Evaluation of Special Surface Treatment Aged Using UV Phase I

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EVALUATION OF SPECIAL TREATMENT AGED USING UV PHASE I

FINAL REPORT

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By

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16. Abstract Research was undertaken to evaluate the effectiveness of Tensar's specialty polymer cement slurry (coating) in reducing aging of asphalt binders and mixtures. The study was also aimed at evaluating the effect of this material on performance characteristics of asphalt binder and asphalt concrete through laboratory investigation. The plan required preparation and testing materials at different aging levels. The materials included the asphalt binders and mixtures prepared with and without a coating level of Tensar's coating. Aging was achieved through rolling thin film oven (RTFO), pressure aging vessel (PAV), and Ultraviolet (UV) chamber.

Aging in the UV chamber was conducted for 3 days, 7 days, 14 days, and 28 days. Testing for the binder included dynamic shear rheometer (DSR), bending beam rheometer (BBR), and Fourier transform Infrared spectroscopy (FTIR). Mixture testing was conducted using the third scale model mobile load simulator (MMLS3).

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INTRODUCTION

A polymer-modified cement slurry material, referred to as "Tensar's coating" within this report, is a relatively new ultra thin surfacing system for asphalt pavements. Tensar's coating was designed to extend pavement life by providing an ultra thin protective coating, which is believed to simultaneously seal existing cracks, provide a protective barrier against tire wear, against chemical attack, reduce aging due to UV degradation, and reduce temperature fluctuations in the underlying asphalt.

RESEARCH OBJECTIVES

The objective of this study is to evaluate the effect of Tensar's specialty polymer-modified cement slurry on aging and performance characteristics of asphalt binder and asphalt concrete through laboratory investigation.

RESEARCH APPROACH AND SCOPE OF WORK

This work included a limited literature review and controlled laboratory testing of a series of asphalt binder and concrete specimens with and without the polymer-modified cement slurry coating. Testing that has been completed includes determination of asphalt binder characteristics at low, intermediate and high temperatures. Asphalt concrete specimens were prepared during this project but material characterization testing was not conducted due to challenges faced in aging the material in the Ultraviolet chamber. The only mechanical testing completed for asphalt concrete was testing with the Model Mobile Load Simulator (MMLS3) on the coated and control slabs. In general, the testing program consisted of the following 7 tasks.

1. Construction of Ultraviolet Light Lamp System.
2. Evaluation of Aging Magnitude in Pressure Aging Vessel.
3. Evaluation of Aging Magnitude through Conventional Mixture Aging.
4. Evaluation of UV Aging Magnitude through Binder Tests at Intermediate and High Temperature.
5. Evaluation of UV Aging Magnitude through Binder Tests at Low Temperature.
6. Evaluation of UV Aging Magnitude through Asphalt Concrete Tests.
7. Evaluation of Coating Effect Through MMLS3 Tests.

During this phase (Phase I), tasks 1, 2, 4, 5, and 7 were completed. Due to the need of reconfiguring the Ultraviolet (UV) radiation chamber, the work for Task 6 was shifted towards extended aging of asphalt binders and was not completed under this phase. The resilient modulus of Task 3 could not be completed due to equipment problems.

EXPERIMENTAL PROGRAM

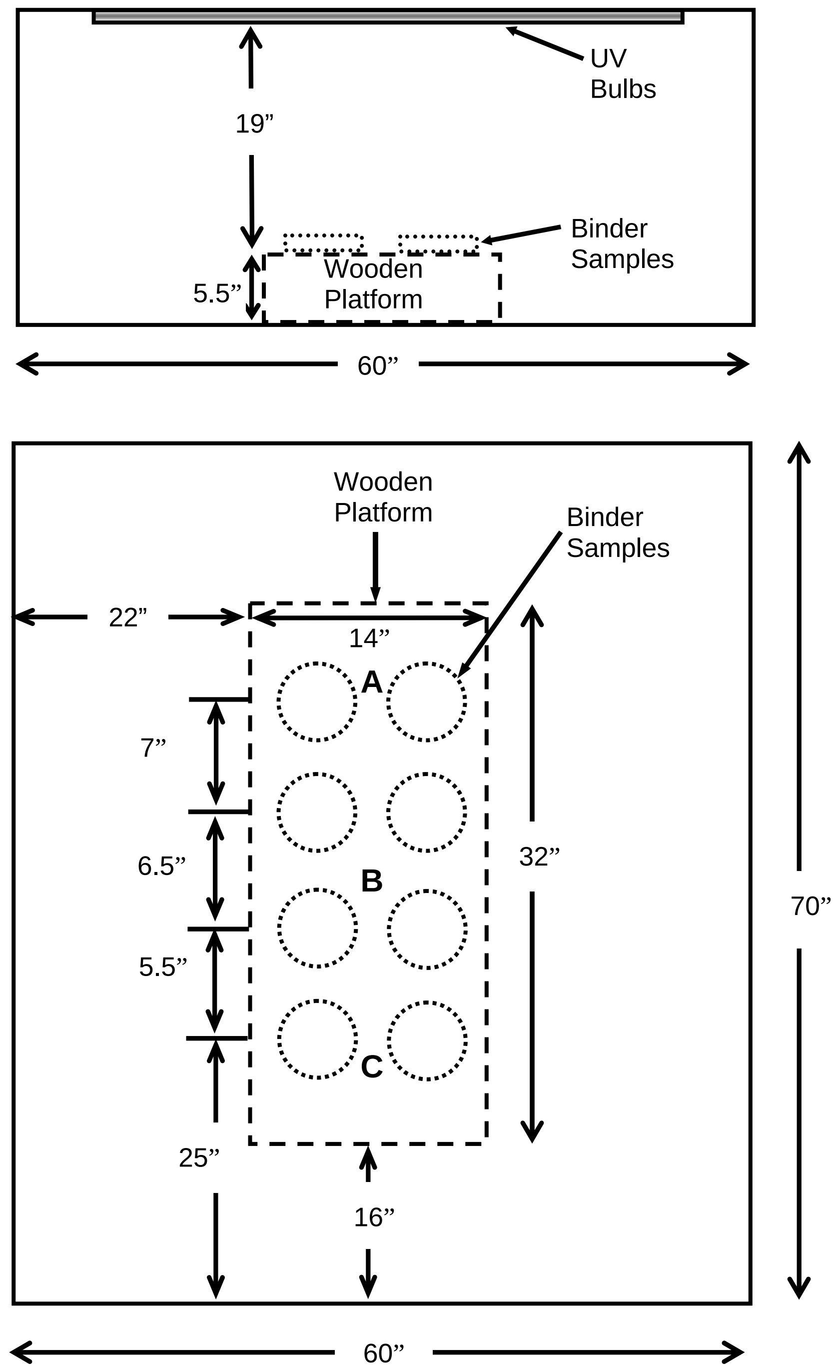
As mentioned previously, the work was to be completed under 7 tasks. These tasks included the following.

1. Construction of Ultraviolet Light Lamp System.

A network of eight ultraviolet lamps (4 sets of 2 lamps each) was mounted to an open frame such that UV radiation could be applied to the test specimens. The lamps emitted UV-B radiation at a wavelength of 313 nm. Thermocouples were used to monitor the temperature. A radiometer was used to measure the intensity of the applied UV-B radiation at the same distance from the lamps as the aged specimens. Figure 1 shows the constructed UV aging chamber. A flexible reflective material was used to enclose the sides and top of the chamber. Schematics with dimensions of the profile and plan views of the chamber are given in Figure 2.

Figure 1. UV aging chamber.

(a)



(b)

Figure 2. UV aging chamber schematics: (a) profile view and (b) plan view.

2. Evaluation of Aging Magnitude in Pressure Aging Vessel

A PG 64-22 binder was selected for this study. Eight asphalt specimens were prepared, four coated with Tensar’s coating and four without coating (control). Each specimen was approximately 50 g and 2-3 mm thick (without the coating). The specimens were aged in a pressured aging vessel according to AASHTO R28. At the end of the aging, the binder was removed from the coating. Tests were conducted on both the control and experimental binder in the Bending Beam Rheometer.

3. Evaluation of Aging Magnitude through Conventional Mixture Aging.

Six asphalt concrete specimens were prepared using a Superpave Gyratory Compactor. Each specimen was approximately 50 mm thick. The following were completed:

a. Measure bulk specific gravity of specimens.
b. Measure maximum theoretical specific gravity of specimens in loose form.
c. Apply coating to 3 of the six specimens.
d. Allow the six specimens to stand at room temperature for 24 hours.
e. Condition all six specimens in the oven according to AASHTO R30.
f. Apply the coating to the other side of three coated specimens.
g. Allow the six specimens to stand at room temperature for 24 hours.
h. Condition all six specimens in the oven according to AASHTO R30.

The indirect tensile resilient modulus could not be completed due to equipment problems.

4. Evaluation of UV Aging Magnitude through Binder Tests at Intermediate and High Temperature.

A PG 64-22 binder was selected for this study. Eight asphalt specimens were prepared, four coated with Tensar's coating and four without coating (control). Each specimen was approximately 50 g and 2-3 mm thick (without the coating). Two coated and control specimen pairs were exposed to UV aging for 3 days, and the second set of two coated and control pairs were exposed to UV aging for 7 days. Figure 2-b shows the location of the specimens with respect to the UV lamps. Table 1 lists the UV-B radiation intensity measured at the given locations. At the end of the aging time period, the coating was removed. Fourier Transform Infrared Spectroscopy (FTIR) and Dynamic Shear Rheometer tests (at 64°C and 22°C) were conducted on neat and aged binders.

Table 1. UV-B Radiation Applied to Task 4 Binder Specimens

Location	Measured UV Radiation ($\mu W/cm^2$)
A	106
B	103
C	104

5. Evaluation of UV Aging Magnitude through Binder Tests at Low Temperature.

A PG 64-22 binder was selected for this study. The binder was aged short-term using the rolling thin film oven (to simulate short term aging during construction and also to prevent excessive deflection under the bending beam rheometer). The binder was then mixed with a filler to create a mastic of asphalt/filler. Four specimens were prepared. Tensar's coating was applied to two of the four pans (experimental samples versus the control ones which did not have coating).

The original proposed task was to have the specimens exposed to UV aging for 7 days. However, based on results from Task 4 (no significant difference between UV-aged and non-UV aged material), this aging time was extended to 14 and 28 days. These extended times of aging were applied to newly prepared specimens. After removal of the binder from the coating, Bending Beam Rheometer (BBR) samples were prepared and tested at -12°C.

6. Evaluation of UV Aging Magnitude through Asphalt Concrete Tests.

Ten asphalt concrete specimens were prepared using a Superpave Gyratory Compactor (SGC). Each specimen was approximately 50 mm thick. The following were completed:

a. Measure bulk specific gravity of specimens.
b. Measure maximum theoretical specific gravity of specimens in loose form.
c. Apply coating to five of the 10 specimens.

The original plan was to conduct the following:

d. Expose only the surface of all 10 specimens to UV aging. The original plan was to conduct UV aging for 7 days. Based on results from Task 4, it was determined not to conduct the 7 day aging under ambient temperatures.
e. Measure the permanent deformation of two of the coated specimens (after removal of coating) and permanent deformation of two of the uncoated specimens

in repeated shear constant height test (RSCHT) for 5000 cycles at 52°C under haversine loading.

f. Apply the coating to the other side of three coated specimens (not tested in RSCHT).
g. Expose the newly coated surface of these coated specimens and unaged surface of three control specimens to UV aging.
h. Measure indirect tensile resilient modulus and indirect tensile strength of all six specimens.

Since 7-day binder aging at ambient temperature proved to be insufficient, the remaining work on this task was aborted and instead extended aging of asphalt binder (14 and 28 days) was conducted.

7. Evaluation of Tensar's Coating Effect through MMLS3 Tests

a. Test Slab Construction. Two scaled test pavement sections were constructed in the Civil Infrastructure Testing and Evaluation Laboratory (CITEL), and each section consisted of a steel base, a 1-inch layer of a rubber material having a Shore hardness of 60, and two 1.5-inch layers of hot mix asphalt. The asphalt layer was a typical PA 9.5 mm Superpave mix. A Pavement Quality Indicator™ (PQI, TransTech Systems Inc. Model 301) was used to estimate the asphalt density across the test sections. The slabs were cured in an open area and exposed to air and sun radiation for 13 days prior to the accelerated trafficking. The temperature of the slabs was monitored throughout the curing phase. The asphalt surface of one test section was then coated with Tensar's coating, and one test section remained uncoated. The coating was supplied and applied by representatives of Tensar Corp.
b. Accelerated Trafficking. Both the treated and untreated sections of the constructed test slab were subjected to channelized accelerated trafficking using the Model Mobile Load Simulator, 1/3 scale (MMLS3). The test temperature was ambient temperature. Slab temperature was recorded with time throughout testing.
c. For each section, rut development and cracking was recorded after a specified number of cycles had been applied and also after completing all load cycles. Rutting was measured using a profilometer (MLS Test Systems P900) at 0, 5000, 100,000, and 400,000 cycles. The number of load cycles was limited to 400,000.
d. Nondestructive measurement of modulus was made before trafficking and after trafficking to investigate the change in stiffness properties as a result of repeated loading of slabs. These measurements were conducted using Portable Seismic Pavement Analyzer (PSPA).

e. Air Voids/Density Measurements. Five asphalt cores were extracted from each slab from the trafficked and untrafficked areas after completion of trafficking cycles. A trafficked and non-trafficked comparison of the air voids/density was made.

MATERIALS

Only one binder source, a PG 64-22 binder from United Refineries was used in preparing laboratory specimens. For the asphalt concrete, a Superpave 9.5 mm plant-produced mix from HRI Inc. was utilized. The job mix formula for this mix is given in the Appendix.

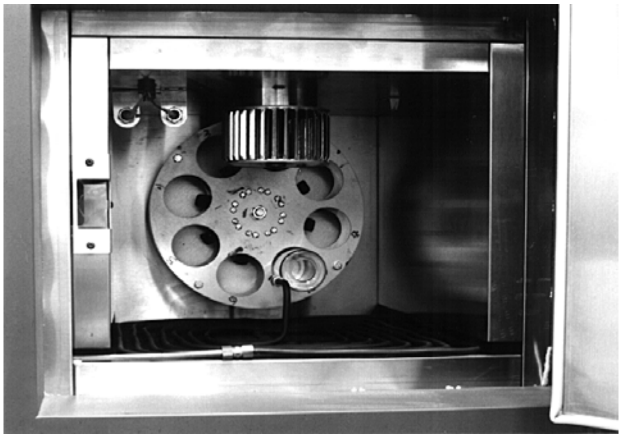
TESTING EQUIPMENT

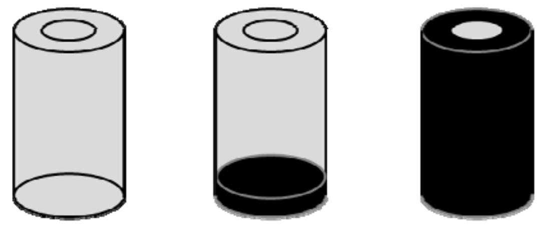
The main pieces of equipment used during this study included the following:

Rolling Thin Film Oven (RTFO)
Pressure Aging Vessel (PAV)
Dynamic Shear Rheometer (DSR)
Bending Beam Rheometer (BBR)
Fourier Transform Infrared Spectroscopy (FTIR)
Ultra Violet Aging Chamber
6-inch diameter coring unit
Third Scale Model Mobile Load Simulator (MMLS3)
Portable Seismic Pavement Analyzer (PSPA)

Rolling Thin Film Oven

The asphalt cement binders were aged in accordance with AASHTO T240-97 "Effect of Heat and Air on a Moving Film of Asphalt (Rolling Thin Film Oven Test)". This technique simulates short term aging on the binder during construction and early stages of construction. RTFO consists of an oven chamber that houses a vertical circular carriage (Figure 3-a). The carriage, which holds eight RTFO specimen bottles (each contains 35 grams of binder; Figure 3-b), rotates about its center. A single air jet is located in the oven. Hot air, at a temperature of 163°C, is blown into the center of each RTFO bottle as it passes in front of the jet. A fan continually circulates the air within the oven chamber. This exposure to hot air continues for 85 minutes.





(a) (b)

Figure 3. Rolling thin film oven test (a) oven chamber and (b) specimen bottles

Pressure Aging Vessel

Long-term aging is simulated using the pressure-aging vessel (PAV; Figure 4) following AASHTO R 28 “Standard Practice for Accelerated Aging of Asphalt Binder Using a Pressurized Vessel.” Each PAV container carries 50 grams of binder. All containers are housed inside a sealed chamber where 100-C hot air is applied to the specimens under 2.1 MPa pressure for 20 hours. The residue from the multiple pans is then combined into a single container, heated, and stirred to blend. The blended material is then poured into individual containers for further testing. Vacuum degassing is applied to all the asphalt binders tested as part of the follow-up study.

Dynamic Shear Rheometer

The Dynamic Shear Rheometer (DSR; Figure 5) measures shear complex modulus G* and phase angle δ by measuring the shear strain response of the specimen to a torque as shown in Figure 6.

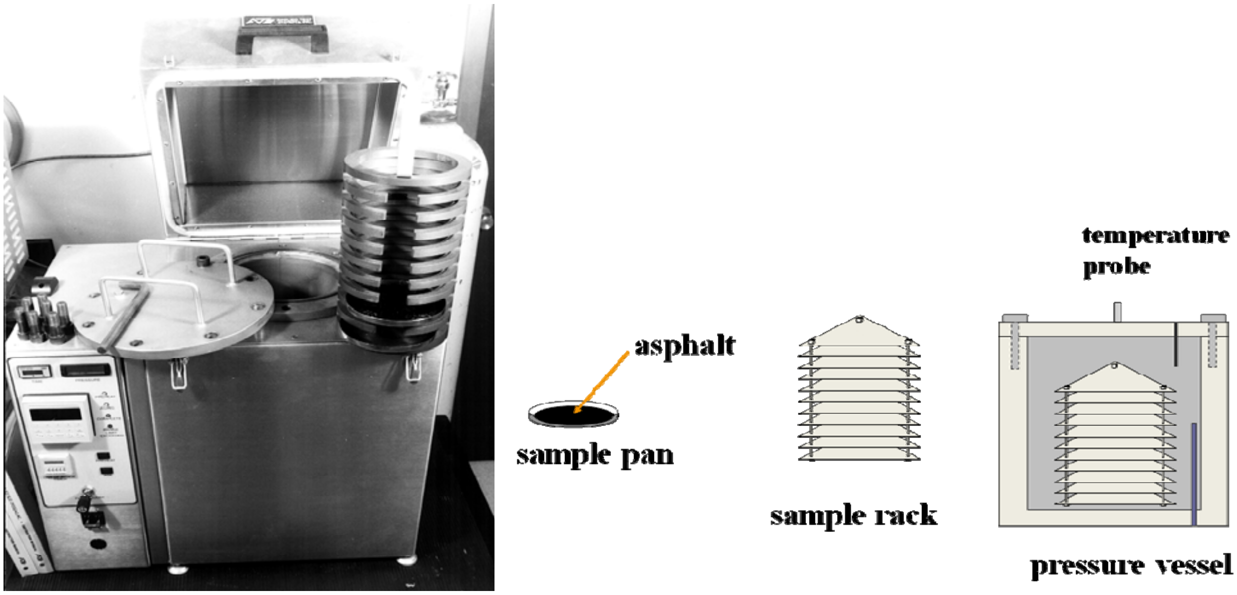


Figure 4. Pressure aging vessel.

Figure 5. Dynamic shear rheometer.

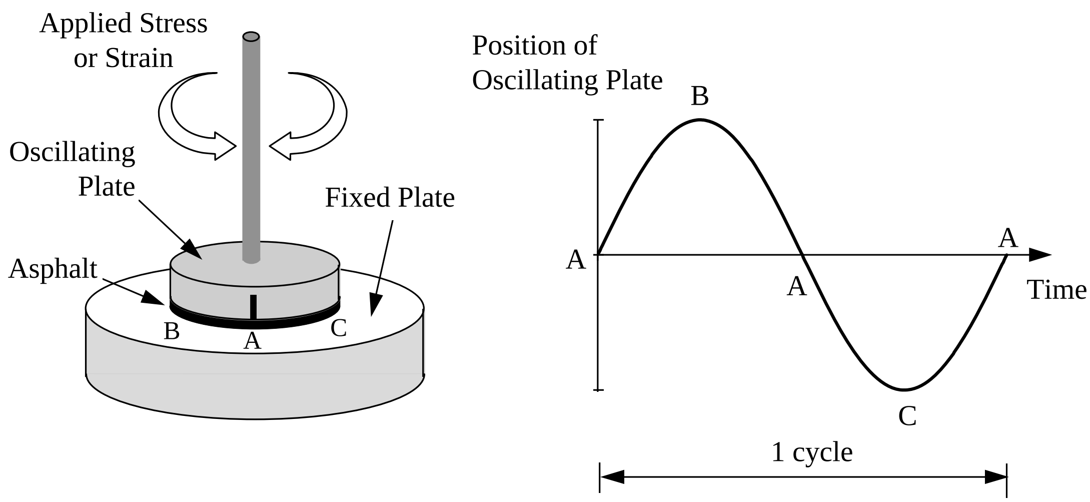


Figure 6. Schematics of Dynamic Shear Rheometer Test.

Bending Beam Rheometer

The bending beam rheometer (BBR; Figure 7) is used to characterize the low temperature stiffness properties of binders. It measures the creep stiffness (S) and logarithmic creep rate (m). These properties are determined by measuring the response of a small binder beam specimen to a creep load at low temperatures (Figure 8).

Figure 7. Bending beam rheometer.

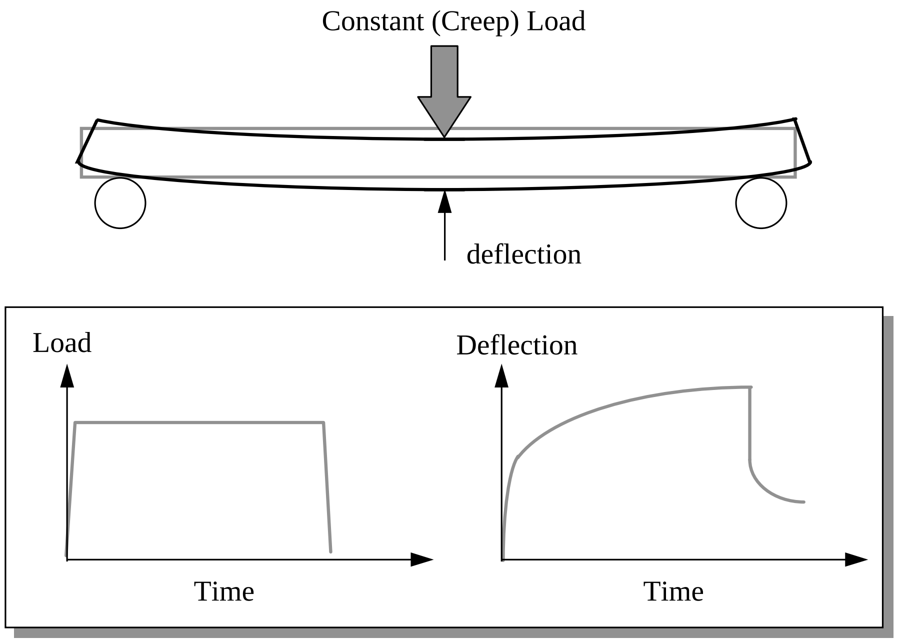


Figure 8. Concept of bending beam rheometer and the corresponding results.

PREPARATION OF SPECIMENS

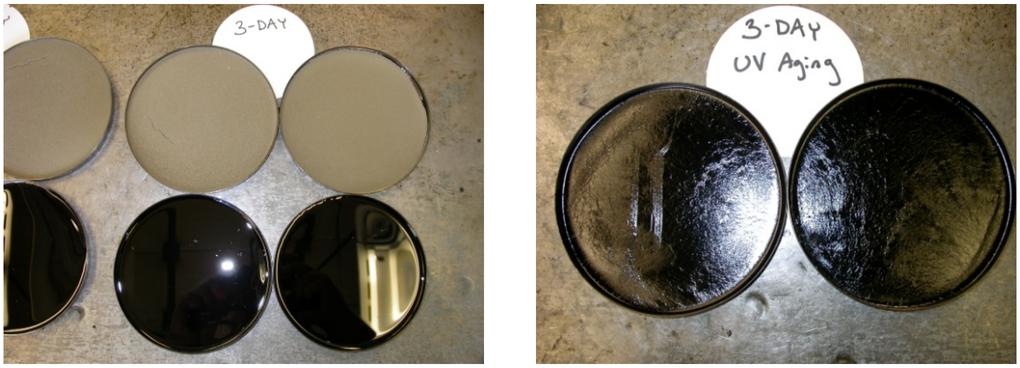
Preparation of Asphalt Binder Specimens

In preparation of the binder samples for Task 2, eight PAV pans were used. The inside vertical wall of four of the pans were lined with ScotchBlue Painter's Tape for easy removal of Tensar's coating after aging. The binder was heated in an oven at 135^{o}C until it was sufficiently fluid to pour into the PAV pans. Fifty grams of binder were poured into each of the eight pans, and then placed back into the oven for a few minutes to allow for flattening of the binder in the pans. The pans were then cooled on a flat and level surface. After cooling four of the pans were coated with Tensar's coating. Each pan was coated with 98 grams of the Tensar coating. After coating four pans, all eight pans were placed into an oven at 40^{o}C for 72 hours to cure, with trays of water underneath the pans. After the 72 hour curing, the pans were placed into the Pressure Aging Vessel to perform AASHTO R28 aging of the binder for 20 hours at 110^{o}C and 2.10 MPa. Upon removing the pans from the PAV, the binder from the four control pans was scraped into a beaker and the binder from the four coated pans was scraped into a separate beaker after removing the Tensar coating from the surface of the binder. It was more difficult to remove the binder from the coated pans, as the Tensar coating material had to be broken and carefully removed as not to contaminate the binder with the coating material. It was also noticed that a portion of the binder had squeezed through the edges of the pans of the coated pans, and migrated to the top of the Tensar coating, as seen in Figure 11. The two beakers containing aged binder were then placed in a vacuum oven for 30 minutes at 170^{o}C under 15 KPa suction for degassing. Afterwards, the binder specimens were ready for testing with the Bending Beam Rheometer.

(a) (b)

Figure 9. Task 2 coated binder specimens (a) before PAV and (b) after PAV

To prepare the binder samples for Task 4, eight PAV pans were used. The same procedure was used to prepare the binder samples as Task 2, with the exception that no ScotchBlue Painter’s Tape was used on the inside walls of the PAV pans. The samples were cured in a way similar to the materials of Task 2. After the curing process was complete, the eight binder samples were put into the Ultraviolet light chamber for the UV aging part of the task. The UV radiation was measured at various locations where the binder samples were to be placed. After three days, two coated and two control samples were removed from the UV chamber. The pans were placed into an oven at 135^{o}C for 15 minutes for the binder to become sufficiently fluid to pour into storage tins. The binder residue in the control pans was scraped using a hot putty knife to help pour it into the tins. The coated samples were more difficult to pour, the Tensar coating had to be broken and carefully removed to prevent any contamination of the binder. After removing the Tensar coating, the binder was poured and scraped using a hot putty knife into storage tins. After seven days the remaining coated and control binder samples were removed from the UV chamber. The binders were removed from the pans the same way as the three day samples and put into storage tins. The images in Figure 12 show the difference between the samples before aging and after 3 days of UV aging. With all of the binder ready for testing, Dynamic Shear Rheometer tests were performed on each of the coated and control samples at 22^{o}C and 64^{o}C. DSR tests were also performed on neat unaged binder, PAV aged binder, and RTFO aged binder for comparison.



(a) (b)

Figure 10. Binder specimens (a) prior to UV aging and (b) after 3 days of UV aging.

For Task 5, two batches of binder were aged in the Rolling Thin Film Oven. The binders from both batches were weighed and the amount of filler was determined. The filler amount was 30% of the weight of the binder. The filler was weighed out and placed in an oven at 135^{o}C for 24 hours to remove any moisture. The binders from both batches were heated in an oven and mixed together with the filler using a high speed shear blender at 500 rpm for 10 minutes. After blending the binder and filler, the mastic material was poured into eight PAV pans, each with 50 grams of the mastic material. The top of four binder samples were coated with Tensar's coating, and all eight pans were put into an oven at 40^{o}C for 72 hours with a tray of water underneath them for curing. After the 72 hour curing, all eight samples were placed in the UV chamber. The samples were positioned on a platform in such a way that the top of the samples were 50 mm from the UV lights. The UV radiation was measured at each location of the eight samples and the temperature was recorded for the duration of the UV aging. After 14 days, two coated and two control samples were removed. The binder was heated in an oven at 135^{o}C for 15 minutes until sufficiently fluid to pour into storage tins. Any residue binder was scraped from the PAV pans using a hot putty knife and then poured into the storage tins. The other four samples were left in the UV chamber for an additional 14 days of UV light exposure. After the additional 14 days (for a total of 28 days of aging), the mastic binder material was then heated and poured into prepared Bending Beam Rheometer molds. The samples were conditioned and then tested using the BBR at -12^{o}C.

Preparation of Asphalt Concrete Specimens

For Task 3, plant produced hot mix asphalt concrete from a local company (HRI Inc.) was used. The asphalt concrete was heated in an oven at 150^{o}C and then weighed out, based on pre-calculated mass, onto trays of a specific mass. The asphalt was then poured into molds for compaction with a Superpave Gyratory Compactor, to an approximate height of 50 mm. A total of six samples were compacted. After compaction, the samples were cooled at room temperature for 24 hours. After cooling, each of the samples had their bulk specific gravity measured. In addition, the maximum theoretical specific gravity of the asphalt in loose form was measured. Air voids of each specimen was determined based on bulk and maximum theoretical specific gravity. The top of three of the compacted asphalt samples were coated with Tensar's coating and all six samples were cured at room temperature for 24 hours. After curing, all six samples were placed in an oven at 85^{o}C for 60 hours for long term aging according to AASHTO R30. After 60 hours, all six samples were removed and cooled. The bottom of the three samples that were originally coated on the top, were then coated with Tensar's coating. All six samples were then cured at room temperature for 24 hours. After curing, all six samples were placed back in the oven, with the newly coated surface facing upward, and aged 85^{o}C for an additional 60 hours. This completed the aging process. After 60 hours, the samples were removed from the oven to cool. Currently, the samples are ready to be tested using MTS servo-hydraulic system. From these tests, the indirect tensile resilient modulus of specimens will be determined. Afterwards, the indirect tensile strength of specimens will be determined using Instron electro-mechanical testing system.

For Task 6, the same plant produced asphalt concrete was used to make ten gyratory compacted specimens. The asphalt was heated in an oven at 150^{o}C until thoroughly hot, and then it was weighed out, based on pre-calculated mass, into trays. After weighing out the ten batches, the trays were put back into the oven for 1 hour to ensure the mixture was at the correct compaction temperature. After checking the asphalt temperature, gyratory specimens were made one at a time. The trays of asphalt were scraped into the Superpave gyratory compactor mold and compacted to an approximate height of 50 mm. After compaction, the specimens were extruded from the mold and placed in front of a fan to cool to room temperature. After cooling, each of the specimens had their bulk specific gravity measured. To measure bulk specific gravity, the specimen is weighed dry, and then placed into a 25^{o}C water bath for 4 minutes; the specimen is weighed underwater at the end of the 4 minutes. The specimen is then removed from the water bath and quickly dried with a terry cloth towel to obtain the saturated surface dry (SSD) condition. The specimen is then weighed again under SSD condition. With these three weights and the theoretical maximum specific gravity which was found in Task 3, the percent of air voids is determined. After determination of air voids, specimens were divided into two groups with similar average air void. The five specimens that made the coated group were dried overnight in front of a fan. After drying each specimen, a tape was placed around the top edge of the specimen to create a space on the specimen surface for the Tensar coating to stay within while curing. The Tensar coating dry powder was mixed with water and a total of 113 grams of Tensar coating mixed material was placed on the top surface of the specimen. All ten specimens were then put into a 25^{o}C oven for 72 hours with a tray of water underneath them for curing. After curing, the specimens were then taken to the UV chamber for Ultraviolet light aging. Before putting the specimens into the UV chamber, a platform was made to accommodate specimens in a way that the top of the specimens would be 50 mm from the light source. The UV radiation was measured at each of the ten locations of where the specimens were placed. After taking radiation readings the specimens were placed into the UV chamber for the start of UV aging process. The temperature was recorded using two thermocouples in the UV chamber for the entire length of aging.

For Task 7, there were two molds made to compact the slabs in. The molds were made with a steel bottom and wood sides, with an interior dimension of 25.5 inches wide by 54 inches long. With the interior dimension of the mold known, the amount of asphalt needed was calculated. A 1 inch layer of neoprene was placed in the bottom of the mold and a layer of tack coat, diluted with water at a ratio of 1:1, was sprayed on top of the neoprene at a rate of 0.2 L/m^2. While the sprayed tack coat was being cured, the buckets of asphalt were placed in an oven at 155^{o}C. There was a thermocouple installed on top of the neoprene to record the temperature during testing. When the asphalt was at the correct compaction temperature, half of the buckets were added to the mold on top of the neoprene for the bottom layer. The asphalt was compacted using an Ingersoll Rand single drum vibratory roller. A total of ten passes were made to compact the bottom layer. After every second pass, the density of the asphalt was measured and recorded, using the Pavement Quality Indicator, for a total of five density readings. A thermocouple was placed on top of the bottom layer before compacting the top layer to record the temperature during testing. The top layer was compacted using the same method as the bottom layer and density readings were also recorded the same way.

The second slab was prepared in the same manner as the first slab. After both of the slabs were cooled, the surface thermocouple was installed by drilling a small hole ½ inch deep and gluing the thermocouple in place on each slab. Afterwards, both of the slabs were placed outdoors for the elemental exposure and curing portion of Task 7 for a total of 13 days. During this time, the temperature was being recorded using the installed thermocouples (Figure 13). After the 13 days of outdoor exposure was complete both of the slabs were brought indoors to dry before the Tensar coating was applied to the coated slab (Figure 14). The Tensar coating was applied by an employee of Tensar.

Figure 11. Test slabs exposed to outdoor environment for curing.

Figure 12. Test slab being coated with Tensar's coating.

ANALYSIS, INTERPRETATIONS, AND FINDINGS

<u>Measuring the Effect of Tensar's Coating on PAV Aging Magnitude Through Low Temperature Testing</u>

As explained under Task 2, control and coated binders were aged in a Pressure Aging Vessel followed by testing in the Bending Beam Rheomter at -12°C. Results are shown in Figure 15. These results are based on three replicates for coated specimens and four replicates for control specimens. The coefficient of variation on stiffness was 0.015 and 0.005, respectively, both very low and indication of good repeatability in test results. Similarly, very low variation was observed of the m value from BBR test. This index is a measure of the rate at which stresses are relaxed, and the higher the index is, the faster the rate of stress relaxation will be, and therefore the better resistance against low temperature cracking. It can be seen that the presence of the coating has resulted in significant reduction of stiffness and an increase in relaxation index m value, both favorable outcomes. This implies that coating has significantly reduced the level of binder aging induced by PAV.

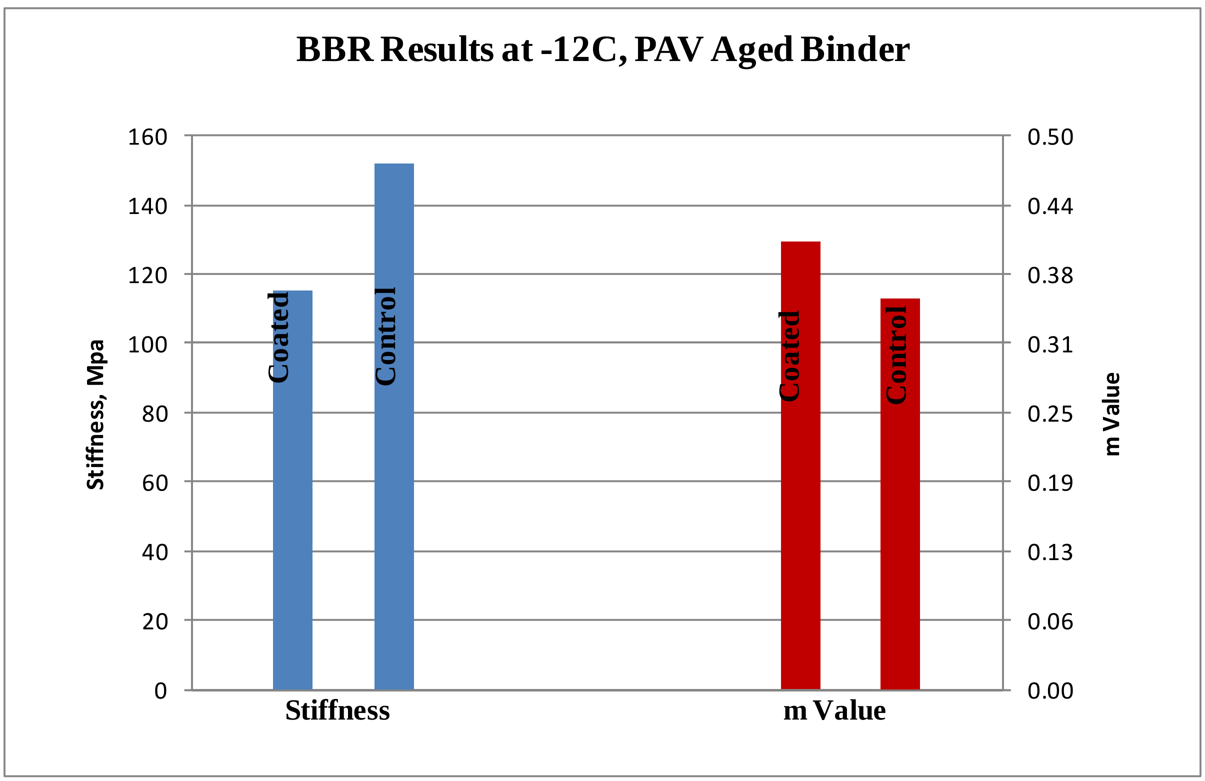


Figure 13. BBR results at -12 deg C, PAV-aged binder specimens.

Measuring the Effect of Tensar's Coating on UV Aging Magnitude through Low Temperature Testing

As explained under Task 5, the control and coated binders were aged in the Rolling Thin Film Oven. After aging, the binder was then blended with a filler at 30% of the weight of the binder. Samples were then prepared and coated and placed in the UV chamber for 14 and 28 days. After 14 days, two control and two coated samples were removed and the binder was tested using the BBR at -12C. Then after an additional 14 days, the second group of two control and two coated samples were removed and also tested using the BBR at -12C. The results are shown in Figures 16 and 17. The error bars in Figure 17 indicate the 95 percent confidence interval on the mean stiffness for different conditions. In general, there is no significant difference observed between 14 day and 28 day conditions and between coated and control conditions.

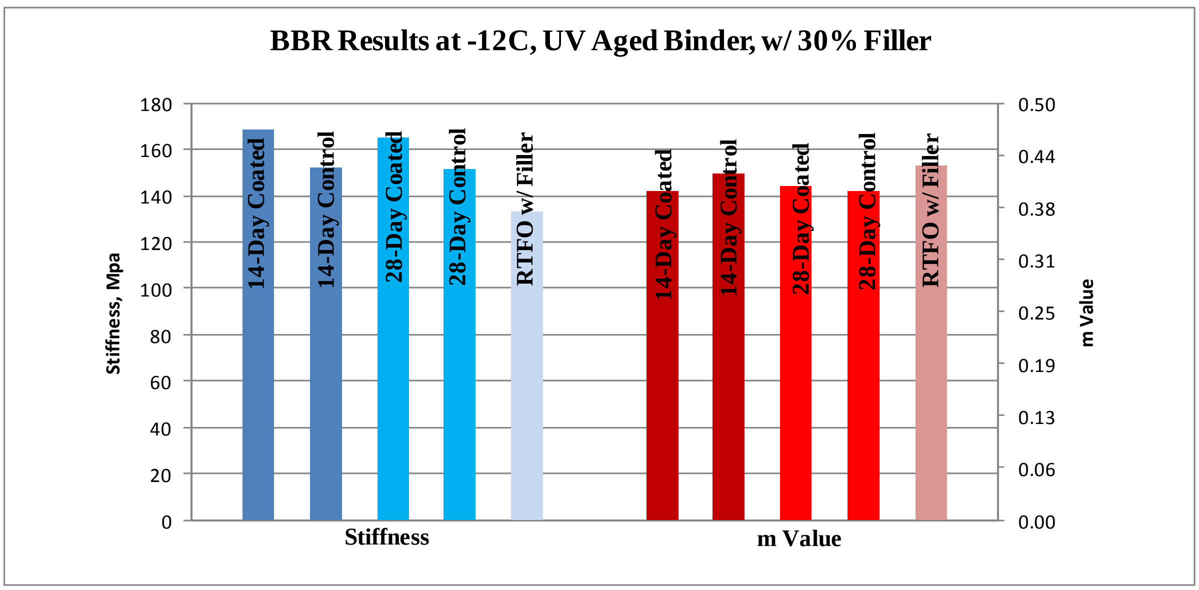


Figure 14. BBR Results at -12C, UV Aged with 30% Filler

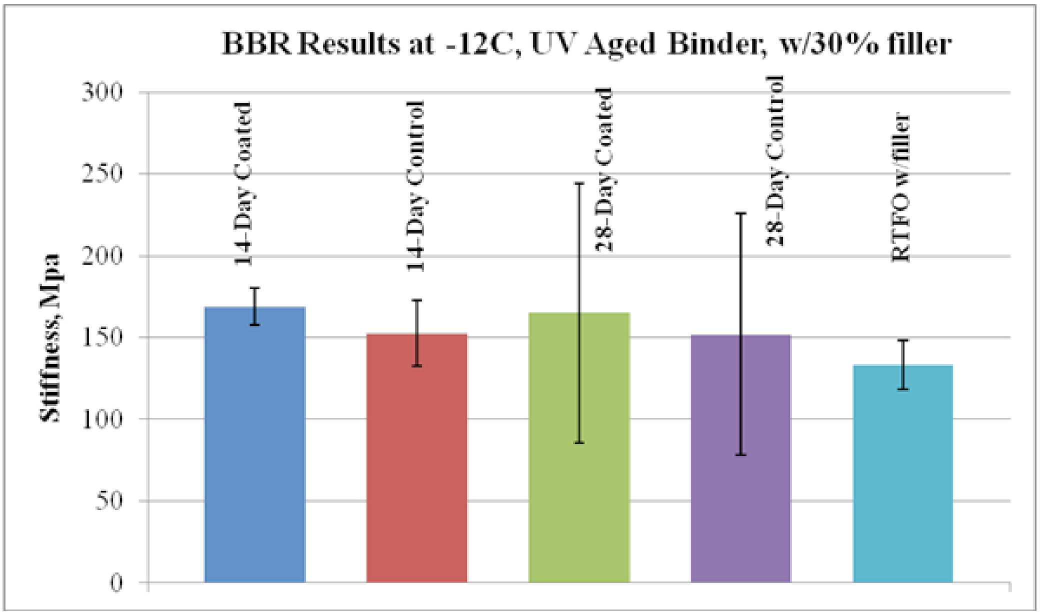


Figure 15. 95% Confidence Interval on the BBR Stiffness

Effect of Coating on UV Aging Magnitude through Intermediate and High Temperature Testing

Complex modulus and phase angle of binder specimens was determined using dynamic shear rheometer (DSR) after exposure to the ultraviolet radiation for 3 days and 7 days, respectively. The UV radiation configuration discussed under Task 1 above was used for this purpose. In addition to UV aged specimens, neat unaged binder, short-term aged binder using RTFO, and long term aged binder using PAV were also tested using DSR. Testing was conducted at 64°C and 22°C to capture properties both at high and intermediate pavement temperature. The results, as shown in Figures 18 through 21, indicate that there is not much difference between the properties after 3 days UV aging and 7 days of UV aging. However, the results do indicate some limited aging has occurred compared to neat unaged binder. This aging is evident from the graph for modulus and for phase angle. Statistical one tailed t-test assuming unequal variances shows that this increase in stiffness or decrease in phase angle due to UV aging is not significant. The graphs indicate that both short term aging with RTFO and long term aging with PAV do change modulus and phase angle significantly and way beyond what is observed from 3-day and 7-day UV aging.

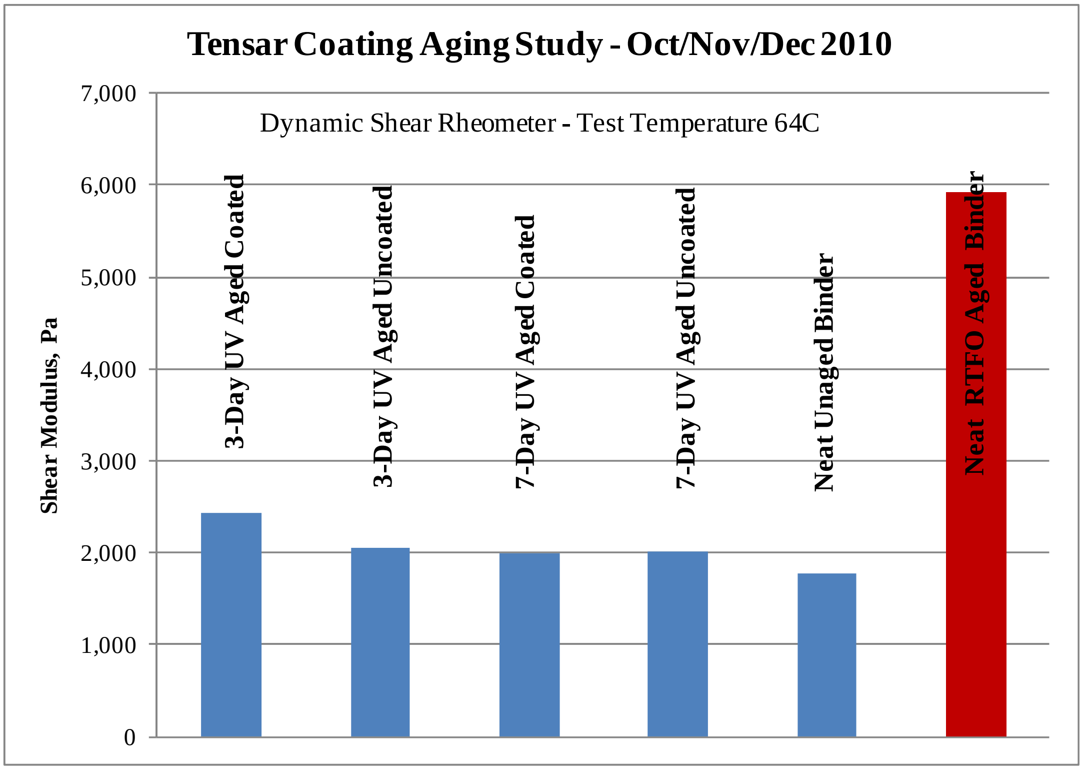


Figure 16. DSR shear modulus results for UV-aged, neat unaged, and neat RTFO aged binder tested at 64C

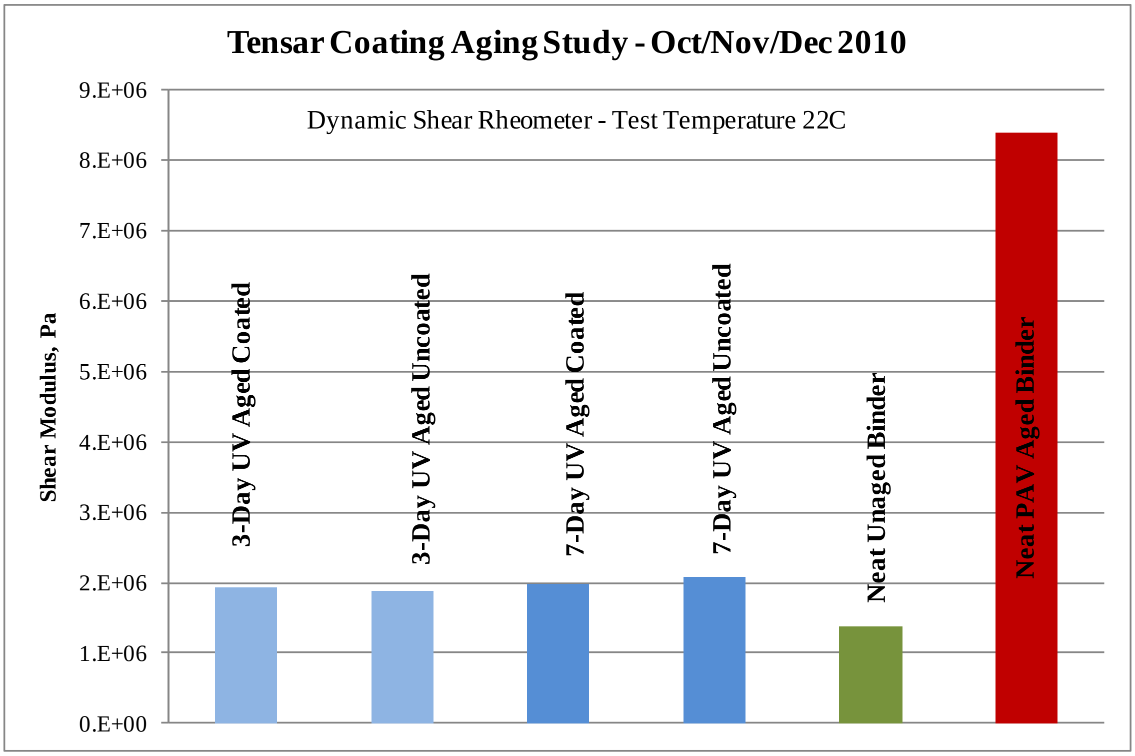


Figure 17. DSR shear modulus results for UV-aged, neat unaged, and neat PAV-aged binder tested at 22C.

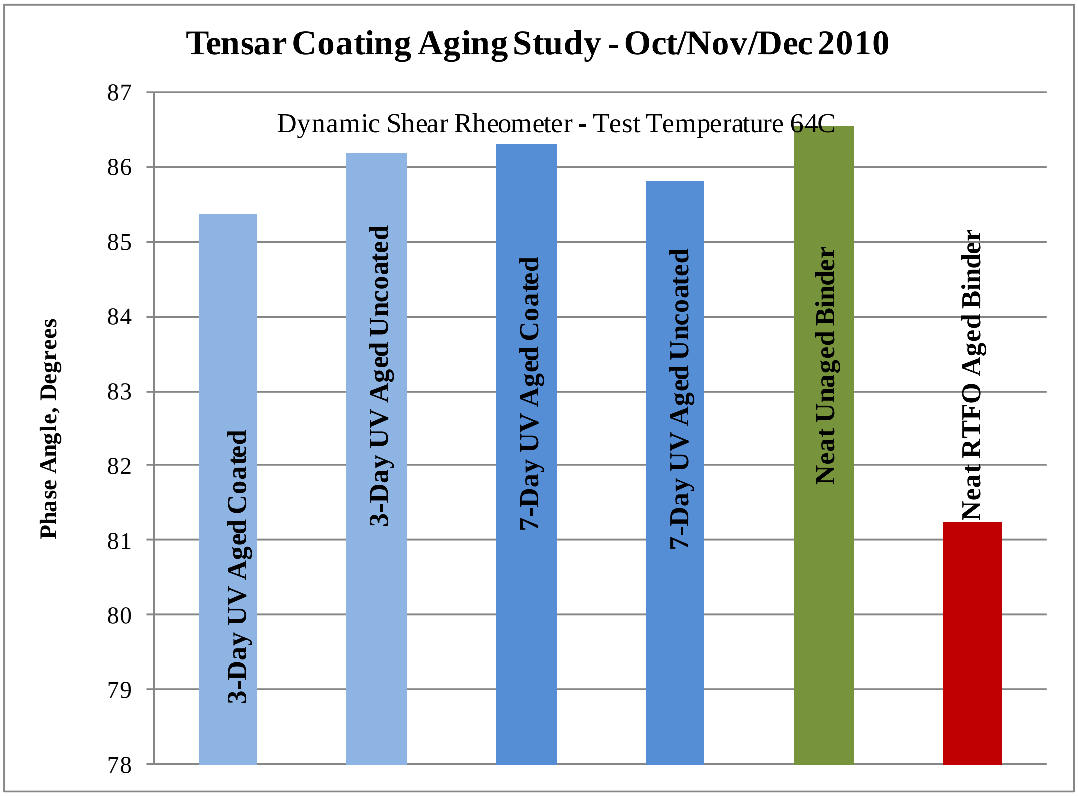


Figure 18. DSR phase angle results for UV-aged, neat unaged, and neat RTFO-aged binder tested at 64C.

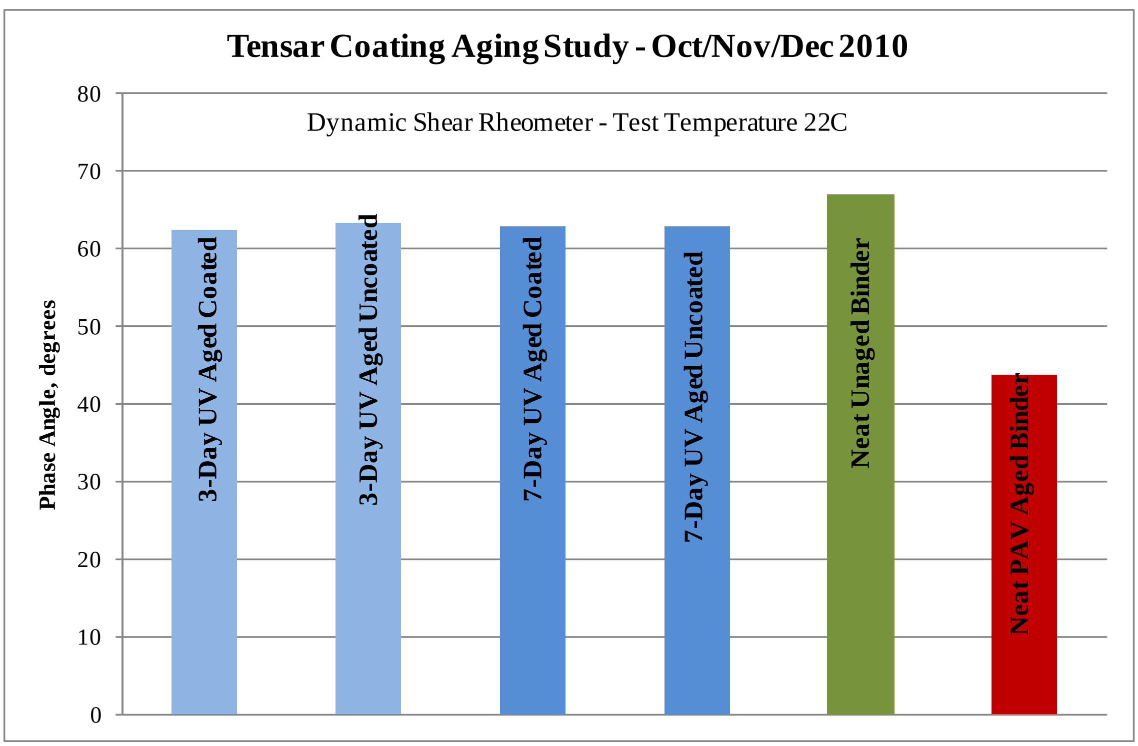


Figure 19. DSR phase angle results for UV-aged, neat unaged, and neat PAV-aged binder tested at 22C.

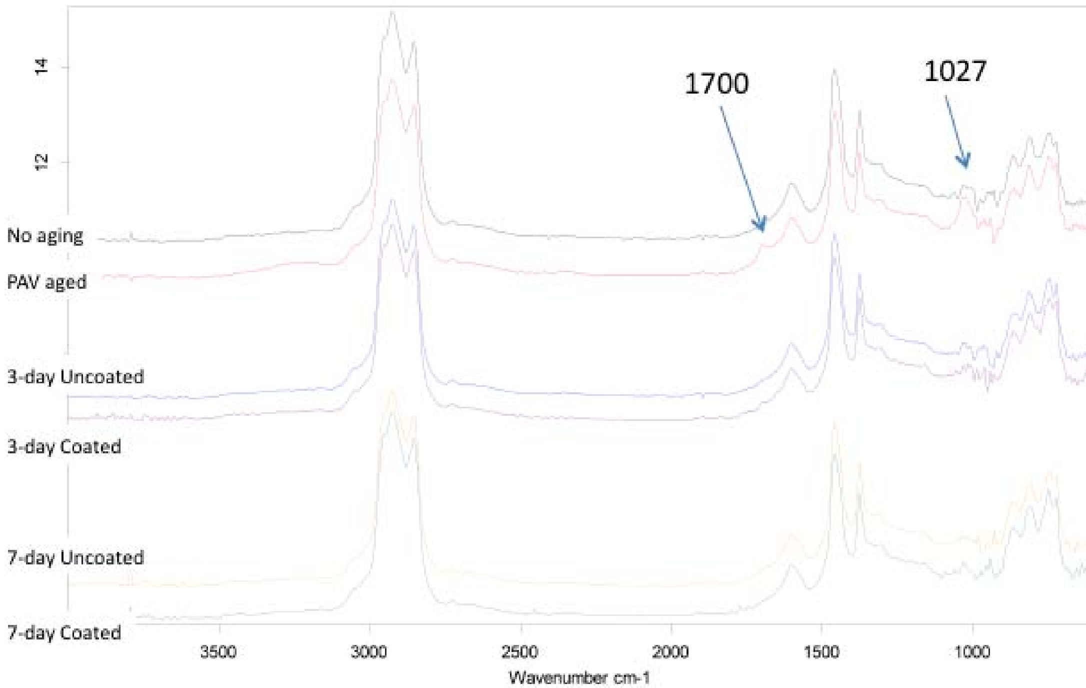


Figure 20. FTIR-PAS spectra for unaged, PAV-aged, and UV-aged binder specimens.

FTIR-PAS spectra (Figure 22) were acquired on a Bruker IFS/66s (Bruker Optics, Billerica, MA) spectrometer equipped with an MTEC Model 300 photoacoustic sampling accessory (MTEC Ames, IA). By using a photoacoustic accessory, the samples could be analyzed without physical manipulation or dilution. Sample spectra were acquired in rapid scan mode with a 500 Hz modulation frequency and by averaging 8 scans at 8 cm-1 resolution. All spectra are normalized to the spectrum of a carbon black reference sample. The only significant observable difference is the growth of a peak at ~ 1700 cm-1 and ~ 1027 cm-1 in the PAV aged spectrum compared to the un-aged spectrum. These peaks are likely attributable to the C=O and S=O stretching modes, respectively. The spectra appear very similar for the 3-day and 7-day coated and uncoated specimens. This finding is consistent with the DSR measurements in that the impact of UV aging was not observed. However we expect to see a difference once the UV aging intensity and time are increased.

Air Void of MMLS3 Slab Cores

Figure 23 shows the locations of 6-inch cores that were obtained from each slab. The bar chart in Figure 24 indicates that the air void of the coated slab is considerably higher than that of the control slab.

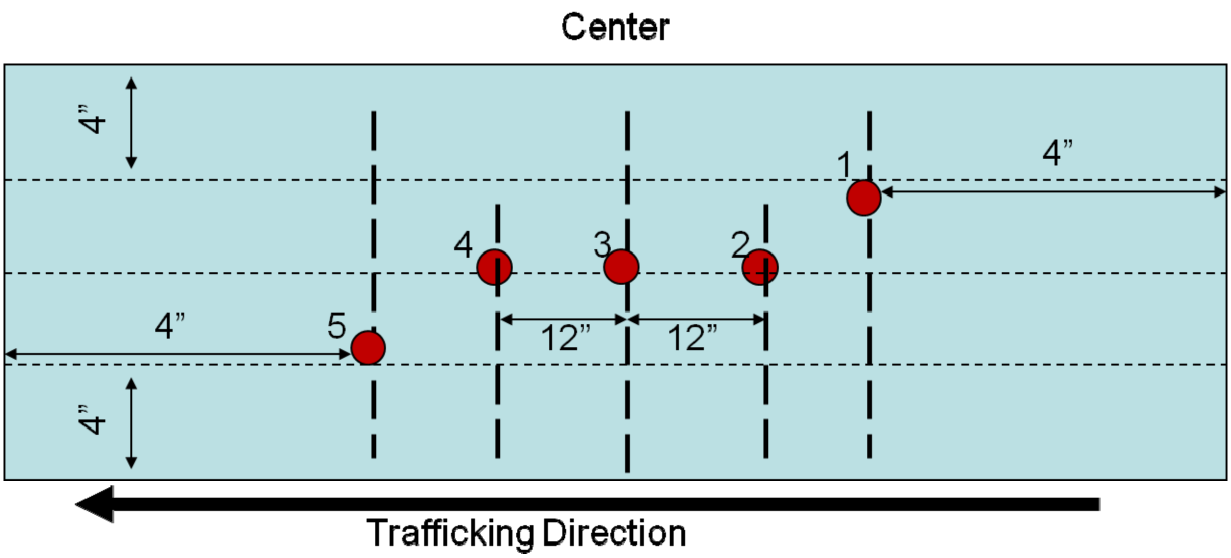


Figure 21. Core extraction locations from test slabs.

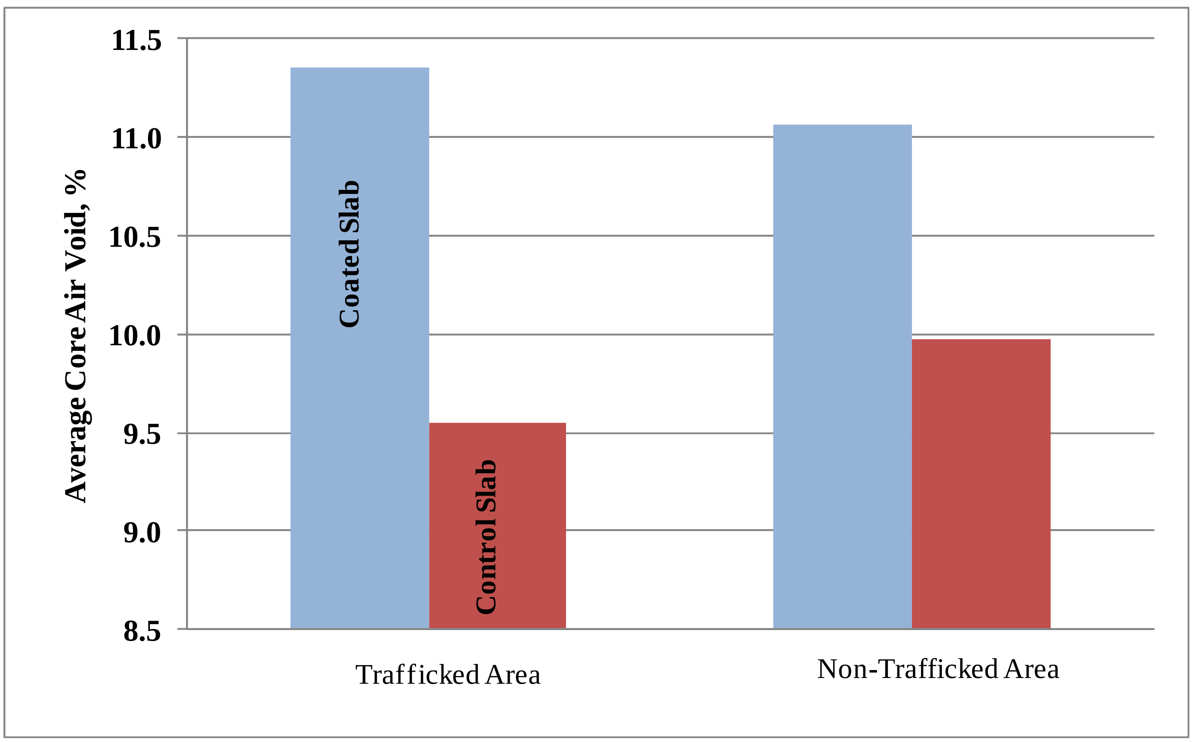


Figure 22. Average air void based on cores extracted from test slabs.

PSPA Modulus

High frequency modulus was determined for each slab using Portable Seismic Pavement Analyzer (PSPA). Measurements were conducted at 15 locations as shown in Figure 25.

Measurements were also conducted after the following number of cycles: 5k, 10k, 25k, 50k, 75k, 100k, 150k, 200k, 250k, 300k, and 400k.

The bar chart of Figure 26 shows the PSPA results for location #8 at the center of slab after 5,000 and 400,000 cycles. The moduli from different depths are averaged to generate these graphs. These results indicate similar modulus levels for 5,000 and 400,000 cycles. Slightly higher modulus of the control section is possibly due to low air void content of this slab compared to the coated slab.

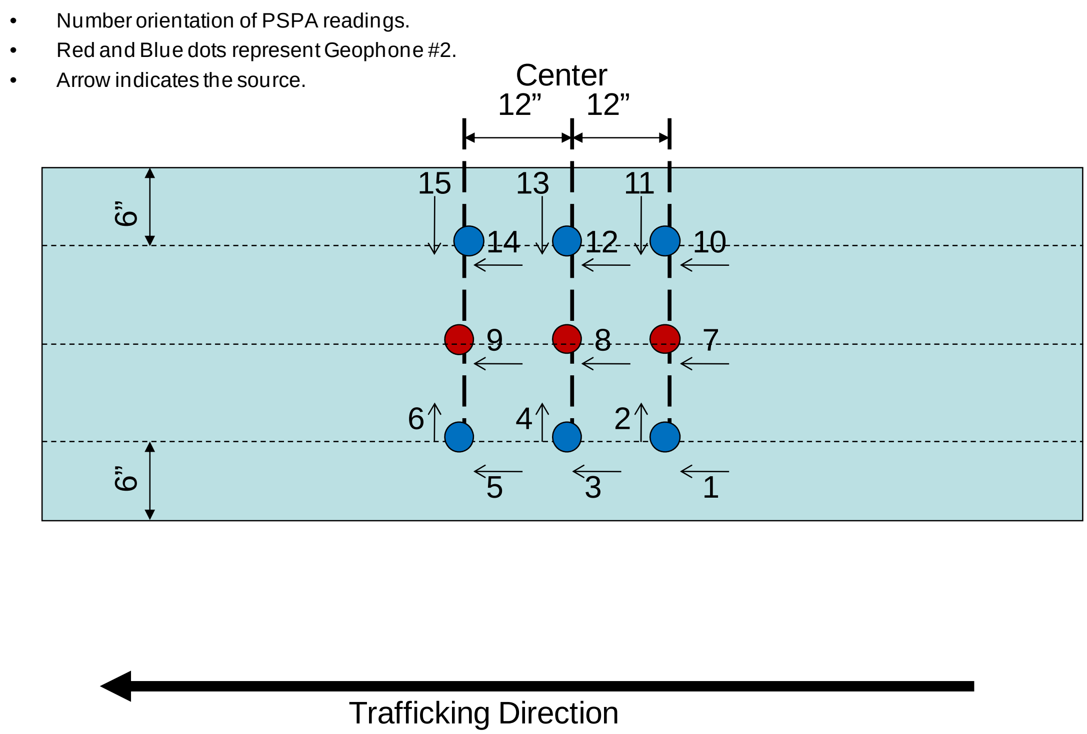


Figure 23. PSPA measurement locations.

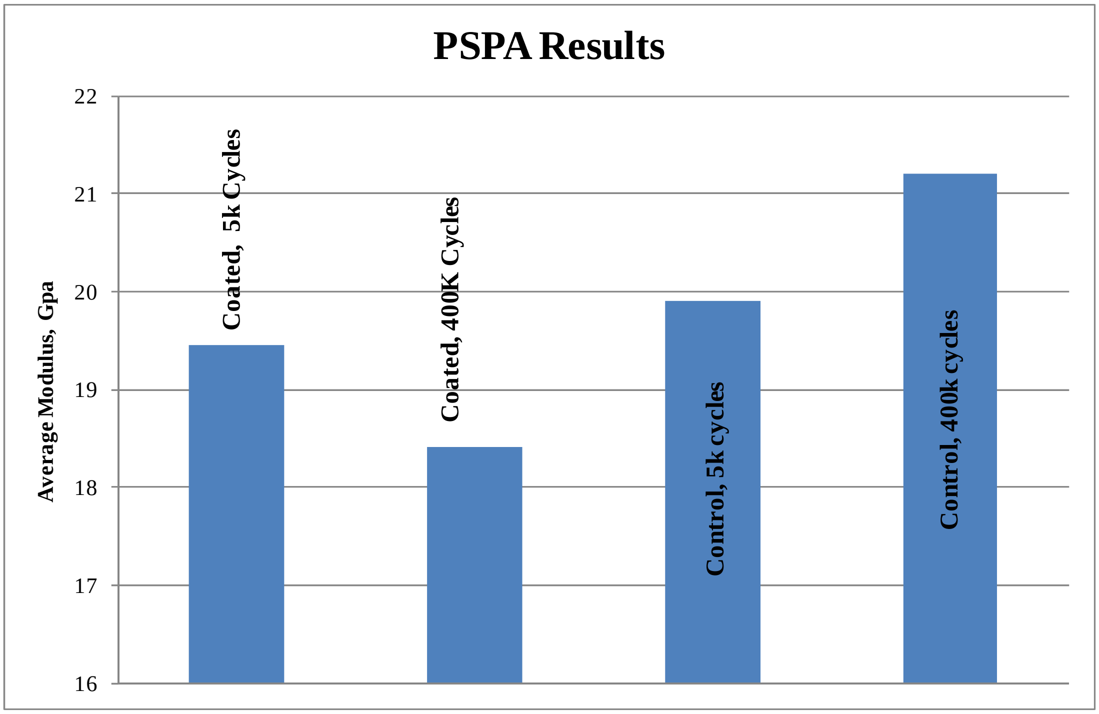


Figure 24. PSPA results for slab center (location #8) after 5000 and 400,000 cycles.

Evaluation of Coating Effect through MMLS3 Tests

The average, minimum, and maximum recorded temperatures of the slabs during the curing phase (13 days) and the accelerated testing are summarized in Tables 2 and 3.

Table 2. Slab Temperatures Measured During the Curing Phase

Slab	Measurement Location within Slab	Minimum (deg C)	Maximum (deg C)	Average (deg C)
Control	Top	3.9	40.9	16.0
	Middle	5.0	41.0	16.6
	Bottom	5.1	39.6	16.4
Coated	Top	4.3	44.7	16.4
	Middle	4.8	44.1	16.8
	Bottom	4.9	42.0	16.8

Table 3. Slab Temperature Measured During Accelerated Testing

Slab	Measurement Location within Slab	Minimum (deg C)	Maximum (deg C)	Average (deg C)
Control	Top	28.8	28.8	24.4
	Middle	27.7	27.7	24.3
	Bottom	27.0	27.0	24.2
Coated	Top	18.7	25.9	22.8
	Middle	19.6	26.2	23.2
	Bottom	19.8	26.4	23.3

The profiles were measured at three locations along the wheel path. Measurement locations perpendicular to the wheel path are shown in Figure 27, indicated by red lines numbered 1, 2 and 3. Figures 28 and 29 show the rutting profiles of the uncoated and coated test slabs, respectively, measured at location 2 (also called location C0500).

When comparing Figures 28 and 29, it appears that the total rutting after 400,000 cycles is approximately the same for both the uncoated (control) and coated slabs. An alternative comparison can be made between rutting at 5,000 cycles and rutting at 400,000 cycles, as shown in Figure 30. At location 150 mm (slab center), the difference in rutting for the control case is 6.73 mm, while the difference for the coated slab is only 4.54 mm. In other words, the coated slab appears to reduce the overall rutting for the same number of cycles.

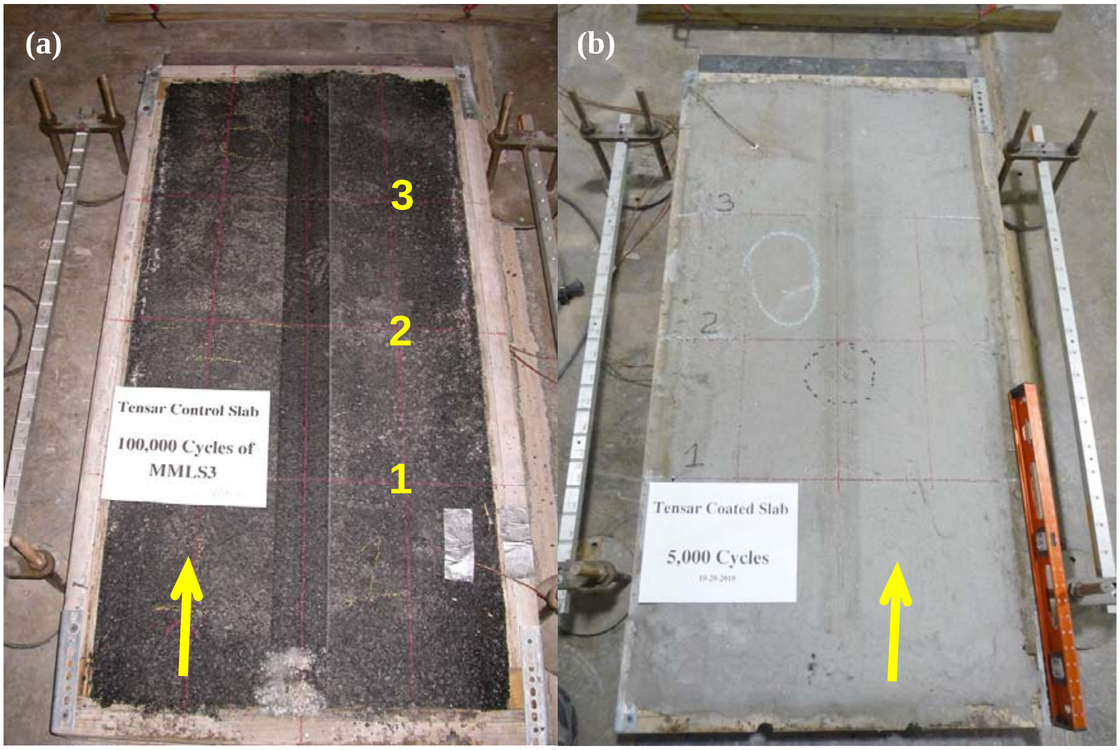


Figure 25. Profile measurement locations for (a) control slab and (b) coated slab. Arrows indicate trafficking direction.

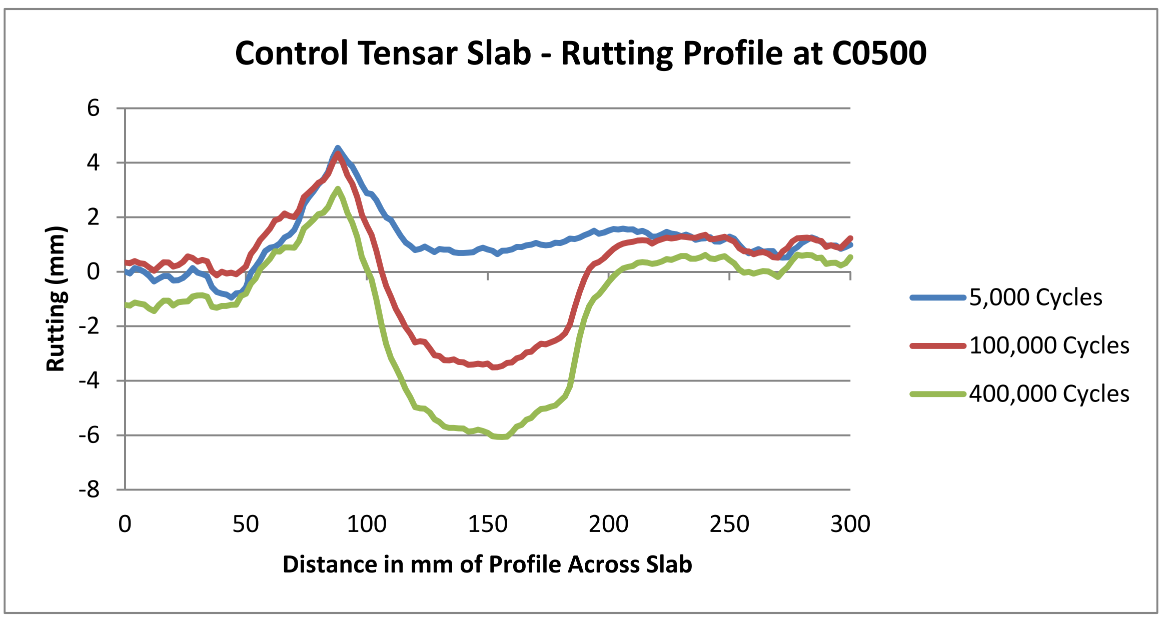


Figure 26. Rutting profiles of uncoated slab at 5000, 100000, and 400000 cycles. Profiles measured at the center of the wheel path.

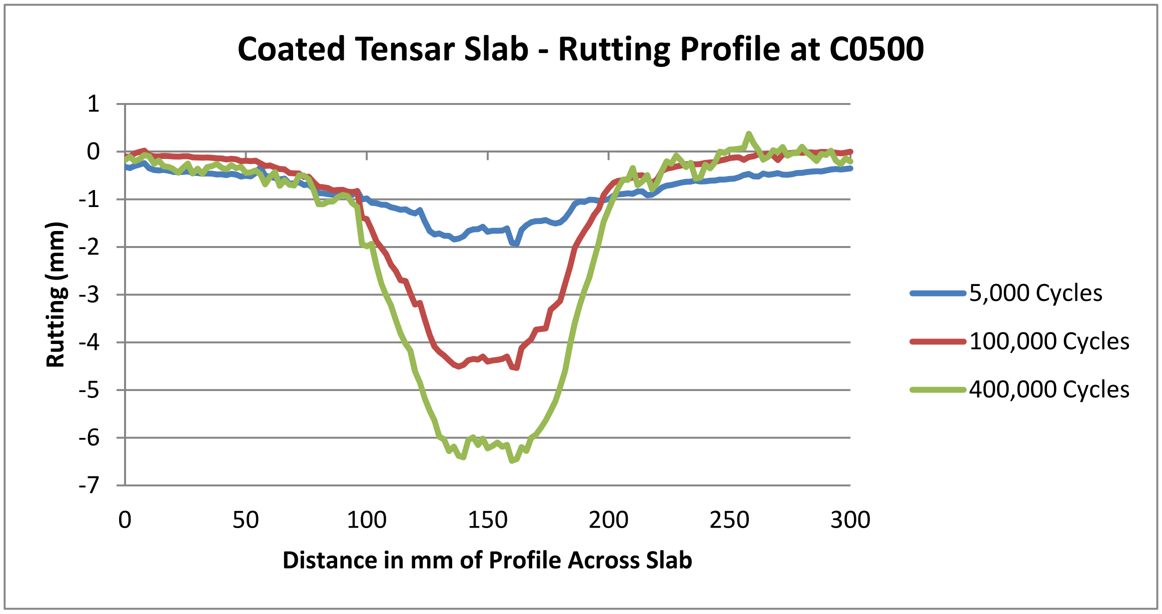


Figure 27. Rutting profiles of slab coated with Tensar's coating at 5000, 100000, and 400000 cycles. Profiles measured at the center of the wheel path.

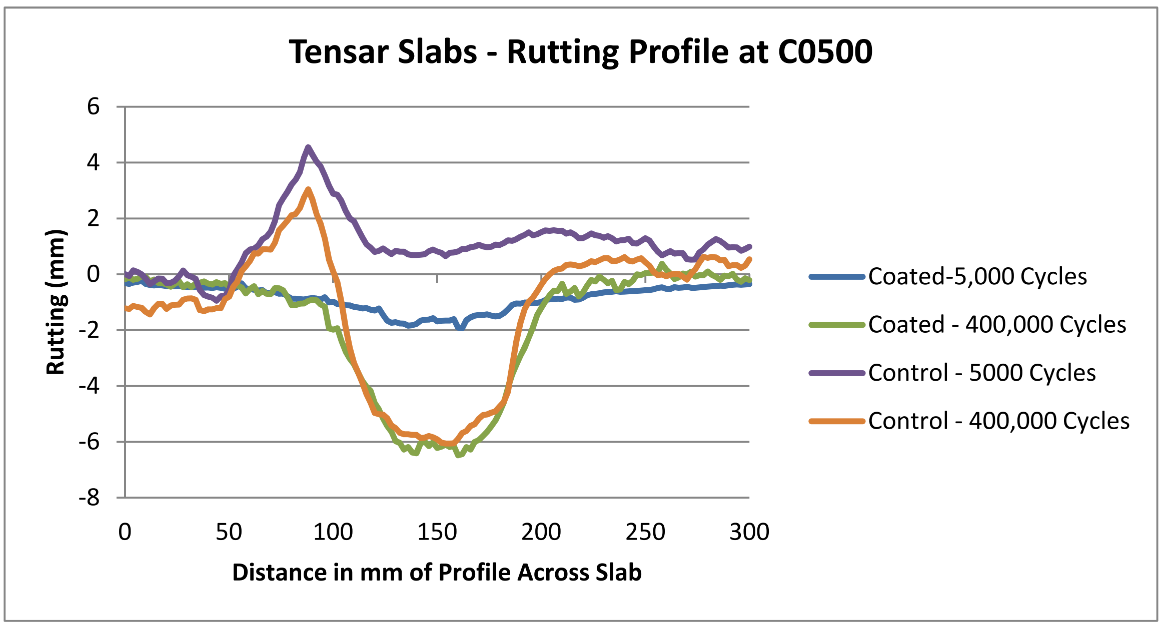


Figure 28. Comparison rutting profiles between control and coated slabs at 5000 and 400000 cycles.

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary and Conclusions

Research was undertaken to evaluate the effectiveness of Tensar's specialty polymer cement slurry (coating) in reducing aging of asphalt binders and mixtures. The study was also aimed at evaluating the effect of this material on performance characteristics of asphalt binder and asphalt concrete through laboratory investigation. The plan required preparation and testing materials at different aging levels. The materials included the asphalt binders and mixtures prepared with and without a coating level of Tensar's coating. Aging was achieved through rolling thin film oven (RTFO), pressure aging vessel (PAV), and Ultraviolet (UV) chamber. Aging in the UV chamber was conducted for 3 days, 7 days, 14 days, and 28 days. Testing for the binder included dynamic shear rheometer (DSR), bending beam rheometer (BBR), and Fourier transform Infrared spectroscopy (FTIR). Mixture testing was conducted using the third scale model mobile load simulator (MMLS3).

The following conclusions are based on the results obtained from this laboratory testing:

- Under BBR low temperature testing for asphalt binder, the Tensar coating resulted in significant reduction of stiffness and an increase in relaxation index m value, implying that the coating has significantly reduced the level of aging induced by PAV.
- Under BBR low temperature testing for asphalt mastic, no significant difference was found in stiffness between the binders aged under UV for 14 days versus those aged under UV for 28 days. Furthermore, no significant difference was found in stiffness between the level of aging between coated and uncoated binders.
- DSR results indicate a minimal difference between the binder properties after 3 days UV aging and 7 days of UV aging. However, the results do indicate some limited aging has occurred compared to neat unaged binder. These results are consistent with FTIR-PAS spectra results.
- Cored specimens from the MMLS3 slab indicate that the measured air void of the coated slab is considerably higher than that of the control slab. However, both the trafficked and untrafficked regions show this trend. The slightly higher modulus of the control section may be due to the low air void content of this slab compared to the coated slab.
- When comparing the difference in rutting from MMLS3 at 5000 cycles and 400,000

cycles, the coated slab appears to reduce the overall rutting for the same number of cycles given that the coated slab has higher air voids.

Recommendations for Extended Work, Phase II:

- The original plan for this work included mechanical testing of asphalt concrete mixtures. However, this research indicated that the level of UV aging achieved under ambient temperatures and the time frames used were not sufficient to affect the binder stiffness and modulus significantly. Hence, mechanical testing on mixtures was not conducted under this research. To address this issue, UV aging time was extended from the original 7 days to 28 days. It is expected that with future modifications to the UV aging chamber and extended aging times, it will be possible to induce sufficient aging to evaluate the effectiveness of Tensar's coating. It is proposed that the UV aging duration and temperature be significantly increased.
- It is recommended that a PG 76-xx or A PG 70-xx be selected and tested to determine whether coating can decrease stiffness to a level that results in improving the asphalt grade at low temperature. The study requires PAV aging and testing of exactly the same number of specimens as the original work.
- It is recommended to consider using a wondering traffic pattern applied with the MMLS3 in evaluating Tensar's coating. While a wandering traffic pattern better models real traffic conditions, the applied random pattern cannot be repeated exactly from one pavement slab to the next. Consideration should also be given to channelized trafficking. Channelized trafficking is a much more aggressive technique, but allows for a direct comparative analysis. Both techniques have their own merits, and the choice should depend on the goals of the study.

APPENDIX

TR-448A (11-14-08)	JOB MIX FORMULA REPORT	SUPPLIER CODE	MATERIAL CLASS
pennsylvania DEPARTMENT OF TRANSPORTATION	JMF NO.	HRI14B41	SR9.5
	2010 (Year) / 3561 (Number)	Design ESAL'S	.3 to <3
		AGGREGATE SRL	M
		ORIGINAL APPROVAL DATE:	3/1/06

DATE ____________ SPEC 9.5mm PO ____________

SUPPLIER NAME HRI INC. LOCATION Curlin Gap Plant 103

BITUMINOUS PLANT TYPE AB TONS PER HOUR 350 ECMS NO. ________

SR & SEC ________ CONTRACTOR ____________ LOCATION ____________

Mix Time	
Dry	Wet
7	35

Material Supplier Code	Material Code	Material Class	% In Mix	Bulk Sp. Gr.	% Absorption
HAP14A14	207	B-3(W)	36.3	2.735	0.69
HAP14A14	207	B-3(A.S.)	18.2	2.745	0.93
HAP14A14	203	A8	25.5	2.796	0.73
NOBLT14	17	RAP	15.0	2.760	0.0
UNRCO	1	64-22	5.0	1.029	
NUST1					
VALR1					

JOB MIX FORMULA AND DESIGN

	AC %	.075 mm #200	.150 mm #100	.300 mm #50	.600 mm #30	1.18 mm #16	2.36 mm #8	4.75 mm #4	9.5 mm 3/8	12.5 mm 1/2	19 mm 3/4	25 mm 1	37.5 mm 1 1/2	50 mm 2	F/A	Pbe
Design	5.8	5.5	8.0	12	17	27	44	70	98	100					1.00	5.5
% Virgin AC		5.0	% Reclaimed AC				0.8									

MIX CHARACTERISTICS (Gyratory)

Gyrations @ Nini	Gyrations @ Ndes	Gyration @ Nmax	Design ESAL's	Combined Agg Gravity Gsb	Max Density Gmm	Ndes Density Gmb
7	75	115	.3 to <3	2.749	2.524	2.423
% Voids @ Nini	% Voids @ Ndes	% Voids @ Nmax	% VMA @ Ndes	% VFA @ Ndes	Lbs / Cu. Ft.	Specimen Wt
14.4	4.0	2.5	17.0	76.5	157.5	4820.0

IGNITION FURNACE DATA

Oven Make	Set Temp.	Sample Size	AC Correction Factor	#200 Correction Factor
GILSON	538	1200.0	0.22	0.3

TSR DATA

AC Supplier	Dry PSI Strength	Wet PSI Strength	TSR Value	Date TSR's were done	Date of Boil Test
UNRCO	204.6	184.5	90.2	1/25/09--Bull. 27 ch 3	

Combined Aggregate Consensus Properties

AASHTO T176 Sand Equivalent	AASHTO T304 Uncompacted Void Content	ASTM D5821 Coarse Aggregate Angularity	ASTM D4791 Flat & Elongated
85.4	47.2	100	0.8

GRADATION CHART IS PART OF THIS JOB MIX FORMULA

Designed by Richard Weaver Necept # 6 Date 01/15/10

Approved and Submitted by Richard Weaver Date 1-15-10

Reviewed by District Materials Engineer [illegible] Date [illegible]

Page 1 Manual Entry