Properties of Arizona TR + binders in multiple stress creep and recovery test

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ABSTRACT. *The Multiple Stress Creep Recovery (MSCR) test has received increased attention by agencies as a means to specify and purchase asphalt cement binder. These agencies are using the protocol to either grade all asphalt cements or only as a means to screen for modification. The Arizona Department of Transportation is one agency that has been examining this protocol. The principal type of modified asphalt cement used in the state is a terminal blended rubber with polymer additive, referred to as a TR+ binder. In this paper, these binders have been tested and evaluated to determine their MSCR based performance grade and also to see if the MSCR test can detect the presence of the rubber and polymer additive. Limited comparisons are drawn between the TR+ binders and other, polymer only modified asphalts. It is found that the TR+ binders generally grade at a higher traffic level in the MSCR based system and also that the MSCR test detects the presence of the modifier.*

KEYWORDS: *terminal blend rubber; rheology; MSCR; polymer modification*

1. Introduction

Limitations to the high temperature Superpave grading parameter have been well documented in the literature [1-5]. This parameter, the ratio of shear modulus, $|G^*|$, to the sine of the linear viscoelastic phase angle, δ, is determined via repeated oscillatory loading at 10 rad/s, but at different temperatures. The limitations are particularly pronounced when it comes to assessing polymer modified asphalts. As a result, numerous agencies have adopted surrogate tests, so-called PG plus tests, to better differentiate their binder grades and ensure that they are receiving modified asphalts. The resultant proliferation of disparate tests has helped promote the development and use of a universal standard, the Multiple Stress Creep Recovery (MSCR) test method [1-2,6]. The test is based on a theory that in order to better relate asphalt binder properties to asphalt mixture rutting performance one must consider the nonlinear viscoelastic characteristics of the asphalt binder.

The MSCR test has been used for two different applications. In one, Departments of Transportation (DOTs) are using it to screen for polymer modification (examples include Texas and Nevada). In this case the results of the test are compared to a standardized curve to determine whether modification is or is not present. In the second, the test result is combined with other tests at different aging levels and temperatures to establish the purchase grade of the binder. This procedure follows essentially the same process as in AASHTO M320 [7], but replaces the binder test on short-term aged material with the MSCR test. The full process is outlined in AASHTO M332 [8] and has been adopted by the states of New York, Maryland, and others. The binder grade resulting from AASHTO M332 is similar to the PG grade, but is specific to both traffic and climate condition whereas the one resulting from M320 is related to climate alone. Thus in using AASHTO M320 it is left to the interpretation of the engineer how to handle pavements carrying higher traffic volumes.

The state of Arizona is one state that has been evaluating the MSCR test for some time. In this process they have experimented on several rubber based asphalts, referred to as TR+ binders in the State's nomenclature. In this paper the results of these tests are reviewed and compared with a separate database of polymer modified asphalts. The objective is to determine whether the TR+ binders show any differences in test metrics than these polymer modified asphalts.

2. Materials and Test Method

2.1. Asphalt Binder

For the purposes of this study a total of 56 different asphalt samples and 71 test sample conditions were evaluated. These binders are summarized in Table 1.

Table 1. *Summary of binder properties*

Group	Binder Grade	Samples	Sample Numbers
A	PG 76-22TR+	10	1-10
	PG 70-22TR+	13	11-23
B	PG 76-22TR+, 76	4	24-27
	PG 76-22TR+, 70		28-31
	PG 76-22TR+, 64		32-35
	PG 70-22TR+, 70	7	36-42
	PG 70-22TR+, 64		43-49
C	PG 76-28	3	50-52
	PG 76-22	2	53-54
	PG 70-34	1	55
	PG 70-28	5	56-60
	PG 70-22	5	61-65
	PG 64-34	2	66-67
	PG 64-28	4	68-71

The database is divided into three groups. Groups A and B include only the Arizona TR+ asphalt binders and Group C are other, non-TR+ binders that have been polymer modified. The TR+ specification requires minimum contents of 8% digested crumb rubber and 2% SBS polymer. The Arizona Department of Transportation (*A*DOT) tests for solubility via ASTM D2042 (minimum 97.5% in Trichloroethylene), elastic recovery via AASTHO T301 (minimum of 55%), maximum phase angle via AASHTO T315 (maximum of 75°) and softening point via AASHTO T53 (minimum of 50 to 60°C depending on exact grade). The difference between Group A and Group B binders is that Group A binders were only tested at the ADOT specified high temperature grade (70 or 76°C) while Group B binders were tested at this temperature plus one or two standard temperatures lower. Group C binders were also tested at multiple temperatures, but only the results at their high temperature grade are presented in this paper. It should be noted that the details of the modification in Group B binders are not known.

2.2. Test Method

The MSCR test method is detailed in AASHTO T350 [9]. It essentially involves the application of 10 cycles of creep and recovery shear loading (1 second loading and 9 seconds of rest) at both 0.1 kPa and 3.2 kPa. A series of 10 pre-test cycles are also applied prior to the measurement cycles. The test is performed under isothermal conditions in a shear rheometer with samples 25 mm in diameter and 1 mm thick. For each cycle, three strain values are defined: initial strain (ε_0), strain at the end of the creep portion (ε_c), and strain at the end of the recovery portion (ε_r). The location of these strain values are shown in Figure 1.

The non-recoverable creep compliance (J_{nr}) calculations are carried out using Equations - at both the 0.1 kPa and 3.2 kPa levels denoted by the subscripts 0.1 and 3.2 respectively. The values calculated from these equations are J_{nr} and the percent recovery (R). These values are used to calculate two key parameters, the non-recovered creep compliance at 0.1 and 3.2 kPa ($J_{nr0.1}$ and $J_{nr3.2}$ respectively) and the percentage of maximum strain that recovers after 3.2 kPa loading ($R_{3.2}$).

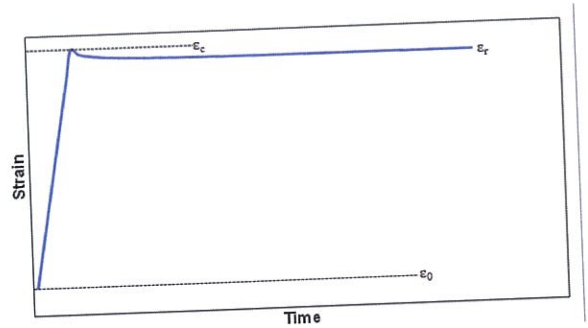

Figure 1. *Location of strain values during a creep/recovery cycle*

$$\varepsilon_1 = \varepsilon_c - \varepsilon_0 \quad (1)$$

$$\varepsilon_{10} = \varepsilon_r - \varepsilon_0 \quad (2)$$

$$\varepsilon_r(3.2, N) = \frac{(\varepsilon_1 - \varepsilon_{10}) \times 100}{\varepsilon_1} \quad \text{For cycles } N = 1 \text{ through } N = 10 \quad (3)$$

$$R_{3.2} = \frac{SUM[\varepsilon_r(3.2, N)]}{10} \quad (4)$$

$$J_{nr}(3.2, N) = \frac{\varepsilon_{10}}{3.2} \quad (5)$$

$$J_{nr3.2} = \frac{SUM[J_{nr}(3.2, N)]}{10} \quad (6)$$

3. Results and Discussion

The $J_{nr3.2}$ results for each binder group are presented in Figure 2. Also shown in this figure are horizontal lines indicating the current proposed traffic level grading limits from AASHTO M332. The regions between these lines correspond to binder grading limits at the (S)tandard, (H)igh, (V)ery high, and (E)xtreme traffic levels. It is observed that in almost all cases the binders exhibit responses that would rank them as High (10-30 million ESALs), Very High (>30 million), or Extreme (>30 million + standing traffic) in regards to traffic level resistance. It is noted, although not shown that separate analysis of non-modified ADOT binder types shows that most of these binders grade at the standard traffic level. In this case, the TR+ binders show a substantial change in the rheological properties. It can be inferred (although

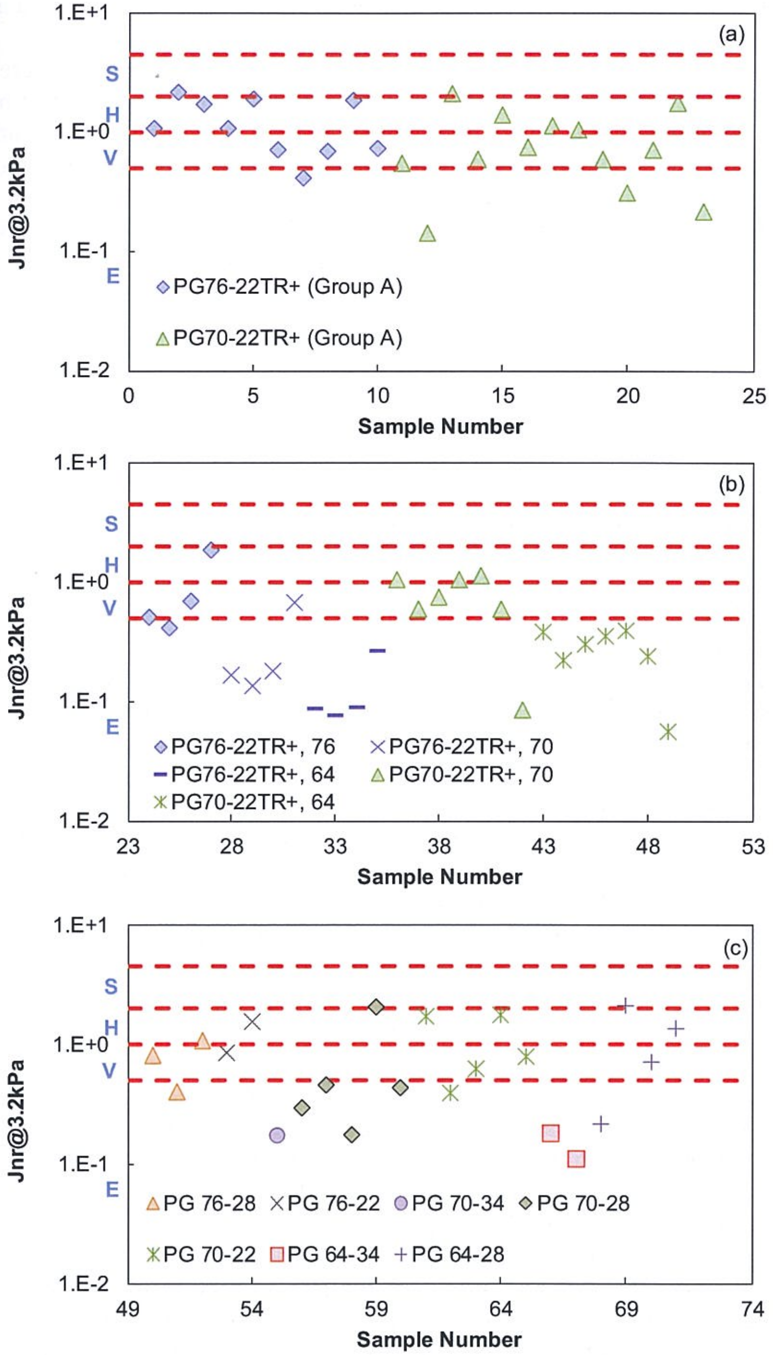

Figure 2. *$J_{nr3.2}$ results for; (a) Group A, (b) Group B, and (c) Group C binders*

not rigorously linked) that the performance of these modified asphalts would also be improved relative to the standard ADOT binders.

The results for Group B binders are shown at their current high temperature grade as well as the nearest two six degree increments. The results indicate that these binders would grade at one or two higher traffic levels at a lower temperature. Again, although it is not shown here, the increase in traffic grade by reducing the test temperature is similar with standard, non-modified asphalts.

As stated earlier, the second primary use of the MSCR test is to identify the presence of elastomeric binder modification. For this purpose the function shown in Equation has been suggested.

$$R_{3.2} = \begin{cases} 29.37\left(J_{nr3.2}\right)^{-0.263} & J_{nr3.2} \geq 0.1 \\ 55 & J_{nr3.2} < 0.1 \end{cases} \tag{7}$$

The basic form of the function can be surmised from a basic understanding of the role of the modification process. Modified binders tend to recover a higher percentage of the imposed strain than non-modified asphalts due to the presence of the elastomeric polymer. Recall that $R_{3.2}$ depends on both the amount of recovered strains and the magnitude of the strain resulting from the imposed loading. In the case of modification, the elastic recovery of the modifier would be expected to be similar across all base binder types (assuming binder/modifier compatibility). However, the total viscoelastoplastic response of the base binder could differ. In the case where the base binder is more compliant, the total binder deformation would be greater and thus the amount of modifier related recovery would be muted. In this case the $R_{3.2}$ required to detect modifier should decrease. While the basis for the functional form can be arrived at through rational considerations, the precise values of the function have not yet been derived. Thus, the function shown in Equation represents an experimentally derived function based on controlled modification and resultant testing.

The function in Equation is shown along with the different groups of binder in Figure 3. It can be observed by comparing parts (a) and (b) to part (c) that the TR+ binders exhibit similar characteristics to other, more traditionally modified asphalts. It is also seen from part (b) that while the conclusion regarding modification does not change the actual position of the points in the space does change. This observation clearly indicates that the vertical distance from the standard relationship is not a quantitative estimate of modification, merely an indication of the presence of modification. Comparing the TR+ binders in part (a) and the TR+ graded at only the highest temperature in part (b) to the equivalent PG grade in part (c) (e.g., compare PG 76-22 from (c) to PG 76-22TR+) it is observed that, in general, the TR+ binders tend to locate at higher recovery and lower J_{nr}. This may suggest a greater degree of internal binder structure formation with the TR+ binders. However, extreme care should be taken in making this conclusion based on the phenomenological nature of the curve itself, the fact that no information is available on the base binder, and the above observation from part (b) regarding temperature and location in the space.

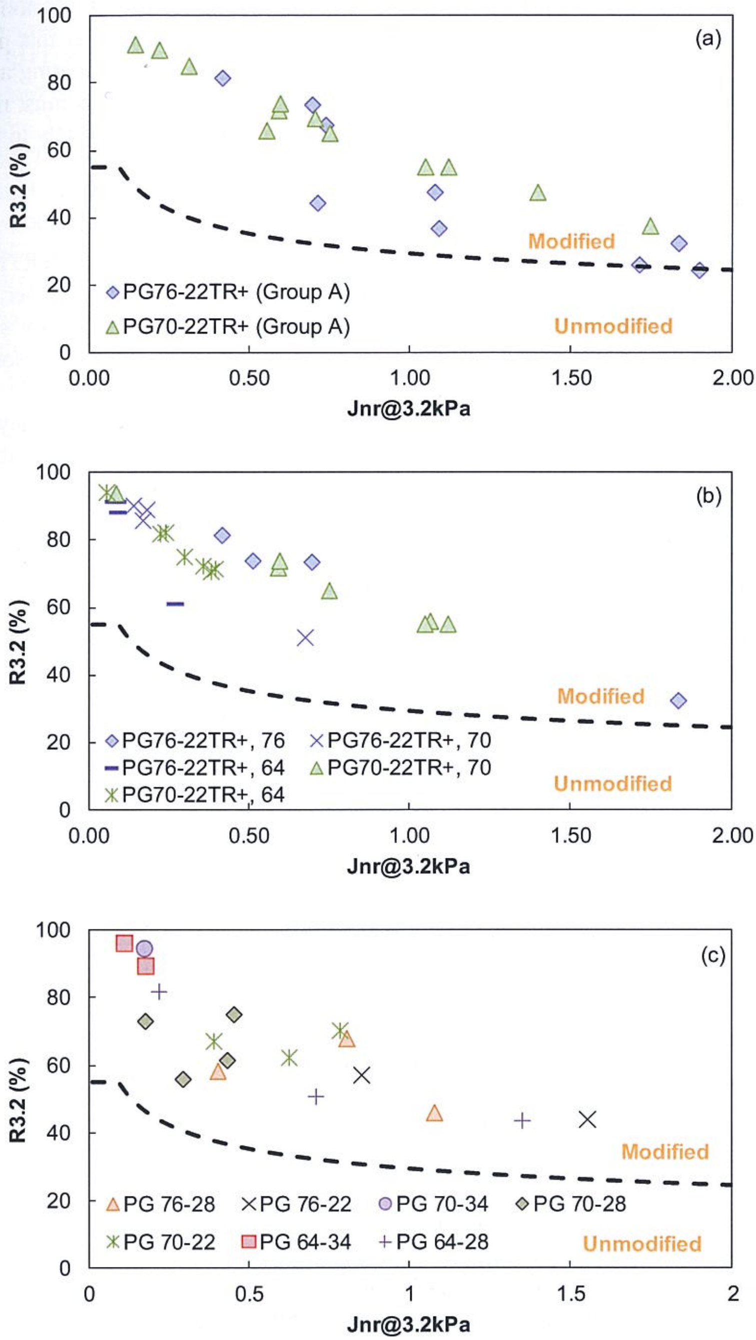

Figure 3. *Recovery curves for; (a) Group A, (b) Group B, and (c) Group C binders*

It should be noted that all of binders in this dataset have been formulated to non-MSCR specifications. This factor could contribute to the large number of samples that plot well above the recovery line, and is a factor to take into account when considering a change to a MSCR based system. Presumably, a system wherein manufacturers must meet the standard curve shown in Figure 3 could result in binders that lie more closely to the line.

4. Conclusions

This paper has examined the response of binders produced under ADOT's TR+ specification under MSCR testing. Although not explicitly shown in this paper, MSCR testing with the TR+ binders could be performed as it would be with any standard binder. It was found that these binders exhibit low J_{nr} values, which is consistent with their usage on higher traffic volume facilities. An assessment of these binders in the framework of the AASHTO M332 grading system suggests that they would grade to be used in High, Very High, or Extreme traffic conditions. The ability of MSCR to detect the modification was also assessed. It was found that the TR+ binders were located above the standard recovery curve. However, care should be exercised in concluding that TR+ binders are "better" modified since the origin of the standard curve is phenomenological and not tied to any specific microstructural configuration.

5. Acknowledgements

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Polymeric suspension additives for improving key performance properties of asphalt rubber binders and mixes

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ABSTRACT. *The use of Ground Tire Rubber (GTR) to modify asphalt binder in paving applications is an environmental goal and for all good reasons. Although such use of GTR is a long established practice commercially, it has been plagued by ongoing issues such as lack of Separation Stability, lack of Elastomeric Properties as measured by Mean Phase Angle (MPA) and Multiple Stress Creep Recovery (MSCR), and lack of adequate compaction and workability due to high binder viscosity. These Quality drawbacks have restrained the widespread use of GTR not only in the United States but also globally.*
The novel and patented Rheopave Technology is a solution to all of the drawbacks mentioned above and facilitates the use of GTR in applications globally with ease of binder manufacturing and mix performance that matches the "Gold Standard" of Styrene Butadiene Styrene (SBS) modified asphalt binders.

KEYWORDS: *ground tire rubber, MSCR, hybrid, RheoPave, binder, GTR,*

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1. Introduction

The number of motor vehicles (trucks, SUV's, cars,etc) on roads continues to increase every year. In the United States alone some 300 million used tires are discarded each year and it is estimated that over one billion used tires a year are discarded around the globe. With countries such as China and India, and the continents of Africa and South East Asia experiencing exponential growth this presents an environmental challenge to Governments, States and City Authorities for decades to come. Not being able to manage the volumes of discarded tires can often lead to environmental issues such as dump-site fires, unsightly debris scattered by floods and hurricanes, etc. This makes the recycling of used tires highly desirable, with the incorporation into asphalt pavements being the premier option to benefit society and reduce the carbon footprint moving forward.

In the early stages of the development and use of GTR with asphalt, it was envisaged as a cheap alternative to more expensive prime polymers such as Styrene Butadiene Styrene (SBS), Styrene Butadiene Rubber (SBR), Terpolymers, and Natural Rubber. In times of high asphalt prices linked to high crude oil prices, GTR was seen as a cheap filler and substitute to replace part of the binder volume. Unfortunately, these approaches hindered the technology development of GTR until performance issues and premature pavement failures placed a "black-eye" firmly on the use of GTR. These issues brought home a clear message for the need for quality enhancements to improve the practices of utilizing GTR in asphalt pavements going forward.

2. Background

2.1. Early Developments and Applications of GTR

The use of GTR in asphalt binders and mixtures has been practiced for several decades and was motivated by factors such as the cost reduction versus virgin polymers and the cost reduction versus the periodic escalation in crude oil prices. Environmental considerations motivated Federal, State and City officials to support and get behind the use of GTR at an early stage.

There were some early challenges with the quality and acceptance of GTR itself including the production and availability of quality consistent GTR. Quality GTR for asphalt pavements needs to be free from residual tire components such as metal shavings from the wire reinforcing, fiber from the cording reinforcement, dirt from unwashed tires, and any other extraneous contaminants. Such contaminants effectively reduce the active composition of the GTR and downgrade some of the key properties such as adhesive and cohesive strength of the binder and the mix. Yet another challenge was maintaining the consistency of the particle size distribution of GTR was tremendously difficult by the older commercial grinding technologies employed. Finally, there was the misconception and mind-set that ambient ground GTR was superior to cryogenically ground GTR without sound reasoning or technical evidence to support.

Recognizing the demand and opportunity for high quality GTR, the tire recovery and grinding industry went through a technology evolution. The design and implementation of highly sophisticated methods of recovery, cleaning, segregation and classification of the tire materials combined with significant advancements in the actual grinding technology lead to more consistent and superior quality GTR. This evolution incorporated both ambient grinding and especially cryogenic grinding technologies.

Lehigh Technologies Inc. based in Tucker, Georgia are a leading GTR producer and supplier and employ the highest standards of used tire materials collection, segregation and classification. Lehigh employs a highly advanced cryogenic grinding process to produce consistent and quality GTR. Unfortunately, not all GTR producers can meet the stringent quality demands Lehigh has instituted on themselves that leads to some variation in GTR quality from batch-to-batch. For example, GTR is imported into Korea from Lehigh Technologies, Inc. USA because local producers in Korea, or Asia for that matter, are not able to meet the required quality standards.

Both Ground Tire Rubber (GTR) and Micronized Rubber Powder (MRP) are consistent quality raw materials for which uses are growing rapidly in high performance applications. The successes in these high end applications and markets depends on the utmost quality and product consistency – specifically particle size distribution, cleanliness and compositional consistency. Market education on the raw material itself needs to expand from current practices of simply requesting a mesh size.

One of the formulation and processing methods employed by early technologies to compensate for the variability and poor quality of GTR was to digest the GTR or even tire chips in hot binder at temperatures exceeding 470°F (243°C) over prolonged digestion times ranging from 16 hours to 24 hours. Such processes destroy the GTR particles through oxidation and reduce the organic tire components soluble in the asphalt binder with the carbon black as residue. Thereafter aromatic oils and SBS polymer is added to the decomposed GTR binder mixture to restore some of the useful properties required. One of the properties claimed by this drastic oxidation process is Trichloroethylene (TEC) Solubility and it is highly questionable as to whether this property is really relevant for GTR binders and pavement mixes. Further prolonged digestion and super-heating by such processes severely ages the asphalt binder. Also, these types of processes are very energy consuming, generate substantial emissions and have long batch cycle times. It will be evident further in this Paper that the Rheopave Technology circumvents all of these drawbacks and works in conjunction with the GTR to create a homogenous GTR stable modified asphalt binder.

2.2. The need for a polymeric suspension additive

Rheopave Technology was conceptualized, formulated and patented to facilitate the efficient and specification compliant production of GTR binder, mix and pavement per the requirements of customers. Opportunity arose to put this technology to the test when Florida Department of Transportation (FDOT) made it their mission to elevate the quality of GTR binders used in their State. For many years FDOT specified Asphalt Rubber Binder with 5% GTR (ARB 5) and Asphalt Rubber Binder with 12% GTR (ARB 12). In both these binders, the GTR was stirred into the binder at specified temperature and time and tested for compliance with Brookfield Viscosity specifications.

The difficulty faced with such binders was mainly separation stability since the GTR particles had a tendency to settle to the bottom in binder resulting in substantial variations in the composition and quality of the binder from truck load-to-truck load. This problem in turn translated into wide variations in the aggregate mix quality delivered to the paving site and variations in pavement quality.

Often times truck drivers complained that after discharging the GTR binder, there was as much as 400 gallons of residual GTR left behind in the bottom of the conveying tankers that could not be pumped out and presented them with severe cleaning issues.

California attempted to address such issues by requiring the GTR binder to be produced and kept under constant agitation at the aggregate mixing plant i.e. transport of GTR binder from a blending terminal to a mixing plant was strictly forbidden. However, even such precautions did not circumvent the problems associated with GTR binders in terms of binder quality and aggregate mix quality variability.

3. Development of FDOT PG 76-22ARB

The State Materials Office of the Florida Department of Transportation (FDOT) recognized the need for improvements in GTR binder, aggregate mix and pavement placement quality while at the same time maintaining and promoting the environmental benefits of used tire recycling. The objectives of FDOT were three-fold:

(a) Maintain the current levels of commercially used GTR into asphalt binders.
(b) Enhance the quality of GTR binders used to be comparable to the "Gold Standard" of SBS based Polymer Modified (PMA) PG 76-22 binder.
(c) Work with Industry through a Binder Task Group comprising FDOT and Industry representatives to achieve this new GTR standard and specification.

The Binder Task Group met at regular intervals under the auspices of FDOT and the first step was to agree on a specification for GTR binder. Essentially the specification for SBS modified PG 76-22 PMA was adopted as the new GTR standard with some test specifications including Separation Stability, TCE Solubility and Brookfield Viscosity adjusted to address the practical difficulties faced with GTR compared to SBS. The Separation Stability specification was set at 15°F (Cigar Tube difference in softening point) with the understanding that this will be the starting value to be tightened after review of commercially produced batches over time. TCE Solubility was not required since GTR is mostly insoluble in TCE and solubility is not a determining factor in asphalt binder performance.

The GTR content of the binder was set at a minimum of 7% by weight of the binder giving formulators the option to optimize the GTR content without causing any issues with aggregate mix production, placement and compaction. The individual technology developers were to advise the mixing plants and contractors on the appropriate binder handling, aggregate mixing, placement and compaction temperatures suited to their respective products.

Table 1. *FDOT PG 76-22ARB Requirements*

PROPERTY			TEST METHOD	SPECIFICATIONS
ORIGINAL BINDER				
FLDOT Section 916 Requirements, PG 76-22ARB				
Flash Point COC, °F			T48	450 min.
Viscosity, Pa•s		135°C	T316	3.0 max.
Separation Test	Softening Point, Top 1/3, °F		D7173	Report
	Softening Point, Bottom 1/3, °F			
	Difference, °F			15 max
Dynamic Shear (2mm gap)	(G*/sinδ, 10 rad./sec.), kPa	76°C	T315	1.0 min.
	Phase Angle, δ, °			75 max.
RTFOT RESIDUE				
FLDOT Section 916 Requirements, PG 76-22ARB				
Mass Change, % (Mass Loss is reported as Negative)			T 240	1.0 max.
MSCR	$J_{nr3.2}$, kPa^{-1}	67°C	M332	1.0 kPa^{-1} max
	Recovery 3.2, %			≥29.37 $(Jnr, 3.2)^{-0.2633}$
PRESSURE AGING RESIDUE (100°C, 300 psi, 20 hr.)			R 28	
FLDOT Section 916 Requirements, PG 76-22ARB				
Dynamic Shear (G*•sinδ, 10 rad./sec.), kPa		26.5°C	T 315	5,000 max.
Creep Stiffness	Stiffness, MPa (60 sec.)	-12°C	T 313	300 max.
	m Value			0.300 min.

FDOT proceeded to request Industry Representatives to supply PG 76-22 ARB binder samples for testing for compliance. These samples were supplied and coded by FDOT so as to maintain anonymity of the different technologies. Test results obtained were summarized by FDOT and presented and discussed at the Binder Task Group meeting and the general consensus was that the samples tested were realistic and achievable in commercial production and indeed aligned with the "Gold Standard" of PG 76-22 PMA SBS modified.

The next step was for each of the participating Industry suppliers to participate in a FDOT supervised field evaluation trial to verify the quality of the PG 76-22 ARB binder, produced aggregate mix and pavement to be constructed. Ranger Construction participated in this trial and selected the Rheopave Technology based PG 76-22 ARB which was produced at the South Florida Materials Corporation Terminal in Riviera Beach, Florida. The binder produced for the field trial was sampled and tested by FDOT Materials Testing Laboratory as well as by an Independent Approved Certification Laboratory and confirmed to comply with FDOT Specifications for PG 76-22 ARB binder as shown in Table 2 below.

Table 2. *Rheopave Technology 76-22ARB Production for FDOT Trials.*

Property (Specification)	*Batch 1*	*Batch 2*
PG Grade (76 – 22°C)	*86.2-30.9* *82-28*	*81.8-30.4* *76-28*
Separation Stability (Max. 15°F)	*0.3*	*1.7*
MSCR @ 67°C: Jnr / % Recovery (<1.0 / >35%)	*0.24 / 56.1%*	*0.36 / 46.6%*
Rotational Viscosity @ 135°C (<3000 cps)*	*4800*	*4000*

*Viscosity waived as binder was proven to be pumpable.

The above binder was transported from the South Florida Materials Corporation Terminal to the Ranger mixing plant some 45 minutes away by tank truck and discharged into a holding tank. This tank was sampled by FDOT and the test results confirmed compliance with the PG 76-22 ARB binder specifications. Thereafter, 448 tons of the PG 76-22 ARB mix was produced by the Ranger Construction mixing plant and transported and paved on SR 704/OKEECHOBEE BV from East of Military Road to East of Congress Road at a compacted mat thickness of one inch.

Table 3 provides the data recorded by FDOT testing of the mix and field density measurements.

Table 3. *FDOT trial mix results*

Contractor: Ranger
Binder : SFMC
Location: SR 704
LOT: 3
Sublot: 1

Roadway: 43280000
Tonnage: 448 tons
County: Palm Beach
Type Mix: SP-12.5
Lift:

FIN: 427020-1 (E4N35)
Design: SP 13-11294A --> listed as RA 1000
Details: SR-704/OKEECHOBEE BV FROM EAST OF MILITARY TO EAST OF CONGRESS
Thickness: 1"

NO TRANSFER TO LD

Samples	AV	AC	Lab Gmb	Gmm	Field Density (92%) Core 1	Core 2	Core 3	Core 4	Core 5	Sublot 1
		6.50	2.274	2.369						
QC 1	4.18	6.60	2.271	2.370	2.183	2.196	2.17	2.126		91.52
VT 1	3.90	6.43	2.269	2.361	2.176	2.188	2.16	2.117		91.49
IV 1	4.24	6.47	2.259	2.359	2.202	2.148	2.206	2.142		92.20
PC (S)	4.14	6.55	2.267	2.365						
										92.26
Project Ave	4.00	6.42	2.276	2.371	2.187					

	P-8	P-200	Pb	Va	%Gmm
PF	1.00	1.05	1.05	1.05	1.05
CPF			1.05		

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Binder passed all requirements for PG 76-22 (ARB)

As can be seen from the FDOT data recorded, target field compaction was consistently achieved and FDOT staff present and the paving contractor commented that the mix was very workable and in fact behaved somewhat similar to a Warm Mix.

Following this successful field evaluation trial, Rheopave Technology produced PG 76-22 ARB was formally approved by FDOT and listed on the FDOT Quality Product Listing (QPL) in July 2013. Thereafter, several ongoing commercial batches of Rheopave Technology based PG 76-22 ARB were produced by South Florida Materials Terminal and mixed and have been paved successfully by contractors in Florida since July 2013.

3.1. Rheopave Chemistry at Work

Ground Tire Rubber was previously considered to be mostly a filler material and an asphalt extender that was more economical than polymer modified binders but very variable in quality.

Rheopave Technology is a unique polymer chemistry that actively networks with the ground tire rubber particles and the asphalt binder. Active sites are created on the ground tire rubber surface to form a three-dimensional network structure between the Rheopave molecules, the asphalt binder molecules and the ground tire particle surfaces. A stable and uniform matrix is the achieved result of this homogenous matrix. In this way the previously inert ground tire rubber particles are activated and made compatible with the asphalt binder thus contributing to the stiffness modulus, elastic properties and crack arresting properties of the binder. In addition, the mixture load bearing properties are enhanced to improve the long-term pavement life. The performance benefits of the Rheopave chemistry in transforming the hitherto inert filler ground tire rubber material into an active component of the binder are:

(a) Separation Stability

The formation of the network chemistry described above stabilizes the GTR particles as a uniform suspension throughout the medium of the asphalt binder for consistent performance. This active networking effectively minimizes the tendency of the GTR particles to separate from the asphalt binder that can problematic during handling and transportation. At the mixing plant such phase separation, as pointed out above, is the key cause of inconsistent and variable mix resulting in pavement ravelling and fatigue failures. On the other hand the uniform network structure created by Rheopave Technology ensures a uniform binder quality such that the binder coating on the aggregates is of uniform film thickness to promote good binder to aggregate adhesive and cohesive strength necessary for a long useful pavement life. The effectiveness of the Rheopave Technology is clearly evidenced by the excellent separation stability as measured by FDOT and Independent Approve Certification Laboratory as recorded in Table 2 and Table 3 and is at least as good as SBS based PG 76-22 PMA.

(b) Multiple Creep Recovery (MSCR)

A simple mixture of just GTR into asphalt binder such as the FDOT ARB 5 and ARB 12 has poor binder stiffness modulus as well as poor repeated creep and recovery of the pavement with repeated traffic loading and unloading (i.e. frequency of traffic movement over a given section of pavement). Such pavement mixtures are highly susceptible to rutting, shoving, raveling and cracking as well as being prone to fatigue failures as the pavement expands and contracts with seasonal temperature changes.

Rheopave Technology actively networks with the GTR particles and provides polymeric benefits to the asphalt binder thus enhancing the stiffness modulus and the MSCR (stretching/expansion and recovery/relaxation of the pavement with traffic loading and unloading) of the asphalt binder. This benefit enables the pavement to withstand prolonged and repeated traffic loadings and fatigue with seasonal temperature changes.

This necessary and important effect on MSCR is clearly demonstrated in the binder data in Table 2 and exceeds the minimum values specified for PG 76-22 ARB. Further, the Rheopave Technology has proven to produce consistently compliant MSCR values in a range of asphalt binders from different sources.

c) Mean Phase Angle

Neat asphalt binder is a visco-elastic material with poor elastic properties at elevated temperatures such as pavement temperatures in hot climates. Therefore polymers are incorporated as binder modifiers to provide the required elastic properties. The Mean Phase Angle (MPA) is a measure of the minimum required binder elasticity and in the case of the FDOT specification it should be less than 75° as measured by the Dynamic Shear Rheometer (DSR) at 76°C. The unique networking chemistry of the Rheopave Technology actively enhances the elastic modulus of the GTR binder to be compliant with the Mean Phase Angle requirements consistently and over a wide range of asphalt binders from different sources.

3.2. Performance Grading

The FDOT specifications for Performance Grading (PG) of the PG 76-22 ARB has been consistently achieved using a wide range of asphalt binders from different refineries. Also, the Rheopave Technology is robust and versatile to produce even higher grades of binders such as PG 82-22 or PG 82-28. This makes the Rheopave Technology suitable for tropical climates as well as cold climates and for challenging and stressful traffic loading conditions such as race car tracks, airport runways, airport taxi ways, airport aprons and harbour wharfs as well as heavily trafficked roads into and out of heavy freight handling harbours.

3.3. Rheopave Technology Matching the "Gold Standard"

The key differences ARB 5 and ARB 12 compared to the Gold Standard of SBS based PG 76-22 PMA are:

(a) Poor Separation Stability.
(b) Poor Mean Phase Angle.
(c) Poor Multiple Stress Creep Recovery
(d) Poor mix workability and compaction due to stiffness and stickiness and requiring excessively high mix and lay down temperatures.

The Rheopave Technology addresses the deficiencies above such that there is no longer a difference between the SBS and ARB binders in every aspect such as binder quality, mix quality, ease of paving and pavement quality i.e. the "Gold Standard" is matched.

3.4. Production and Handling of Rheopave Binders

One of the objectives of the Rheopave Technology was to ensure that a high quality GTR binder meeting the Gold Standard of SBS based PG 76-22 PMA can be produced in commercial quantities with ease and similar or shorter batch cycle times. This has been accomplished by the following processing steps for commercial production:

(a) A batch concentrate of 4-6% Rheopave beads is wetted out into asphalt binder PG 67-22 at 375°F to 385°F in a mixing tank equipped with pump circulation and paddle mixer.
(b) This mixture is circulated through a Siefer Mill for the same time as for SBS to disperse the Rheopave into the binder.
(c) The dispersed Rheopave concentrate is then discharged into a Let Down Tank with the mixer/agitator switched on. This process is repeated until the required number of concentrate batches are produced to match the tank batch size target.
(d) The same mixing tank is used to wet out the 40 mesh GTR into hot binder PG 67-22 to produce a 20% GTR concentrate at 375°F to 385°F by pump circulation and paddle mixing. This dispersion process for the GTR saves batch cycle time and energy and takes about 20 minutes. The required number of 20% GTR concentrate batches are made to match the tank batch size targeted.
(e) The wetted out and dispersed 20% GTR concentrate batches are discharged into the Let Down Tank already containing the dispersed Rheopave concentrate with continued agitation. It is at this critical stage that the Rheoopave, GTR particles and binder interact to form the network structure by co-mingling.
(f) Neat virgin binder PG 67-22 is added to the Let Down Tank as dilution binder to achieve the specified GTR and Rheopave content for the formulation.

3.5. Customer Feedback

Feedback from a producer of the Rheopave based PG 76-22 ARB is that the process batch cycle time is shorter and simpler than that employed with other technologies enabling them to meet demand comfortably. The stability of the Rheopave binder means that it may be held in storage for over two weeks without deterioration and this is important to contractors in the event of project delays due to weather or other unforeseen delays. Several thousands of tons of Rheopave based PG 76-22 ARB mixes have been paved in Florida by three major paving contractors since July 2013 and this momentum continues to grow.

3.6. Conclusion

The Rheopave Technology has raised the bar as a standard for Ground Tire Rubber based asphalt binders in the Paving Industry. This has been achieved by the unique Rheopave chemistry combined with high quality economical GTR produced by Lehigh Technologies, Inc. This Paper has illustrated the research and implementation that has gone into using GTR in a responsible and effective way by FLDOT. The Rheopave Technology has been at the forefront of this advancement in closing the gat between GTR and SBS. It can be said that there is no longer a performance difference with SBS polymer modified asphalt and Rheopave Technology GTR modified asphalt.

4. Biliography

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