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16. Abstract

Reflection cracking is a major concern when placing an overlay on a cracked pavement. The opening and closing of joints and/or cracks induced by daily temperature cycles is a major contributor to reflection cracking. This mechanism is currently being simulated in the laboratory at the Texas Transportation Institute (TTI) using a specially modified overlay-tester device.

To evaluate the overlay tester concept laboratory results are presented on cores from four Texas projects, three of which performed very poorly and one which performed excellently. The asphalt mixture on US 175 in Dallas was placed on a cracked stabilized base and did not have a single reflection crack after 10 years in service, whereas the mixtures on two projects were badly cracked after only few months. The results clearly show that the upgraded TTI overlay tester can effectively differentiate between the reflection cracking resistance of different asphalt mixtures. It is also found that the reflection cracking resistance of asphalt mixture has a good correlation with the asphalt binder properties.

In this report the upgraded TTI overlay tester is also used to quantify the benefits of modified asphalt binders. This benefit is demonstrated with a single mix where specimens were prepared with a variety of asphalt binders. The mix prepared with PG 64-22 plus 3 percent SBR latex demonstrated superior reflection cracking resistance while still maintaining adequate rutting resistance.

It is proposed that the overlay tester is a practical device which can be incorporated into mixture design systems, to complement the current systems, which often focus solely on minimizing rutting potential. In many instances it is necessary to optimize both crack resistance and rutting potential to obtain adequate long-term pavement performance.

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UPGRADED OVERLAY TESTER AND ITS APPLICATION TO CHARACTERIZE REFLECTION CRACKING RESISTANCE OF ASPHALT MIXTURES

by

Fujie Zhou
Assistant Research Scientist
Texas Transportation Institute

and

Tom Scullion, P.E.
Research Engineer
Texas Transportation Institute

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TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843-3135

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There is no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new useful improvement thereof, or any variety of plant, which is or may be patentable under the patent laws of the United States of America or any foreign country.

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CHAPTER 1

INTRODUCTION

BACKGROUND

TxDOT's recent focus on hot-mix asphalt (HMA) design has been to evaluate the rutting potential and moisture susceptibility of new mixes with the Hamburg wheel tracking device. Less attention has been paid to crack resistance of the new HMA surfaces. This crack resistance is a concern because to perform well in the field an HMA overlay must have a balance of both good rut and crack resistance properties. Stiffer binders and good stone-to-stone contact may provide improved rut resistance but they may also reduce the mix flexibility and crack resistance. Cracks appear in flexible pavements primarily through either fatigue or reflection cracking mechanisms. Classical fatigue cracks are associated with weak areas in the pavement structure where heavy truck loads induce high tensile strains at the bottom of the HMA layer. These strains initiate cracks which eventually propagate to the surface. The classical fatigue measurement of HMA surfaces has been under evaluation for over 40 years. Great advances have been made in the equipment and understanding of the fatigue mechanism. However, the fatigue test itself has not been implemented as a design tool primarily because the test procedure is very time consuming. To obtain a single fatigue curve can take several weeks with expensive repeated load test equipment.

Reflection cracks, on the other hand, are initiated by existing discrete subsurface defects such as joints, cracks, or areas of stripping. The cause of reflection cracking can be either environmental or load associated. The reflection cracking mechanism has received less attention than the classical fatigue studies. However, for many TxDOT applications fatigue cracking is not the prime concern. The main performance issue is reflection cracking. This issue is particularly true when selecting HMA surfaces for rigid pavements, flexible pavements with stabilized bases, or simply when the existing pavement has badly cracked. It is well known that when reflection cracks propagate through the HMA overlay the infiltration of water can cause rapid deterioration of the underlying pavement structure and foundation. Although reflection cracks significantly shorten pavement service life, there is a lack of simple test equipment and procedure for routine use to characterize the reflection cracking resistance of asphalt mixtures before they are placed on the existing cracked pavements. Furthermore, neither the NCHRP1-37A-2002 design guide nor NCHRP 9-19 (Superpave Support and Models Management) is specifically addressing the laboratory test on the reflection cracking. Therefore, there is an urgent need to develop a practical test equipment and associated design methodology for characterizing the reflection cracking resistance of asphalt mixtures. The upgraded Texas Transportation Institute (TTI) overlay tester is developed in this project to address this problem.

Mechanisms of Reflection Cracking

HMA overlays often exhibit a joint and/or cracking pattern similar to that which existed in the old pavements shortly after opening to traffic. This propagation of a joint or crack from the existing pavement into and through a new HMA overlay is known as reflection cracking. Reflection cracking is most common in asphalt overlays placed on rigid pavements, but it also occurs in asphalt overlays on cracked asphalt concrete pavements, and in asphalt pavements with stabilized bases. Two types of reflection cracking, as illustrated in Figure 1, have been reported: traditional single reflection cracking and double reflection cracking. When and which type of reflection cracking occurs depends upon the degree of horizontal joint or crack movement and the magnitude of vertical deflections across the joint or crack induced by traffic load and environmental effects. Double reflection cracks reported by Marchand and Goacolou (*1*), Gaarkeuken, et al. (*2*), and Zhou and Sun (*3*), are located a few inches on each side of the centerline of the old joint/crack. Compared to the traditional reflection cracking located directly above the joints/cracks, double reflection cracking does occur but it is less frequent than the single reflection crack case. Advanced 3-D finite element analysis results (*3*) indicated that the double reflection cracking occurred only at joints/cracks with significant vertical movement, such as thin asphalt overlay over existing PCC pavements with poor support. Therefore, in the remainder of this report only the traditional reflection cracking is discussed.


(a) Traditional Single Reflection Cracking (b) Double Reflection Cracking

Figure 1. Two Types of Reflection Cracking.

Traditional Single Reflection Cracking

In traditional reflection cracking, only one crack is observed at the surface of asphalt overlay right above the joint or crack in the existing pavement. This type of reflection cracking is caused mainly by the daily temperature variations, especially in the wintertime. Daily temperature variations are the primary factors inducing horizontal movement of the subsurface joint or crack. If the overlay is fully bonded with the underlying pavement, tensile stress is created in the overlay directly above the joint or crack. This induced stress is proportional to the relaxation property of asphalt mixture and the movement taking place in the joint or crack; that in turn is proportional to the slab length (or space between the cracks), temperature variation, and the coefficient of thermal expansion of underlying pavement material. When the induced tensile stress exceeds the tensile strength of the asphalt overlay, a single crack just on top of the joint or crack will occur. With repeated traffic loading and/or temperature cycles, the initiated crack will further propagate until reaching the surface of asphalt overlay.

The above mechanism of traditional reflection cracking has been summarized by Rigo (*4*) in the second international conference on "Reflection Cracking in Pavements." That is, it is the opening and closing of the joint or crack caused by the temperature variations that induce the reflection cracking initiation and take part in the initial propagation; the traffic loadings play the role in the second step of the crack propagation. In fact, these mechanisms have been validated by Jayawickrama and Lytton *(5)*, finding that "the number of days to failure due to thermal movements was directly correlated to the observed pavement performance." They will be further validated by the field data in this report.

Therefore, in order to characterize the reflection cracking resistance of asphalt mixtures, it is crucial to simulate the horizontal opening and closing of subsurface joints or cracks. The TTI overlay tester was specially designed to simulate this mechanism.

TTI Overlay Tester

The TTI overlay tester was designed by Lytton and his associates *(6)* in the late 1970s to simulate the opening and closing of joints or cracks which are the main driving forces inducing reflection crack initiation and propagation. The key parts of the apparatus, as shown in Figure 2, consist of two steel plates, one fixed and the other movable horizontally to simulate the opening and closing of joints or cracks in the old pavements beneath an overlay. There are two overlay testers in TTI: one is a small overlay tester for a specimen size of 375 mm (15 in) long by 75 mm (3 in) wide with variable height; the other is a large overlay tester for larger size specimen of 500 mm (20 in) long by 150 mm (6 in) wide with variable height. Both overlay testers have been successfully used by Pickett and Lytton *(7)*, Button and Epps *(8)*, Button and Lytton *(9)*, and Cleveland, et al. *(10)* to evaluate the effectiveness of geosynthetic materials on retarding reflection cracking. These applications indicate that the overlay testers have the potential to characterize the reflection cracking resistance of asphalt mixtures. The goal of the current project is to develop the overlay tester concept into a practical laboratory test for routine pavement design. One limitation of the previous work was that long beam samples were required. These samples are relatively difficult to fabricate in the laboratory and more difficult to get from the field. To solve these problems, an upgraded TTI overlay tester was developed with the goal of being able to test 150 mm (6 in) samples which could be fabricated in the lab or obtained from standard field cores. It is also critical to validate the new test equipment with the asphalt mixtures of known performance before full-scale implementation.

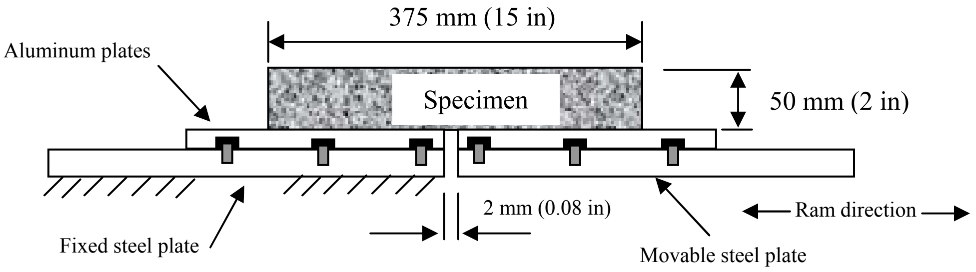


Figure 2. Concept of TTI Overlay Tester.

OBJECTIVES

The overall objectives of this project were to:

- Develop the upgraded overlay tester and associated test protocol.
- Validate the upgraded overlay tester concept.
- Characterize reflection cracking resistance of TxDOT Type D mixture with different binders and other TxDOT asphalt mixtures.

REPORT ORGANIZATION

This report is organized into five chapters. Chapter 1 focuses on the background information relative to the project. Chapter 2 presents the development of the upgraded overlay tester and associated test protocol. In Chapter 3 the upgraded overlay tester is validated using the asphalt concretes of known field performance from State Highway (SH) 6, US84, US175, and others. Chapter 4 describes overlay testing on TxDOT Type D HMA with six different binders. Finally, Chapter 5 presents a summary of conclusions and recommendations in this project. In addition, a testing protocol is presented in the Appendix.

CHAPTER 2

DEVELOPMENT OF UPGRADED OVERLAY TESTER

INTRODUCTION

In this chapter the upgraded overlay tester is briefly described. Then the data interpretation and repeatability of the overlay tester are discussed. Finally, based on the test results obtained, an overlay testing protocol is proposed.

UPGRADED OVERLAY TESTER

The objective of upgrading the TTI overlay tester is to make a more useful tool, which can be routinely used by engineers to measure the reflection cracking resistance of asphalt mixture and evaluate the reflection cracking resistance of field cores. In order to overcome the limitation of previous overlay testers and make the overlay tester easier to operate, the TTI small overlay tester system was upgraded to a fully computer-controlled system. Figure 3 shows the upgraded TTI overlay tester equipment. The main feature of the upgraded TTI overlay tester is the specimen size: 150 mm (6 in) long by 75 mm (3 in) wide with heights from 38 mm (1.5 in) to 50 mm (2 in). This specimen size was determined based on the fact that both 50 mm (2 in) asphalt overlay and 150 mm (6 in) core drill have been used statewide in Texas. For 50 mm (2 in) thick field cores, it is easy to get a 38 mm (1.5 in) high overlay tester specimen after trimming the tack coat layer and underseal. Furthermore, the 3-D finite element program — ABAQUS— was used to analyze the stress distribution of different sizes of specimens. For example, as shown in Figure 4, the main tensile stress of asphalt concrete is limited to the middle 63.5 mm (2.5 in) part of the specimen. This means that the end effect has little influence on the overlay testing results. Therefore, it is reasonable to use 150 mm (6 in) long specimens in the overlay tester.

The proposed specimen size makes the overlay tester more practical and easier to use, since this size specimen can be readily fabricated from Superpave Gyratory Compactor (SGC) or cut from field cores. In addition, the special programs for one-phase loading and two-phase loading (discussed later) have also been built into the upgraded system, and the test data, including time, displacement, and force, can be automatically recorded and saved as an Excel file.

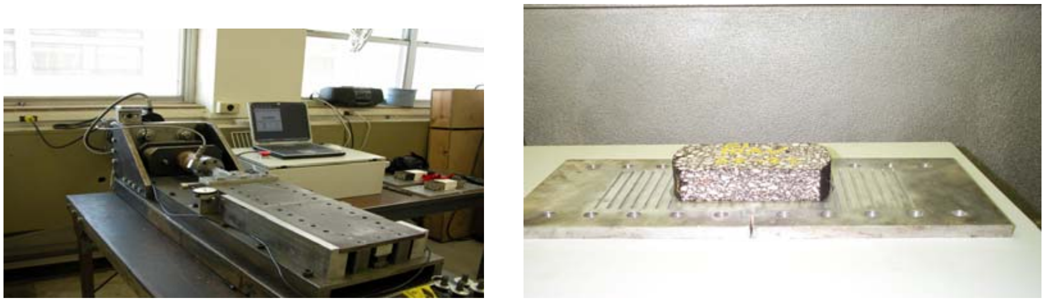


Figure 3. Upgraded TTI Overlay Tester Equipment, Plate, and Specimen.

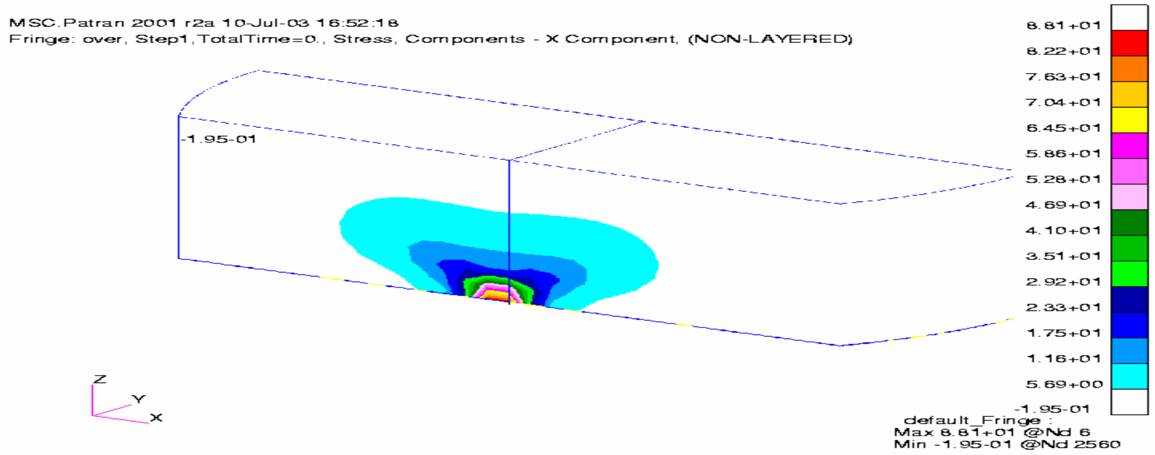


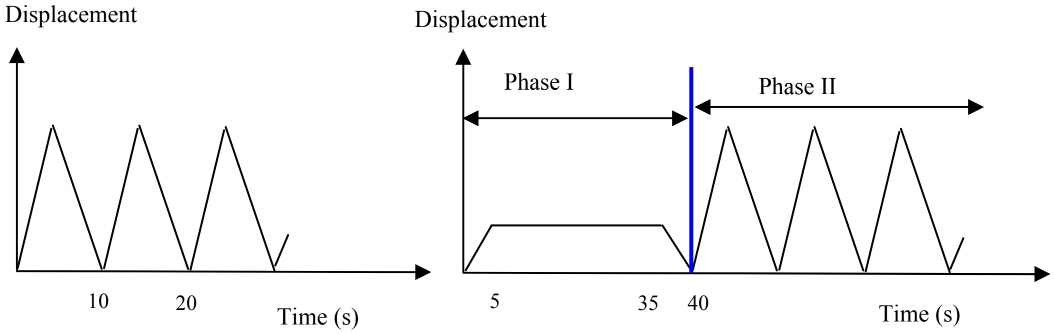
Figure 4. Illustration of Tensile Stress Distribution of Asphalt Concrete under 0.381 mm (0.015 in) Opening.

The upgraded overlay tester can be conducted in controlled displacement mode under the following conditions:

- temperature: 0 – 25 ºC (32 – 77 ºF);
- opening displacement: 0 – 2 mm (0 – 0.08 in);
- loading rate: 10 min. (or more) per cycle – 10 seconds per cycle; and
- loading type:
  - Procedure A (one-phase loading): the loading is applied in a cyclic triangular waveform with constant magnitude, as shown in Figure 5a. The reflection cracking life of the asphalt mixture, as discussed later, can be determined based on the recorded loading data. Fracture properties of the asphalt mixture can also be evaluated in the overlay testing.
  - Procedure B (two-phase loading): this two-phase loading is designed for advanced users. As illustrated in Figure 5b, the first phase is a constant displacement waveform having a ram displacement of 0.18 mm (0.007 in). The measured displacement and associated load from 5 to 35 seconds are utilized to determine a

relaxation modulus curve. The second phase is conducted until the specimen fails. The second phase is similar to Procedure A.

Note that Procedure A is most frequently used for determining reflection cracking life. However, Procedure B was recently recommended by Cleveland, et al. (*10*) for advanced mechanistic analysis. Normally the overlay tester is used at room temperature 25 ºC (77 ºF) in a controlled displacement mode until the failure occurs at a loading rate of one cycle per 10 seconds with a maximum displacement of 0.64 mm (0.025 in). This amount of horizontal movement is approximately equal to the displacement experienced by PCC pavements undergoing 14 ºC (30 ºF) changes in pavement temperature with a 4.5 m (15 ft) joint or crack spacing. The detailed calculation is presented in the Appendix (Overlay Testing Protocol).



(5a) (5b)

Figure 5. Schematic Diagram of Loading Types.

DATA INTERPRETATION

The overlay testing data include the time, displacement, and load corresponding to a certain number of loading cycles. In addition, the crack length can be manually measured. Two types of information can be gained from the overlay tester: one is the reflection cracking life of asphalt mixture under certain test conditions; the other is fracture parameters of asphalt mixture. These are discussed below.

Definition and Determination of Reflection Cracking Life of Asphalt Mixture

Similar to traditional beam fatigue test, reflection cracking life of asphalt mixture is defined as the number of cycles needed to propagate a crack through a specimen under a defined test condition. As later found, this value is a good indicator of reflection cracking resistance of asphalt mixtures. In the past the number of cycles to failure was subjectively determined by the operator’s visual observation of the crack. The life was defined as the number of cycles until a crack was clearly present on the top of the specimen.

In this project it is proposed to automate the reflection life determination by analyzing the load and displacement versus the time plot. A typical set of data is presented in Figure 6, showing load and displacement for each opening and closing cycle. From observations of the results from many overlay tests it is proposed that this plot has three distinct phases, as described below.

- Phase I: Crack initiation and early propagation

In this phase the load and displacement have similar shapes. As the displacement increases, the load increases too. The load decreases rapidly as the crack starts to propagate through the specimen. In this specimen Phase I lasted only 2 cycles.

- Phase II: Late crack propagation

Phase II is the late stage of crack propagation which is monitored as a slow decrease in maximum load. However, the key feature here is that the maximum load remains in phase with the maximum displacement.

- Phase III: Specimen failure

In this phase the crack has propagated completely through the specimen. The maximum load occurs well before the maximum displacement. The small amount of load is associated with minor adhesion as the specimen gap is closed and the two halves of the specimen bond together. However, these bonds are easily broken.

The specimen shown in Figure 6 failed very quickly. Using the evaluation scheme described above, the reflection cracking life was set at 6 cycles at the prevailing test conditions.

A wide variety of reflection cracking lives have been determined based on the testing completed to date. Some specimens fail in one or two cycles, whereas others have not failed after 1500 cycles at which the test is terminated. The longer the reflection cracking life of the sample, the better its reflection cracking performance is in the field.

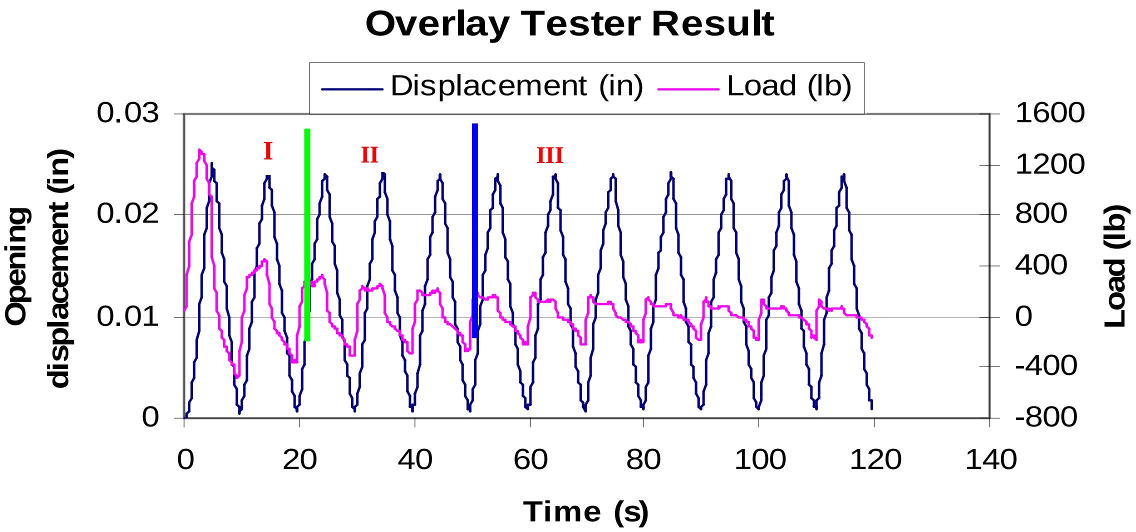


Figure 6. Typical Overlay Tester Result.

Determination of Fracture Parameters

Generally, Paris' Law (*11*) provided in Equation 1 is used to describe the rate of crack growth of asphalt mixture, although Paris' Law is based on linear elastic fracture mechanics.

$$\frac{dc}{dN} = A(\Delta K)^n \qquad \text{(Eq. 1)}$$

where:

c = crack length,
N = number of load repetitions,
$\frac{dc}{dN}$ = rate of crack growth,
ΔK = change of stress intensity factor during loading and unloading, and
A, n = fracture parameters for the asphalt mixture.

As one of the pioneers of using fracture mechanics to predict the reflection cracking of asphalt overlay, Lytton and his associates (*7, 10*) has developed a series of theoretical methodologies to determine the fracture properties (A, n). In order to address the viscoelastic fracture properties of asphalt mixture, the viscoelastic J-Integral, which provides a means to determine the energy release rate for elastic-plastic behavior (*12*), was suggested in lieu of the stress intensity factor defined in Equation 1. Recently, pseudo strain energy and pseudo viscoelastic J-Integral concepts were utilized to characterize the fracture damage process (Cleveland, et al. [10]). These methodologies have been well documented (*7, 10*).

VARIABILITY OF UPGRADED OVERLAY TESTING

The first step in evaluating the overlay tester concept, especially with the recommended small sample size, is to determine the repeatability of the test. As discussed previously, both reflection cracking life and fracture properties (A and n) of asphalt mixture could be determined from the overlay testing. However, only the reflection cracking life is discussed herein because it is the primary output of the overlay testing and this value can be easily used by the engineers to design asphalt overlay mixtures.

Overlay Testing Repeatability

In general, the smaller the specimen, the more variable the test results are. There is significant concern about the repeatability of the upgraded TTI overlay tester. Thus, two types of TxDOT mixtures, Type D and CMHB-C using PG64-22 asphalt binder, were selected to make six identical specimens (150 mm [6 in] diameter by 57 mm [2.25 in] high) for each mixture. All the specimens were molded using SGC. Then, the specimens were first cut to be 38 mm (1.5 in) high using the double-blade saw; after that, 37 mm (1.5 in) was trimmed from each side of the specimens. The air void content of each specimen was controlled within 7±0.5 percent, which is similar to the required air void content of the specimens for TxDOT Hamburg test. Finally, six overlay tester specimens for each mixture were glued to the overlay tester plates. The testing was conducted under room temperature 25 ºC (77 ºF) and the opening displacement was set to 0.64 mm (0.025 in).

Figure 7 shows the reflection cracking lives of six identical Type D specimens. The average reflection cracking life is 140 cycles. The corresponding standard deviation and coefficient of variation are 11.7 and 8.3 percent, respectively. These results clearly indicate that the overlay testing is repeatable.

Figure 8 illustrates overlay testing results on CMHB-C mixture. This mixture failed very quickly and each of the specimens failed after 2 cycles. This mixture was judged as very poor.

The results from Figure 7 will be used in the next section of this report to determine the number of samples to test for a given level of accuracy.

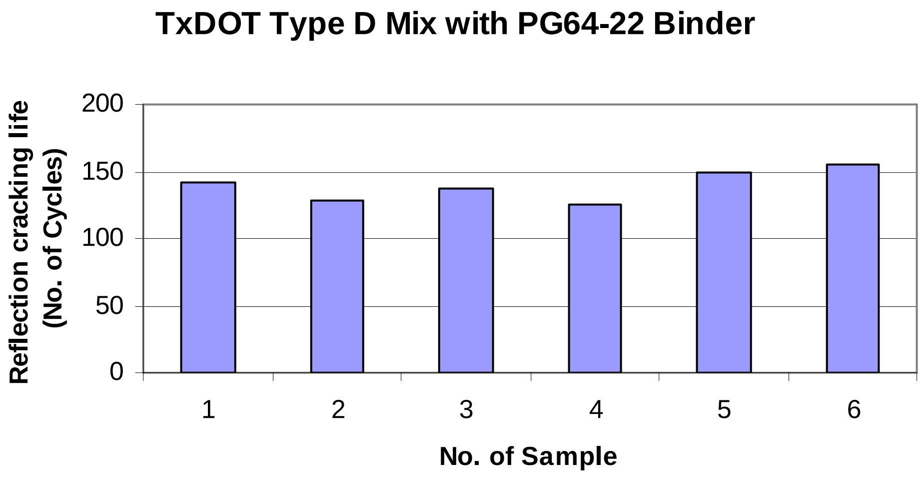


Figure 7. Repeatability of Overlay Testing on TxDOT Type D Mixture.

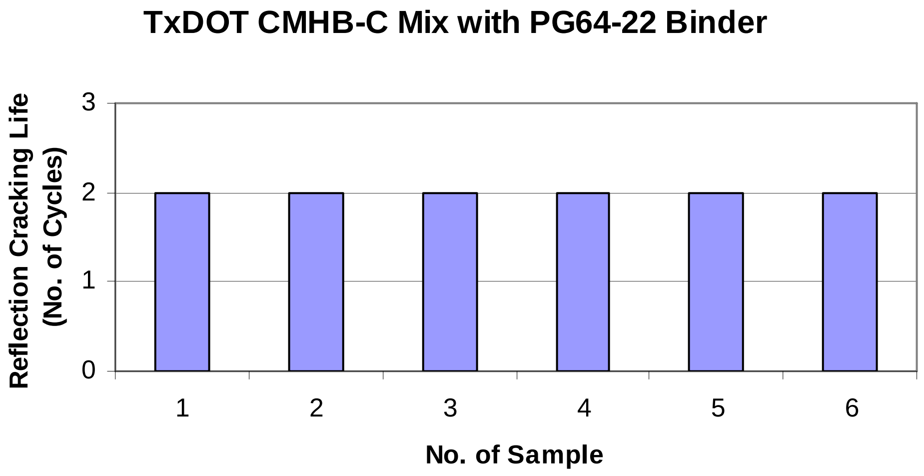


Figure 8. Repeatability of Overlay Testing on TxDOT CMHB-C Mixture.

Number of Specimens

Another important issue for the overlay testing is the number of specimens required to obtain an estimate of the material property within certain tolerances, since variation inevitably occurs from specimen to specimen even in the same material. This is a classic application of confidence intervals in a statistical analysis. For a known population variance, the number of replicates required to achieve the specified levels of tolerance and reliability is defined in the following well-known Equation 2 (*13*):

$$n = \left(\frac{Zs}{\Delta x} \right)^2 \qquad \text{(Eq. 2)}$$

where:

n = number of specimens,
Z = two-tailed probability statistic from the standard normal distribution,
s = population standard deviation,
$\Delta\chi$ = specified tolerance value $(= x_{average} * specified \text{ tolerance} (\%))$, and
$x_{average}$ = average value of population.

That is, for a Z value of 1.96, the average value of reflection cracking life of *n* specimens will be within ± $\Delta\chi$ of the "true" reflection cracking life of asphalt mixture for 95 percent of the time.

To provide a conservative estimate only the results from the Type D samples are considered. Figure 9 shows the relationship between the number of specimens and the specified tolerance. It can be seen that the average reflection cracking life of two specimens, for Type D mixture, will be within ± 12 percent of the "true" reflection cracking life of asphalt mixture with 95 percent reliability.

The recommendation of this analysis is that TxDOT should measure 3 replicates to get an error of less than 10 percent.

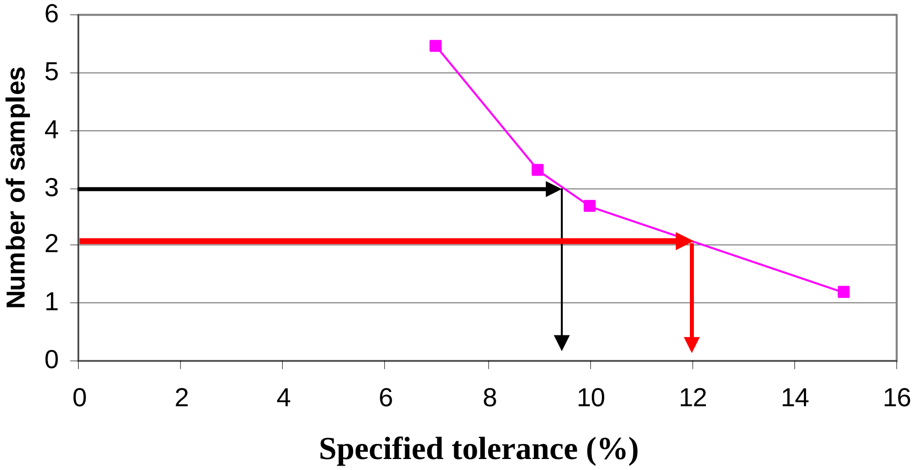


Figure 9. Relationship between Number of Specimens and Specified Tolerance of Reflection Cracking Life for TxDOT Type D Mixture.

OVERLAY TESTING PROTOCOL

Overlay testing protocol has been developed based on the repeatability study and the experience gained from past studies. The following section briefly introduces the main part of the protocol. The detailed protocol is attached in the Appendix.

- Test Specimen

  Size — Overlay testing will be performed on 150 mm (6 in) long by 75 mm (3 in) wide by 38 mm (1.5 in) high specimens sawed from gyratory compacted mixtures or field cores.

  Gyratory specimens — Prepare 150 mm (6 in) diameter by 57 mm (2.25 in) high specimens to the required air void content (say 7 percent) in accordance with Tex-241-F.

  > Note — Testing should be performed on test specimens 38 mm (1.5 in) high meeting the specific air void tolerances. The air void content of gyratory specimen with 57 mm (2.25 in) high and 150 mm (6 in) diameter required to obtain a specified test specimen air void content must be determined by trial and error. Generally, the test specimen air void content is 1.5 to 2.5 percent lower than the air void content of the gyratory specimen when the test specimen is removed from the middle of 150 mm (6 in) diameter specimen.

  Sawing — The specimens were first cut to be 38 mm (1.5 in) high using the double-blade (or single-blade) saw. Then, 38 mm (1.5 in) was trimmed from each side of the specimen.

- Glue the specimen —A cut specimen is epoxied to the horizontal surface plates with half the length of the beam resting on each plate.

- Overlay tester procedure — Although two types of Procedures (A and B) have been built into the upgraded overlay tester system, only Procedure A is recommended with the consideration of quick implementation in TxDOT district laboratories. Procedure A was designed for routine use. The repeated loading is applied until failure occurs at a loading rate of one cycle per 10 seconds using a cyclic triangular waveform with constant magnitude of 0.63 mm (0.025 in), as shown in Figure 5a.

- Calculations

  - Determine the air void content for each specimen.

  - Determine the reflection cracking life of each specimen (see data interpretation section).

  - (Advanced application only) Determine the fracture mechanics properties: A and n. Detailed methods have been documented in References *(7)* and *(10)*.

- Evaluation of failure plane

  At the conclusion of the test it is important to work at the failure face of the cracked sample. Determine whether or not the crack propagated primarily through the asphalt beside or if the aggregate was directly involved. Two secondary modes of cracking have been observed: firstly debonding and secondly aggregate crushing.

Field validation is an important aspect of testing verification. After finishing development of an upgraded overlay tester, researchers turned to creating a reliable field validation procedure. The goal of field validation is to determine whether the upgraded overlay tester concept and test protocol is a reasonable representation of the real-world system, and if the desired accuracy exists between the laboratory and the real-world system. This issue will be discussed in the following section.

CHAPTER 3

FIELD VALIDATION OF UPGRADED OVERLAY TESTER

INTRODUCTION

Since 2000, the TTI small overlay tester has been successfully employed to characterize the reflection cracking resistance of different asphalt concretes with known field performance. Cores from three poorly performing pavements were tested in the overlay tester. As described earlier reflection cracks quickly appeared in new overlays placed on US175, US84, and SH6. These are to be compared with the results obtained on the Special Pavement Studies 5 (SPS5) section on US175 near Dallas. This overlay was placed over a stabilized base and had no reflection cracks after 10 years in service. These cores provided a valuable opportunity to validate the TTI overlay tester concept. Furthermore, the asphalt mixtures tested by the overlay tester cover TxDOT Type C mixtures with PG76-22 tire-rubber; Type D with PG64-22; Type D asphalt mixture with 30 percent recycled asphalt concrete; and Type D asphalt mixture with 75 percent recycled asphalt concrete, which are quite representative. The detailed information is presented as follows.

CASE 1: SPS5 SECTIONS ON US175

The Long-Term Pavement Performance (LTPP) program was initiated in 1987 by the Strategic Highway Research Program (SHRP). The SPS5 sections in Texas were built on US175 in 1991 to compare the effectiveness of rehabilitation treatments for thin and thick overlays, constructed with virgin and recycled hot mixes, on milled and non-milled surfaces. The eight test sections representing the combinations of these three features were placed adjacent to each other for comparison.

US175 is a moderately traveled highway with two lanes per direction. The average daily traffic (ADT) for this roadway in 2000 was 29,510 vehicles, about 14 percent of which were trucks. The main problem associated with US175 was cracking. However, the average FWD deflection was low at the range of about 0.127 mm (5 mils) at 40 kN (9000 lb). The deflection level was compatible to those normally observed on Interstate Highways. Therefore, there was no structural problem with these sections. After 10 years of service, no significant distress can be found on the SPS5 sections. Although many transverse cracks were observed on the shoulder, they discontinued at the travel lanes. The performance for all SPS5 sections has been excellent.

Several 150 mm (6 in) diameter cores were taken in year 2000 from two sections: 125 mm (5 in) virgin and recycled asphalt overlays, then shipped to TTI for testing on the overlay tester. Since the reflection cracking is the bottom-up type of crack, the bottom layer plays a key role in resisting the reflection cracking. Thus, the bottom layer was tested on the overlay tester. Three cores were cut and trimmed into overlay tester specimens, 150 mm (6 in) long by 75 mm (3 in) wide by 50 mm (2 in) high. In this evaluation all the tests were performed at 25 ºC (77 ºF) with 1 mm (0.04 in) opening displacement and 10 seconds per cycle loading rate.

Figure 10 shows the test results with average values from 3 cores. It can be seen that the virgin mixture has much better reflection cracking resistance than the recycled mixture. As seen later, both are more resistant to reflection cracking than the remixer process even after 10 years of service.

Besides overlay tester, the penetration tests were performed on the binders extracted from the two cores. The penetration numbers at 25 ºC (77 ºF) are all above 35 for both SPS5 mixtures.

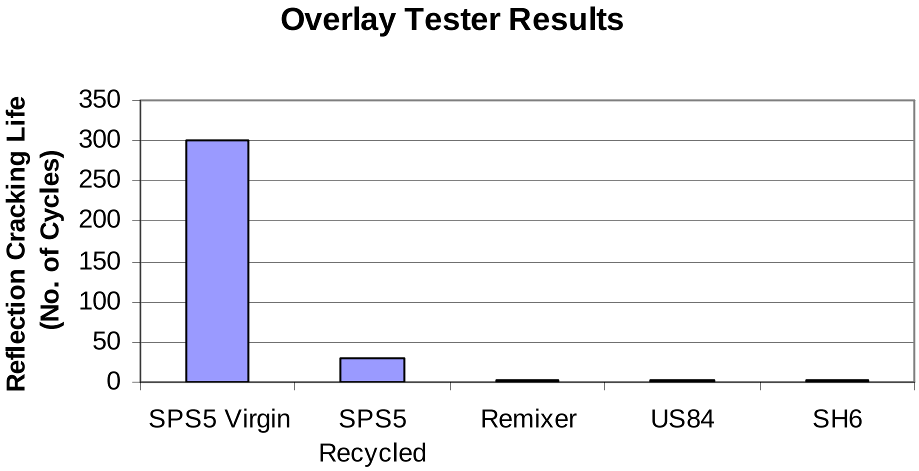


Figure 10. Overlay Tester Results from TxDOT Projects.

CASE 2: US175 AND US84 REMIXER

The Remixer is a hot-in-place recycling process. The top 38 mm (1.5 in) of asphalt pavement is initially heated. The Remixer machine mills it, then about 25 percent of the new asphalt mixture is added and mixed with the recycled material. A 48 mm (1.9 in) thick recycled pavement was then compacted with a vibrating steel-wheel and pneumatic rollers. The added asphalt mixture was a standard TxDOT Type C mixture with PG64-22 binder. In addition, approximately 0.5 percent of polymer-modified emulsified rejuvenator was added to the new mixture.

This Remixer section is a few miles away from the SPS5 section on US175 so that both traffic and environmental conditions are the same as that of the SPS5 section. The reflection cracks shown in Figure 11 appeared at the surface less than one month after the remixer overlay. The same Remixer was also used on the US84 asphalt overlay project, in the Abilene District, Texas, where severe transverse cracks reflected through the overlay only a few weeks after opening to traffic. This premature reflection cracking clearly indicates that the thermal stress induced by the opening and closing of joints or cracks was the main contributor to reflection cracking, because the cracks were full width and only a low amount of traffic was applied to the section. This observation appears to confirm both the mechanism of reflection cracking discussed above and the significance of the overlay tester to simulate the thermal reflection cracking.

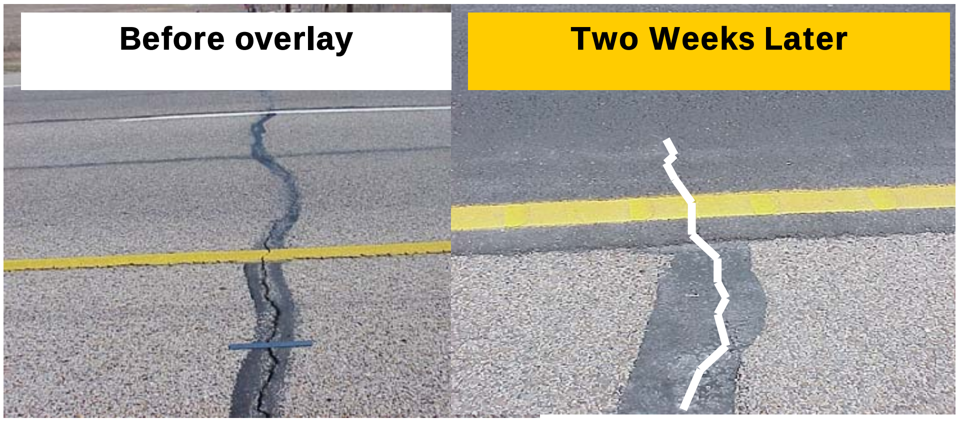


Figure 11. Reflection Cracking on US175 Remixer Section.

Cores were taken from both US175 and US84 remixer in year 2000. Similarly, three cores from US175 and US84, respectively, were cut, trimmed, and finally tested by the overlay tester under the same test conditions as that used on SPS5 cores. The average value of the test results is also presented in Figure 10. After two cycles, asphalt mixtures from both US175 and US84 broke. Compared to the recycled and virgin asphalt mixtures from SPS5, the reflection cracking resistances of US175 and US84 Remixers are much poorer. The overlay testing results match the field performance of those materials very well. This observation reveals that the overlay testing can effectively differentiate between the reflection cracking resistance of asphalt mixtures.

In addition to the overlay testing, penetration tests at 25 ºC (77 ºF) were conducted on the extracted asphalt binder from two US175 cores. The penetration was 25. This value is lower than the extracted SPS5 binder after 10 years of service. The hardness of the binder is one contributing factor to the poor field performance.

CASE 3: SH6

SH 6 is a moderately traveled highway with two lanes per direction. The main lanes of the existing pavement consist of an asphalt overlay over concrete pavement, but the left turn lane was jointed concrete slabs. A level-up TxDOT Type D hot mixture with PG64-22 binder was applied on the main traffic lanes before the 50 mm (2 in) TxDOT Type C asphalt mixture with PG76-22 tire-rubber binder was laid down on both main traffic lanes and the left turn lane in October 2002. After wintertime, the reflection cracks shown in Figure 12 were found on the left turn lane. However, there is still no crack in the main traffic lane. This observation further confirms the mechanism of reflection cracking, since traffic is much less in the left turn lane than the main lanes. It was the opening and closing induced by thermal (expansion and contraction) variation that caused the occurrence of reflection cracking.

Cores were taken from both the left turn lane and traffic lanes (surface layer only). Following the same procedures as stated previously, overlay tester was employed to characterize the reflection cracking resistance of these cores. Figure 10 shows the test results. After two cycles the specimens broke. Laboratory testing of these cores indicates that the binder in the failed mixture was prematurely aged. It was suspected that this binder was "burnt" during construction.

Figure 12. Reflection Cracking on the Left Lane of SH6.

SUMMARY

The above overlay tester results on the field cores with different reflection cracking performance indicate that the upgraded overlay tester can effectively differentiate between the reflection cracking resistance of asphalt mixtures. It also appears feasible to use the small specimens to evaluate the reflection cracking resistance of asphalt mixture. It is clear that a relationship exists between reflection cracking resistance of asphalt mixture and the associated asphalt binder. Stiff binders have poorer reflection cracking resistance than soft binders.

CHAPTER 4

APPLICATION OF UPGRADED OVERLAY TESTER TO EVALUATE TXDOT TYPE D MIXTURES WITH DIFFERENT BINDERS

INTRODUCTION

As validated in the previous chapter, the upgraded overlay tester can be used to evaluate the reflection cracking resistance of asphalt concrete over PCC or cracked flexible pavements. In this chapter the upgraded overlay tester will be used to characterize the reflection cracking resistance of TxDOT's Type D mixture with nine different binders. In addition, TTI also ran the dynamic modulus test, flow time test, flow number test, Hamburg test, and APA to check the permanent deformation properties of those mixtures. Only overlay testing results are discussed in the following sections. Other results will be reported later.

OVERLAY TESTING ON TXDOT TYPE D MIXTURES WITH SIX DIFFERENT BINDERS

The asphalt mixture used for this study was from the US281 asphalt overlay project, southwest of Fort Worth, Texas. This laboratory investigation focuses on the effect of binder type on reflection cracking resistance. The same aggregate and gradation as that used in the field project were used for molding the specimens. The only factor changed was the binder type. Table 1 illustrates the aggregate gradation used. Table 2 presents information on the binders used. The field asphalt mixture design was based on Koch PG64-22 plus 3 percent residual UltraPave UP 70 SBR latex polymer, and the optimum asphalt content was determined to be 5.1 percent. After discussion with the project director, the same optimum asphalt content (5.1 percent) was used in the laboratory study for all other binders, since the binder type has minor affect on the optimum asphalt content for modified asphalts.

Table 1. US281 Asphalt Overlay Mixture Gradation.

Sieve Size	Contractor's Cumulative Pass (Total % 100)	TxDOT Specs. (%)
12.5 mm (1/2 in)	100	98-100
9.5 mm (3/8 in)	98.9	85-100
4.75 mm (No. 4)	64.2	50-70
2.0 mm (No. 10)	36.8	32-42
0.425 mm (No. 40)	18.7	11-26
0.180 mm (No. 80)	8.1	4-14
0.075 mm (No. 200)	3.0	1-6

Table 2. Binders Used in This Project.

Specimen No.	1	2	3	4	5	6	7*
Binder Type	PG64-22	PG70-22	PG76-16 Air Blown	PG76-22 Tire Rubber	PG76-22 SBS	PG76-22 Elvaloy	PG64-22+3%SBR

Note: * The specimen with PG64-22 +3 % SBR was taken from US281 asphalt overlay site.

Using the test protocol discussed previously, three 150 mm (6 in) diameter by 57 mm (2.25 in) high specimens for each asphalt mixture were fabricated using SGC. The specimens were then cut and glued to the tester plates. The final air void content of all specimens was controlled within 4±0.5 percent. Finally, the tests were performed following Procedure A (repeated loading until failure) at room temperature (25 ºC [77 ºF]) and 0.64 mm (0.025 in) opening displacement. Figure 13 presents the results from this project.

It is clear that the asphalt mixture with PG64-22 plus 3 percent SBR latex modified binder performed best and its reflection cracking life was 524 cycles. Actually, this result is consistent with the field performance of SPS5 sections (previously discussed). In contrast, the worst was PG76-16 air-blown binder and the corresponding reflection cracking life was only 2 cycles. In general, the reflection cracking life of asphalt mixtures, as shown in Figure 13, generally decreases with the increase in performance grade of asphalt binder used at high temperature. For example, the asphalt mixture with PG64-22 binder performed better than that with PG70-22 binder, which was better than those with PG76-16, PG76-22SBS, PG76-22TR, and PG76-22 Elvaloy.

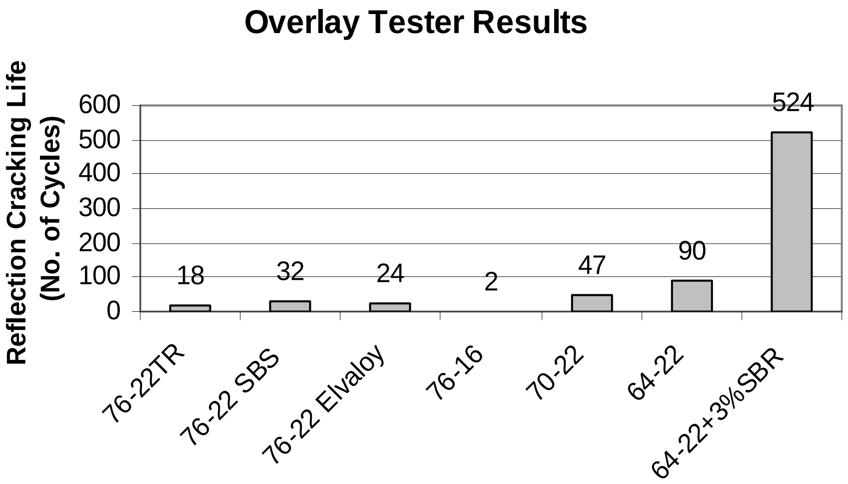


Figure 13. Overlay Tester Results on TxDOT Type D Mixtures.

SUMMARY

Based on the overlay testing results on a TxDOT typical asphalt mixture with different binders and field cores from SPS5, US175, US84, and SH6 (previously discussed in chapter 3), it is recommended that PG76-XX binders, especially PG76-16 air blown should not be used in thin asphalt overlays (for example, 2 in thick overlay). In contrast, PG64-22 with SBR Latex modified binder is recommended for use in asphalt overlay projects. It should also be noted that the rutting resistant properties of asphalt mixtures be considered as well.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Reflection cracking is a major concern when placing an overlay on a cracked pavement. The opening and closing of joints and/or cracks produced by daily temperature cycles is a major contributor to reflection cracking. This mechanism is currently being simulated in the laboratory at the Texas Transportation Institute using a specially modified overlay tester device. After comprehensive studies of the upgraded overlay tester and its application, the following conclusions and recommendations are made:

CONCLUSIONS

- Small asphalt specimens typically 150 mm (6 in) long by 75 mm (3 in) wide with heights from 38 mm (1.5 in) worked well. These specimens can be cut from field cores or molded specimens from the Superpave Gyratory Compactor.
- The upgrade overlay tester is repeatable, and for TxDOT Type D mixture the average reflection cracking life of two specimens will be within ± 12 percent of the specimen mean with 95 percent reliability.
- The upgraded overlay tester concept and associated test protocol developed were validated by four case studies. These case studies are from cores taken on Texas highways; three which performed very poorly and one which performed excellently. The asphalt mixture on US 175 in Dallas was placed on a cracked stabilized base and did not have a single reflection crack after 10 years of service, whereas the mixtures on three other projects were badly cracked after a few months. The results show that the upgraded TTI overlay tester can effectively differentiate between the reflection cracking resistance of different asphalt mixtures. It is also found that the reflection cracking resistance of asphalt mixture has a good correlation with the asphalt binder properties. Stiff binders have poorer reflection cracking resistance than soft binders.
- Finally, the upgraded overlay tester is used to evaluate the reflection cracking resistance of TxDOT Type D asphalt mixtures. Working with specimens where the only variable is the asphalt binder it is demonstrated that the asphalt mixture with stiff binder has much shorter reflection cracking life than those made with soft binders. PG64-22 plus 3 percent SBR latex modified binder performed best; the opposite was true for PG76-16 air-blown binder.

RECOMMENDATIONS

- The upgrade overlay tester is a practical device which can be incorporated into mixture design systems to complement the current systems which often focus on minimizing rutting potential. In many instances it is necessary to optimize both cracking resistance and rutting potential to obtain adequate long-term pavement performance.
- Based on an overlay tester study on PG64-22 with SBR latex modified binder and SPS5 field performance data, it is recommended to develop both rutting and reflection cracking resistance asphalt mixtures using PG64-22 with SBR latex for TxDOT asphalt overlay projects.

- Future research studies should be directed at optimizing both rutting and cracking potential of asphalt layers. The criteria for each will vary based on the existing structure, traffic level, and performance requirements.

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APPENDIX

OVERLAY TESTING PROTOCOL

1. Scope

1.1 This test method covers procedures for preparing and testing asphalt concrete mixtures to determine the reflection cracking resistance over a range of temperatures.

1.2 This test estimates the reflection cracking life based on the stress induced by the thermal movement at the bottom of the layer. Shear stress induced by the traffic load is not addressed in this test.

1.3 This standard is applicable to laboratory prepared specimens of mixtures and/or field cores with nominal maximum size aggregate less than or equal to 19.0 mm (0.75 in).

1.4 This standard may involve hazardous material, operations, and equipment. This standard does not purport to address all safety problems associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1 Texas Department of Transportation (TxDOT) Test Methods:

2.1.1 Tex-241-F	Superpave Gyratory Compacting of Test Specimens of Bituminous Mixtures.
2.1.2 Tex-207-F	Determining Density of Compacted Bituminous Mixtures.
2.1.3 Tex-227-F	Theoretical Maximum Specific Gravity of Bituminous Mixtures.

3. Definitions

3.1 *Reflection Cracking Life* – N_{RCL}, the number of cycles needed to propagate cracking completely through a specimen under defined test condition.

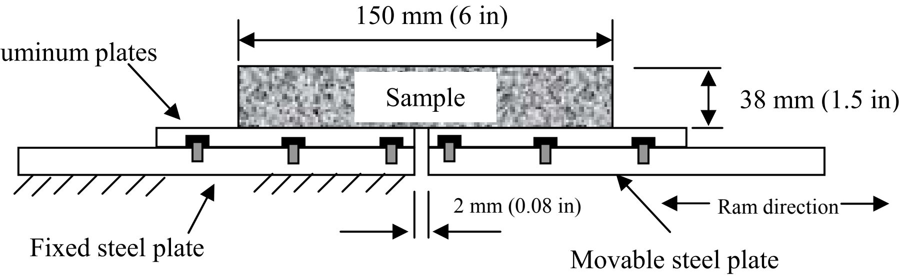
4. Summary of Method

4.1 The repeated loading is applied until failure occurs at a loading rate of one cycle per 10 seconds using a cyclic triangular waveform with constant magnitude of 0.63 mm (0.025 in). The opening displacement and applied stress are measured and used to determine the reflection cracking life of asphalt mixture.

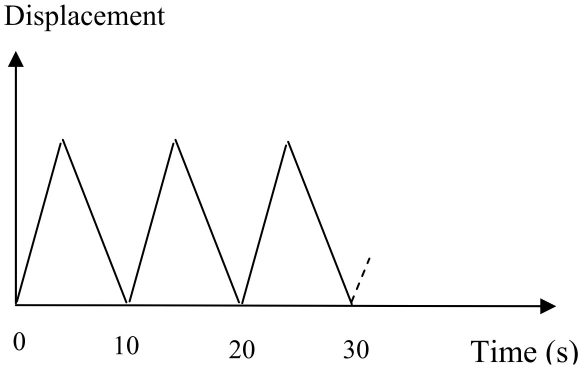
4.2 Figure 14 shows the TTI overlay tester equipment. A specimen glued to the test plates is illustrated in Figure 15. Figure 16 shows a schematic of the test sequence.

Figure 14. TTI Overlay Tester Equipment.

Figure 15. Test Specimen Glued to Plates.



(a) Concept of overlay tester



(b) Schematic of test sequence

Figure 16. Overlay Tester Procedure.

5. Significance and Use

5.1 Current TxDOT asphalt mixture design procedures do not consider the reflection cracking resistance of asphalt mixtures. In this test, the reflection cracking resistance of binder type and content, and aggregate can be measured.

5.2 The overlay tester simulates the performance of asphalt layers placed directly on top of concrete or cracked flexible pavements.

5.3 The reflection cracking life measured over a range of temperatures is an important design property. The results of this test can assist in binder type selection and overall mixture design.

6. Apparatus

6.1 *Overlay Tester System* — An overlay tester system consisting of a testing machine and measuring system plus environmental chamber if cold weather performance is required.

6.1.1 *Testing Machine* — A mechanical testing machine driven by an electric motor through a gear box capable of producing a displacement controlled triangular waveform loading. The testing machine should have a capability of applying load over a range of loading periods from 2 to 10 hours and load levels up to 22.24 kN (5000 lb).

6.1.2 *Environmental Chamber* (if required) — A chamber for controlling the test specimen at the desired temperature. The environmental chamber shall be capable of controlling the temperature of the specimen over a temperature range from 0 to 25 ^{o}C (32 to 77 ^{o}F) with an accuracy of ± 0.5 ^{o}C (1 ^{o}F). The chamber shall be large enough to accommodate the test specimen glued to plates and a dummy specimen with a thermocouple mounted at the center for temperature verification.

6.1.3 *Measurement System* — The system shall be fully computer controlled; capable of measuring and recording the time history of the applied load plus the horizontal displacements. The system shall be capable of measuring the period of the applied load and resulting deformations with a resolution of 0.5 percent.

6.1.4 *Plates* — Plates with a dimension of 300 mm (12 in) long by 150 mm (6 in) wide by 13 mm (0.5 in) high are required to glue the specimen on it. Grooves are cut in the plates at regular intervals as shown in Figure 15. Generally, these plates should be made of hardened or plated steel, or anodized high-strength aluminum. Softer materials will require more frequent replacement. Materials that have linear elastic modulus properties and hardness properties lower than that of 6061-T6 aluminum shall not be used.

6.2 *Superpave Gyratory Compactor* — A gyratory compactor and associated equipment for preparing laboratory specimens in accordance with Tex-241-F is required.

6.3 *Saw* — A machine for sawing test specimens to the appropriate height and width is required. The saw shall have a water cooled diamond cutting edge and shall be capable of cutting specimens to the prescribed dimensions without excessive heating or shock to the specimen.

> Note 1 — A diamond saw greatly facilitates the preparation of test specimens with smooth, parallel ends. Both single and double-bladed diamond saws should have feed mechanisms and speed controls of sufficient precision. Adequate blade stiffness is also important to control flexing of the blade during thin cuts.

7. Hazards

Observe standard laboratory safety precautions when preparing and testing HMA specimens.

8. Testing Equipment Calibration

8.1 The testing system shall be calibrated prior to initial use and at least once a year thereafter or per manufacturer requirements.

> 8.1.1 Verify the capability of the environmental chamber to maintain the required temperature within the accuracy specified.
>
> 8.1.2 Verify the calibration of all measurement components (such as load cell and specimen deformation measurement device) of the testing system.

8.2 If any of the verifications yield data that does not comply with the accuracy specified, correct the problem prior to proceeding with testing.

9. Test Specimens

9.1 *Size* — Overlay tester shall be performed on 150 mm (6 in) long by 76 mm (3 in) wide by 38 mm (1.5 in) high specimens sawed from gyratory compacted mixtures or field cores.

9.2 *Gyratory Specimens* — Prepare 150 mm (6 in) diameter by 57 mm (2.25 in) high specimens to the required air void content in accordance with Tex-241-F.

> Note 2 — Testing should be performed on test specimens 38 mm (1.5 in) high meeting specific air void tolerances. The air void content of gyratory specimens with 57 mm (2.25 in) high and 150 mm (6 in) diameter required to obtain a specified test specimen air void content must be determined by trial and error. Generally, the test specimen air void content is 1.5 to 2.5 percent lower than the air void content of the gyratory specimen when the test specimen is removed from the middle of a150 mm (6 in) diameter specimen.

Note 3 — Currently, it is recommended that laboratory prepared samples be molded to 7 percent air void content. This will better simulate the field condition. This will be upgraded as more results become available.

9.3 *Sawing* — The specimens are first cut to be 38 mm (1.5 in) high using the double-blade (or single-blade) saw. Then trim off 38 mm (1.5 in) from each side of the specimen. This is shown in Figure 17.

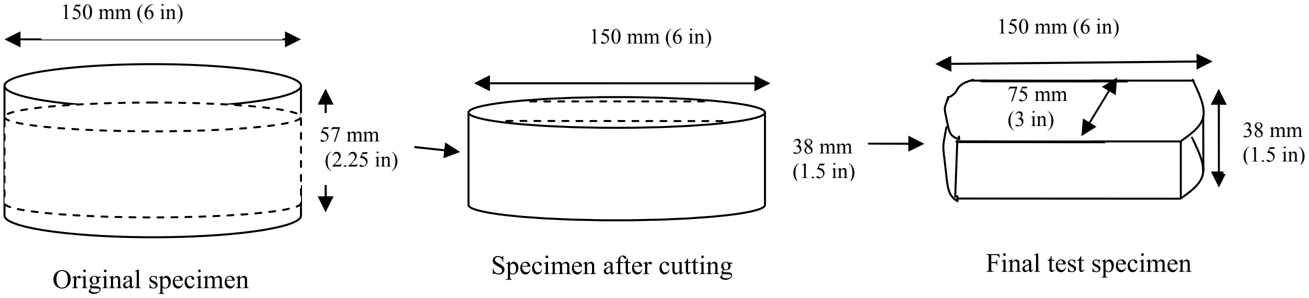


Figure 17. Process of Sawing Specimen.

9.4 *Air Void Content* — Determine the air void content of the final test specimen in accordance with Tex-207-F. Reject specimens with air voids that differ by more than 0.5 percent from the target air voids.

Note 4 — Considerable time can be saved if the cored test specimens were treated as wet, and the weights in water and saturated surface dry were measured immediately or within a short time period after sawing. The test specimens can then be left to dry overnight, the dry weight can be measured the next day, and then they can be immediately prepared for testing.

9.5 *Replicates* — The number of test specimens required depends on the desired accuracy of the overlay tester results. Three replicates are recommended for each mixture.

9.6 *Specimen Storage* — Wrap completed specimens in polyethylene and store in an environmentally protected storage area at temperatures between 5 and 25 °C (41 and 77 °F).

Note 5 — To eliminate the effects of aging on test results, it is recommended that specimens be stored no more than two weeks prior to testing.

10. Gluing the Specimen to the Plates

10.1 A cut specimen is epoxied to the horizontal surface plates with half the length of the beam resting on each plate. Then, put a 4.5 kg (10 lb) or more metal block on the top of the specimen to make sure the specimen sticks to the plates.

Note 6 — Devcon^{TM} two tone 30-Minute Plastic Steel Epoxy Cement is satisfactory for tests conducted at 0 to 25 °C (32 to 77 ºF).

10.2 The glued specimen needs to cure at room temperature, 25 °C (77 ºF), for 4 hours in order to let the glue gain enough strength.

11. Test Procedure

11.1 The recommended test protocol for the overlay tester for use in asphalt mixture design consists of testing the asphalt mixture at a specified temperature (e.g., 25 °C [77 ºF]) and opening displacement of 0.63 mm (0.025 in).

Note 7 — For the testing temperature, it is recommended that overlay tester be conducted at room temperature. In the future, the effective pavement temperature, T_{eff}, (a single test temperature at which reflection cracking would occur equivalent to that measured by considering each season separately throughout the year) will be determined for overlay tester.

Note 8 — The opening displacement of 0.63 mm (0.025 in) is determined based on the following assumptions and calculations:

- Daily temperature variation (Δt): 30 ºF
- Slab length (l): 15 ft
- Coefficient of thermal expansion of PCC (α_t):

  For PCC with gravel: $6*10^{-6}$ in./in./ºF

  For PCC with limestone: $3.5*10^{-6}$ in./in./ºF

Since displacement = $\Delta t * l * \alpha_t$,

displacement for PCC with gravel is 0.0324 in ($=30*15*6*10^{-6}$)

displacement for PCC with limestone is 0.0189 in ($=30*15*3.5*10^{-6}$)

The average displacement is approximately 0.63 mm (0.025 in), which is recommended for overlay tester.

11.2 Place the test specimen glued to the plates in the environmental chamber and allow it to equilibrate to the specified testing temperature. A dummy specimen with a temperature sensor mounted at the center can be monitored to determine when the specimen reaches the specified test temperature. Currently, it is recommended that the overlay tester be conducted at room temperature (25 °C [77 ºF]).

11.3 Fix the plates with glued specimen to the overlay tester using bolts to make sure that the plates move with the overlay tester in a unit.

11.4 The repeated loading is applied until failure occurs at a loading rate of one cycle per 10 seconds using a cyclic triangular waveform with constant magnitude of 0.63 mm (0.025 in) as shown in Figure 16.

12. Calculations

12.1 Determine the air voids for each specimen.

12.2 Determine the reflection cracking life of each specimen.

Note 9 — An Excel Macro is under development to automatically determine the reflection cracking life, and will be delivered to TxDOT.

13. Report

13.1 Report all specimen information including mix identification, storage conditions, dates of manufacturing and testing, volumetric properties, test temperature, opening displacement, and reflection cracking life.