two instances, the paver had to stop for over 20 minutes while waiting for the truck loads of HMA. Furthermore, as can be seen from Figure 7-6, there was a significant variation in the HMA temperature of the truck loads; some where hotter, while some were cold.

These thermal variations may have an impact on the compaction operation, which could lead to non-uniformity in the target compaction thickness and having other defects such as bumps in the completed mat. In particular, researchers observed that more compaction rolling passes were applied on the cold sections to attain the target 1 inch thickness. The planned comparative performance monitoring program of this project will allow an opportunity to monitor the effect of these thermal variations and cold spots on performance. Nonetheless, the average mat temperature was about 290 °F.

Compaction

Two steel rollers, an 18 ton and 5 ton (shown in Figure 7-7), in static mode were used for the compaction operation on the southbound outside lanes. The 18 ton was used as the breakdown roller in two to four passes, with the 5 ton as the finishing roller at two to three passes. Rolling compaction in vibration mode was only conducted at joints.

Figure 7-7. Rolling Compaction – Tarrant County 18 and 5 Ton Rollers.

To accelerate the compaction operation, two 18 ton steel rollers at about two passes each were used on all the other lanes for both the crumb rubber and latex mix. The 18 ton breakdown roller generally followed just behind the paver, but there were a few instances where this pattern was not followed. Additionally, there were also some instances of increased rolling passes, such as on the cold spots or after long spells of paver stoppage. No density measurements were conducted; only the mat thickness at 1 inch thickness was monitored.

In general, the construction crew reported that the latex mix was comparatively less workable; it is very stick and difficult to hand work. By contrast, the crumb rubber required more rolling passes to attain the target mat thickness, supposedly due to its tendency to expand, which was also experienced in the laboratory (Chapter 6). The construction crew also reported that the crumb rubber retained heat much longer than the latex mix. They reported that the latex mix cooled off relatively faster.

Finished HMA Mat

Figure 7-8 shows the completed surfaces for both the crumb rubber and latex mixes. It is clear from Figure 7-8 that the latex mix did not achieve a final surface as smooth as the crumb rubber mix. Nonetheless, the mixes' performance will be monitored and compared.

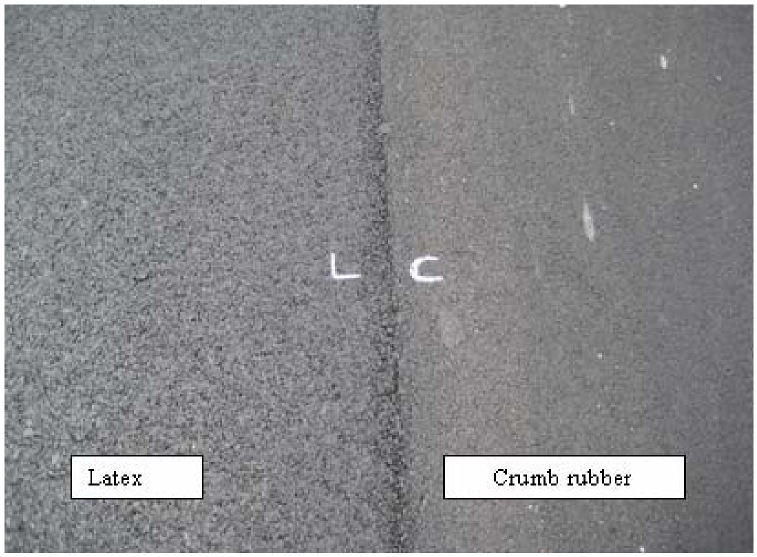

Figure 7-8. Finished HMA Mat – Latex and Crumb Rubber Mixes (Pumphrey Street).

Apart from expressing difficulties in working with the latex mix, the Tarrant County construction crew did not report any major problems, besides the rains disrupting the construction operations.

OTHER PROJECTS

The US 82 (Type F-Hybrid, Texarkana), NCAT test track (Type D, Alabama), and IH 45 (RBL, Houston) are some of the projects that will be monitored to aid in the development of the specifications for thin HMA overlays. TxDOT paid for the inclusion of a CAM mix into the current NCAT test track. This is a national study where the Texas mix is been tested under accelerated loading against mixes from other DOTs. The plan is to put a traffic loading of up to 10 million 18 kip ESALs in approximately a 1 year's period; currently, the mixes have had approximately 4 million 18 kip ESALs. Details of the NCAT test track can be found on www.pavetrack.com.

As part of this project, TTI has requested samples of the mixes used by other DOTs on the NCAT test track so they can be evaluated in both the Hamburg and overlay tester. Rutting and cracking properties are being measured in the TTI laboratory. The goal is to compare our laboratory criteria with the field performance and make modifications/improvements where necessary.

CONSTRUCTION SPECIFICATIONS

In reference to the CAM SS 3109 specification, work is currently ongoing, drafting the construction specification and guidelines for thin overlays. However, elaborate reviews will be made after the construction season based on the site observations, such as the Pumphrey Street project in Fort Worth and the upcoming BU 59 project in Lufkin in November 2007. Recommendations on construction specifications, with full details, will be included in the future reports (R2).

STRUCTURAL EVALUATIONS AND PERFORMANCE MONITORING

With respect to structural design considerations, the intent is to ensure that the sections planned for the very thin overlays have adequate pavement structure and no major near surface defects (such as severe stripping about 2 to 3 inches down). Presently, visual surveys, GPR, and RDD have been utilized for the structural evaluations of existing pavements and judging their suitability for thin HMA overlay placement. These measurements are to be supplemented by limited field coring of sections suspected to be defective, for forensic investigations and laboratory testing. Researchers envisage that these same methods, together with skid resistance measurements, will be employed for performance monitoring and evaluations. Recommendations on the guidelines for structural evaluations and performance monitoring will be included in future reports (R2).

Currently, the sections on US 281 in Austin and US 90 and IH 37 in San Antonio are under structural review. However, defects (surface cracking), such as those shown in Figure 7-2 on US 281 (Marble Falls), could be a cause for concern. Some remedial measures may be necessary prior to thin HMA overlay placement.

SUMMARY

To date, there are five potential demonstration projects for the thin HMA overlay application, two on JCP pavements and three on flexible HMA pavements. As the environment and traffic are all different, these projects will be a good test case for developing Texas' "Very Thin Overlay System" based on the balanced mix-design concept and the CAM SS 3109 specification. The TxDOT-designed Type F-Hybrid mix on US 82 in Texarkana and the NCAT test track in Alabama are another addition for aiding in the development of the thin overlay HMA specifications. Nonetheless, it will be greatly appreciated to have more district projects, both on flexible HMA and rigid concrete pavements or may be even on bridge decks. Consequently, close liaison with TxDOT districts will continue.

CHAPTER 8

SUMMARY OF FINDINGS AND RECOMMENDATIONS

This chapter provides a summary of the work presented in this interim report. It includes a conclusion of the findings and recommendations. The ongoing and future planned works are also discussed in this chapter.

CONCLUSIONS AND RECOMMENDATIONS

Thus far, the balanced mix-design concept, the proposed thin overlay mix-design procedure, and the CAM SS 3109 specification are yielding potentially promising laboratory results for the proposed very thin overlay HMA mixes. These mixes typically consist of a ⅜" NMAS aggregate gradation of predominantly Type F rock and screenings, with a high polymer modified asphalt-binder (PG 76-22S) content on the order of about 7 to 8.5 percent. However, consideration to review the 98 percent target density at 50 gyrations and the OAC verification procedure at 93±0.5 percent density should be undertaken. It was very problematic, in particular, for the limestone mixes to attain the 98 percent target density at 50 gyrations. Also, while some mixes barely passed the OAC verification procedure at 93±0.5 percent density, satisfactory results were, in almost all cases, obtained at 96±0.5 percent density.

Based on the laboratory results presented in this interim report, the CAM SS 3109 specification seems to be satisfactory for the thin overlay aggregates, including the gradation characteristics. In general, high quality clean (no dust) SAC Class A aggregates with low soundness value (< 20 percent), such as the granite and sandstone, exhibited superior laboratory performance based on the Hamburg and overlay tests. Additionally, it is also proposed that such aggregates have a reasonably low WAC of preferably less than 2 percent. This low WAC helps in minimizing asphalt-binder absorption by the potentially water absorptive aggregates such as limestone and the trap rock, with a net result of reducing the effective asphalt-binder content. As the BPT produced pessimistic results, skid resistance characteristics will be measured using TTI's newly acquired DFT device. Recommendations will be included in a draft aggregate specification to be submitted in later reports (R2).

For the materials and mixes evaluated in this interim report, the order of decreasing superior laboratory performance was granite, sandstone, trap rock, and limestone. Nonetheless, these mix designs are yet to be validated for field performance in the demonstration and implementation projects. A complete draft mix-design specification for very thin HMA overlays will be submitted after conducting field performance monitoring and evaluations of selected demonstration/implementation projects.

By contrast, the Hamburg test was found to be too severe for the cold-laid maintenance mixes (HMCL and LRA), particularly at elevated temperatures under wet conditions. While their field performance is fairly satisfactory, these mixes performed poorly during laboratory evaluation in the Hamburg and overlay tests, with visual evidence of stripping. In the absence of water at ambient temperature, however, their laboratory performance was excellent in the Hamburg test, suggesting that these cold-laid mixes are good for application in dry areas but may not perform well under wet conditions or if water infiltrates into the mix. In view of their satisfactory field performance, more laboratory research is recommended with these mixes.

ONGOING AND FUTURE PLANNED WORK

The bullet-list below provides a description of the ongoing and future planned work:

- Explore other high-quality aggregate types and sources, such as crushed gravel, sandstone, and limestone from Capitol Aggregates, for mix designs and laboratory evaluations. In particular, the gravel from the Del Rio quarry has a very low soundness value of 3, while that from Hoban is of a SAC class A. These aggregates will be a good target, especially the gravel that was not evaluated in this interim report. Also, the sandstone from Brownlee quarry, with a SAC class A, is a potential candidate. Exploration with the limestone from Marble Falls is also another feasible option as the limestone from this quarry appears to be of good quality (SAC class B with a soundness value of 9).
- Conduct skid resistance in the laboratory using the DFT device and, if possible, in the field on the demonstration/implementation projects as well. The DFT device is portable and is applicable for both laboratory and field tests. TTI has just recently purchased a DFT device.

- Explore other finer HMA mixes, such as the smoothseal and fiber screed. These mixes are briefly discussed in the subsequent text.
- Continue liaison with the districts for the monitoring of ongoing/upcoming construction projects and performance monitoring thereafter. In line with this task, TTI will monitor and document the scheduled construction of the implementation projects such as on BU 59 in Lufkin in November 2007. On the same basis, liaison will also continue with the districts for additional demonstration/implementation projects, as deemed necessary.
- Continue conducting periodic performance monitoring/evaluations and acquiring of additional field performance data on already existing projects, such as US 82 in Texarkana, the NCAT test track in Alabama, and Pumphrey Street in Fort Worth. Field performance data from these project sites will aid in validating the laboratory mix-design criteria and development of the construction and performance monitoring/evaluation guidelines for the thin HMA overlays.

In view of the fact that there are currently some demonstration/implementation projects in-service and/or scheduled for construction, considerable effort will now be devoted to developing the construction specifications and performance evaluation guidelines in the next phase of this project. On the same basis, the structural design considerations and test methods adopted in judging a pavement's candidature and suitability for a very thin HMA overlay will be reviewed and evaluated. The draft specifications and guidelines will be documented in future reports (R2).

Smoothseal (from Ohio)

These researchers have sourced both plant mix and raw materials (asphalt binder and aggregates) for the smoothseal mix from Ohio, which are currently under laboratory evaluation in the TTI laboratory. Laboratory test results and findings including the full mix characteristics will be reported in the future reports (R2).

The smoothseal mix (Type B) is reported to be performing satisfactorily as an approximately 1 inch thick overlay in Ohio. It is thus considered a good candidate mix for incorporation in this project. The smoothseal mix was discussed in the literature chapter of this interim report; see Chapter 2 and Appendix A. However, full details of the smoothseal mix can be found elsewhere (Technical Bulletin, 2002; FB, 2007).

Fiber Screed

In this phase of the project, these researchers conducted limited Hamburg tests on samples molded from the plant-mix of the fiber screed. Details of the fiber screed, together with the mix-design details, will be included in future reports (R2). Due to the very high asphalt-binder content nature of this mix, special improvised molds were used for fabricating the specimens. As shown in Figure 8-1, failure in the Hamburg test at 122 °F occurred just after 124 load passes.

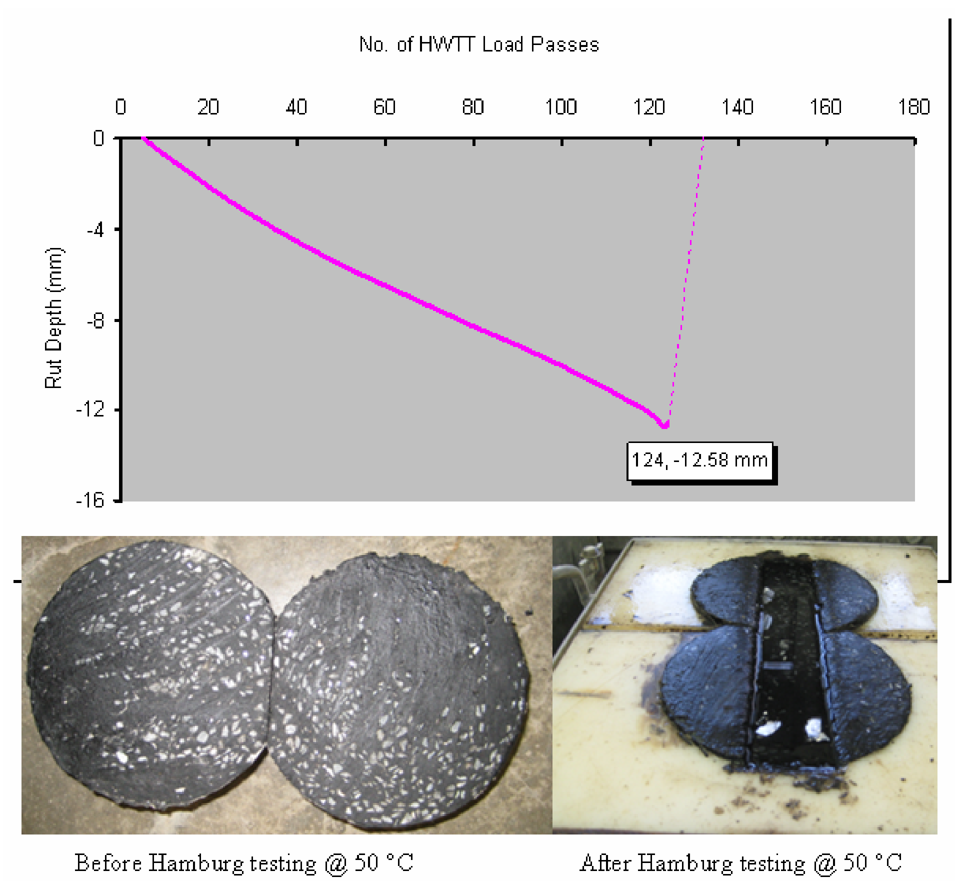

Figure 8-1. Hamburg Test Results for the Fiber Screed Plant-Mix.

By contrast, field reports indicate that this mix is performing well, with no evidence of major rutting where it has been used on rigid concrete pavements in Texas. Consequently, these researchers plan to conduct more tests in the next phase of this project by exploring different test conditions, such as prolonged oxidative aging exposure and other additives such as spraying fine aggregates on the sample surface. In the previous Hamburg tests, no fine aggregates were sprayed on the sample surfaces as it was reported to be for aesthetic appearance only. Additionally, no overlay tests were conducted mainly for two reasons: (1) due to the higher than normal asphalt-binder content, the samples could not hold up without falling apart at room temperature, and (2) with such a high asphalt-binder content, it is most obvious that the samples will satisfactorily pass the overlay test, so it was deemed unnecessary to run the overlay tests.

The fiber screed is also reported to have excellent thermal properties, ideal for crack sealing. Consequently, as per TxDOT's request through Dr. Dar-Hao Chen, 6 inch diameter by 6 inch in height and 4 inch diameter by 6 inch in height samples were molded for evaluating their thermal properties. These samples are shown in Figure 8-2, and laboratory tests are currently ongoing at The University of Texas at Austin and the Center of Transportation Research.

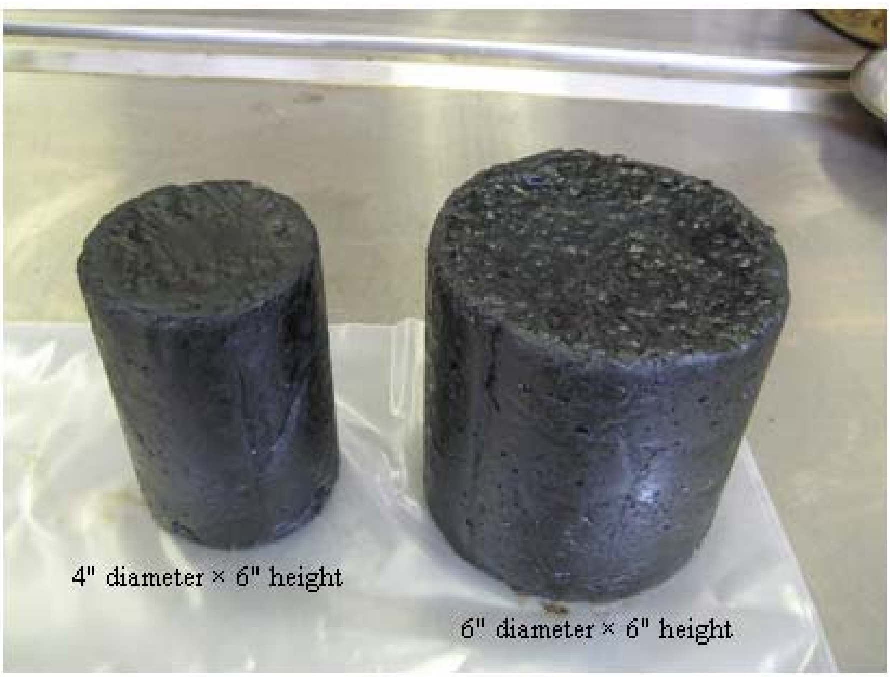

Figure 8-2. Fiber Screed Samples for Thermal Properties Testing.

DELIVERABLE PRODUCTS

The required deliverable product P1 "Manual for the Design and Construction of thin Overlays" from this project is due on August 31, 2008. This product will be submitted on that date and will also be included in the future report (R2) due on October 31, 2008.

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APPENDIX A

POTENTIAL THIN OVERLAY HMA MIX TYPES

Based on the literature search, HMA mixes that are commonly used and/or can be used for thin overlay applications include stone matrix asphalt (No. 4 or ⅜" NMAS), Superpave (No. 4 or ⅜" NMAS), Smoothseal, ultra-thin HMA, ultra thin friction course, NovaChip[RM], micro surfacing, asphalt rubber, TxDOT Type C, TxDOT Type D, etc. Some of these mixes are briefly discussed in this appendix.

SMOOTHSEAL – OHIO

Smoothseal is a PM surface treatment HMA mix developed by the Ohio Department of Transportation (ODOT) that is designed specifically for thin lift thickness placement of less than 1 inch, in the order of 0.375 to 1.5 inch thickness (Technical Bulletin, 2002; FB, 2007). Smoothseal was developed for structurally sound pavements showing signs of aging, oxidation, and/or minor disintegration. Among other benefits, this type of HMA overlay cost effectively extends the pavement life with lower annualized maintenance costs, results in a smoother pavement surface with a higher level of user serviceability (i.e., smoothness, comfort, and quiet ride), and provides increased pavement strength. Experience indicates an average service life of 12 years for smoothseals.

According to this Technical Bulletin (2002), candidate pavements for smoothseal should be structurally sufficient (no major rutting or fatigue cracking) to last the expected life of the PM treatment. Ideally, smoothseal should be used wherever pavement preservation is the primary objective of the treatment and should be applied on pavements exhibiting surface distresses such as raveling, minor cracking, porous, and/or permeable. Where there are significant structural defects (e.g., rutting greater than 0.25 inches or fatigue cracking), thicker overlays or pavement reconstruction is recommended.

Two types of smoothseal exists, Type A and Type B, and they predominantly differ in aggregate NMAS and asphalt-binder content. All use polymer-modified asphalt binders equaling or exceeding a PG 76-22M (where the letter “M” stands for modified). These mixes are shown in Figure A-1, and their aggregate gradations and other mix characteristics are listed in Table A-1.

Figure A-1. Type A and B Smoothseal Mixes (FB, 2007).

Table A-1. Aggregate Gradation Requirements for the Type A and B Smoothseal.

Sieve Size	**Smoothseal Type A**	**Smoothseal Type B**
½"	100	100
⅜"	100	95 – 100
No. 4	95 – 100	85 – 95
No. 8	90 – 100	53 – 63
No. 16	80 – 100	37 – 47
No. 30	60 – 90	25 – 35
No. 50	30 – 65	9 – 19
No. 100	10 – 30	-
No. 200	3 – 10	3 – 8
Mix-Design Characteristics		
Mix-design method	Recipe mix	Marshall method
Typical blend	Mason and concrete sands	½" maximum sized aggregate and sand
Asphalt-binder content	8.5%	≥ 6.4%
Additives	Silicon Dioxide	Silicon Dioxide, 10% RAP also permitted
Overlay thickness	0.625" < thickness < 1.125"	0.75" < thickness < 1.5"

Type A is a recipe finer blend mix of asphalt sand and mason sand with 8.5 percent modified asphalt-binder content. Type B is a Marshall method designed smoothseal mix with ½" maximum sized coarse aggregates and sand particles with a minimum asphalt-binder content of 6.4 percent used on light, medium, or heavily trafficked highways. For heavy traffic conditions, 100 percent two-faced crushed coarse aggregates that provide improved internal friction characteristics and stability are recommended for the Type B smoothseal. For consistent mix performance, a dense aggregate gradation with a narrow band is desired (Table A-1). For both Types A and B, high silicon dioxide content with natural sand is recommended to ensure sufficient frictional characteristics and skid resistance. For enhanced performance, durability, and stability, the use of high quality crushed aggregates and polymer-modified asphalt-binders (e.g., SBR latex rubber, SBS, etc.) is strongly recommended; this applies to both smoothseal types. Ten percent RAP material is also permitted in the Type B smoothseal mix.

With respect to application, a smoothseal overlay typically consists of a single course layer less than or equal to 1.5 inch thick. In general, sufficient thickness must be specified to permit proper placement and adequate compaction of the overlay over the pavement irregularities without exceeding the mix's minimum (1.5 × NMAS) or maximum (3× NMAS) layer thickness requirements. Sufficient compaction thickness should be at least 1.5 times the NMAS over high spots and, at most, three times the NMAS in low spots (i.e., depressions). Consequently, the appropriate compaction lift thickness ranges for Type A and B are 0.625 to 1.125 and 0.75 to 1.5 inch, respectively. Type A smoothseals are suitable for medium traffic and urban applications, while Type B is suitable for most applications including heavy duty and high speed applications. However, all smoothseal mixes require more rigorous and tight QC/QA procedures.

Due to the potential of thin overlay mixes cooling more rapidly than conventional mixes, the production and mix temperature should be high enough to facilitate field compaction without causing binder drain down during transit and/or placement. In general, high temperatures are required for polymer-modified mixes; a temperature (T) range of 290 °F ≤ T ≤ 350 °F is recommended. Uniform mix production, uniform mix temperature, uniform mix delivery to site, uniform head of material in front of screed, and uniform compaction are some of the key aspects to ensure the success and adequate placement of a smoothseal. Because of the high polymer-modified asphalt-binder content and stickiness, handling and raking should be minimized.

All other surface preparatory and placement procedures should follow typical practices. Feathering should be avoided. Butt joints may preferably be used for joint constructions. Typical conventional practices should also be exercised for traffic control during overlay placement. However, these overlays may also be placed at night when weather conditions permit satisfactory compaction. While light vehicular traffic may be allowed, normal traffic should be kept off the overlay until it has cooled to below 150 °F after placement to avoid deformation or glazing under traffic. In summary, the construction specifications for smoothseal include the following:

- Surface temperature ≥ 60 °F.
- Use only non-vibratory static steel wheel rollers – no pneumatic tired wheel rollers.
- Typically apply up to five passes.
- Because of high PG asphalt-binder grade the mix must arrive at the job site hot, no less than 300 °F.
- The mix must be sufficiently hot to compact, but not so hot as to cause asphalt-binder drain down.
- The mix must be at least 209 °F at the time of compaction.
- No dumping on the ground - transfer devices are normally used.
- No anti-strip used with these mixes.
- No density testing is done on these thin lifts.
- It requires minimal hand work.

Thus far, Ohio is happy with both the constructability and performance of the Type B smoothseal. It is a highly durable, rut-resistant, and skid-resistant fine-grade HMA mix, ideally suited for thin PM applications and as a long-lasting surface in rehabilitation or new construction pavement build-ups. Use of this mix produces a smooth quiet ride, with a reasonably high skid resistant surface. Performance data on the existing Type B smoothseal projects indicate skid numbers over 34 based on the ribbed tire skid resistance tests. By contrast, there have been some reported early construction problems with the Type A smoothseal mix, and the Ohio City of Englewood has in fact stopped using this smoothseal type (Rand, 2007).

In general, smoothseal (Type A or B) does not retard reflection cracking. On composite pavements, most cracks reappear very quickly, just after about two to four months. However, even though these cracks reappear, little secondary problems have been reported in Ohio (Rand, 2007). Nonetheless, these observations suggest that smoothseal may not be used for reflection crack retardation. Also, Ohio contractors have reported difficulties for lift placement less than 0.75 inch thick.

Smoothseal costs may vary depending on quantity, location, and other factors, but the pay items may include traffic type (light, medium, or heavy), particularly for Type B smoothseal mixes. On a cubic yard cost comparison basis, smoothseal costs about 35 percent more than conventional HMA mixes. However, the in-place cost per square yard is a lot less than conventional HMA mixes, \$2.58 against \$3.83 (Rand, 2007).

THE ULTRA THIN FRICTION COURSE

UTFC was developed in France and is reportedly used in Australia, Denmark, Ireland, Russia, South Africa, Spain, and the UK (Gilbert et al., 2004). UTFC is a PM HMA mix applied as a cost-effective thin surfacing, in a lift thickness of about 0.4 to 1 inch, to enhance the service life of an existing and structurally sufficient pavement. These new thin surfacings offer high quality functional properties including improved skid resistance, road noise reduction, spray reduction, and surface sealing. UTFC is a special group of open to gap-graded HMA mixes, which typically consist of high quality single sized aggregates, a fine crusher dust, and about 4 to 6 percent straight penetration grade bitumen (asphalt binder). Relatively stiff penetration grade asphalt binders, such as 40/50 or 60/70 depending on the environment and traffic, are used.

The gradation generally has less than 22 to 28 percent of aggregates passing the No. 8 sieve, and the remainder of the aggregate consists of a single-sized rock (between 0.26 inch and 0.51 inch). The gradation gap between the No. 8 and No. 4 ensures adequate VMA and stone-on-stone contact. Because of this gap grading, UTFC is often called ultra-thin gap-graded asphalt (UTOGA) in Australia, gap-graded asphalt placed onto an emulsified-bitumen bond coat and lightly rolled. Anti-stripping agents and fillers, such as lime, may be added to enhance binder adhesion to potentially problematic aggregates.

The South African UTFC is currently designed according to the Marshall method and may be used for all traffic regimes. The construction process basically consists of a self-priming paver followed immediately by about a 10 ton steel-drum static roller with the HMA mix at about 330 °F and the tack coat emulsified pavement surface at about 149 °F (Gilbert et al., 2004). According to Gilbert et al. (2004), the pavement surface temperature should be at least 50 °F and rising. A minimum of two compactive rolling (static) passes is typically used. Although in-situ AVs maybe specified, compaction density is often not measured because the layer is too thin to obtain meaningful results. Because of rapid curing, UTFC may be opened to traffic immediately after placement.

According to Pretorius et al. (2004), if properly designed and constructed, cost savings of about 40 percent can be attained. With the exception of some minor cases of bleeding, satisfactory performance of about 8 to 12 years service life has been reported based on the South African experience (Pretorius et al., 2004). Specifications for the UTFC can be found elsewhere (Gilbert et al., 2004).

STONE MATRIX ASPHALT (SMA)

According to Cooley Jr. and Brown (2003), fine SMA mixes with No. 4 or ⅜" NMAS constitute a viable PM option for thin overlays as they can be placed in thinner lifts with reasonable workability. If the rule for lift thickness to NMAS ratio of three (at most, i.e., $\leq 3\times$ NMAS) is used, a No. 4 NMAS mix could be placed to a lift thickness of less than ¾ inch and a ⅜" NMAS mix to a lift thickness of less than 1.25 inch. In these mixes, use of high quality fine aggregates and high polymer modified asphalt-binder contents of over 6 to about 8.3 percent is recommended to improve workability, reduce permeability, improve ride quality, improve skid resistance, improve general performance, and improve durability characteristics. In fact, fine SMA mixes are considered more workable and impermeable than conventional SMA mixes. Use of high quality aggregates also adds to better skid resistance and durability characteristics. Like conventional SMA mixes, mineral fillers and stabilizing agents such as cellulose fiber (about 0.3 percent) are also added.

To ensure adequate stone-on-stone contact, in particular for the No. 4 NMAS mixes, the break point (BP) sieve, according to Cooley Jr. and Brown (2003), should be the No. 8 sieve and the void in the coarse aggregates (VCA) ratio should be less than 1. VCA is a volumetric parameter used in the determination of stone-on-stone contact in the mix.

The BP sieve is a sieve that identifies the point at which the gap in the gradation begins. The aggregate fraction coarser than the BP sieve size is used to evaluate the existence of stone-on-stone contact in the VCA calculations. Provided all other mix-design requirements are met, a 9 to 15 percent gradation criterion for the aggregate percentage passing the No. 200 sieve is considered sufficient. Based on their findings, Cooley Jr. and Brown (2003) recommended the gradations listed in Table A-2 for fine SMA mixes for overlays.

Table A-2. Recommended Fine SMA Gradations by Volume (Cooley Jr. and Brown, 2003).

Sieve Size		**Aggregate Gradation Specification Limits (%)**	
	mm	**⅜" NMAS**	**No. 4 NMAS**
½"	12.5	100	100
⅜"	9.5	90 – 100	100
No. 4	4.75	26 – 60	90 – 100
No. 8	2.36	20 – 28	28 – 65
No. 16	1.18	13 – 21	22 – 36
No. 30	0.60	12 – 18	18 – 28
No. 50	0.30	12 – 15	15 – 22
No. 200	0.075	8 – 10	12 – 15

Based on the drain down test results, durability considerations, and relative comparison of Asphalt Pavement Analyzer test (rutting) results, Xie et al. (2005) found that the No. 4 NMAS SMA mixes could equally be successfully designed with aggregate gradation fractions passing the No. 200 sieve of less than 12 percent. Nine percent was found to be sufficient as long as all other mix-design requirements are met. Consequently, a gradation criteria of 9 to 15 percent passing the No. 200 sieve (instead of 12 to 15 percent as in Table A-2) was proposed.

With respect to the drain-down test, the No. 8 wire mesh-sized basket is suggested for the No. 4 NMAS SMA mixes as opposed to the current AASHTO T 305-97 0.25 inch standard wire mesh-sized basket (Xie et al., 2005). The drain-down test provides an evaluation of the drain-down potential of an HMA mix during production and transportation, which is very critical in particular for SMA mixes. The standardized acceptable drain-down value is 0.3 percent.

Although not specifically evaluated in the field, laboratory APA and permeameter tests indicated that if properly designed, these fine SMA mixes could yield satisfactory rut resistant and impermeable thin overlay mixes (Cooley Jr. and Brown, 2003). In general, however, SMA mixes have a history of superior performance. Australia, UK, and Europe have successfully placed about ½" NMAS SMA mixes, about 0.5 to 1.5 inch thick overlays, with reasonable field performance results for at least 15 years (Nicholls et al. 2002). The German experience, where SMA was first developed, indicates a service life of up to 18 years for thin SMA overlay surfacings (Belin, 1998). New Zealand has also successfully utilized thin SMA surfacings (about 0.5 to 1.2 inch thick) with expected service lives of at least 15 years, typically for providing texture and skid resistance under high stress environments (Watters, 2006). TxDOT does have a fine Type F SMA mix in their specification, which could be a candidate for thin overlays (TxDOT, 2004a). However, SMA is comparatively costly, on the order of about 25 to 30 percent more than other HMA surfacings.

ULTRA-THIN HMA OVERLAYS - MICHIGAN

Michigan has developed an ultra-thin HMA overlay (No. 4 NMAS) for its PM programs as an alternative to micro-surfacings for thinner lifts less than 1 inch. These ultra-thin HMA overlay mixes are similar to the sand asphalt mixes and are designed according to the Marshall method (MDOT, 2005). Although these mixes can be designed for virtually all traffic regimes, use of polymer-modified asphalt-binders (e.g., PG 76-22S) is recommended for medium to high traffic volumes. Accordingly, Michigan has developed a guide specification for both mix-design and construction of these mixes (MDOT, 2005). The mix-design requirements include a Marshall AV of 4.5 to 5.0 percent, VMA $\leq$ 15.5 percent, a maximum fines/binder ratio of 1.4, a Marshall flow (0.01 inch) of 8 to 16, and a Marshall stability of at least 1200 lbs.

Aggregate physical property requirements include a minimum crushed faces of 50 percent, a minimum angular index of 2.5, and a maximum LA abrasion loss value of 40. However, these requirements are further refined according to traffic levels (low, medium, and high) as detailed in the guide specification (MDOT, 2005). The recommended aggregate gradations are listed in Table A-3 as percentage passing by weight.

Table A-3. Ultra-Thin HMA Overlay Aggregate Gradation (MDOT, 2005).

Sieve Size		**% Passing by Weight**
½″	12.5 mm	100
⅜″	9.5 mm	99 – 100
No. 4	4.75 mm	75 – 95
No. 8	2.36 mm	55 – 75
No. 30	0.60 mm	25 – 45
No. 200	0.075 mm	3 – 8

Depending on the traffic level and environment, unmodified or modified PG asphalt binder may be used, with the asphalt-binder content determined based on the Marshall Method criteria. For medium and high-volume traffic, however, polymer-modified asphalt-binders (e.g., PG 64-28P, PG70-22P, or any other available, P stands for polymer modified) are typically used.

With respect to construction and target density (AV) attainment, the number of rollers method is utilized (MDOT, 2005). Consequently, the number of compactive and finishing rollers is specified based on the square yards per hour of the ultra-thin HMA mix being placed. For average lay-downs greater than 5500 square yard per hour, the minimum number of compaction rollers is three and one for the finishing roller. QC/QA protocols are relatively tight, and the contractor is required to perform at least one QC/QA test per day for gradation, asphalt-binder content (±0.4), and AV (±1.0).

SUPERPAVE HMA MIXES (NO. 4 NMAS)

Superpave mixes with No. 4 NMAS constitute a potential PM option for very thin HMA overlays equal to or less than 1 inch (Cooley Jr. et al., 2002). These mixes provide a very smooth riding surface, can be used for thinner lift thickness applications, correct surface defects (leveling), and decrease construction time. The mixes also provide a use for leftover manufactured screening stockpiles and are very economical surface mixes in particular for low traffic volume applications.

Maryland DOT

Maryland uses these mixes (No. 4 NMAS) as part of their PM program for typical lift thickness of 0.75 to 1 inch with excellent rutting and cracking resistance performance (Cooley Jr. et al. 2002). Maryland's thin HMA overlay mixes generally contain about 65 percent manufactured screenings and 35 percent natural sand with No. 4 or ⅜" NMAS gradation. Typical gradation requirements for the No. 4 NMAS mixes are shown in Table A-4. The asphalt-binder content typically ranges from about 5 to 8 percent at 4 percent optimum design AV.

Table A-4. Design Specifications for the Georgia and Maryland No. 4 NMAS Mixes (Cooley Jr. et al, 2002).

Sieve Size		Aggregate Gradation Requirements	
	mm	**Georgia DOT**	**Maryland DOT**
½"	12.5	100	100
⅜"	9.5	90 – 100	100
No. 4	4.75	75 – 95	80 – 100
No. 8	2.36	60 – 65	36 – 76
No. 50	0.30	20 – 50	-
No. 200	0.075	4 – 12	2 – 12
Mix-Design Characteristics			
Asphalt-binder content (%)		6.0 – 7.5	5.0 – 8.0
Optimum AV (%)		4.0 – 7.0	4.0
% aggregate voids filled with asphalt-binder		50 – 80	-

Georgia DOT

Georgia DOT has used a No. 4 NMAS-like HMA mix for over 30 years for low volume highways and leveling purposes with reportedly good field performance results; it is placed in thin lift thicknesses of not more than 1 inch (Cooley Jr. et al., 2002). These Georgia mixes have been primarily comprised of screenings with a small amount of No. 89 sized rock, resulting in approximately 60 to 65 passing the No. 8 sieve and an average of about 8 percent dust.

The mix-design criteria is based on the Superpave gyratory compactor with a N_{design} of 50 gyrations, 6 to 7.5 percent asphalt-binder content, 50-80 percent aggregate filled with asphalt-binder, and an AV range of 4 to 7 percent; see Table A-4. Satisfactory stability and durability performance have been observed with these mix-design characteristics.

With these mixes, higher design AV content is sometimes used to allow a lower asphalt-binder content for economic considerations but without reducing the mix durability. Typical aggregate gradation requirements are listed in Table A-4. At the same AV level, these mixes are considered to be relatively more impermeable (not very open to both water and air [oxidation] infiltration) than larger NMAS mixes (Cooley Jr. et al., 2002). Note that for both Georgia and Maryland DOTs, durability is indirectly addressed through specifying a maximum percent passing the No. 200 and minimum asphalt-binder content.

NCAT (Alabama) – No. 4 NMAS Superpave

Based on the increasing need for thin HMA overlays as PM surface treatments, NCAT undertook a laboratory study to develop a mix design criteria for No. 4 NMAS Superpave mixes (Cooley Jr. et al., 2002). Using granite and limestone aggregates, the primary criteria targeted in their study were the aggregate gradation control points and volumetric property requirements such as AV, VMA, VFA, and dust-to-binder ratio. From their study findings, a draft specification based on the Superpave volumetric mix-design method was proposed, with the following recommendations (Cooley Jr. et al., 2002):

- Gradations for No. 4 NMAS mixes should be controlled on the No. 16 and No. 200 sieves. On the 1.18 mm sieve, the gradation control points are recommended as 30 to 54 percent. On the 0.075 mm sieve, the control points are recommended as 6 to 12 percent.
- An air void content of 4 percent is recommended to use during the mix-design process.

- For all traffic levels, a VMA minimum limit of 16 percent should be utilized.
- For mixes designed at 75 gyrations and above, a maximum VMA criterion of 18 percent should be utilized to prevent excessive optimum asphalt-binder contents. The VFA criteria should be 75 to 78 percent.
- For mixes designed at 50 gyrations, no maximum VMA criteria should be utilized, but the VFA criteria should be 75 to 80 percent.
- Percent $G_{mm}@N_{ini}$ values currently specified in AASHTO MP2-01 for the different traffic levels are recommended.
- The criterion for dust-to-effective binder ratio is recommended as 0.9 to 2.2.
- The recommended aggregate gradation control points (percent passing) are: ½" (100), ⅜" (95-100), No. 4 (90-100), No. 16 (30-54), and No. 200 (6-12).

Although the mix-design recommendations were successfully validated through laboratory testing, field validation still remains to be done (Cooley Jr. et al., 2002). Based on the above recommendations, Cooley Jr. and his colleagues proposed a "Draft AASHTO Standard for Standard Specification for Superpave Volumetric Mix Design of 4.75 mm NMAS Mixtures." This draft specification is documented elsewhere (Cooley Jr. et al., 2002). Note that although a PG 64-22 binder was utilized, the study also recognized the potential of using higher PG asphalt-binder types (e.g., PG 76-22) and reasonably high asphalt-binder contents for improved durability, performance (rutting and cracking), and workability characteristics.

NOVACHIP™

Originating in France in the 1980s, NovaChip™ is a proprietary and trademarked thin PM HMA mix that was initially developed to increase skid resistance and to seal old pavement surfaces. It also results in lower cycle costs, waterproofing, improved rutting resistance, durability, and improved functional characteristics such as reduced noise, reduced hydroplaning, reduced backsplash, improved aesthetic appearance, etc. (Uhlmeyer, 2003). In the US, it is licensed through Koch Materials, Inc. (now SemGroup Inc.), but currently non-proprietary and non-trademarked names and mix-design specifications, such as ultrathin HMA wearing course or ultrathin bonded wearing course, are in use.

NovaChip^{TM} is typically applied in thin lifts of about 0.75 to 1 inch, and its applications range from high-speed high-traffic volume highways to curbs and gutter sections in cities. It is widely used in Europe and has also been used in various US states, including Alabama, Arizona, California, Colorado, Georgia, Louisiana, Texas, and Virginia. South Africa has also started exploring the use of this mix.

NovaChip^{TM} is a thin gap-graded (0.75" to 0.625") HMA mix; typically with ⅜" NMAS of high quality aggregates and a minimum of about 5 percent polymer modified binder (e.g., PG 76-22) with other additives such as anti-stripping agents. The gap grading ensures good stone-on-stone contact for improved skid and rutting resistance characteristics. Mix-design methods, such as the Marshall, Superpave volumetric, and TxDOT special specification 3244, have reportedly been used.

The NovaChip^{TM} paving process consists of one pass that places a thin gap-graded mix over a liquid membrane, known as Novabond^{TM} with one piece of equipment, the Navopaver (Uhlmeyer, 2003). Novabond^{TM} is a polymer-modified emulsion that is specially designed to seal the existing pavement surface and provide a strong bond with the NovaChip^{TM} mix. Compaction is accomplished with, at most, two passes of double drum-static rollers of sufficient weight (i.e., about 15 ton) to properly seat the aggregate without crushing it. Density is not an issue since this gap-graded mix seats quickly and the thin layer is completed in only two passes. NovaChip^{RM} is a fast place-able and rapid curing HMA mix that can be opened to traffic with minimal time delays (less than an hour).

The reported expected service life of NovaChip^{TM} is at least 10 years (Uhlmeyer, 2003; Cooper and Mohammad, 2004). Australia, France, and the UK utilize other NovaChip^{TM}-like surfacings such as paver-laid seal, UTOGA, Safepave, etc. with at least 12 years service life. Reported concerns with the NovaChip^{RM} are that it is not competitively priced and requires specialy trained, reliable, and quality contractors. Also, reflective cracks have been reported on some NovaChip^{TM} HMA overlays in the US. Additionally, some bonding problems were reported on SH 6 in Houston (Texas), and a replacement was made just after 3 years of service. In the UK, considerable loss in texture in the early life has been reported by Nicholls et al. (2002a, b).

ASPHALT RUBBER - ARIZONA

The Arizona Department of Transportation (ADOT) extensively uses thin HMA overlays, called asphalt rubber, for both rigid (PCC) and flexible (AC) pavement maintenance. The typical placement thickness is about 1 to 1.5 inch. These HMA overlays have been successfully placed on heavily trafficked highways and interstates in climatically diverse regions within Arizona.

The AR asphalt-binder commonly used is 80 percent hot paving grade asphalt and 20 percent ground tire rubber. Gap-graded and open-graded aggregate gradations are used. Two different mix designs are used depending on the pavement type, traffic conditions, and environment. One is an open-graded high frictional characteristic mix with a design AV of over 15 percent and 10 percent asphalt-binder content.

The second mix type has about 3 percent AV with portions of the smaller aggregates and fines that are significantly reduced in terms of the content to create a gap grade; similar to what is known as SMA with oil-saturated rubber particles used in place of inert fillers. The asphalt-binder content is about 7.5 to 8.5 percent. ADOT's nomenclature for the open-graded mix is asphalt rubber-asphalt concrete friction course (AC-ACFC) and asphalt rubber-asphalt concrete (AR-AC) for the gap-graded mix.

ADOT has monitored the cracking, rutting, skid resistance, and ride quality of various pavements overlayed with AR. Thus far, satisfactory performance with very low maintenance costs has been reported for about 10 years service life.

MICRO SURFACINGS AND OTHER HMA MIXES

Other propriety HMA surfacing mixes, such as micro surfacings (cold-asphalt, Ralumac, micro-asphalt, Reditex, Permitex, etc.) are available, but these have limitations and restrictive concerns. Micro-surfacings are typically stiff mixes (contain cement), often cold-laid for thickness placement ranging from 0.2 to 1.6 inch, and predominantly used for filling rutted areas on the pavement surface. These mixes have been reported to often perform poorly on cracked sections due to their high stiffness characteristics.

Other thin HMA overlay mixes used in Australia and the UK are the dense graded ½" NMAS mixes often designed with polymer-modified asphalt-binder and placed to a thickness of about 0.8 to 1.6 inch. Their reported service life is about 10 to 15 years.

Others include thin asphalt concrete (TAC) with generic names such as masterflex, thin pave, etc., typically for about 0.6 to 1.2 inch thick placement with service lives of up to 15 years. However, these mixes are predominantly used for texture and skid resistance improvements. Denmark also extensively utilizes thin HMA overlays for surfacing and waterproofing steel and concrete bridges, with service lives of equally 10 to 15 years (Nicholls et al., 2002a, b).

APPENDIX B

COMPARISON OF MIX DESIGN EXCEL SPREADSHEETS

TEXAS DEPARTMENT OF TRANSPORTATION
FORT WORTH DISTRICT LABORATORY

HMACP MIXTURE DESIGN : SUMMARY SHEET

File Version: 03/08/06 13:24:32

SAMPLE ID:	02510010040045	SAMPLE DATE:	
LOT NUMBER:	001	LETTING DATE:	06/04/2003
STATUS:	COMP	CONTROLLING CSJ:	035301026
COUNTY:	WISE	SPEC YEAR:	1993
SAMPLED BY:	TOM THOMSON	SPEC ITEM:	31175092
SAMPLE LOCATION:		SPECIAL PROVISION:	NONE
MATERIAL:	QCQA1CMB00	MIX TYPE:	Type_B
PRODUCER:	Duininck Bros. Inc.		
AREA ENGINEER:	WILLIAM F. NELSON JR.	PROJECT MANAGER:	GREG CEDILLO

COURSE\LIFT:		STATION:		DIST. FROM CL:	

Target Density:	**96**	Percent

Asphalt Content (%)	Specific Gravity Of Specimen (Ga)	Maximum Specific Gravity (Gr)	Effective Gravity (Ge)	Theo. Max. Specific Gravity (Gt)	Density from Gt (Percent)	VMA (Percent)	Hveem Stability (%)	Static Creep: Creep Stiffness (psi)	Static Creep: Perm. Strain X1000 (in/in)	Static Creep: Slope of SS Curve X 10^9 (in/in/Sec)
3.00	2.359			2.534	93.1	13.9				
3.50	2.372	2.515	2.657	2.515	94.3	13.9				
4.00	2.378	2.496	2.658	2.496	95.3	14.1				
4.50	2.383	2.475	2.655	2.477	96.2	14.4				
5.00	2.391			2.458	97.3	14.5				

Effective Specific Gravity:	2.657

Optimum Asphalt Content:	**4.4**
VMA @ Optimum AC:	**14.3**

Interpolated Values	
Specific Gravity (Ga):	**2.381**
Max. Specific Gravity (Gr):	**2.480**
Theo. Max. Specific Gravity (Gt):	**2.481**

Remarks:

Figure B-1. Example of Typical TxDOT Mix Design Excel Spreadsheet – Summary.

TEXAS DEPARTMENT OF TRANSPORTATION

HMACP MIXTURE DESIGN : SUMMARY SHEET

File Version: 01/28/04 14:02:18

SAMPLE ID:		SAMPLE DATE:	02/07/2005
LOT NUMBER:		LETTING DATE:	September 2004
STATUS:		CONTROLLING CSJ:	1006-02-005
COUNTY:	N/A	SPEC YEAR:	CAM
SAMPLED BY:	LUBINDA	SPEC ITEM:	
SAMPLE LOCATION:		SPECIAL PROVISION:	NONE
MATERIAL:	CAM	MIX TYPE:	Other
PRODUCER:	TTI Lab Design		
AREA ENGINEER:		PROJECT MANAGER:	

COURSE\LIFT:		STATION:		DIST. FROM CL:	

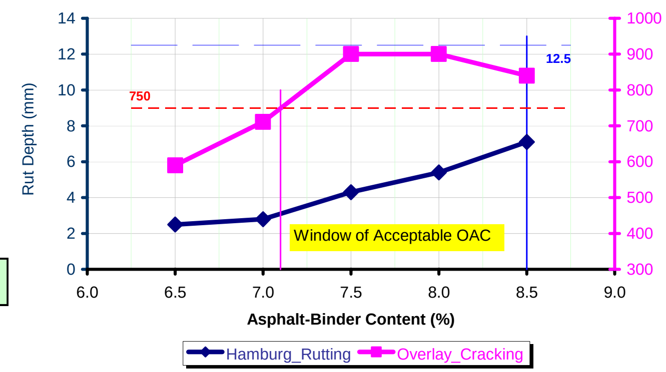
Target Density:	**98**	Percent
No. of Gyrations	**50**	

							Overlay Test	Hamburg Test	
Asphalt Content (%)	Specific Gravity Of Specimen (Ga)	Maximum Specific Gravity (Gr)	Effective Gravity (Ge)	Theo. Max. Specific Gravity (Gt)	Density from Gt (Percent)	VMA (Percent)	Overlay Tester Cycles (Min. 750)	Number Cycles	Rut Depth (mm) (max. 12.5 mm)
6.50	2.338	2.448	2.707	2.443	95.7	19.1	590	20000	2.5
7.00	2.353	2.421	2.695	2.426	97.0	19.0	711	20000	2.8
7.50	2.351	2.408	2.701	2.408	97.6	19.5	900	20000	4.3
8.00	2.355	2.387	2.696	2.391	98.5	19.8	900	20000	5.4
8.50	2.355	2.378	2.707	2.374	99.2	20.2	840	20000	7.1

Effective Specific Gravity:	2.701

Optimum Asphalt Content:	**7.7**
VMA @ Optimum AC:	**19.6**

Interpolated Values	
Specific Gravity (Ga):	**2.353**
Max. Specific Gravity (Gr):	**2.399**
Theo. Max. Specific Gravity (Gt):	**2.401**



Remarks:

OAC Verification @ 93±0.5% Density

		Hamburg Test	
OAC	Overlay Tester Cycles	Number Cycles	Rut Depth (mm)
8.30%	900+	20,000	8.96

Figure B-2. Example of Proposed Mix Design Excel Spreadsheet – Summary.

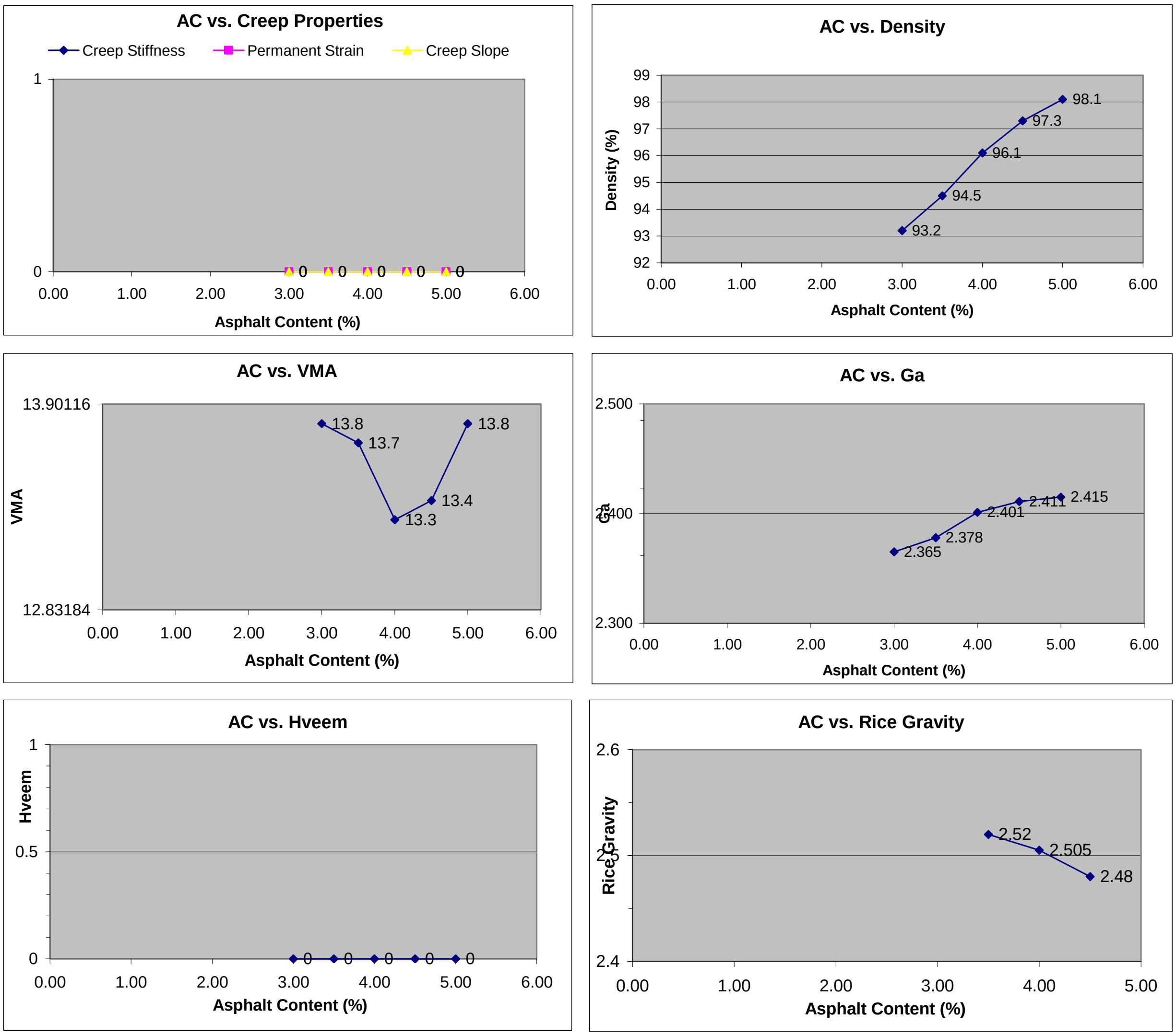


Figure B-3. Example of Typical TxDOT Mix Design Excel Spreadsheet – Charts.

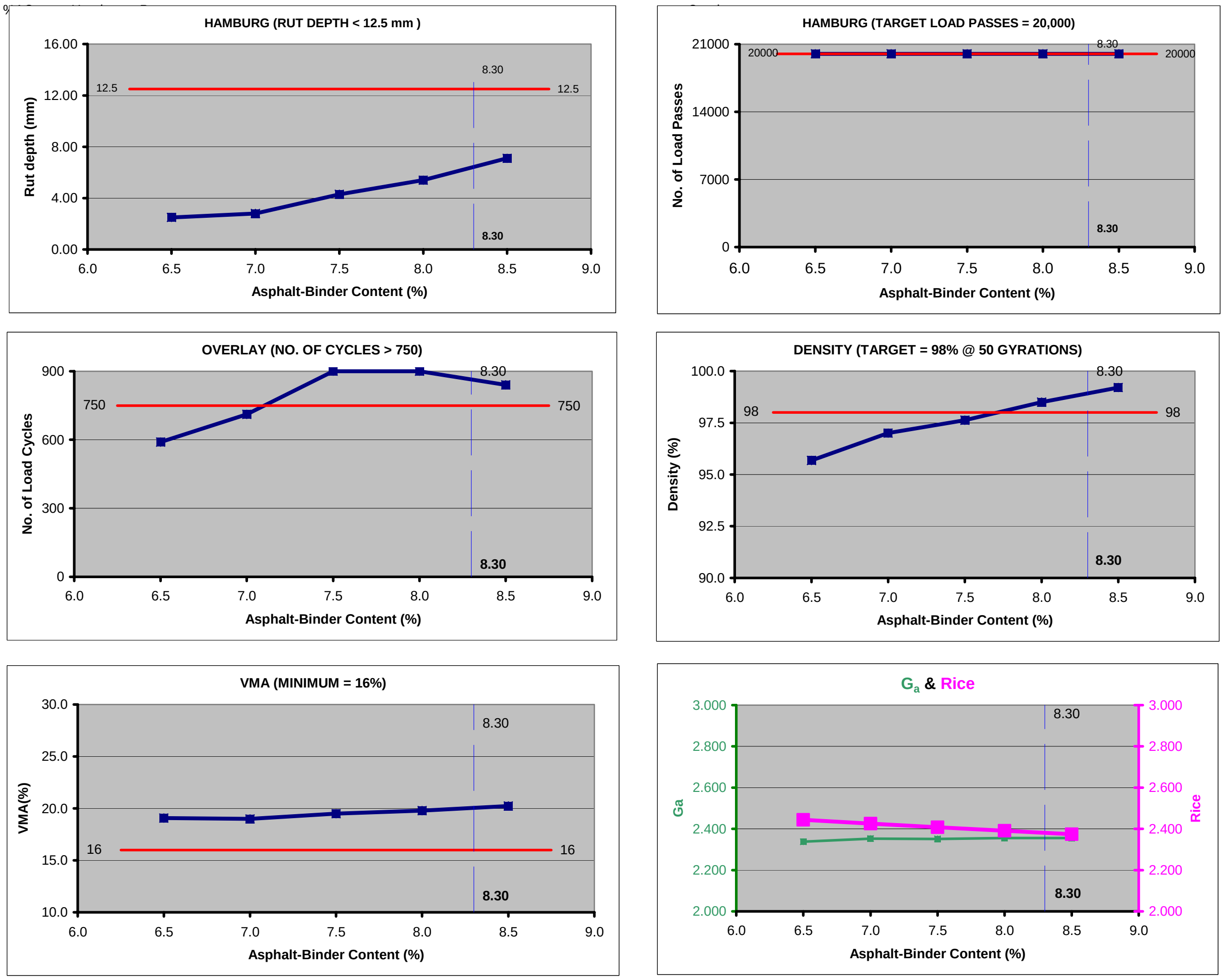


Figure B-4. Example of Proposed Mix Design Excel Spreadsheet – Charts.