Florida Department of
TRANSPORTATION

Evaluation and Implementation of PG 76-22 Asphalt Rubber Binder in Florida

FDOT Office
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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The Florida Department of Transportation (FDOT) has had a long history of recycling ground tire rubber (GTR) from waste tires in highway projects. FDOT first experimented with asphalt rubber binder (ARB) more than 35 years ago. In 1988, the Florida Legislature mandated the investigation of using recyclable materials such as GTR in roadway construction. For more than 25 years, FDOT has effectively satisfied the intent of the Legislature. However, ARB has often been associated with unpredictable performance and handling issues such as the GTR settling out of the binder. These performance and handling issues has resulted in a higher construction cost and made ARB less appealing since a more reliable alternative, PG 76-22 polymer modified asphalt (PMA), was available. As a result, a task team consisting of FDOT and industry members was formed with the goal of finding a way to make ARB handle and perform similar to PG 76-22 (PMA), Florida's "gold standard" binder. This report documents an accelerated pavement testing (APT) study to compare hot mix asphalt mixtures (HMA) constructed using PG 76-22 (PMA) and PG 76-22 (ARB) binders. This APT study represents the final stage of the implementation of a new PG 76-22 (ARB) specification.

1 INTRODUCTION

1.1 Background

The United States Environmental Protection Agency estimates that approximately 220 million pounds, or 12 million tires, are consumed annually through the use of asphalt rubber. Arizona and California use the most asphalt rubber in highway construction while Florida is the next largest user *(1)*. Ground tire rubber (GTR), also referred to as crumb rubber or recycled tire rubber (RTR), may be blended into the asphalt binder by three methods known as the dry process, wet process, and terminal blending *(2)*. The dry process treats relatively coarser GTR particles as an aggregate and introduces it prior to the addition of the asphalt binder. The wet process refers to the blending of fine GTR and asphalt binder at the asphalt plant. This process limits the asphalt production rate to the blending rate of the asphalt rubber binder (ARB). Terminal blending refers to a process where GTR is blended into the asphalt binder at the terminal or refinery and transported to the asphalt plant for use in the final product. The GTR used in terminal blends is typically finer than that used in the wet process. Terminal blending does not limit asphalt production since ARB can be produced off-site and stored for extended periods with proper agitation at the asphalt plant. Terminal blending is the primary method of producing ARB in Florida.

In general, many studies have reported good performance from asphalt mixtures produced with ARBs. Research conducted by the South Carolina Department of Transportation (SCDOT) indicated that mixtures with ARB blended using both dry and wet processes have been performing satisfactorily based on the performance evaluation of five field test sections constructed in South Carolina *(3)*. A study of the performance of terminal blended rubberized asphalt in California found that rubberized asphalt pavements perform well in resisting crack reflection and reducing pavement noise in hot-mix and warm-mix applications *(4)*. In addition, the California study suggested that perhaps the biggest boost in use of terminal blends was California's adoption of Strategic Highway Research Program (SHRP) performance graded (PG) specifications *(5)*. A Federal Highway Agency (FHWA) pooled fund study examined 11 different binders including a terminal blended hybrid ARB consisting of 5.5 % GTR and 1.8 % Styrene-Butadiene-Styrene (SBS) polymer. The hybrid binder exhibited good fatigue cracking and rutting resistance relative to the PG 70-22 control binder and handled like a conventional binder *(6)*. More recently, the National Center for Asphalt Technology (NCAT) found that ARB modified open-graded friction course (OGFC) mixtures were an adequate replacement for OGFC mixtures with polymer modified asphalt (PMA) *(7)*.

The Florida Department of Transportation (FDOT) first studied the use of an ARB on an experimental test section in 1978 as a stress absorbing membrane interlayer to mitigate reflective cracking *(8)*. Ten years later, in 1988, the Florida Legislature set forth a directive as part of the comprehensive Solid Waste Management Act, mandating the FDOT to investigate and determine the feasibility of using certain recyclable materials in roadway construction, including the possibility of using GTR from waste tires. Internal and funded research followed that laid the groundwork for three demonstration projects constructed during 1989 and 1990 *(9, 10, 11)*. Based on the initial success of the research and the field demonstration projects, ARB specifications were developed in 1994 that required asphalt binder with 5 % and 12 % GTR by weight of binder (designated as ARB-5 and ARB-12) in dense graded friction courses (DGFC) and open graded friction courses (OGFC), respectively. A 10 year evaluation of the original three demonstration projects showed that the friction surfaces with ARB had improved resistance to cracking and rutting than control sections with neat binder *(12)*.

For more than two decades, FDOT has effectively satisfied the intent of the Legislature by incorporating GTR in highway applications. However, ARB use has declined over the last eight years after the full-scale adoption of SBS polymer modified PG 76-22 asphalt binder. Despite the improved performance compared to neat binders and less expensive production costs compared to PG 76-22 PMA, ARB was often associated with unpredictable performance and handling issues such as the GTR settling out of the binder. These performance and handling issues resulted in a higher construction cost and made ARB less appealing since a more reliable alternative was available. As shown in FIGURE 1, the ARB production is only about ten percent of the FDOT's HMA production.

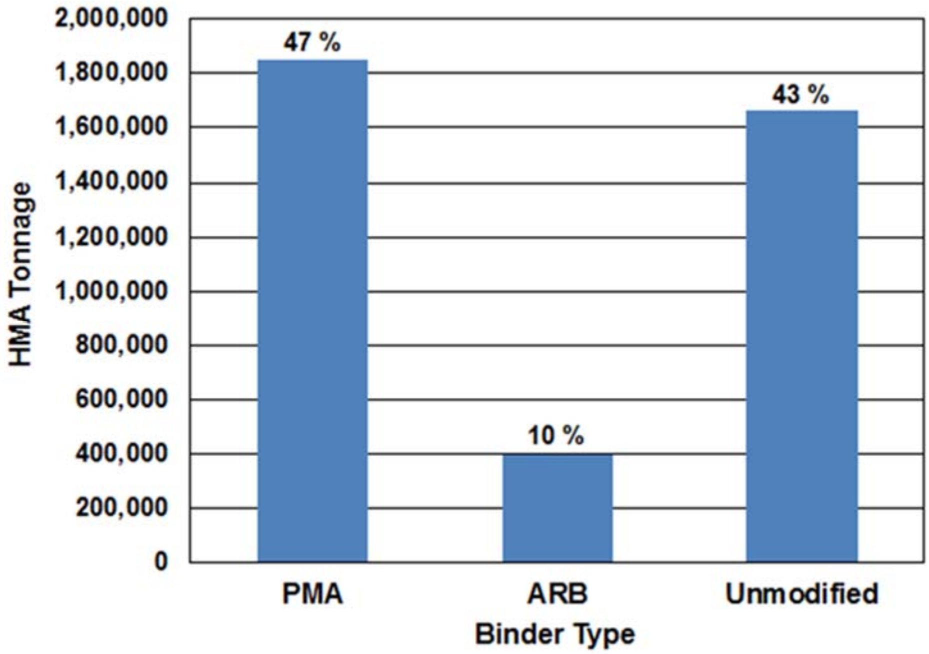

FIGURE 1 FDOT's Asphalt production for fiscal year 2013-2014 by binder type

In response to the inconsistent performance and wavering use of ARB, a task team consisting of FDOT and industry members was formed in 2011 with the goal of finding a way to make ARB handle and perform similar to a PG 76-22 (PMA), Florida's "gold standard" binder, and to modernize ARB specifications. Previous FDOT sponsored research studying the same topic indicated that hybrid binders, binders modified with GTR and SBS, compared favorably to PG 76-22 (PMA) binder *(13)*. Later, a significant amount of internal laboratory work was performed studying the required ARB performance properties and how ARB compared to a polymer modified PG 76-22 (PMA). Ultimately, based on laboratory performance data, the task group developed a specification for a PG 76-22 (ARB) binder which required a similar performance to PG 76-22 (PMA) and included a separation requirement to minimize settlement potential.

1.2 Objectives and Scope

The primary objective of this study was to evaluate the new PG 76-22 (ARB) using accelerated pavement testing (APT). As part of the study, six experimental test pavements were constructed and tested using three different binder suppliers. Four of the pavement sections were constructed using PG 76-22 (ARB). Since the test sections used a dense graded friction course mixture, a fifth section was constructed using ARB-5 for comparison. Finally, a sixth section was built using the "gold standard" PG 76-22 (PMA) as a control section. Laboratory testing supplemented the APT results and provided an indication of cracking performance for each of the test sections.

2 FLORIDA'S PG 76-22 (ARB) SPECIFICATION

The new PG 76-22 (ARB) specification requires that the binder include a minimum of 7 % GTR by weight of binder and that a PG 76-22 is met per AAHSTO M 320, with the exception of solubility. Polymer modification was made optional, and a separation test (ASTM 7173-11 / AASHTO T 53-11) was added with a criterion of a maximum of 15˚ Fahrenheit. The Multi-Stress Creep Recovery (J_{nr} and % Recovery, AASHTO T 350) was also implemented for all modified binders. While the specification was implemented in July 2013, validation of the specification was demonstrated through FDOT's APT study, test sections at the National Center for Asphalt Technology (NCAT), and four FDOT field test sections. A brief description of the NCAT and FDOT test sections is provided below while the remainder of this paper documents the APT study performed using FDOT's Heavy Vehicle Simulator (HVS) and supporting laboratory data.

During NCAT's 2012 research cycle, FDOT sponsored the construction of a PG 76-22 (ARB) test section accompanied by a control section with PG 76-22 (PMA). The test sections were placed in an area of the track which had a history of cracking since cracking performance was the primary objective of this study. TABLE 1 shows the cracking performance as of October 2014 after 10 million ESALs (as reported by NCAT *(14)*). While less cracks were observed on the section with PG 76-22 (PMA), cracks in both sections were found to be low severity and the cracking performance would be rated as satisfactory when considering resurfacing thresholds.

Four field test sections consisting of three dense graded friction courses and one open-graded friction course were constructed between June 2012 and May 2013 in different regions of Florida. Each of these sections utilized a hybrid PG 76-22 (ARB) that included a minimum of 7 % GTR and SBS. While long-term performance data of these test sections are not yet available, each of the test sections are performing well with no signs of deterioration and each are comparable to their ARB-5 or PG 76-22 (PMA) control sections. In addition, no issues were encountered during construction. TABLE 2 provides a summary of the four test sections.

TABLE 1 Cracking Performance of FDOT Sections as Reported by NCAT

Test Track Section	Section Description	Rut Depth, mm	Cracked Area, %		
			Lane	Right Wheel Path	Left Wheel Path
E7A	PG 76-22 (PMA)	2.2	10	5	16
E7B	PG 76-22 (ARB)	2.0	16	19	15

TABLE 2 FDOT's PG 76-22 (ARB) Field Test Sections

County	Route	Mix Type	Tonnage Placed	Date Constructed
Hernando	US-19	FC-5 (OGFC)	452	06/2012
Jefferson	SR 20 (US-19/27)	FC-12.5 (DGFC)	508	01/2013
Leon	SR-20	FC-12.5 (DGFC)	800	05/2013
Palm Beach	SR-704	FC-12.5 (DGFC)	448	05/2013

3 ACCELERATED PAVEMENT TESTING

3.1 Experiment Design

In order to better understand the properties of PG 76-22 (ARB) binders on asphalt performance, several suppliers that were part of the FDOT/industry task team were contacted to determine the feasibility of constructing test sections using PG 76-22 (ARB) binders from multiple sources. After several discussions with the paving contractor and the binder suppliers, it was determined that the experiment would include three binder suppliers who would provide four PG 76-22 (ARB) binders. Test sections were also constructed using ARB-5 and PG 76-22 (PMA) binders as comparisons since these binders have been used extensively in the past for dense-graded friction courses. General descriptions of each binder are shown in TABLE 3. The PG 76-22 (ARB) specification requires that the binder include a minimum of 7 % GTR by weight and addition of polymer is optional. As a result of the proprietary nature of each blend, exact proportions of GTR and SBS polymer remain confidential. The GTR C binder was the only PG

76-22 (ARB) modified solely with GTR while the other three include a combination of GTR and SBS polymer. The Hybrid A-H included a higher amount of SBS polymer than the Hybrid A-L binder.

TABLE 3 Binder Suppliers and Type

Binder Producer	Binder Type	Modifier	Mixture ID
A	PG 76-22 (PMA)	SBS	PG 76-22 (PMA)
A	ARB-5	5 % GTR	ARB-5
A	PG 76-22 (ARB)	Min 7 % GTR and SBS (Lower % GTR)	Hybrid A-L
A	PG 76-22 (ARB)	Min 7 % GTR and SBS (Higher % GTR)	Hybrid A-H
B	PG 76-22 (ARB)	Min 7 % GTR and SBS	Hybrid B
C	PG 76-22 (ARB)	Min 7 % GTR	GTR C

3.2 Construction of the Test Lanes

Six test lanes measuring 12 feet wide and 150 feet long were milled and resurfaced for the APT study. Approximately 1 inch of existing asphalt remained in place after the milling operation. Each lane was resurfaced with two 1.5 inch lifts of a 12.5 mm Nominal Maximum Aggregate Size (NMAS) fine-graded Superpave mixture consisting of granite aggregate and 5.1 % asphalt content, the design content using the PG 76-22 (PMA). The asphalt mixtures for each lane were the same except for the binder type. The supporting layers included a 10.5 inch limerock base and a 12 inch stabilized subgrade consisting of a mixture of limerock and native soil as indicated in FIGURE 2. The pavement structure represented a typical Florida roadway.

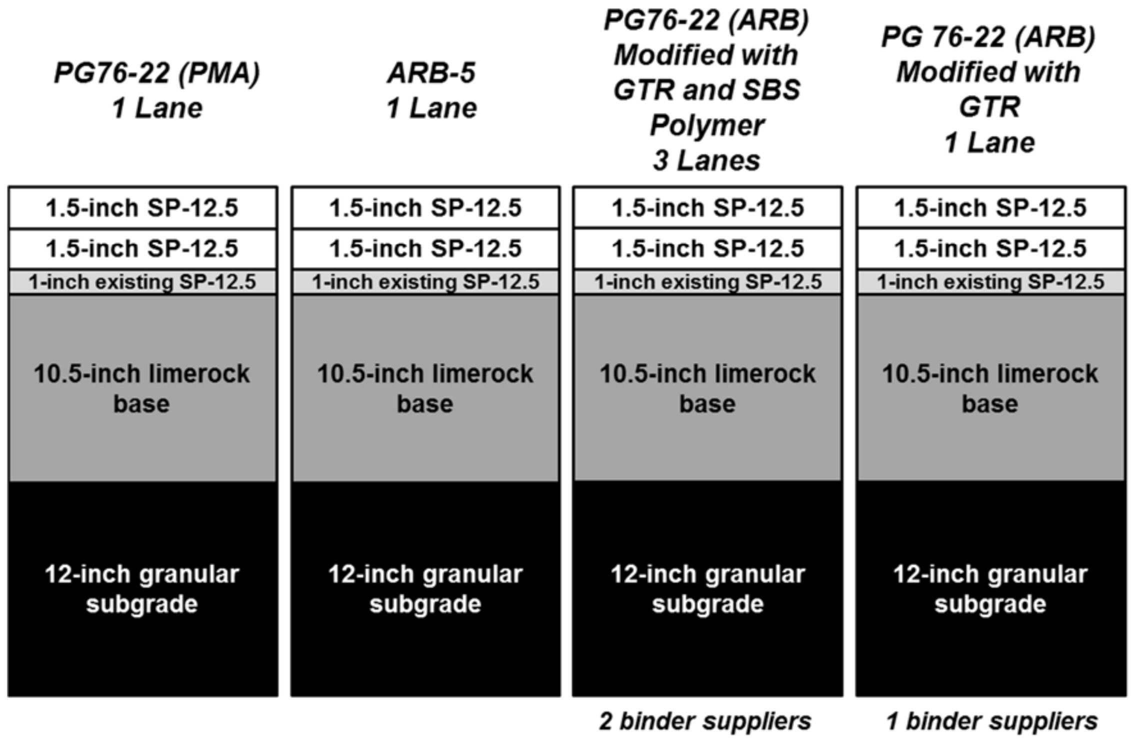

FIGURE 2 Test pavement structures

The test sections were constructed according to standard FDOT specifications. The PG 76-22 (PMA) and ARB-5 binders were pumped from the contractor's on-site storage tanks. Since ARB is typically produced through the terminal blend process in Florida, the PG 76-22 (ARB) binders were pumped from the supplier's tankers delivered to the plant during asphalt production. Similar compaction effort was applied to all of the test lanes and no problems were encountered during placement of the asphalt mixtures. TABLE 4 summarizes the in-place gradations and volumetric properties of the asphalt mixture sampled upon delivery and after compaction. In-place density was also checked using cores obtained from each test lane.

TABLE 4 Gradation and Volumetric Properties of Sampled Asphalt Mixtures

Sieve Size, mm	Design	As-Built Properties					
		PG 76-22 (PMA)	ARB-5	Hybrid A-L	Hybrid A-H	Hybrid B	GTR C
19.0	100	100	100	100	100	100	100
12.5	100	98	99	99	99	99	99
9.5	87	87	87	91	89	91	91
4.75	62	62	61	65	62	65	64
2.36	41	42	41	44	40	43	42
1.18	29	30	30	31	29	31	30
0.60	22	23	23	24	22	23	23
0.30	12	13	14	14	13	14	13
0.150	4	5	5	6	5	5	5
0.075	2	3	3	3	3	3	3
% AC	5.1	5.0	5.0	4.8	4.6	5.0	5.0
% AV at N_{design}	4.0	3.4	3.7	3.6	4.1	3.7	3.5
% Density (3 cores)	93.0	93.6	94.6	93.7	91.8	91.9	93.6

3.3 Rutting Performance

Accelerated loading was performed using FDOT's HVS with a Super Single tire (Goodyear G286 A SS, 425/65R22.5) loaded to 9 kips and inflated to 110 psi. A wheel wander of 4 inches was used and the test temperature was maintained at 50 °C. Insulated panels are attached to the HVS to maintain the required testing temperature. The HVS and Super Single tire are shown in FIGURE 3. A more detailed description of FDOT's APT facility is described elsewhere *(15)*. To normalize the effect of construction variability and different pavement aging times prior to testing, at least three tests were performed for each lane using a randomized test sequence. Rut depth measurements were conducted periodically using a laser-based profiling system mounted on the underside of the HVS carriage. Rut tests are typically terminated when a 12.5 mm rut depth is reached, which is considered failure, or until a total of 100,000 wheel passes have been completed.

FIGURE 3 FDOT's Heavy Vehicle Simulator

FIGURE 4 shows the average rut progression of each test lane. All of the mixtures showed overall good rutting performance. Cores and previous HVS studies have shown that rutting is confined to the asphalt layer due to the quality and strength of the unbound granular layers. In general, all mixtures with a PG 76-22 (ARB) exhibited slightly better rutting resistance than the control or the mixture with ARB-5. In particular, mixtures with Hybrid B and GTR C binders showed the best rutting performance. Overall, the rutting performance of PG 76-22 (ARB) mixtures appears to be comparable to that of a standard PG 76-22 (PMA) mixture and any differences observed in FIGURE 4 should be considered minor.

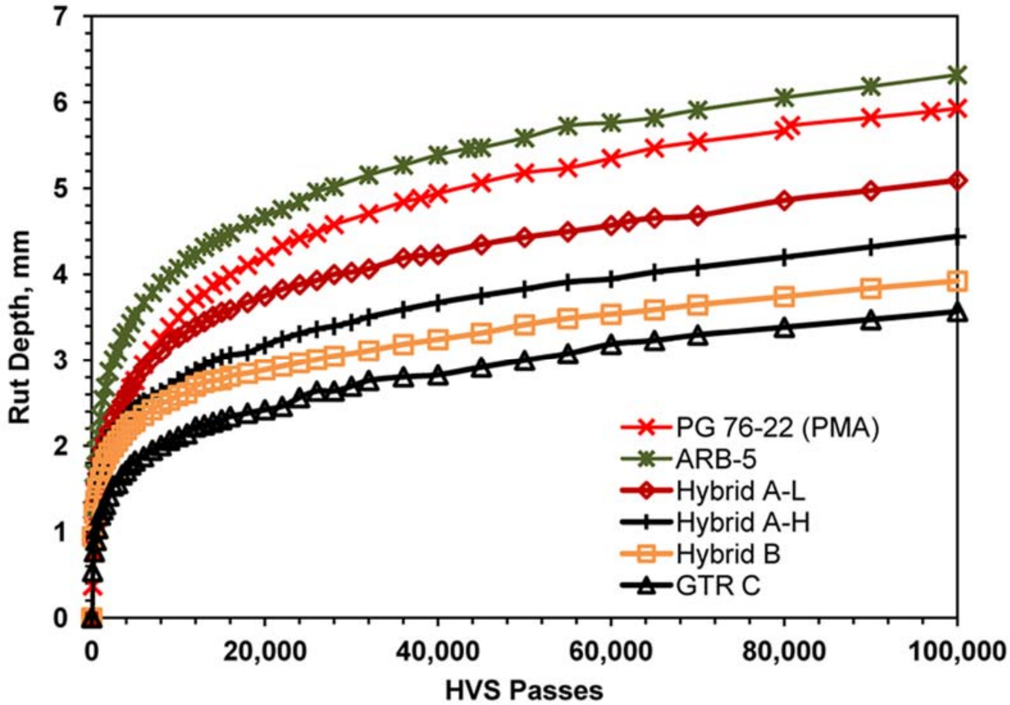

FIGURE 4 APT rut profiles

4 LABORATORY TEST RESULTS

4.1 Asphalt Binder

Asphalt binder collected at the asphalt plant during construction was tested to determine whether it met FDOT's performance graded binder requirements. The GTR C binder failed the % recovery of the MSCR test (AASHTO TP 70-12) and the Bending Beam Rheometer (BBR) creep stiffness test (AASHTO T 313-12). In addition, the GTR C binder as well as the Hybrid A-H binder failed the separation test (ASTM D 7173-11). Lastly, the Hybrid A-H binder did not meet the recommended rotational viscosity requirement (AASHTO T 316-11). It should be noted that the separation and rotational viscosity tests are primarily storage stability indicators. Contractors may continue to use binders that fail the rotational viscosity test, but they are urged to use caution and should consult with the supplier regarding any special handling procedures. Since the PG 76-22 (ARB) was pumped from the supplier's tanks, no issues were observed during construction. The PG 76-22 (PMA) binder passed all specification requirements that were in place at the beginning of the APT study. However, the MSCR test was not a requirement for

PG 76-22 (PMA) at this time and was not conducted on the control binder. In addition, the ARB-5 material passed the rotation viscosity test, which was the only quality control requirement in the former ARB specification. TABLE 5 summarizes the laboratory test results for the PG 76-22 (ARB) binders used in this study.

TABLE 5 Binder Laboratory Test Results

Test	Test Temp., °C	Hybrid A-L	Hybrid A-H	Hybrid B	GTR C	Specification Requirement
	Original Binder					
Separation Test, Softening Point Difference, °F	N/A	11	**17**	6	**26**	Max. 15 °F
Flash Point, COC	N/A	500+	500+	500+	500+	Min 450 °F
Rotational Viscosity	135	2.21	**3.10**	1.73	2.51	Max 3 Pa·s[(a)]
DSR, G*/sinδ, @ 10 rad/s (with 2.00 mm gap)	76	1.28	1.31	1.41	2.35	Min 1.0 kPa
Phase Angle	76	68.0	68.6	73.0	74.4	Max. 75 degrees
	RTFO Residue					
RTFOT, % Mass Change	163	-0.118	-0.158	-0.160	-0.226	Max ±1.000 %
MSCR (with 2.00 mm gap)	67					
% Recovery, 3.2 kPa^{-1}		68.94	49.70	55.52	**35.71**	% $R_{3.2} \geq 29.37(J_{nr3.2})^{-0.2633}$
J_{nr}, 3.2 kPa^{-1}		0.322	0.559	0.297	0.357	"V" grade = Max 1.0 kPa^{-1}
J_{nr}, % Difference		17.93	54.52	24.30	21.92	Max 75 %
	PAV Residue					
DSR, G* sin δ, @ 10 rad/s	26.5	1580	1110	3190	3200	Max 5000 kPa
BBR Creep Stiffness, S	-12	110	70	153	168	Max 300 MPa
BBR Creep Stiffness, m-value		0.358	0.385	0.300	**0.299**	Min 0.300

(a) FDOT allows binders with values higher than 3 Pa·s to be used with caution and only after consulting with the suppler as to any special handling procedures, including pumping capabilities.

NOTES:

1. ARB-5 binder did pass rotational viscosity requirement of the FDOT specifications (range 4.0 - 6.0 Poise) with a result of 4.6 Poise at 300 °F.
2. PG 76-22 (PMA) binder passed all requirements of the July 2012 FDOT specifications (MSCR test was not a requirement for PG 76-22 (PMA) at the beginning of the APT study).

4.2 Asphalt Mixture

Asphalt material was sampled from delivery trucks during construction of the HVS test lanes for use in laboratory mixture testing. Samples were reheated and prepared to determine dynamic modulus, flow number, and fracture properties using the Superpave indirect tension (IDT) tests. The asphalt dynamic modulus and flow number were determined using the Asphalt Mixture Performance Tester (AMPT) according to AASHTO TP 79. Dynamic modulus tests conducted using three temperatures and four loading frequencies were used to construct a master curve with a reference temperature of 20 °C. FIGURE 5 presents the dynamic modulus master curves and TABLE 6 shows the flow number and dynamic modulus at a single temperature and load frequency. The dynamic modulus values are within a reasonable range, but the Hybrid A-H and Hybrid A-L mixtures appear to have a dynamic modulus that is relatively less stiff than the mixtures with other binders. Dynamic modulus data at lower frequencies is often associated with rutting performance while cracking performance is related to dynamic modulus data collected at higher frequencies. The measured dynamic modulus values suggest that the GTR-C, Hybrid-B, and PG 76-22 (PMA) mixtures should have the best rutting performance.

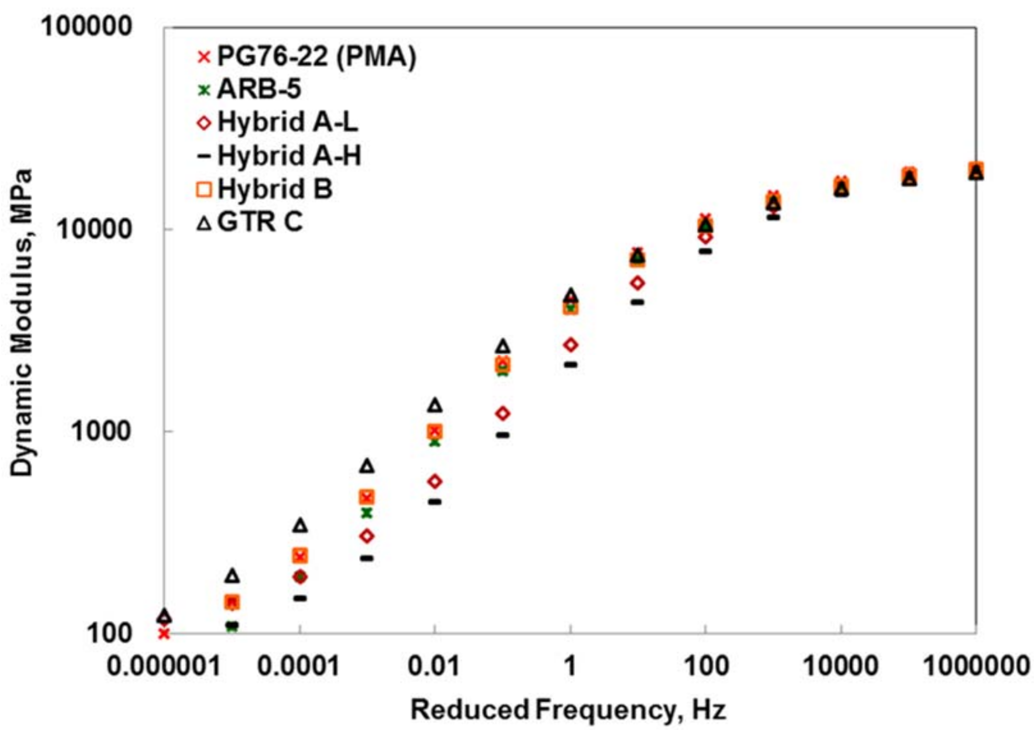

FIGURE 5 Dynamic modulus master curves

Superpave IDT tests were performed to determine mixture properties related to fracture resistance. All IDT tests were performed at 10 °C, which has been shown to correlate well with field cracking performance of Florida pavements *(16, 17)*. The energy ratio (ER) concept was used as an indication of cracking resistance. The ER model links asphalt mixture damage and fracture to dissipated creep strain energy (DCSE). This parameter allows the evaluation of different pavement structures since it includes the influence of mixture fracture properties and pavement structural characteristics. According to this model, crack initiation or propagation occurs when the damage induced exceeds the DCSE threshold in any region of asphalt mixture. Typically, higher ER values are associated with a higher DCSE limit and lower creep rate and represent a more crack resistant pavement. Detailed information on the ER parameter is presented elsewhere *(17)*. FIGURE 6 describes how the DCSE threshold ($DCSE_f$) can be determined using the stress-strain response measured from the Superpave IDT strength test.

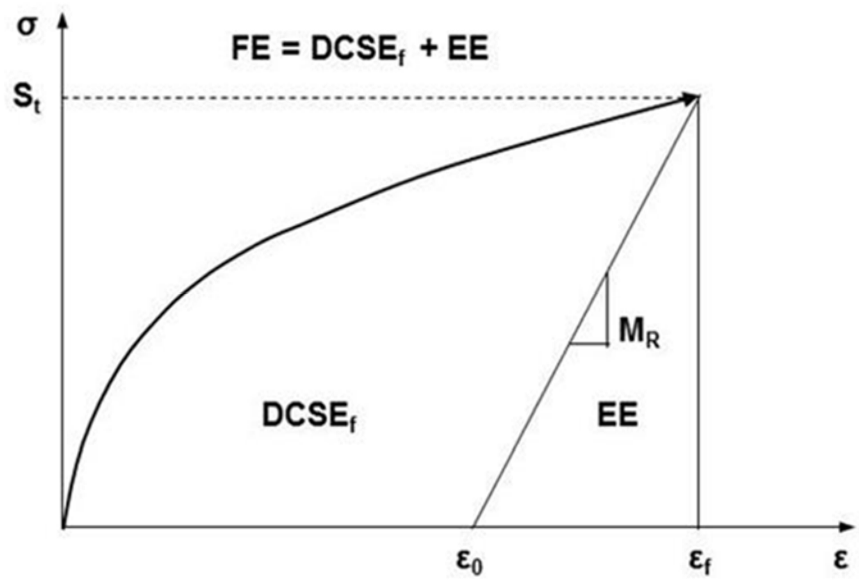

FIGURE 6 Determination of $DCSE_f$ using Superpave IDT test results

$$M_R = \frac{S_t}{\varepsilon_f - \varepsilon_0} \rightarrow \varepsilon_0 = \frac{M_R \cdot \varepsilon_f - S_t}{M_R} \quad (1)$$

$$\text{Elastic Energy (EE)} = \frac{1}{2} S_t \left(\varepsilon_f - \varepsilon_0\right) \quad (2)$$

$$\text{Fracture Energy (FE)} = \int_0^{\varepsilon_f} S(\varepsilon) d\varepsilon \quad (3)$$

$$\text{Dissipated Creep Strain Energy to failure } \left(DCSE_f\right) = \text{FE} - \text{EE} \quad (4)$$

Where M_R = resilient modulus, S_t = tensile strength, ε_f = failure strain, and ε_o = strain determined by resilient modulus, failure strain, and tensile strength.

All mixtures exhibited ER values in ranges expected to result in adequate cracking performance. Mixtures with Hybrid A-L and Hybrid A-H binders were found to show relatively lower ER values than other mixtures. Both of these mixtures were found to have a significantly higher creep rate which indicates a greater rate of damage accumulation and relatively worse cracking resistance. It should be noted that these mixtures also had relatively lower dynamic modulus values and were produced by the same supplier. While the AMPT and IDT test results for these mixtures are still considered satisfactory, there may be evidence that some formulations produce better performing binders. TABLE 6 summarizes the laboratory mixture test results including AMPT properties and mixture fracture properties measured from Superpave IDT tests. It is interesting to note that the two binders with the greatest flow number (Hybrid B and GTR C) were also found to have the best rutting performance as shown in FIGURE 7. However, the flow numbers for these mixtures are significantly greater than the flow number of the other mixtures while the actual rutting performance is only slightly better. The disparity in the relationship should be investigated further.

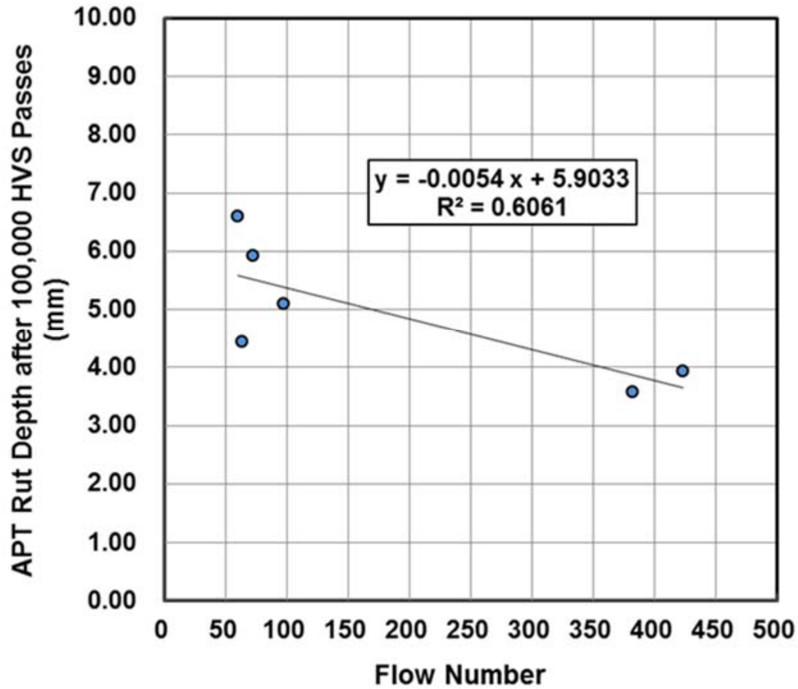

FIGURE 7 APT rut vs. flow number results

TABLE 6 APT and Laboratory Mixture Test Results

Mixture ID	HVS Rut Depth, mm	AMPT Properties		Fracture Properties at 10 °C		
		Dynamic Modulus, ksi (1 Hz, 20 °C)	Flow Number	Fracture Energy (KJ/m^3)	Creep Rate (1/GPa·sec)	Energy Ratio
Control	5.9	699	72	2.8	4.0E-04	4.2
ARB-5	6.6	573	60	5.4	9.8E-04	4.5
Hybrid A-L	5.1	421	97	5.0	1.4E-03	2.6
Hybrid A-H[(a)]	4.4	271	63	7.2	3.0E-03	2.5
Hybrid B	3.9	696	423	4.7	4.5E-04	6.6
GTR C[(b)]	3.6	657	382	2.7	3.3E-04	5.0

(a) Failed separation test
(b) Failed separation test, MSCR % recovery, and compliance value

5 SUMMARY AND CONCLUSIONS

An APT study and supporting laboratory testing have shown that asphalt mixtures that use a PG 76-22 (ARB) may be as effective in resisting rutting and cracking as mixtures that use a PG 76-22 (PMA). This study and other test sections have validated the PG 76-22 (ARB) developmental work that began with the formation of the FDOT/industry task team three years ago. Ultimately, the new PG 76-22 (ARB) specification will continue to encourage the use of recyclable materials in roadway construction projects while requiring improved and more reliable ARB performance. The main findings of the APT study are summarized below.

- All mixtures showed good rutting performance. Rutting resistance of PG 76-22 (ARB) mixtures was found to be comparable to that of mixture with a standard PG 76-22 (PMA).
- Based on the results of Superpave IDT tests, all mixtures exhibited a good range of ER values, which indicated satisfactory cracking resistance.
- The Hybrid A-H and GTR C binders failed to meet the separation test requirements. In addition, the Hybrid A-H binder was found to have relatively lower dynamic modulus and fracture properties. This data may suggest that there is an optimum range of GTR and SBS proportions that provide stability to the resulting binder and variations in each supplier's formulations may result in differences in performance, storage, or transportation. Additional research would be necessary to verify this hypothesis.
- Adoption of a performance graded ARB specification replaced two ARBs (ARB-5 and ARB-12) with one (PG 76-22 (ARB)), which simplifies binder production for a supplier and storage at the contractor's asphalt plant.

6 ACKNOWLEDGEMENTS

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