Evaluation of a Heavy Polymer Modified Binder through Accelerated Pavement Testing

James Greene
(Corresponding Author)
Florida Department of Transportation, Materials Research Park
5007 N.E. 39th Avenue, Gainesville, FL 32609
Phone: (352) 955-6329
E-mail: james.greene@dot.myflorida.com

Bouzid Choubane
Florida Department of Transportation, Materials Research Park
5007 N.E. 39th Avenue, Gainesville, FL 32609
Phone: (352) 955-6302
E-mail: bouzid.choubane@dot.myflorida.com

Sanghyun Chun
University of North Florida
5007 N.E. 39th Avenue, Gainesville, FL 32609
Phone: (352) 955-6313
E-mail: sanghyun.chun@dot.myflorida.com

Word Count: Abstract = 141 Text = 3417 Tables and Figures = 13 x 250 = 3250 Total = 6808
ABSTRACT

In 2001, the Florida Department of Transportation (FDOT) conducted an experimental study to assess the effect of polymer modified PG76-22 asphalt binder on rutting resistance of Superpave mixtures through Accelerated Pavement Testing (APT). The success of this study led to the use of PG76-22 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 do 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 PG82-22 requirements. Results of the study indicated that the use of a heavy polymer modified binder improved rutting and cracking performance of asphalt mixtures.
INTRODUCTION

Background

In 2001, the Florida Department of Transportation (FDOT) conducted an experiment to study the rutting resistance Superpave mixtures with polymer modified PG76-22 and unmodified PG67-22 asphalt binders through Accelerated Pavement Testing (APT) (1). This study led to the use of PG76-22 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 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, 6, 7). Recently, FDOT has drafted a developmental specification to allow PG82-22 asphalt binder on a case-by-case basis. The current cost of PG82-22 asphalt binder is approximately $100/liquid ton more than PG76-22 asphalt binder and $250/liquid ton more than unmodified PG67-22 asphalt binder. Prior to implementation, the benefits of a PG82-22 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 PG82-22 requirements.

Objectives and Scope

The objective of this study was to evaluate the rutting and fatigue resistance of three asphalt binder types: (1) a polymer modified PG82-22, (2) a polymer modified PG76-22, and (3) an unmodified PG67-22. 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.

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 12.5 mm fine-graded Superpave mixture consisting of granite material and 5.1 % asphalt binder. The asphalt mixtures for each lane were similar except for the asphalt binder type which included, respectively, an unmodified PG67-22, a Styrene Butadiene Styrene (SBS) modified PG76-22, or a SBS modified PG82-22. The primary difference in the modified binders was the amount of SBS polymer that was used. During rut testing, 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 9000 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 12.5 mm 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 both test track lanes and test pit lanes.

**FIGURE 1. Pavement structures.**

### MATERIAL PROPERTIES

During construction of the test sections, asphalt binder was collected at the plant and HMA was sampled from delivery trucks. The asphalt binder was blended by the supplier to meet the requirements of PG67-22, PG76-22, and PG82-22 according to the current FDOT specifications. FDOT is considering the PG+ system but has not yet adopted the new grading system. The PG82-22 binder included approximately 6% SBS polymer modifier which is double that of the PG76-22 binder. Laboratory tests were conducted to characterize the asphalt binders and HMA.

#### Asphalt Binder Properties

*Dynamic Shear Rheometer*

The dynamic shear rheometer (DSR) measures the complex modulus ($G^*$) and phase angle ($\delta$) 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. DSR properties are shown in FIGURE 2. According to FIGURE 2(c), the PG82-22 binder exhibited the greatest rutting resistance potential, as indicated by the $G^*/\sin\delta$ parameter. FDOT specifies a minimum $G^*/\sin\delta$ of 1.0 kPa and a maximum phase angle ($\delta$) of 75° for a PG76-22 original asphalt binder. A developmental
specification requires a phase angle of 65° for a PG82-22 original asphalt binder. Both polymer modified asphalt binders evaluated have met the respective requirements.

![Graphs showing DSR properties for each asphalt binder and temperature evaluated.](image)

**FIGURE 2 DSR properties for each asphalt binder and temperature evaluated.**

**Multiple Stress Creep Recovery**

The Multiple Stress Creep Recovery (MSCR) test evaluates an asphalt binder’s potential for permanent deformation using the DSR apparatus and is conducted according to AASHTO MP 19. 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).
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 64 °C. Polymer modified binders appear to exhibit higher elastic response and are less sensitivity 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 ($J_{nr}^{max.}$) may reduce roadway rutting by 50 % and APT rutting with the FHWA Accelerated Loading Facility (ALF) by 30 to 40 % (10).

Fracture energy of binder, which can be determined by calculating the area under the stress-strain curve, is an important property associated with fatigue resistance of asphalt mixture. A new binder fracture energy test was recently developed at the University of Florida to assure accurate prediction of binder fracture energy at intermediate temperatures (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 PG82-22 binder

---

**TABLE 1 AASHTO Specifications for MSCR Data**

<table>
<thead>
<tr>
<th>Asphalt binder grade</th>
<th>Standard (S)</th>
<th>Heavy (H)</th>
<th>Very Heavy (V)</th>
<th>Extreme (E)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic level/speed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 10 million ESALs or &gt; 45 mph</td>
<td>4.0</td>
<td>2.0</td>
<td>1.0</td>
<td>0.5</td>
</tr>
<tr>
<td>10 to 30 million ESALs or 15 to 45 mph</td>
<td>75</td>
<td>75</td>
<td>75</td>
<td>75</td>
</tr>
<tr>
<td>&gt; 30 million ESALs or &lt; 15 mph</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J_{nr}^{max.}, kPa</td>
<td>4.0</td>
<td>2.0</td>
<td>1.0</td>
<td>0.5</td>
</tr>
<tr>
<td>J_{nr}^{max.} difference, %</td>
<td>75</td>
<td>75</td>
<td>75</td>
<td>75</td>
</tr>
</tbody>
</table>

---

**FIGURE 3 MSCR test results.**

(a) MSCR average recovery  
(b) MSCR non-recoverable creep compliance

---

**Binder Fracture Energy**

Fracture energy of binder, which can be determined by calculating the area under the stress-strain curve, is an important property associated with fatigue resistance of asphalt mixture. A new binder fracture energy test was recently developed at the University of Florida to assure accurate prediction of binder fracture energy at intermediate temperatures (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 PG82-22 binder
exhibits greater fracture energy, which reflects better HMA fracture resistance than PG76-22 and PG67-22 binders.

![Graph showing binder fracture energy](image)

**FIGURE 4 Binder fracture energy.**

**HMA Properties**

*Mixture Design and HMA Placement*

The HMA was designed as a 12.5mm 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 a Dominant Aggregate Size Range (DASR) porosity and Disruption Factor (DF) within ranges indicative of good rutting and fatigue resistance. A complete description of these parameters (i.e. DASR porosity and DF) including concept, theoretical development, and calculation procedure has been presented elsewhere ([12, 13]). 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 PG82-22 binder due to the increased stiffness. The contractor applied compaction effort following the paver earlier for the PG82-22 lane so that compaction temperatures were greater. The compaction temperature for the mixture using PG82-22 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 were within the acceptable range.
TABLE 2 Gradation and Volumetric Properties of Sampled HMA Mixtures

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Job Mix Formula</th>
<th>PG67-22</th>
<th>PG76-22</th>
<th>PG82-22</th>
</tr>
</thead>
<tbody>
<tr>
<td>¾ in. (19.0 mm)</td>
<td>100</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
<tr>
<td>½ in. (12.5 mm)</td>
<td>98</td>
<td>97.3</td>
<td>97.4</td>
<td>97.8</td>
</tr>
<tr>
<td>3/8 in. (9.5 mm)</td>
<td>88</td>
<td>86.3</td>
<td>86.1</td>
<td>86.6</td>
</tr>
<tr>
<td>No. 4 (4.75 mm)</td>
<td>59</td>
<td>57.8</td>
<td>57.4</td>
<td>57.5</td>
</tr>
<tr>
<td>No. 8 (2.36 mm)</td>
<td>40</td>
<td>39.2</td>
<td>38.5</td>
<td>39.1</td>
</tr>
<tr>
<td>No. 16 (1.18 mm)</td>
<td>29</td>
<td>28.7</td>
<td>27.9</td>
<td>28.4</td>
</tr>
<tr>
<td>No. 30 (600 µm)</td>
<td>22</td>
<td>22.1</td>
<td>21.4</td>
<td>21.7</td>
</tr>
<tr>
<td>No. 50 (300 µm)</td>
<td>12</td>
<td>13.2</td>
<td>12.8</td>
<td>13.0</td>
</tr>
<tr>
<td>No. 100 (150 µm)</td>
<td>4</td>
<td>4.9</td>
<td>4.7</td>
<td>5.0</td>
</tr>
<tr>
<td>No. 200 (75 µm)</td>
<td>2.0</td>
<td>2.8</td>
<td>2.7</td>
<td>2.8</td>
</tr>
<tr>
<td>% Asphalt Binder</td>
<td>5.1</td>
<td>4.9</td>
<td>4.8</td>
<td>4.7</td>
</tr>
<tr>
<td>% Air Voids at N&lt;sub&gt;des&lt;/sub&gt;</td>
<td>4.0</td>
<td>3.3</td>
<td>4.0</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Superpave Indirect Tension

Superpave Indirect Tension (IDT) tests were conducted to determine mixture properties found to be the most strongly related to HMA cracking performance (14, 15, 16). The standard Superpave IDT tests including resilient modulus, creep compliance, and strength test, were conducted at 10 °C. A complete description of the test procedures and data analysis is presented elsewhere (17). All tests were conducted using cores obtained from the test track lanes immediately after construction. Due to time limitations, only mixtures with PG76-22 and PG82-22 asphalt binders were evaluated.

FIGURE 5(a) shows that the initial fracture energy of the PG76-22 and PG82-22 mixtures was within an acceptable range (12). The slightly lower fracture energy of the PG82-22 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 PG82-22 binder reduced the damage rate by 66 % compared to that of PG76-22. The energy ratio, shown in FIGURE 5(c), represents the fracture resistance of asphalt mixtures and can be used to evaluate cracking performance (14). The PG82-22 mixture exhibits a relatively higher energy ratio, which indicates better cracking resistance compared to the mixture with PG76-22 binder.
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.
APT Rut Resistance

Rut testing was conducted at 50 °C using a 455 mm wide-base single tire loaded to 9000 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 history 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 9, after 100,000 passes, the lane with PG76-22 and PG82-22 binders rutted approximately 0.5 and 0.8 times less than the lane without polymer modified asphalt binder, respectively.
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, 21, 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 4 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.
TABLE 3 APT Shear and Rut Depth Summary

<table>
<thead>
<tr>
<th>Pass Number</th>
<th>PG67-22 Rut, inch</th>
<th>PG67-22 Shear Area/WP Area</th>
<th>PG76-22 Rut, inch</th>
<th>PG76-22 Shear Area/WP Area</th>
<th>PG82-22 Rut, inch</th>
<th>PG82-22 Shear Area/WP Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0.06</td>
<td>0.21</td>
<td>0.03</td>
<td>0.44</td>
<td>0.06</td>
<td>0.23</td>
</tr>
<tr>
<td>5,000</td>
<td>0.24</td>
<td>0.60</td>
<td>0.16</td>
<td>0.50</td>
<td>0.14</td>
<td>0.28</td>
</tr>
<tr>
<td>10,000</td>
<td>0.28</td>
<td>0.63</td>
<td>0.19</td>
<td>0.52</td>
<td>0.15</td>
<td>0.20</td>
</tr>
<tr>
<td>20,000</td>
<td>0.32</td>
<td>0.61</td>
<td>0.22</td>
<td>0.49</td>
<td>0.17</td>
<td>0.30</td>
</tr>
<tr>
<td>100,000</td>
<td>0.41</td>
<td>0.72</td>
<td>0.29</td>
<td>0.45</td>
<td>0.21</td>
<td>0.27</td>
</tr>
</tbody>
</table>

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. The average 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 PG67-22 binder. It should be noted that the 455 mm wide-base tire loaded to 12,000 pounds and inflated to 100 psi was used for this experiment.

![FIGURE 9 APT strain measurements.](image)

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:

\[
N_f = 0.00432 \times K \times C \times \left(1/e_i\right)^{0.9492} \left(T/E\right)^{0.281}
\]  

(1)
Greene, Choubane, and Chun

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

At 68 °F, the predicted fatigue lives of the PG82-22 and PG76-22 sections are more than 20 times greater than the PG67-22 section. The fatigue life of the PG82-22 section is approximately seven times greater than the fatigue life of the PG76-22 section.

**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 PG82-22 asphalt binder show 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 PG82-22 requirements was found to have, comparatively, the best performance characteristics.
- The use of PG82-22 binder significantly reduced the damage rate of HMA. HMA with PG82-22 binder exhibited a relatively higher energy ratio (ER), which indicates better cracking resistance than HMA with PG76-22 binder.
- A heavy polymer modified binder should be considered to enhance pavement performance for use in areas with a history of excessive rut depth.
- 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.

**ACKNOWLEDGEMENTS**

The work represented herein was the result of a team effort. The authors would like to acknowledge Patrick Upshaw, Greg Sholar, Sungho Kim, Tanya Nash, Kyle Sheppard, Lance Denmark, Jason White, and FDOT's State Materials Office Bituminous Laboratory for their diligent efforts and contributing knowledge.

**REFERENCES**


