High Temperature Characteristics of Modified Asphalt Binders

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Executive Summary

Two separate modified binders were obtained, one modified with styrene-butadiene-styrene (SBS), the other with ground tire rubber (GTR). Superpave tests were utilized to assign a high PG grade to each. Each sample was aged using the Rolling Thin Film Oven (RTFO) to simulate short term aging. Two replicates of each original and RTFO aged binder sample underwent the Dynamic Shear Rheometer (DSR) test to verify the performance grade of each. One RTFO sample of each binder went through the MSCR test to determine creep and recovery characteristics.

The SBS binder graded as a PG 70, while the GTR binder graded as a PG 76. True grades were determined to be PG 73.6 for SBS and PG 77.8 for GTR. The MSCR data showed that SBS is much more effective in recovery, although SBS is also more stress sensitive. For low stress, SBS recovered at a rate of 78.1% while GTR recovered at a rate of 31.2%. At high stress loading, SBS displayed 18.8% recovery and GTR only displayed 1.9% recovery. For SBS, the non-recoverable creep compliance for 0.1 kPa and 3.2 kPa loading was 1.25 kPa^{-1} and 10.6 kPa^{-1}, respectively. Meanwhile, the J_{nr} values for GTR were much higher, as they were calculated to be 11.5 kPa^{-1} and 30.9 kPa^{-1}. $J_{nr,diff}$ was much higher for SBS at a rate of 742% while GTR had a $J_{nr,diff}$ of 168%.

However, the high J_{nr} values and low recovery rates during some of the tests indicate that the data is inconsistent and unreliable. When inputting the J_{nr} values into the polymer validation equation, the high stress GTR trial does not even come close to passing, although it is known that this binder was modified. This shows that standard Superpave test specifications may need to be adjusted to account for modified samples.

Introduction

In the asphalt industry, mix designs are tailored for specific applications. In other words, an asphalt parking lot in Minnesota is not composed the same way as a highway in Texas. One of the major components of the mix design is the asphalt binder used. Binders are graded based on their suitability for use in different temperature conditions. The Superpave grading system assists in this, providing guidelines for how to grade a certain binder based on a series of tests run at different aging and temperature conditions.

The Superpave system assigns a high and low performance grade (PG) in order to describe the binder's behavior in the most extreme conditions. The high grade describes the highest 7-day average temperature while the low grade represents the area's lowest temperature recorded. High temperature tests are aimed at determining the binder's resistance to permanent deformations, like rutting, while low temperature tests determine the binder's resistance to cracking. So, a PG 64-22 binder would be characterized as softer and more prone to rutting at high temperatures than a PG 76-22.

However, in order to improve the performance of a binder, modifiers can be used. One application of binder modifiers is to either increase or decrease the stiffness. A lower stiffness may improve mixing or compaction, while a high stiffness may help resist permanent deformations throughout the life of the pavement.

This research paper summarizes and analyzes the results of the study of two commonly used binder modifiers, ground tire rubber (GTR) and styrene-butadiene-styrene (SBS). High temperature characteristics were studied to determine the relative advantages and disadvantages of each modifier. The two binder samples were graded according to Superpave specifications, and the Multiple Stress Creep Recovery (MSCR) test was utilized to compare their creep and recovery behavior. Conclusions were drawn about the relative applications of the two modifiers and their characteristics in general.

Experimental Procedures

Binder samples were obtained from Doug Jury of William Charles Construction in Rockford, IL. Included were two different samples modified with GTR and SBS. The SBS sample was a PG 70-28 binder, while the 12% GTR sample was a PG 58-28. The GTR sample's modification increased the stiffness to perform as a PG 70-28, as well.

Superpave tests were performed on the samples in order to verify the grades. All Superpave tests were performed according to Superpave and ASTM standards. In order to simulate short term aging, the Rolling Thin Film Oven (RTFO) test was utilized in accordance to ASTM D2872. Samples of both modifications were aged identically. After aging was complete, high temperature grade verification was done using the Dynamic Shear Rheometer (DSR) in accordance to ASTM D7175. Two replicates of each binder type and aging were graded in order to verify results. For the samples that went through the RTFO, one of each modifier type also went through the Multiple Stress Creep Recovery (MSCR) test. The MSCR test was run according to AASHTO T350 with a gap of 2 mm.

After the tests that verified the PG grade of the samples, the MSCR test was aimed at analyzing the creep and recovery characteristics of the binders. The results of the MSCR test were compared in order to analyze the effects that the different binder modifiers have during real-life applications. In the analysis of the MSCR results, the non-recoverable creep compliance (J_{nr}) and percent recovery were calculated. The non-recoverable creep compliance represents how much strain is "non-recoverable" after the recovery period and it is calculated relative to the stress applied during the test (0.1 kPa or 3.2 kPa). In addition, the percent J_{nr} difference between the 0.1 kPa and 3.2 kPa tests was also calculated. Lastly, the J_{nr} values were run through the polymer validation equation to validate numerically that these binders were modified.

Results

After running unaged and RTFO aged samples through the DSR, the SBS modified binder graded as a PG 70, as expected. All four SBS DSR tests (two unaged, two RTFO aged) resulted in a PG 70 grade. In addition, the average true PG grade of the SBS binder was 73.6. For the GTR modified binder, the DSR tests resulted in a grade of PG 76 and a true grade of PG 77.8. Three of the four GTR DSR tests resulted in a PG 76, while one resulted in a PG 70. The one test that graded as a PG 70, which was one of the two RTFO aged replicates, had a true PG grade of 75.4, just under the PG 76 threshold. So, while the RTFO aged replicates did not grade the same way, it is still safe to assume the GTR binder was a PG 76 with the data that was obtained.

	G*/sin					
	S1 70	S1 76	S1 82	S2 70	S2 76	S2 82
SBS Ori.	1270.2	761.6		1268.7	756.8	
GTR Ori.	2002.6	1146.5	698.0	2049.9	1225.9	769.6
SBS RTFO	3096.1	1823.5		3429.2	1966.7	
GTR RTFO	3640.0	2090.8		5058.0	2999.9	1787.5

Table 1: DSR results

	True PG		PG Grade	
	Sample 1	Sample 2	Sample 1	Sample 2
SBS Ori.	72.9	72.8	70	70
GTR Ori.	77.7	78.6	76	76
SBS RTFO	73.9	74.8	70	70
GTR RTFO	75.4	79.6	70	76

Table 2: PG grade results from DSR tests

One of each RTFO aged SBS and GTR sample went straight into the MSCR test after grade verification was completed. The most noticeable difference between the two modified binders was the difference in percent recovery. The SBS modified binder displayed much higher recovery than the GTR. During the 0.1 kPa loading, the SBS modified sample had 78.1% recovery while the GTR modified sample had 31.2% recovery. Likewise, during 3.2 kPa loading, SBS modified binder recovered at a rate of 18.8%, while GTR recovered at a rate of only 1.9%. The strain-time plots for each MSCR test are included in the appendices.

Because of the difference in recovery, the non-recoverable creep compliance (J_{nr}) of the GTR modified binder was much higher than SBS. During 0.1 kPa loading, the J_{nr} for GTR was 11.5 kPa^{-1} while SBS displayed a J_{nr} of 1.3 kPa^{-1}. Similarly, during 3.2 kPa loading, the average J_{nr} value for GTR was 30.9 kPa^{-1} while SBS had an average J_{nr} value of 10.6 kPa^{-1}. The large difference between J_{nr} values for 0.1 kPa and 3.2 kPa loading resulted in a J_{nr} percent difference of 742% for SBS and 169% for GTR. Because of the very large $J_{nr,diff}$ for both modifiers, it can be concluded that these materials are very stress sensitive.

Also, the J_{nr} values can be run through the following polymer validation equation:

$$Recovery\,\% \ \geq 29.37 * J_{nr}^{-0.26}$$

The unaged and RTFO aged SBS binders, as well as the unaged GTR binder, passed. However, the RTFO aged GTR binder failed. It is known that this binder is polymer modified, so the GTR binder did not perform as expected. Results are shown below, as well as in the appendices section.

			% recovery	validation
SBS	Jnr(0.1)	1.254	78.1196136	27.6923449
	Jnr(3.2)	10.570	18.7874288	15.9091326
	Jnr(% diff)	742.986		
GTR	Jnr(0.1)	11.506	31.1799105	15.5620289
	Jnr(3.2)	30.932	1.85912438	12.0337032
	Jnr(% diff)	168.836		

Table 3: J_{nr}, percent recovery, and polymer validation summary

Discussion/Conclusions

The two different modified binders graded differently, as the SBS binder graded as a PG 70 and the GTR as a PG 76. However, the true PG grades were closer, as the SBS graded as a PG 73.6 and the GTR graded as a PG 77.8. So, it can be expected that the GTR is slightly stiffer than the SBS. Ideally, if time allowed, another replicate of RTFO aged GTR binder would have been run through the DSR to further validate the grade of this binder. The two RTFO aged GTR replicates had significantly different results. However, since the unaged GTR binder consistently graded as a PG 76 and the RTFO sample that did grade as a PG 70 had a true PG grade of 75.4, it is assumed that this binder really is a PG 76.

The results of the MSCR test yielded very mixed results. The SBS binder displayed much higher recover than GTR, showing that this modifier would perform better when preventing permanent deformations like rutting. It was actually noticeable when working with the two binders how much more elastic the SBS modified binder was in comparison to GTR. The GTR binder was more clearly modified visually, but when actually working with the samples, the SBS binder was definitely more elastic and flexible.

However, the data clearly had considerable error, as the J_{nr} values were very high. The PG+ grading system proposes which application a binder is suitable for based on the J_{nr} values during 3.2 kPa loading. The max value of J_{nr} is 4.0 kPa^{-1}, which is for standard loading. The J_{nr} values calculated during these tests at 3.2 kPa were 10.6 kPa^{-1} and 30.9 kPa^{-1}, not allowing the samples to be graded in the PG+ system. In addition, the $J_{nr,diff}$ values for both SBS and GTR were well above the 75% upper boundary, showing that these materials acted with high stress sensitivity. Also, the GTR modified sample had only 1.9% recovery during 3.2 kPa loading, which is extremely low. This did not even come close to passing the polymer validation check. Since we know that this binder is, in fact, polymer modified, this tells us that something during the testing was not reliable.

One possible error that could explain the recovery issue is that GTR polymer chains tend to be much shorter than SBS polymer chains, and do not mix as well when combined with asphalt binder. During the MSCR test, the GTR chains might not be getting stretched as intended, and instead may be getting pulled apart. When a polymer chain is stretched instead of torn, it acts elastically when the load is released, increasing recovery. However, when a chain is torn, the extra elasticity is not present anymore. This would significantly decrease the recovery.

The DSR was set to a 2 mm gap during the MSCR test. This may have not been big enough. If the strands are long enough to be touching the top and bottom plate, the data can be negatively affected. A 4 mm gap could have been utilized to further rely on the elasticity of the strands present in the binder.

The main takeaway from these tests is that Superpave specifications may not always produce reliable data for modified binders. The standards may need to be adjusted to account for binders that have been altered by external materials. One of the changes that may need to take place is an increase in gap size for DSR and MSCR tests. If the gap size is increased, the polymer chains and particles in the binder get stretched further, and there is a higher likelihood that the results are not negatively affected by the position of the strands in the sample.

However, with the results that were obtained, there are still some conclusions that can be made. The GTR samples had much higher J_{nr} values and their recovery was smaller in comparison to the SBS samples. This shows that GTR modified binder may be more applicable to pavements that do not have very heavy or fast moving traffic loading. SBS modified binder displayed high recovery, although the J_{nr} values were still considerably large. In comparison to GTR, though, SBS binder may be more applicable to heavier and faster traffic. In general, the recovery characteristics of the SBS binder make this modifier more effective in preventing permanent deformations.

Acknowledgments

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Appendices

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	cycle	Ɛ1	Ɛ10	%recovery	Jnr
SBS 0.1	1	0.562648	0.130319	76.838	1.303
	2	0.562923	0.126789	77.477	1.268
	3	0.565388	0.125349	77.830	1.253
	4	0.569069	0.125497	77.947	1.255
	5	0.571199	0.123423	78.392	1.234
	6	0.574026	0.124414	78.326	1.244
	7	0.576916	0.123566	78.582	1.236
	8	0.580749	0.124446	78.572	1.244
	9	0.584206	0.125606	78.500	1.256
	10	0.585168	0.124446	78.733	1.244
SBS 3.2	1	33.711047	23.438238	30.473	7.324
	2	42.065553	32.781572	22.070	10.244
	3	42.559158	34.209424	19.619	10.690
	4	42.310596	34.185789	19.203	10.683
	5	41.861707	33.971548	18.848	10.616
	6	41.561701	33.879873	18.483	10.587
	7	41.274711	33.776289	18.167	10.555
	8	41.160962	33.859789	17.738	10.581
	9	41.032343	33.886399	17.415	10.589
	10	41.063564	33.859789	17.543	10.581
GTR 0.1	1	1.490031	0.942215	36.765	9.422
	2	1.601669	1.036506	35.286	10.365
	3	1.670103	1.140917	31.686	11.409
	4	1.753895	1.107526	36.853	11.075
	5	1.760224	1.224397	30.441	12.244
	6	1.695766	1.205332	28.921	12.053
	7	1.694015	1.190655	29.714	11.907
	8	1.706871	1.207516	29.256	12.075
	9	1.661490	1.243154	25.178	12.432
	10	1.670118	1.207516	27.699	12.075
GTR 3.2	1	107.258054	105.307111	1.819	32.908
	2	104.713488	103.009653	1.627	32.191
	3	103.959367	101.943800	1.939	31.857
	4	102.047802	100.098063	1.911	31.281
	5	99.254234	97.372247	1.896	30.429
	6	97.853019	95.883891	2.012	29.964
	7	98.661920	96.795669	1.892	30.249
	8	98.764168	96.910619	1.877	30.285
	9	97.470562	95.579784	1.940	29.869
	10	98.565686	96.910619	1.679	30.285

Table 4: MSCR results

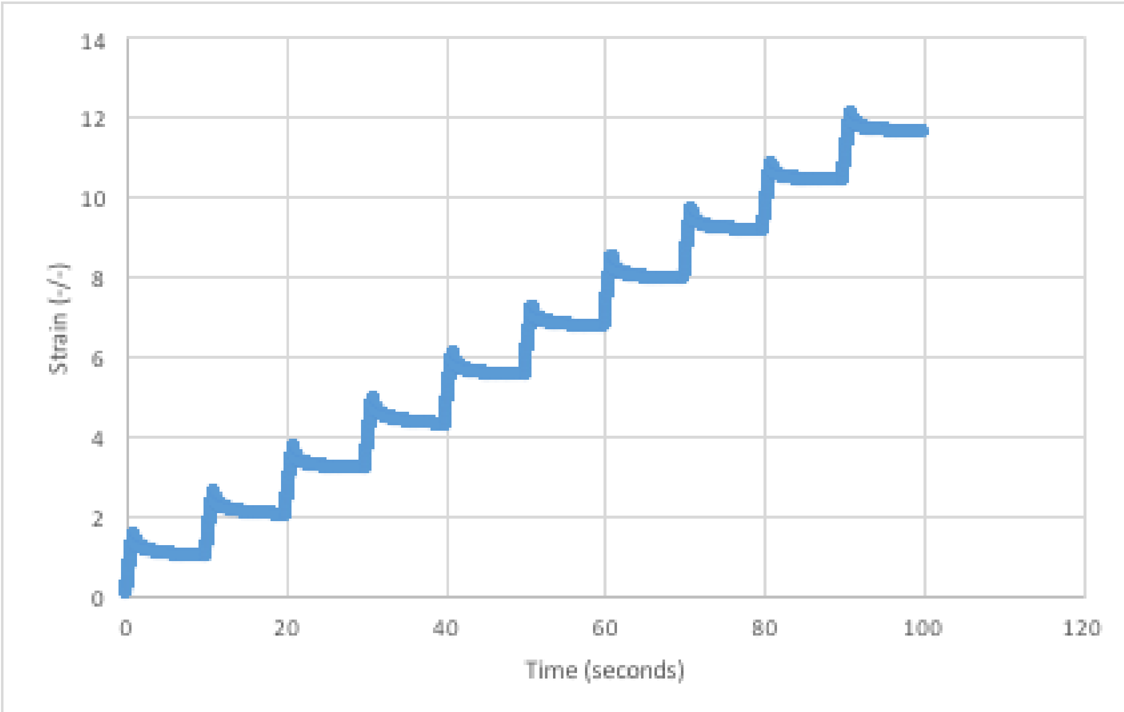

Figure 1: Strain-time plot for GTR binder at 0.1 kPa

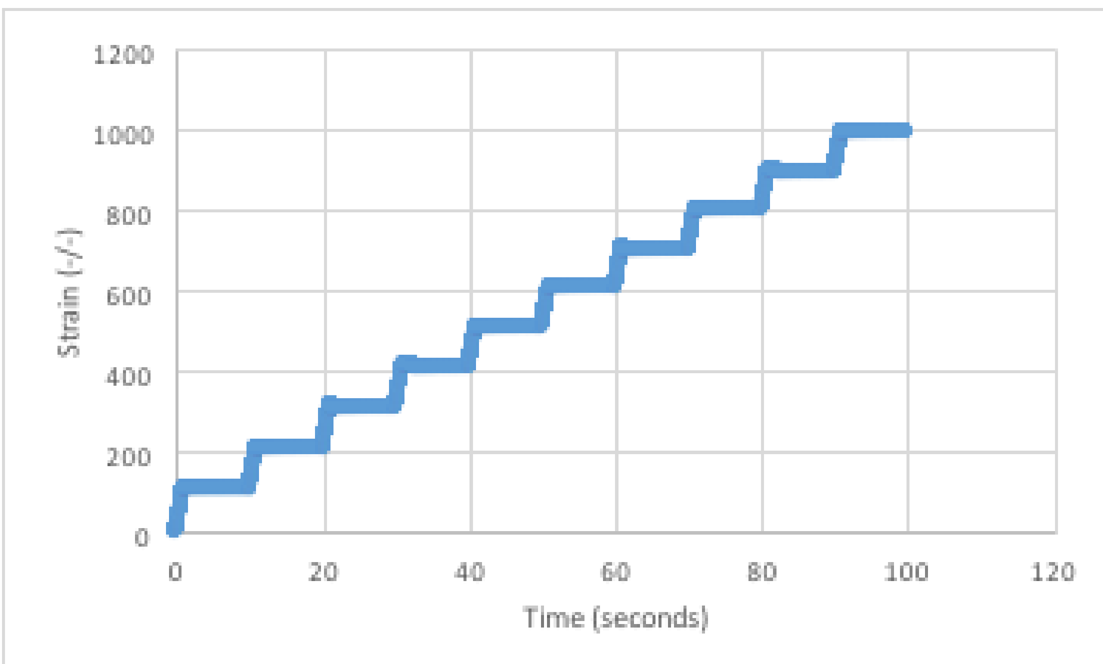

Figure 2: Strain-time plot for GTR binder at 3.2 kPa

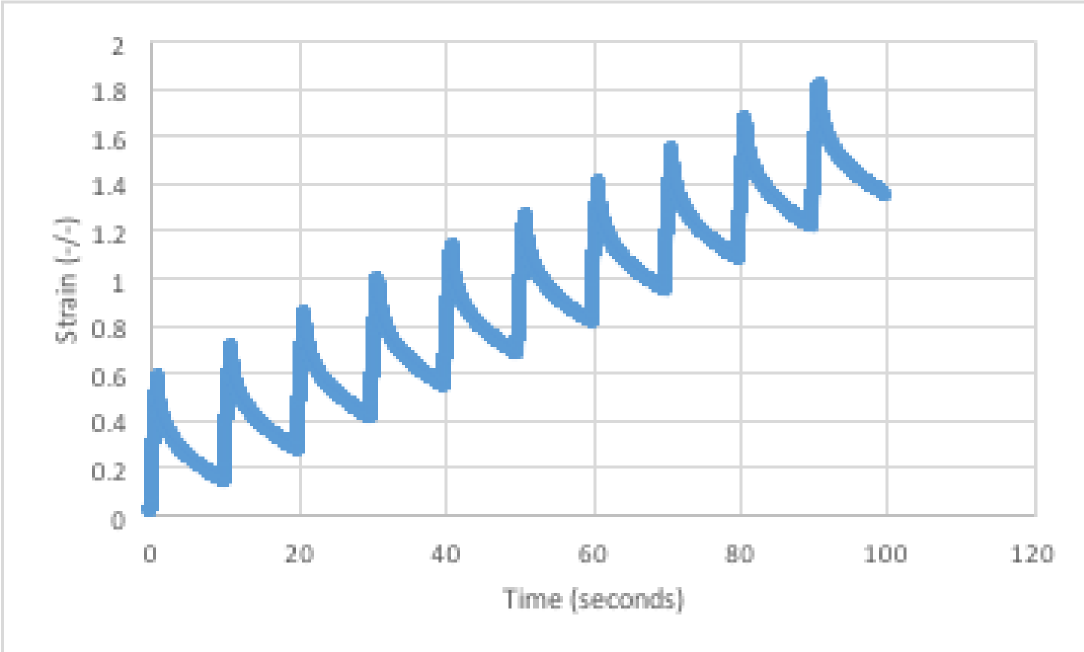

Figure 3: Strain-time plot for SBS binder at 0.1 kPa

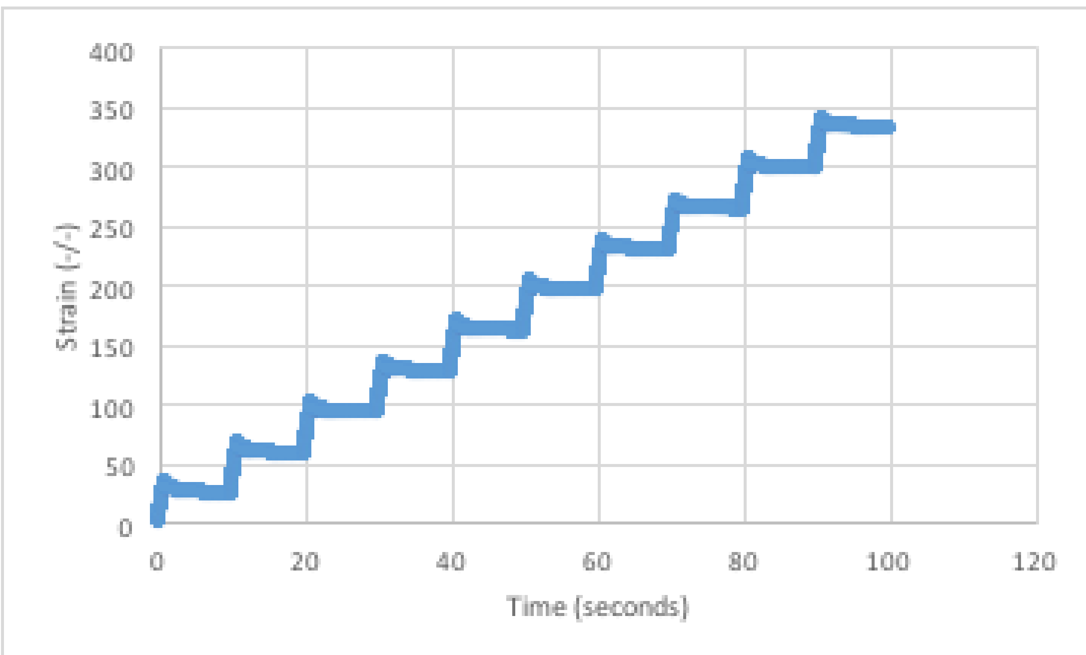

Figure 4: Strain-time plot for SBS binder at 3.2 kPa