Florida Department of
TRANSPORTATION

Evaluation and Implementation of a Heavy Polymer Modified Asphalt Binder through Accelerated Pavement Testing

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1 EXECUTIVE SUMMARY

In 2001, the Florida Department of Transportation conducted an experimental study to assess the effect of polymer modified PG 76-22 asphalt binder on rutting resistance of Superpave mixtures through Accelerated Pavement Testing. The success of this study led to the use of PG 76-22 binder on the final structural course for traffic level D (10 to < 30 million equivalent single axle loads, or ESALs) mixtures and the top two structural courses for traffic level E (≥ 30 million ESALs) mixtures. At times, however, localized failures still occur at locations with concentrated truck traffic and low speeds. In response, a follow-up APT study was conducted to evaluate the performance of a polymer-modified asphalt binder meeting PG 82-22 requirements. Results of the study indicated that the use of a heavy polymer modified binder improved rutting and cracking performance of asphalt mixtures. This report documents the findings of the study and efforts to implement the use of heavy polymer modified binders.

2 INTRODUCTION

2.1 Background

In 2001, the Florida Department of Transportation (FDOT) conducted an experimental study to assess the effect of polymer modified PG 76-22 asphalt binder on rutting resistance of Superpave mixtures through Accelerated Pavement Testing (APT) *(1)*. This study was critical to the widespread adoption of PG 76-22 asphalt binder and in developing guidelines for its use. FDOT's Flexible Pavement Design Manual was revised to direct the use of PG 76-22 asphalt binder in the final structural course for traffic level D (10 to < 30 million equivalent single axle loads, or ESALs) mixtures and the top two structural courses for traffic level E (≥ 30 million ESALs) mixtures. Subsequently, annual statewide Pavement Condition Surveys (PCS) have indicated that the amount of pavements rated as deficient due to excessive rutting has steadily decreased over the last ten years. Other research has also shown that the use of polymer modified asphalt binder improves rutting resistance as well as fracture resistance *(2-3)*. FDOT has not yet had polymer modified mixtures in place long enough to fully quantify the additional life that can be expected, but others have estimated an additional five to ten years of service life may be possible *(4)*. However, localized failures still occur at some locations with concentrated truck traffic at low speeds.

Recent studies have indicated that increased rutting resistance can be achieved with a heavy polymer modified asphalt binder *(5-7)*. The current cost of PG 82-22 asphalt binder is approximately $100/liquid metric ton more than PG 76-22 asphalt binder and $250/liquid metric ton more than unmodified PG 67-22 asphalt binder. Prior to implementation, the benefits of a PG 82-22 asphalt binder should be better quantified to justify its use. In response, an APT study was conducted to evaluate the performance of a polymer modified asphalt binder meeting PG 82-22 requirements.

2.2 Objectives and Scope

This study evaluated the rutting and fatigue resistance of three asphalt binder types: 1) a polymer modified PG 82-22, 2) a polymer modified PG 76-22, and 3) an unmodified PG 67-22. To allow for a faster and a more practical assessment under closely simulated in-service conditions, APT was considered to address the study objectives. APT is generally defined as a controlled application of a realistic wheel loading to a pavement system simulating long-term, in-service loading conditions. This allows the monitoring of a pavement system's performance and response to accumulation of damage within a much shorter time frame.

3 APT EXPERIMENT DESIGN

Three test track lanes measuring 12 feet wide and 150 feet long were milled and resurfaced for the APT portion of the study that focused on rut resistance evaluation. Each lane was resurfaced with two 2 inch lifts of a fine-graded Superpave mixture consisting of granite material and 5.1 % asphalt binder. The asphalt mixtures for each lane were identical except for the asphalt binder type which included, respectively, an unmodified PG 67-22, a Styrene Butadiene Styrene (SBS) modified PG 76-22, or a SBS modified PG 82-22. The primary difference in the modified binders was the amount of SBS polymer that was used. During the evaluation of rutting, the pavement was heated to 50 °C and trafficked with a 455 mm wide base single tire (Michelin X One XDA-HT Plus 455/55R22.5) loaded to 9,000 pounds and inflated to 100 psi. A wheel wander of 4 inches was used for each test. A previous FDOT study showed that, when compared to a standard dual tire, the 455 mm wide base single tire produced similar rut depths *(8)*.

Two additional test lanes measuring 50 feet were constructed on test pits for the evaluation of fatigue resistance. Each test pit consisted of two 1.5 inch lifts of fine-graded Superpave placed directly on the base surface prepared with a prime coat. Previous APT experience has shown that fatigue cracking is unlikely if a standard FDOT pavement structure with a water table of at least three feet below the base is used. Therefore, the water table was raised to the bottom of the base to weaken the pavement structure. The test pit dimensions allowed only one test per binder type so only the modified binders were evaluated. Three strain gauges were placed at the bottom of the asphalt layer to measure the longitudinal strain. A Super Single (Goodyear G286 A SS, 425/65R22.5) loaded to 12,000 pounds and inflated to 110 psi was used to load the test pits without wheel wander. Figure 1 illustrates the pavement structures for evaluation of rutting and fatigue resistance.

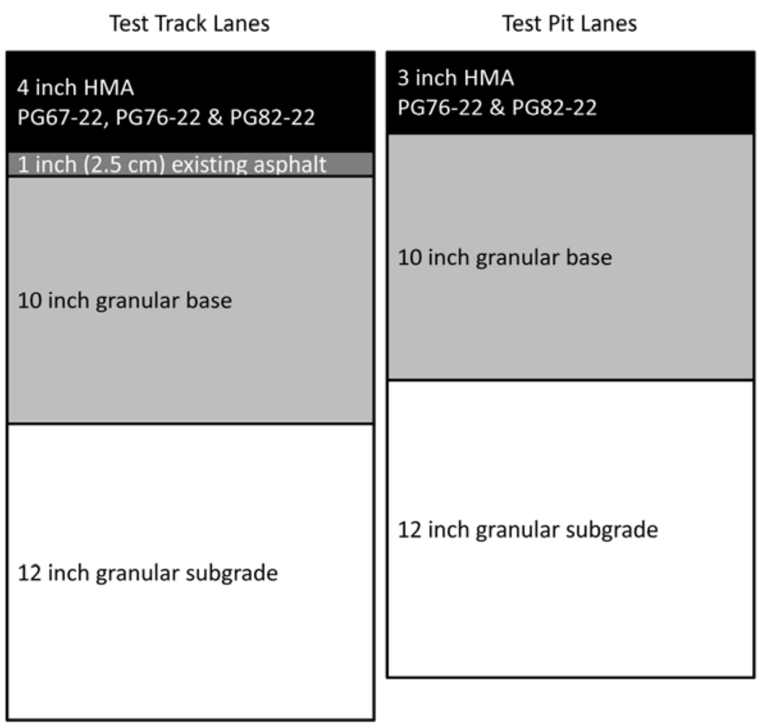


FIGURE 1. Experimental pavement structures

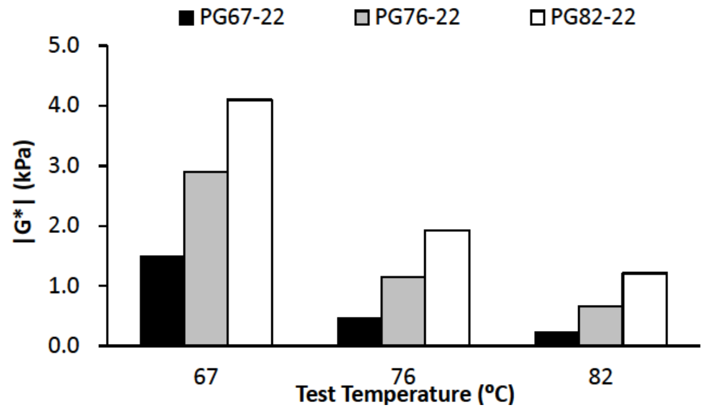
4 MATERIAL PROPERTIES

During construction of the test sections, asphalt binder was collected at the plant and hot mix asphalt (HMA) was sampled from delivery trucks. The asphalt binder was blended by the supplier to meet the requirements of PG 67-22, PG 76-22, and PG 82-22 according to the current FDOT specifications. The PG 82-22 binder included approximately 6 % SBS polymer modifier, approximately double that of the PG 76-22 binder. Laboratory tests were conducted to characterize the asphalt binders and HMA.

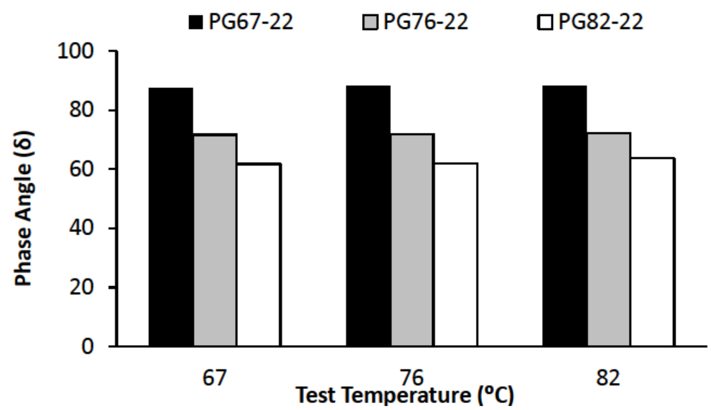
4.1 Asphalt Binder Properties

4.1.1 Dynamic Shear Rheometer

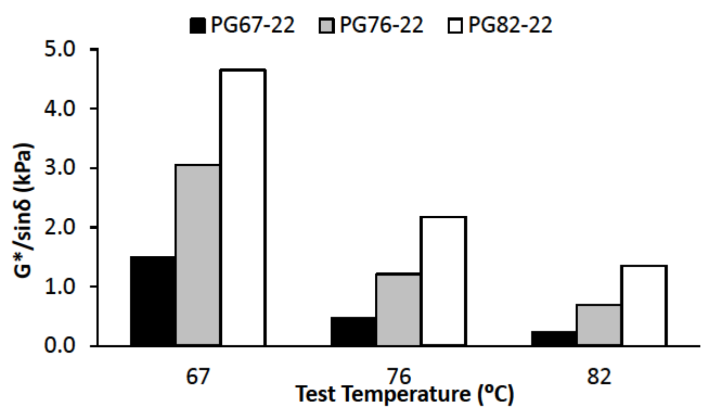
The dynamic shear rheometer (DSR) measures the complex modulus (G*) and phase angle (δ) of asphalt binder to determine the elastic and viscous components at pavement service temperatures. DSR tests were performed on the original asphalt binder at the upper temperature of each binder grade and the results indicate the PG 82-22 binder exhibited the greatest elasticity, stiffness, and rutting resistance potential. FDOT specifies a minimum $G^*/\sin\delta$ of 1.0 kPa and a maximum phase angle (δ) of 75° for a PG 76-22 original asphalt binder. A developmental specification requires a phase angle of 65° for a PG 82-22 original asphalt binder. Both polymer modified asphalt binders evaluated have met the respective requirements. Figure 2 shows the DSR properties measured.



(a) complex modulus |G*|



(b) phase angle, δ



(c) DSR G*/sinδ

FIGURE 2. DSR properties

4.1.2 Multiple Stress Creep Recovery

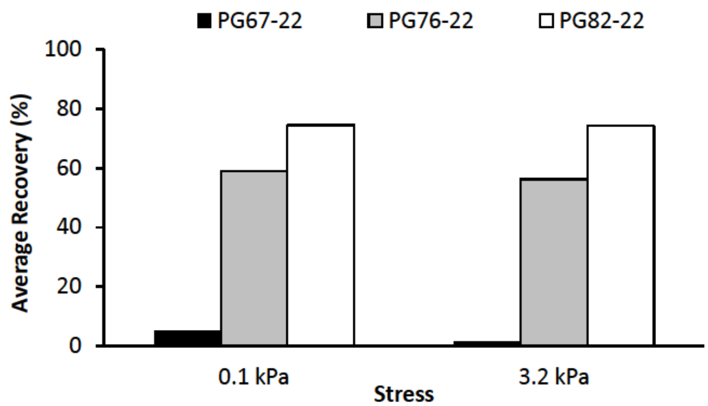
The Multiple Stress Creep Recovery (MSCR) test evaluates an asphalt binder's potential for permanent deformation using the DSR apparatus. Ten creep/recovery cycles are performed with a stress of 0.1 kPa applied for 1 second with a 9 second rest period. The stress level is then increased to 3.2 kPa for an additional ten cycles. The average non-recovered strain for the ten creep and recovery cycles is divided by the applied stress yielding the non-recoverable creep compliance (J_{nr}). J_{nr} has been used as an indicator of the asphalt binder's resistance to permanent deformation under repeated load. Specifications have been developed based on the non-recoverable creep compliance and are shown in Table 1 *(9)*.

TABLE 1. AASHTO MSCR specifications *(9)*

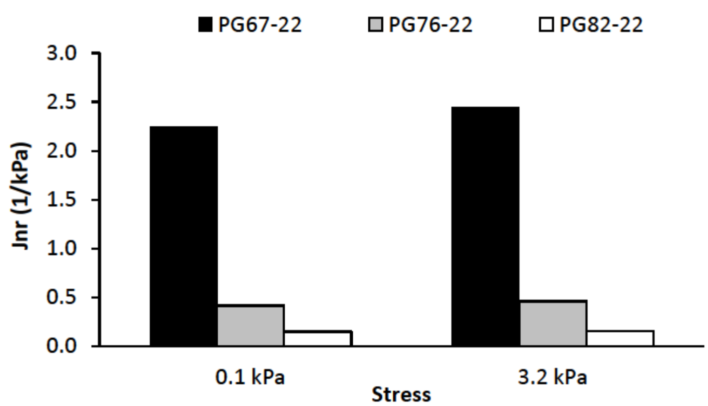
Asphalt binder grade	Standard (S)	Heavy (H)	Very Heavy (V)	Extreme (E)
Traffic level/speed	< 10 million ESALs or > 72 kph	10 to 30 million ESALs or 24 to 72 kph	> 30 million ESALs or < 24 kph	> 30 million ESALs and < 24 kph
J_{nr} max., kPa^{-1}	4.0	2.0	1.0	0.5
J_{nr} max. difference, %	75	75	75	75

Asphalt binder samples were collected from the plant and conditioned in a rolling thin film oven (RTFO). MSCR tests were performed on the RTFO residue at a temperature of 64 °C. Polymer modified binders appear to exhibit greater elastic response and are less sensitive to stress changes, as indicated by the percent recovery shown in Figure 3(a). Based on Figure 3(b), polymer modified binders exhibit lower non-recoverable creep compliance than the base binder for both stress levels. A Federal Highway Administration (FHWA) study suggested that a 50 %

reduction in the non-recoverable creep compliance (J_{nr}) may reduce roadway rutting by 50 % and APT rutting with the FHWA Accelerated Loading Facility (ALF) by 30 to 40 % *(10)*.



(a) average recovery



(b) non-recoverable creep compliance

FIGURE 3. MSCR test results

4.1.3 Binder Fracture Energy

The University of Florida recently developed a new binder fracture energy test procedure to assure accurate prediction of binder fracture energy at intermediate temperatures as part of a FDOT funded study *(11)*. The study showed that binder fracture energy appears to be a fundamental property of asphalt binder and is independent of test temperature and loading rate.

Asphalt binders were subjected to short and long term aging conditions by conditioning them with a RTFO and pressurized aging vessel (PAV), respectively. Binder fracture tests were conducted at 10 °C. Figure 4 represents the binder fracture energy test results and clearly indicates that PG 82-22 binder exhibits greater fracture energy, which reflects better HMA fracture resistance than PG 76-22 and PG 67-22 binders.

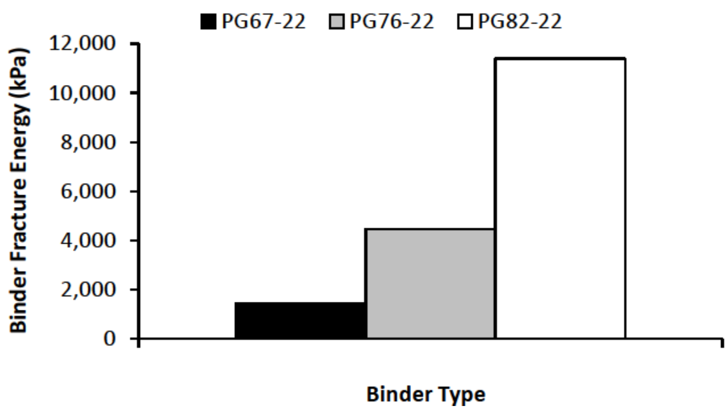


FIGURE 4. Binder fracture energy

4.2 HMA Properties

4.2.1 Mixture Design and HMA Placement

The HMA was designed as a 12.5 mm Nominal Maximum Aggregate Size (NMAS) fine-graded Superpave mixture using the same gradation, granite aggregate, and 5.1 % asphalt binder content. Previous research showed that the gradation used for this study had good rutting and fatigue resistance *(12)*. Several standard quality control tests were performed to verify the uniformity and quality of the HMA. Table 2 shows the gradations and volumetric properties of mixtures sampled from the delivery trucks. The gradation, percent asphalt binder, and percent air voids are within normal ranges.

During construction of the test lanes, there was some concern that adequate density may be difficult to obtain on the lane with PG 82-22 binder due to the increased stiffness. The contractor applied compaction effort following the paver earlier for the PG 82-22 lane so that compaction temperatures were greater. The compaction temperature for the mixture using PG 82-22 asphalt binder was slightly less than 340 °F, the maximum temperature allowed by the developmental specification. Additional static and vibratory passes were also used. A non-nuclear Pavement Quality Indicator (PQI) device was used to estimate the compacted HMA density after each pass of the roller. Cores were used to verify the final density measurements for each lane which were within the acceptable range.

TABLE 2. Gradation and volumetric properties of sampled HMA mixtures

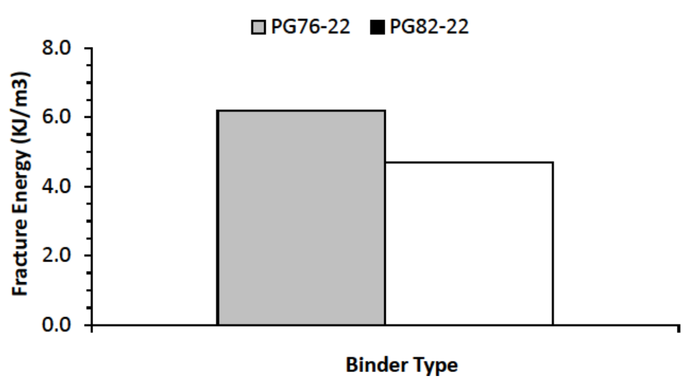
Sieve Size	Job Mix Formula	PG 67-22	PG 76-22	PG 82-22
3/4 in. (19.0 mm)	100	100.0	100.0	100.0
1/2 in. (12.5 mm)	98	97.3	97.4	97.8
3/8 in. (9.5 mm)	88	86.3	86.1	86.6
No. 4 (4.75 mm)	59	57.8	57.4	57.5
No. 8 (2.36 mm)	40	39.2	38.5	39.1
No. 16 (1.18 mm)	29	28.7	27.9	28.4
No. 30 (600 µm)	22	22.1	21.4	21.7
No. 50 (300 µm)	12	13.2	12.8	13.0
No. 100 (150 µm)	4	4.9	4.7	5.0
No. 200 (75 µm)	2.0	2.8	2.7	2.8
% Asphalt Binder	5.1	4.9	4.8	4.7
% Air Voids at N_{des}	4.0	3.3	4.0	4.0

4.2.2 Superpave Indirect Tension Tests

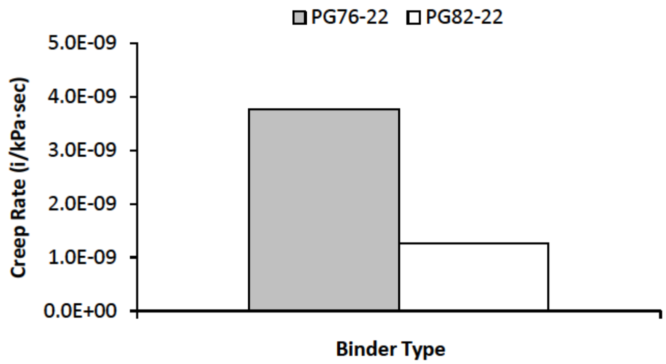
Superpave Indirect Tension (IDT) tests were conducted to determine mixture properties found to be the most strongly related to HMA cracking performance *(13-15)*. The standard Superpave

IDT tests including resilient modulus, creep compliance, and tensile strength were conducted at 10 °C. A complete description of the test procedures and data analysis is presented elsewhere *(16)*. All tests were conducted using cores obtained from the test track lanes immediately after construction. Due to time limitations, only cores with PG 76-22 and PG 82-22 asphalt binders were evaluated.

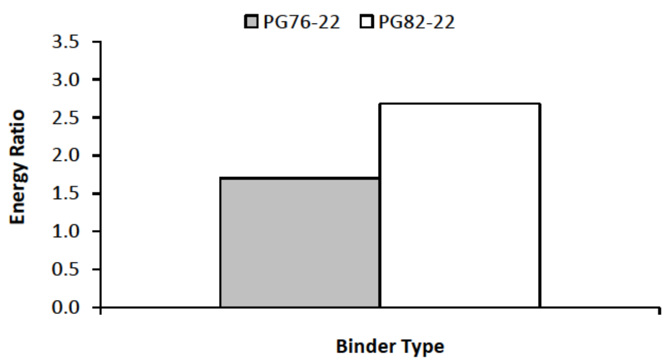
Figure 5(a) shows that the initial fracture energy of the PG 76-22 and PG 82-22 mixtures was within an acceptable range *(17)*. The slightly lower fracture energy of the PG 82-22 mixture was possibly associated with stiffening and embrittlement effects of heavy polymer modified binder on mixture behavior. The creep rate, shown in Figure 5(b), indicates that the use of PG 82-22 binder reduced the damage rate by 66 % compared to that of PG 76-22. The energy ratio, shown in Figure 5(c), represents the fracture resistance of asphalt mixtures and can be used to evaluate cracking performance *(15)*. The PG 82-22 mixture exhibits a relatively higher energy ratio, which indicates better cracking resistance compared to the mixture with PG 76-22 binder.



(a) fracture energy



(b) creep rate



(c) energy ratio

FIGURE 5. IDT fracture properties

5 ACCELERATED PAVEMENT TESTING

In FDOT's APT program, accelerated loading is performed using a Heavy Vehicle Simulator (HVS), Mark IV model. The HVS is electrically powered (using an external electric power source or electricity from an on-board diesel generator), fully automated, and mobile. Rut depth measurements are made using a laser profiler. Fatigue resistance was assessed using strain gauges located at the bottom of the HMA layer. A complete description of the test facility has been presented elsewhere *(18-19)*. The HVS and test tracks are shown in Figure 6.

FIGURE 6. FDOT's HVS and APT tracks

5.1 APT Rut Resistance

Rut testing was conducted at 50 °C using a 455 mm wide-base single tire loaded to 9,000 pounds and inflated to 100 psi. A wheel wander of 4 inches was used for each test. Multiple tests were performed for each binder type and the test sequence was randomly selected to account for construction variability. Rut depth measurements were obtained periodically using a laser-based profiling system mounted on the underside of the HVS wheel carriage. Figure 7 shows the average rut progression for each test lane. The APT rut profile data showed that rut depth decreased as the amount of polymer modifier added to the asphalt binder increased. As indicated in Figure 7, after 100,000 passes, the lane with PG 76-22 and PG 82-22 binders rutted approximately 0.5 and 0.8 times less than the lane without polymer modified asphalt binder, respectively.

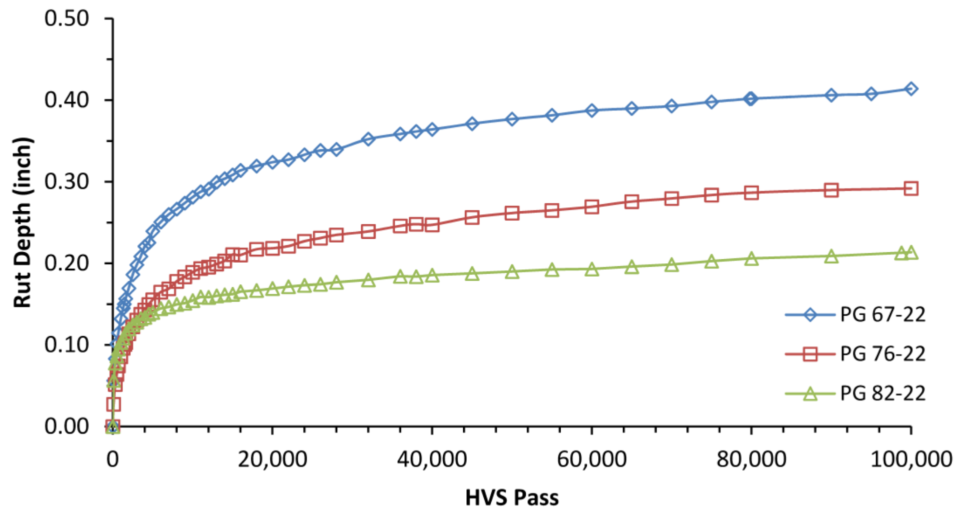


FIGURE 7. Rut depth progression

Shear deformation and densification are the primary causes for rutting of flexible pavements. One method used by FDOT and others to determine the portion of rutting generated from shear flow is to estimate the area or volume of accumulated material at the edge of the rutted wheel path and compare it to the empty area or volume below the wheel path *(20-22)*. One could reasonably assume that the material at the edge of the wheel path is displaced by shear flow. If the area of displaced material is equal to the area of the material below the wheel path, it could be assumed that the majority of rutting is due to shear flow or instability rather than densification. Therefore, mixtures with a larger shear to wheel path area ratio indicate rutting is primarily due to shear and instability rather than densification.

Figure 8 illustrates the transverse rut profiles after 100,000 passes and Table 3 summarizes the rut and shear data for several pass levels. In general, as the amount of polymer modifier added to the asphalt binder increased, lower shear to wheel path area ratios are measured. This implies that mixtures with a heavy polymer modified binder may provide greater resistance to shear flow or mixture instability.

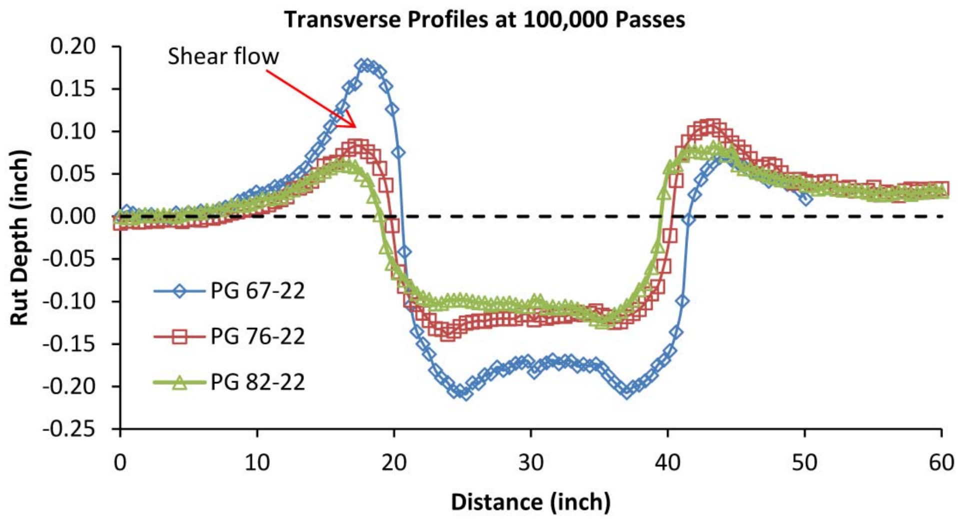


FIGURE 8. Transverse rut profiles after 100,000 passes

TABLE 3. Shear and rut depth summary

Pass Number	PG 67-22		PG 76-22		PG 82-22	
	Rut, inch	Shear Area /WP Area	Rut, inch	Shear Area /WP Area	Rut, inch	Shear Area /WP Area
100	0.06	0.21	0.03	0.44	0.06	0.23
5,000	0.24	0.60	0.16	0.50	0.14	0.28
10,000	0.28	0.63	0.19	0.52	0.15	0.20
20,000	0.32	0.61	0.22	0.49	0.17	0.30
100,000	0.41	0.72	0.29	0.45	0.21	0.27

5.2 APT Fatigue Resistance

A Super Single tire loaded to 12,000 pounds and inflated to 110 psi was used to load the test pits without wheel wander for fatigue resistance evaluation. Falling weight deflectometer (FWD) measurements indicated that the base modulus was reduced from 80 ksi to less than 40 ksi after the water level was raised and stabilized.

More than 500,000 HVS passes were completed on the test pits without observation of fatigue cracks. Tensile strain at the bottom of the HMA, shown in Figure 9, was measured at various times to capture the pavement response for a wide temperature range. The temperature range is different for each test pit section since testing was conducted a few months apart. For comparison, strain data is included from a previous experiment for the same pavement structure that included a similar gradation, aggregate type, and an unmodified PG 67-22 binder. It should be noted that a 455 mm wide-base tire loaded to 12,000 pounds and inflated to 100 psi was used for this experiment.

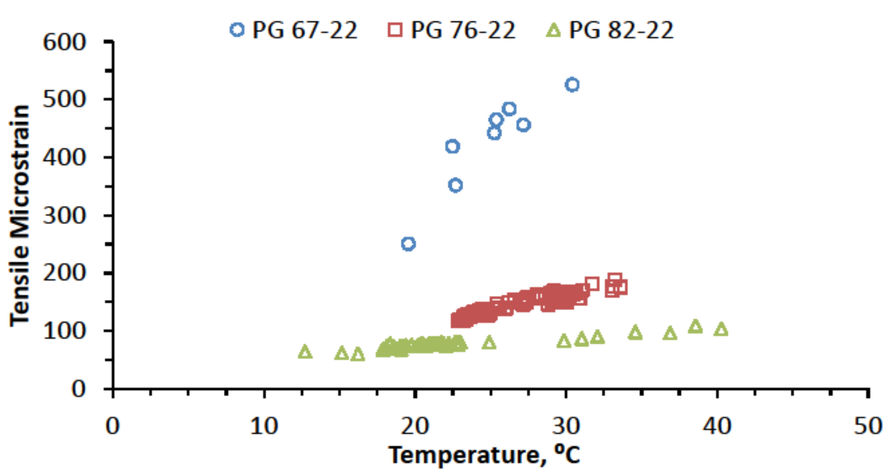


FIGURE 9. Strain measurements

Both mixtures using modified binders appear to have considerably improved fatigue performance compared to the mixture using unmodified binder. Fatigue life can be estimated using a number of different transfer functions. One such function is presented in AASHTO's Mechanistic Empirical Pavement Design Guide *(23)*. The fatigue transfer function is shown below:

$$N_f = 0.00432 \times K \times C \times (1/\varepsilon_t)^{3.9492} (1/E)^{1.281} \qquad (1)$$

Where, N_f = repetitions until fatigue failure (50 % cracking of lane area), K = thickness calibration factor, C = regional or national calibration factor, ε_t = tensile strain, E = asphalt modulus (psi), and h_{ac} = thickness of asphalt layer (inches).

At 20 °C, the predicted fatigue lives of the PG 82-22 and PG 76-22 sections are more than 20 times greater than the PG 67-22 section. The fatigue life of the PG 82-22 section is approximately seven times greater than the fatigue life of the PG 76-22 section.

6 IMPLEMENTATION

FDOT has created developmental specifications to allow the use of PG 82-22 binder. The primary changes include an increase in maximum compaction temperature from 166°C to 171°C and a decrease in phase angle (δ) requirements from 75 degrees to 65 degrees for PG 82-22 binder as compared to PG 76-22 binder. Rutting history of potential projects and feasibility of the use of PG 82-22 binder are reviewed prior to authorization of use.

During 2012, two resurfacing projects were constructed with PG 82-22 binder. The first project is located on SR 60 in Hillsborough County. The deepest rut depths were greater than 1 inch and were found at the intersection of SR 39 and on ramps to a nearby weigh station. The second project is located on the mainline pavement in Nassau County on SR 200. This project had average rut depths of 1 inch just six years after a previous resurfacing. A 0.6 mile section with the greatest rutting received a PG 82-22 binder while a 1.65 mile section was built using a

PG 76-22 polymer modified binder. Test sections along the SR 200 project have been established for annual monitoring of rut depth, smoothness, and cracking.

7 SUMMARY AND CONCLUSIONS

FDOT engineers are seeking solutions for pavements with histories of excessive rutting and where existing strategies have not worked. Often, these pavements are at locations with concentrated and slow moving truck traffic. The HVS is an ideal tool to investigate these harsh conditions. This study has shown that asphalt mixtures that use a PG 82-22 asphalt binder have an increased resistance to rutting and fatigue when compared to standard asphalt binders currently used by FDOT. A summary of findings and conclusions are presented below:

- The use of polymer modifiers improved binder properties related to rutting and cracking performance of HMA mixtures. Binder meeting PG 82-22 requirements was found to have the best performance characteristics.
- The use of PG 82-22 binder significantly reduced the damage rate of HMA. HMA with PG 82-22 binder exhibited a relatively higher energy ratio, which indicates better cracking resistance than HMA with PG 76-22 binder.
- The use of polymer modified binders reduced rutting and increased fatigue resistance, particularly when a PG 82-22 binder is used.
- A PG 82-22 binder can be used when there has been a history of excessive rutting and when found to be feasible. Two projects with considerable rutting have been constructed using PG 82-22 binder to date. A test section has been established on SR 200 in Nassau County to compare the long-term performance of a PG 82-22 and PG 76-22 binders.

- It should be noted that only one gradation and one aggregate type was evaluated during this study. Additional research is recommended to quantify the improvement due to heavy polymer modified binder on different gradations and aggregates.

8 ACKNOWLEDGEMENTS

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