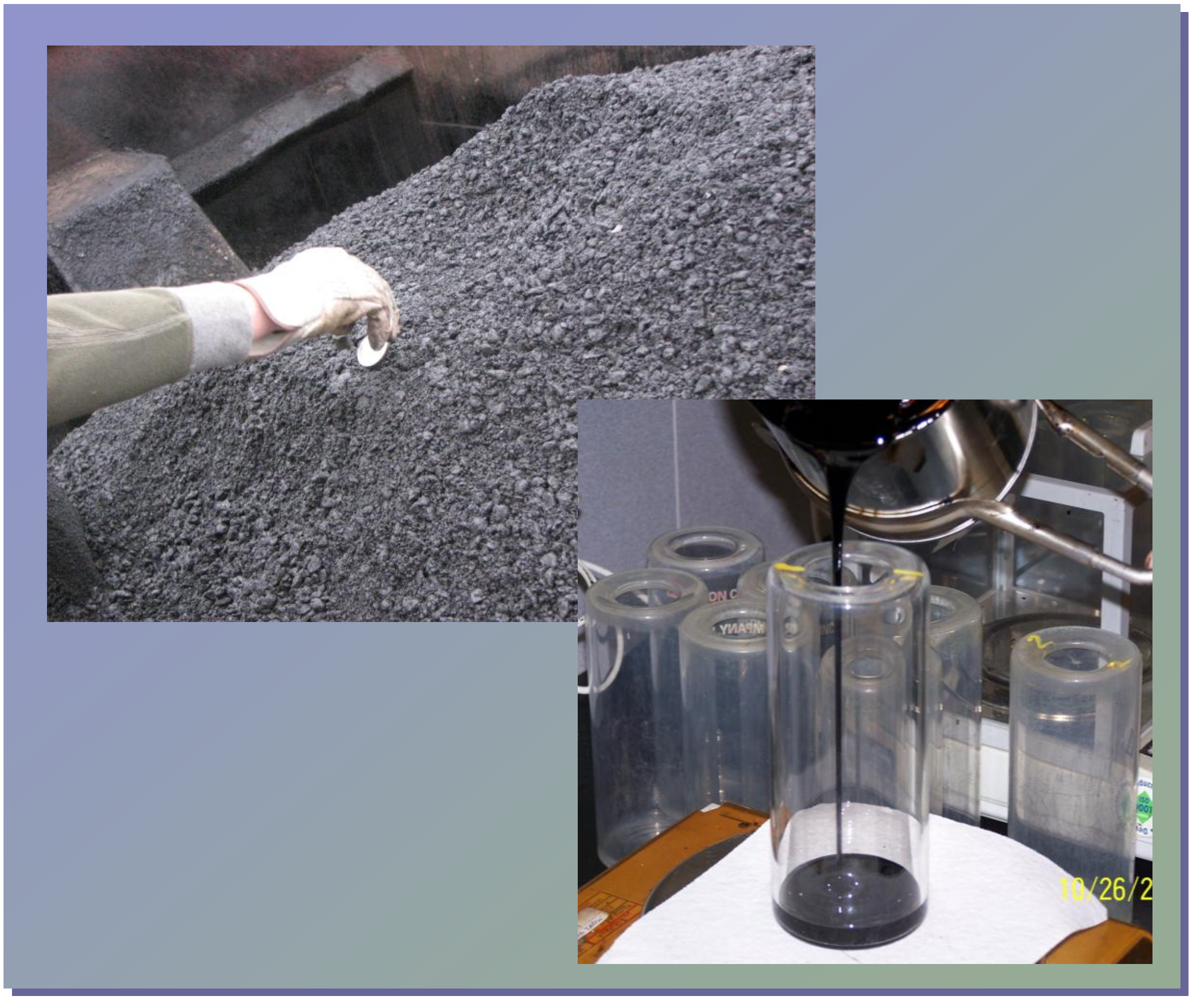
New Hampshire DOT

Research Record



New Hampshire Binder and Mix Review

Final Report

Prepared by the University of New Hampshire Department of Civil Engineering for the New Hampshire Department of Transportation, in cooperation with the U.S. Department of Transportation, Federal Highway Administration

Technical Report Documentation Page

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16. Abstract

This review was initiated to compare relative rut testing and "simple performance tests" (now known as Asphalt Mix Performance Tests) for the New Hampshire ½ inch mix with 15% Recycled Asphalt Pavement (RAP). The tested mixes were made from various neat and modified asphalt liquids. The asphalts were tested with the full battery of Strategic Highway Research Program binder tests to assess stiffness comparisons and low temperature cracking properties.

Binder testing results indicate that Polyphosphoric Acid (PPA) may slightly decrease the low temperature performance and the styrene-butadiene rubber (SBR) modified binder would perform better at low temperatures than the styrene-butadiene styrene (SBS) modified binder. With respect to rutting, the Multiple Stress Creep Recovery (MSCR) results indicate the PPA binder may increase rutting susceptibility and the SBR modified binder would perform better than the SBS modified binder.

Mixture testing results indicate the PPA mixture will perform better with respect to rutting, but the Model Mobile Load Simulator (MMLS3) tests show the opposite. Air void content differences for the MMLS3 specimens could be affecting the results. The difference in fatigue performance will be dependent on the pavement structure. A stiffer mixture is generally better for thicker pavements, but may not be for thinner structures.

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NHDOT Binder and Mix Review

Final Report

August 2012

By:

Jo Sias Daniel, Ph.D., P.E.

Introduction

This review was initiated to compare relative rut testing and "simple performance tests" (now known as Asphalt Mix Performance Tests) for the New Hampshire ½ inch mix with 15% RAP. The tested mixes were made from various neat and modified asphalt liquids. The asphalts were tested with the full battery of SHRP binder tests to assess stiffness comparisons and low temperature cracking properties.

<u>Binder Testing</u>

Asphalt binder testing was conducted by the NHDOT Chemistry Lab and by FHWA. The result of the testing by NHDOT is summarized in Table 1 below. The FHWA PG Binder grading results are shown in Table 2. FHWA conducted the binder grading according to M320 and MP1-a protocols. Except for the PG 64-28 neat binder from Pike, the grades from both methods were identical. The continuous PG grade and the critical cracking temperature are also shown.

Table 1. NHDOT Binder Testing Results

	Irving Neat 64-22	**Trigent Neat 64-28**	**Irving PPA 64-28**	**Irving SBS 70-28**
Rotational Viscosity, Pa-s	0.4625	0.4825	0.5000	0.9675
Mass Change, %	-0.006	-0.562	-0.515	-0.611
DSR				
Original, kPa	1.467	1.254	1.382	1.418
Phase Angle, deg.	86.24	85.00	84.08	81.17
RTFO, kPa	3.486	3.694	3.886	4.119
Phase Angle, deg.	82.60	79.21	78.63	71.80
PAV, kPa	2788	2408	1914	3159
Phase Angle, deg.	48.44	47.77	58.83	48.04
Bending Beam				
Creep Stiffness, Mpa	137	208	235	237
m-value	0.336	0.334	0.326	0.307
Direct Tension				
Stress, %	2.454	1.138	0.901	1.225
Strain, MPa	4.06	3.80	3.64	4.33
Critical Cracking Temp.	-26.1	-29.5	-28.4	-30.0

Table 2. FHWA Binder Test Results

Contractor	Binder	PG Grade M320	PG Grade MP1-a	Continuous PG Grade	Critical Cracking Temperature (C)
Pike	64-22 neat	64-22	64-22	67.1-26.4	-24
	64-28 neat	64-28	64-22	67.9-30.6	-27
	64-28 PPA	64-28	64-28	67.0-29.0	-28
	70-28 SBS	70-28	70-28	73.2-29.7	-28
Continental	58-28 neat	58-28	58-28	60.7-29.8	-29
	64-22 neat	64-22	64-22	66.0-26.4	-22
	64-28 neat	64-28	64-28	65.7-30.9	-30
	70-28 SBR	70-28	70-28	72.3-32.0	-31

FHWA also conducted DSR testing on the various binders over a range of temperatures and frequencies to construct master curves. The binder master curves at a reference temperature of 21.1C for all binders are shown in Figure 1. Figure 2 shows that the two PG 64-22 binders are very similar. The three PG 64-28 binders shown in Figure 3 are very similar as well; the PPA modified binder is slightly stiffer at the high frequencies. Figure 4 shows that the SBS modified binder is stiffer than the SBR modified binder at the higher frequencies.

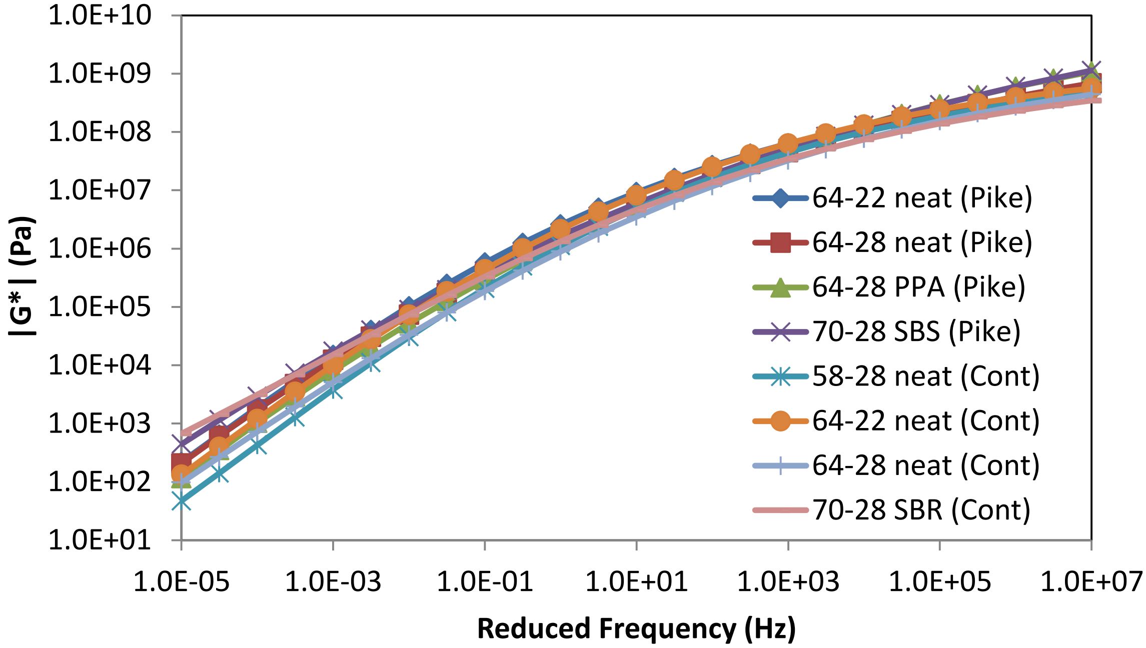

Figure 1. Binder Master Curves

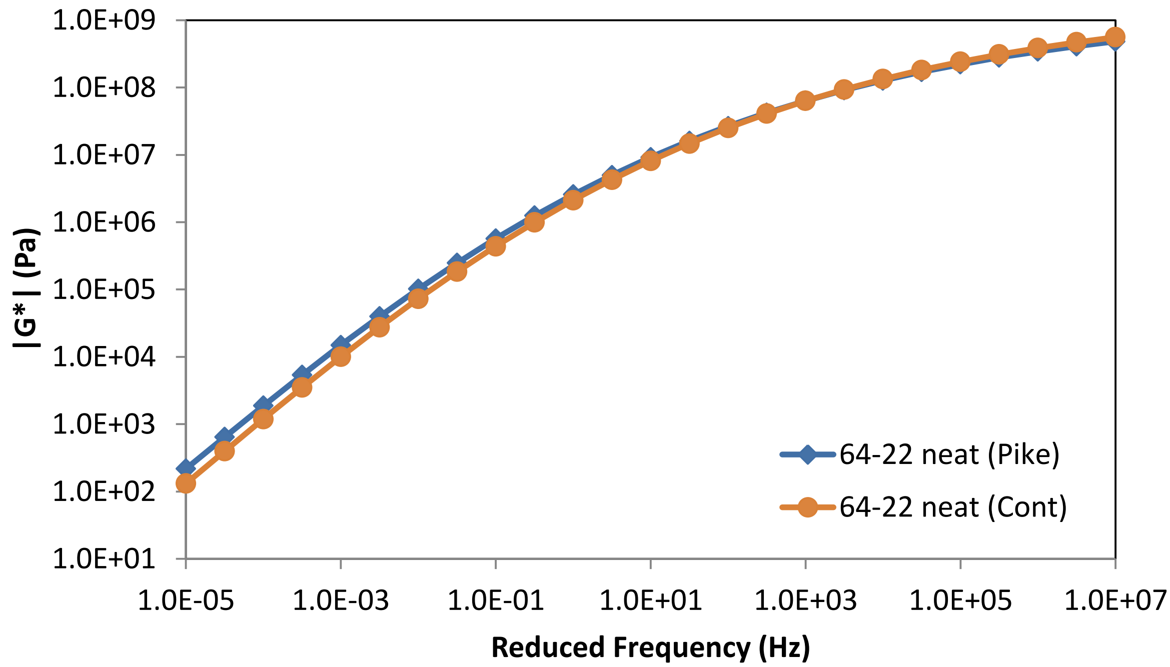

Figure 2. PG 64-22 Binder Master Curves

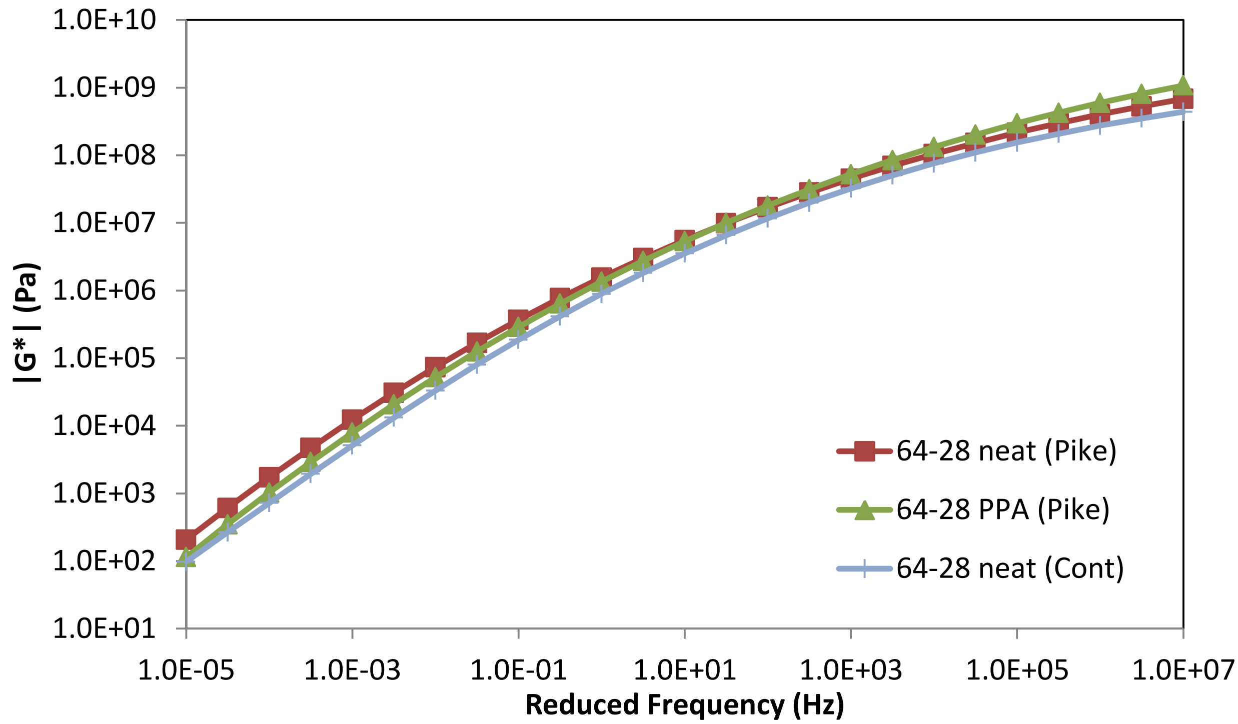

Figure 3. PG 64-28 Binder Master Curves

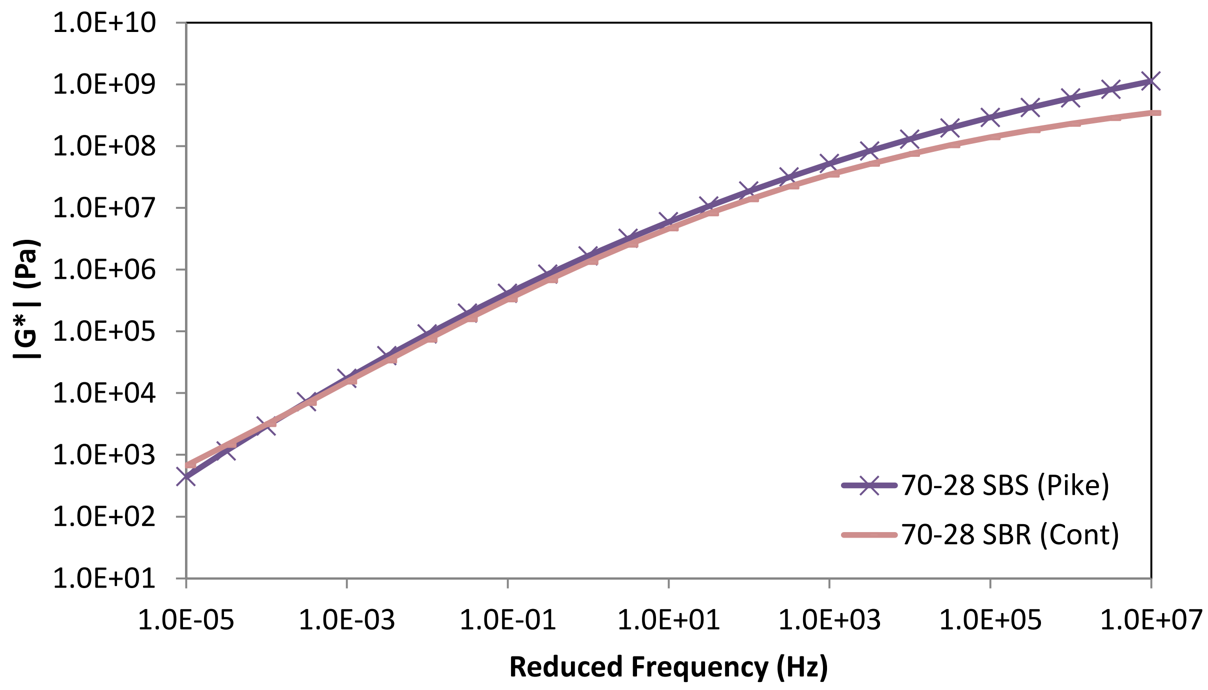

Figure 4. PG 70-28 Binder Master Curves

Multiple Stress Creep and Recovery (MSCR) testing was also conducted by FHWA on all of the binders. The results are summarized in Table 3 below. The high PG grade row is highlighted for each binder; according to current recommendations, J_{nr} values at the 3.2 kPa stress level should be below 4.0 for the standard traffic designation that corresponds to less than 10 million ESALs. The PPA increases the J_{nr} value for the PG 64-28, indicating that mixtures with this binder may be more susceptible to rutting. The PG 70-28 binder with SBR has a J_{nr} value below 2.0, which puts it into the "H" (heavy) traffic designation and indicates that mixtures with this binder would be less susceptible to rutting than those with the PG 70-28 binder with SBS.

Table 3. MSCR Testing Results

Contractor	Binder	Test Temp., °C	Non-recoverable Compliance, Jnr		Percent Recovery, %		sensitivity
			0.1 kPa	3.2 kPa	0.1 kPa	3.2 kPa	
Pike	PG 64-22 (Neat)	52	0.33	0.34	14.00	10.33	0.04
		58	0.91	0.98	5.67	1.00	0.07
		64	2.78	3.08	3.67	0.67	0.11
		70	6.43	7.24	0.67	0.33	0.13
	PG 64-28 (Neat)	52	0.26	0.28	27.33	23.33	0.07
		58	0.65	0.73	18.00	11.00	0.12
		64	2.09	2.48	8.33	2.00	0.19
		70	4.69	5.66	4.67	0.00	0.21
	PG 64-28 (PPA)	52	0.31	0.33	24.33	20.00	0.07
		58	0.83	0.94	16.00	9.00	0.13
		64	2.62	3.05	7.00	1.00	0.16
		70	5.77	6.82	2.33	0.33	0.18
	PG 70-28 (SBS)	58	0.25	0.29	39.00	32.00	0.14
		64	0.89	1.13	25.33	13.33	0.26
		70	2.01	2.67	16.33	5.00	0.33
		76	4.12	5.77	12.33	2.00	0.40
Continental	PG 58-28 (Neat)	46	0.38	0.40	14.00	10.50	0.04
		52	1.04	1.12	7.67	4.00	0.07
		58	2.84	3.14	3.67	0.67	0.11
		64	6.24	7.06	1.00	0.00	0.13
	PG 64-22 (Neat)	52	0.42	0.44	10.00	6.33	0.05
		58	1.10	1.18	2.67	0.00	0.07
		64	2.76	3.04	0.00	0.00	0.10
		70	6.28	7.06	0.00	0.00	0.13
	PG 64-28 (Neat)	52	0.38	0.46	28.67	16.33	0.19
		58	0.97	1.25	19.33	4.00	0.29
		64	2.33	3.11	11.33	0.00	0.33
		70	5.32	7.23	5.67	0.00	0.36
	PG 70-28 (SBR)	58	0.18	0.24	55.00	42.33	0.31
		64	0.45	0.67	44.33	24.00	0.49
		70	0.96	1.56	38.67	14.33	0.63
		76	2.13	3.86	30.33	4.00	0.81

Mixture Testing

Mixture testing was conducted by FHWA and UNH. FHWA conducted dynamic modulus and flow number tests using an AMPT. Pike and Continental shipped loose mix to FHWA where specimens were fabricated to a target 7% air void content for testing. The air void contents of the individual specimens are shown in Table 4. Testing was conducted on 3-4 replicate specimens and then averaged for presentation. UNH conducted rutting tests using the MMLS3 equipment. The results of the mixture testing are summarized in the sections below.

Table 4 Dynamic Modulus Specimen Air Void Contents

Mixture	Specimen								Avg
	1	2	3	4	5	6	7	8	
64-22 Neat Pike 15% RAP	7.4	7.5	7.9	7.6	7.7	7.4	7.3	7.2	7.4
64-28 Neat Trigeant 15% RAP	7.1	7.1	7.2	7.1	6.8	6.9	7.0	6.9	6.9
64-28 Neat Trigeant 20% RAP	6.5	6.6	6.8	7.0	7.1	6.7	6.8	6.9	6.8
64-28 PPA Irving 15% RAP	7.2	6.6	6.6	6.9	6.9	6.6	6.9	6.9	6.8
70-28 SBR Latex 15% RAP	6.6	6.8	6.5	6.9	6.5	6.5	7.0	7.0	6.7
70-28 SBS Hudson 15% RAP	6.5	6.6	6.3	6.4	6.8	6.8	6.6	6.8	6.7
70-28 SBS Hudson 20% RAP	6.0	6.1	6.2	6.7	6.2	6.4	6.2	6.0	6.2

Dynamic Modulus and Phase Angle

Dynamic Modulus

Figure 5 shows the dynamic modulus master curves for all mixtures. Overall, the Continental mixtures are softer than the Pike mixtures. For both sets of mixtures, the PG 64-22 mixture shows the overall stiffest response and the modified 70-28 mixtures show the softest response. The PG 64-28 mixtures are shown in Figure 6. The Pike and Continental neat mixtures are almost identical. The addition of more RAP (from 15% to 20%) stiffens the Pike mixture. The addition of PPA does not have much effect at the lower frequencies, but causes a stiffer mixture at the higher frequencies, roughly equivalent to the 20% RAP mixture. Figure 7 shows the PG 70-28 mixtures. The Continental SBS mixture shows the softest response. The SBS and SBR Latex Pike mixtures have similar stiffness at low and intermediate frequencies, but the SBR mixture becomes stiffer at high frequencies; the SBR mixture becomes even stiffer than the 20% RAP mixture. The addition of more RAP stiffens the mixture with the PG 70-28 binder over the whole frequency range, although the 20% RAP mix does have a lower air void content, which will increase the mixture stiffness as well.

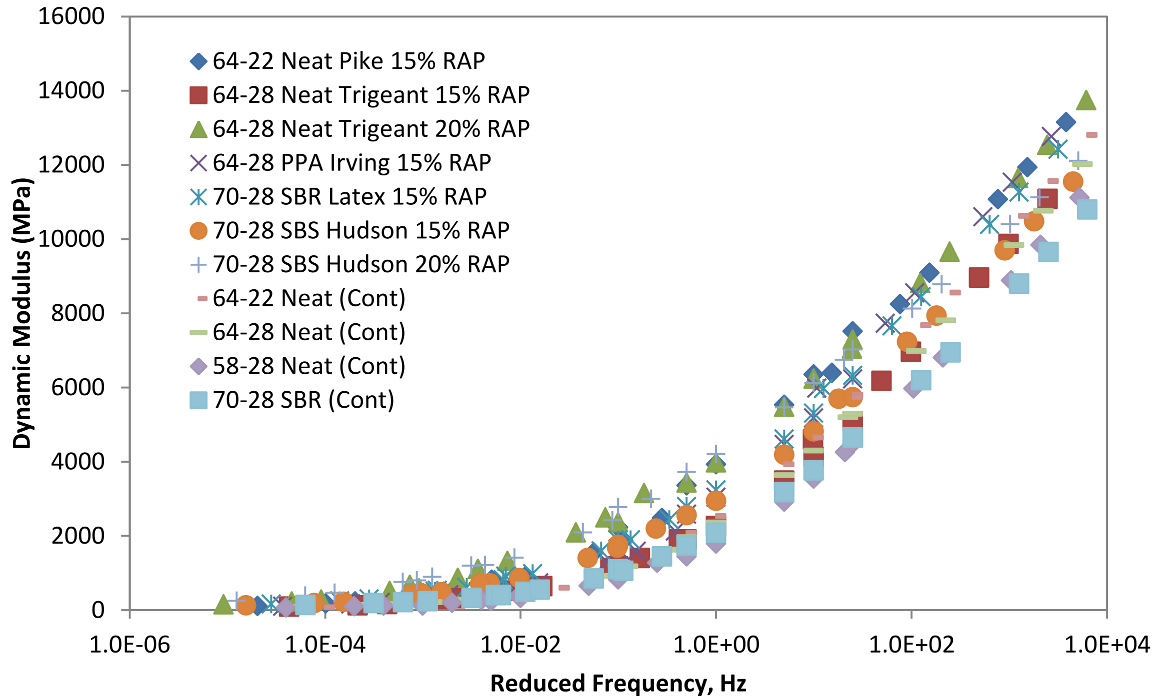

Figure 5 Dynamic Modulus Master Curves for All Mixtures

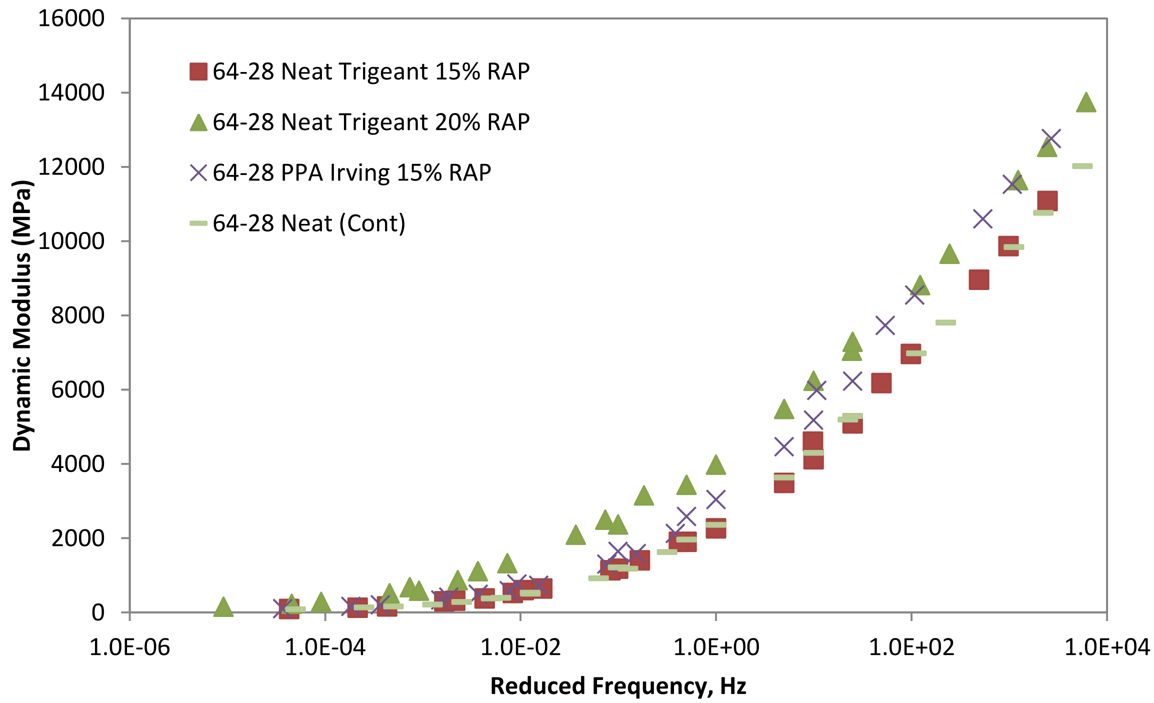

Figure 6 Dynamic Modulus Curves for PG 64-28 Mixtures

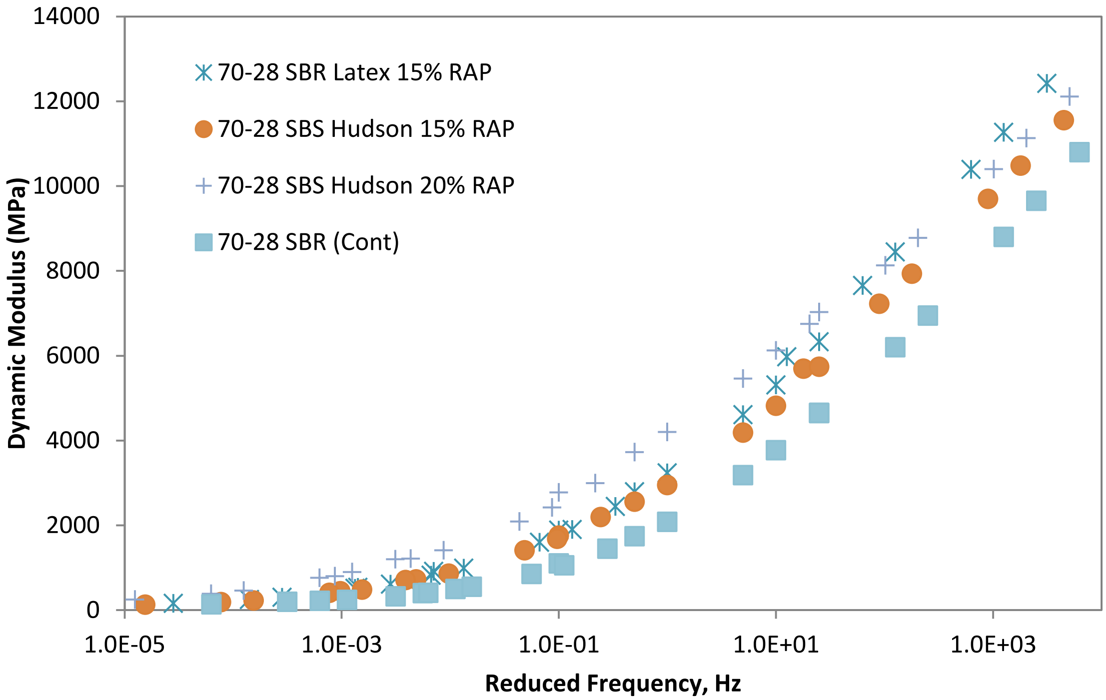

Figure 7 Dynamic Modulus Master Curves for PG 70-28 Mixtures

Phase Angle

The phase angle represents the relative viscous or elastic response of the material; a higher phase angle indicates a more viscous response and a lower phase angle indicates a more elastic response. The phase angle master curves for all mixtures are shown in Figure 8. Overall, the PG 58-28 mixture has the highest phase angle, which is expected. A comparison of the PG 64-28 mixtures is shown in Figure 9. The Pike and Continental mixtures with the neat binder are similar. The PPA decreases the phase angle at the higher frequencies and the addition of more RAP decreases the phase angle at the intermediate to high frequencies. Figure 10 shows the PG 70-28 mixtures; the Continental mixture has the most viscous response. The SBR Latex and SBS mixtures are very similar while the addition of RAP decreases the phase angle. The decrease in phase angle with the 20% mixture could be a combination of the higher RAP content and lower air void content of the specimens.

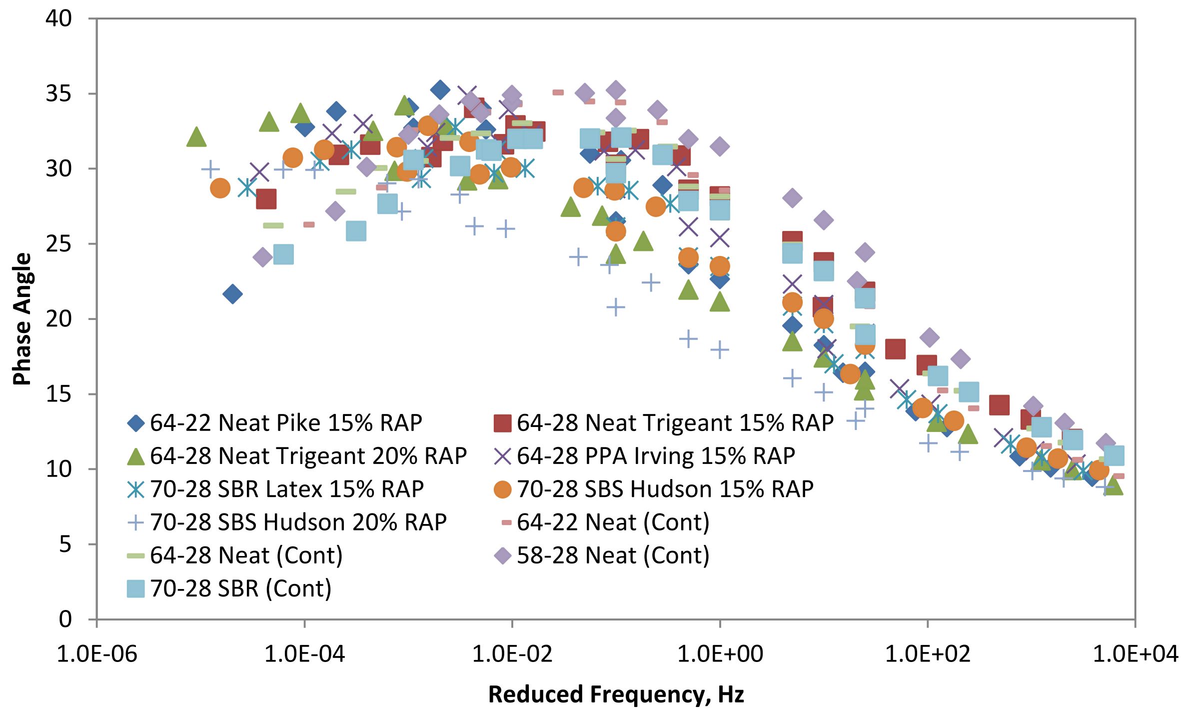

Figure 8 Phase Angle Master Curves for All Mixtures

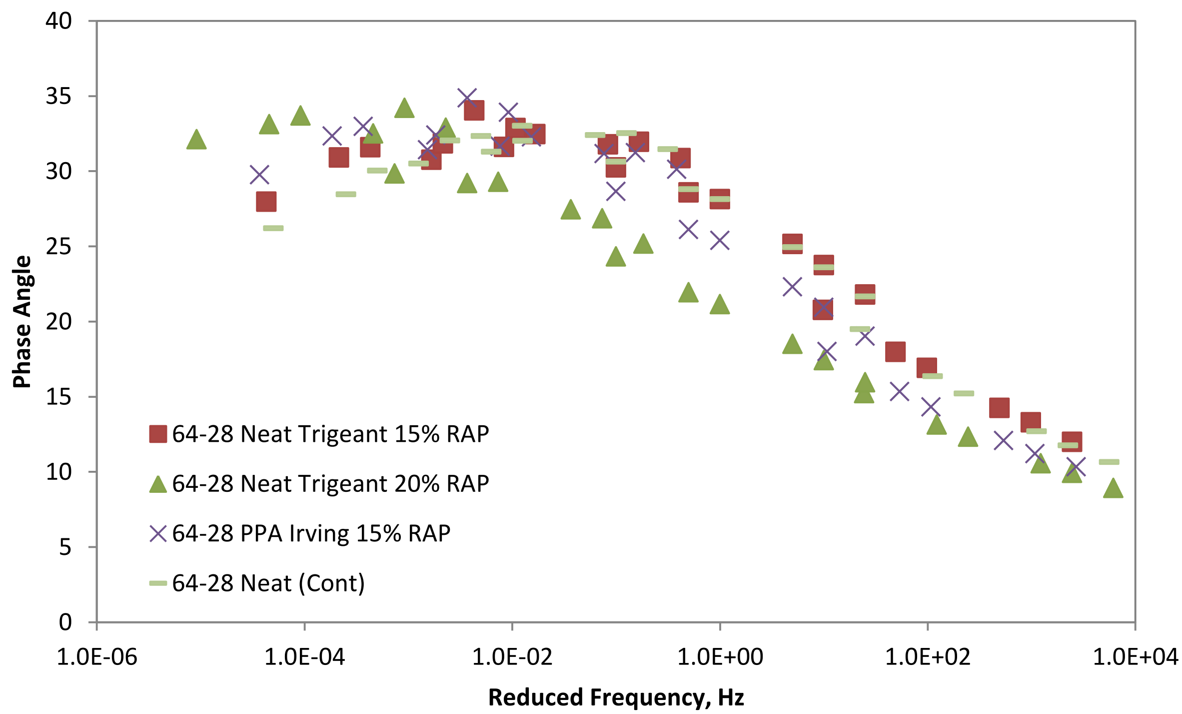

Figure 9 Phase Angle Master Curves for PG 64-28 Mixtures

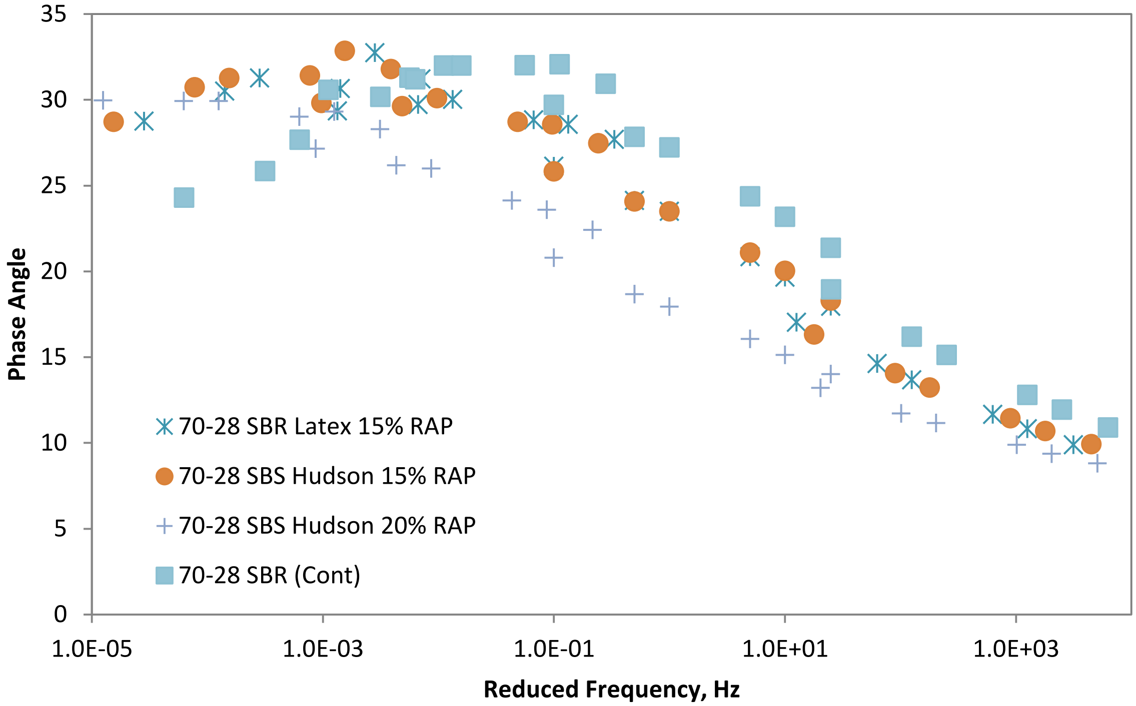

Figure 10 Phase Angle Master Curves for PG 70-28 Mixtures

Flow Number

The flow number testing was conducted at 52°C for all mixures and the analysis followed NCHRP 9-29 protocols. The Flow Number data for the Continental and Pike mixtures are shown in Figure 11 and Figure 12, respectively. The Continental mixtures have flow numbers that are more than an order of magnitude less than those measured for the Pike mixtures. The Continental mixtures all experienced more than 5% strain (Figure 13), while none of the Pike mixtures did. Of the Continental mixtures, the PG 64-28 mixture performed the best. Error bars representing the standard deviation of the test results are shown for the Pike mixtures in Figure 12 and Figure 14. The flow number data for the Pike mixtures show some differences in average response for various mixtures, but the error bars overlap, indicating these differences are not statistically significant. The total strain at the end of the test (10,000 cycles), shown in Figure 14, does show differences in performance among the various Pike mixtures. The addition of PPA decreases the amount of strain for the PG 64-28 mixture and the increase in RAP content decreases it further, although the RAP mixture has a lower asphalt content and air void content, which will also reduce the amount of strain. The SBR and SBS PG 70-28 mixtures have similar performance, while the 20% RAP decreases the amount of strain for the SBS mixture.

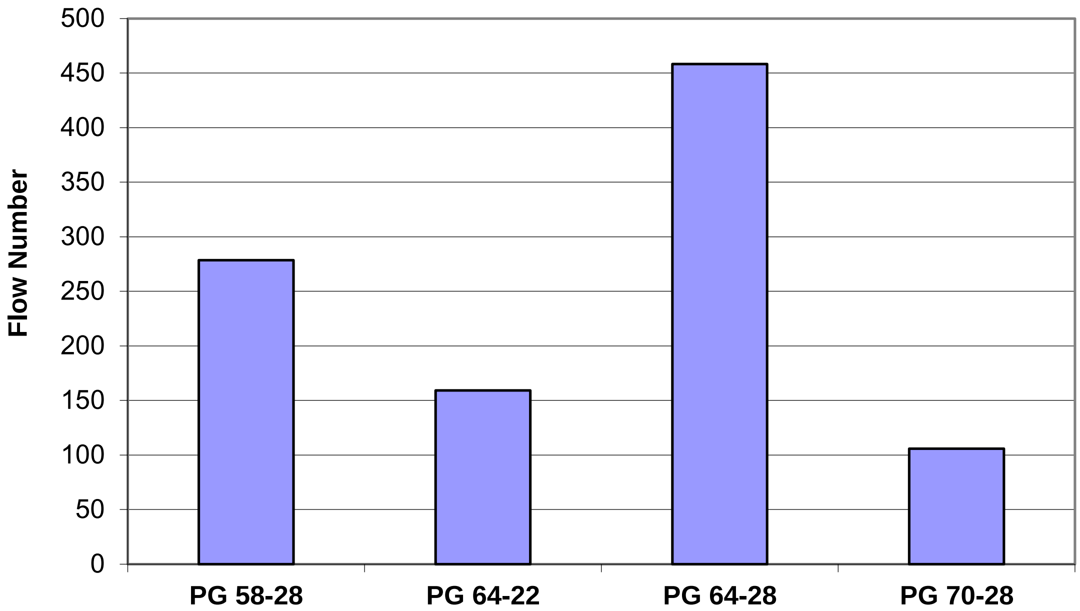

Figure 11 Flow Number for Continental Mixtures

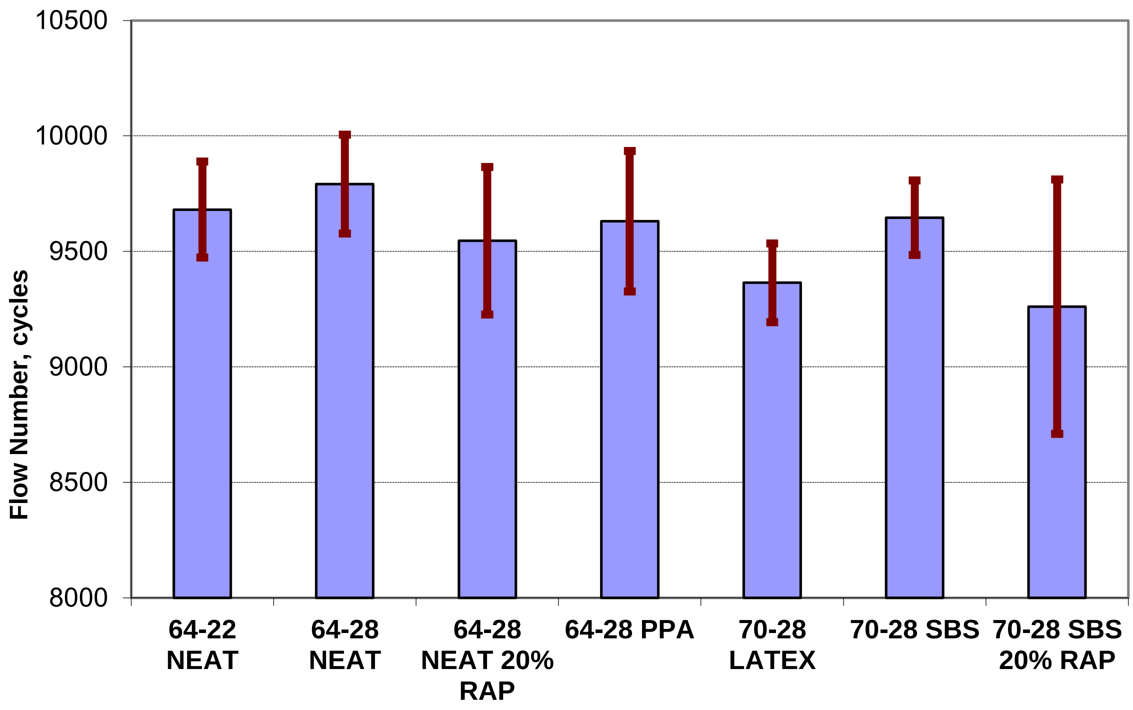

Figure 12 Flow Number for Pike Mixtures

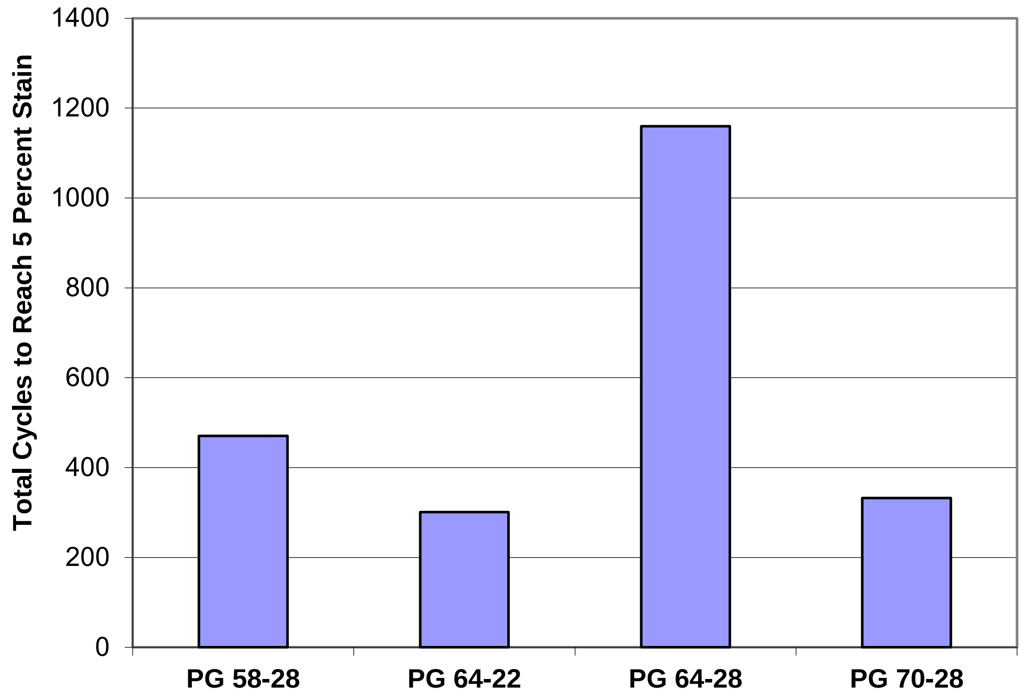

Figure 13 Cycles to 5% strain for Continental Mixtures

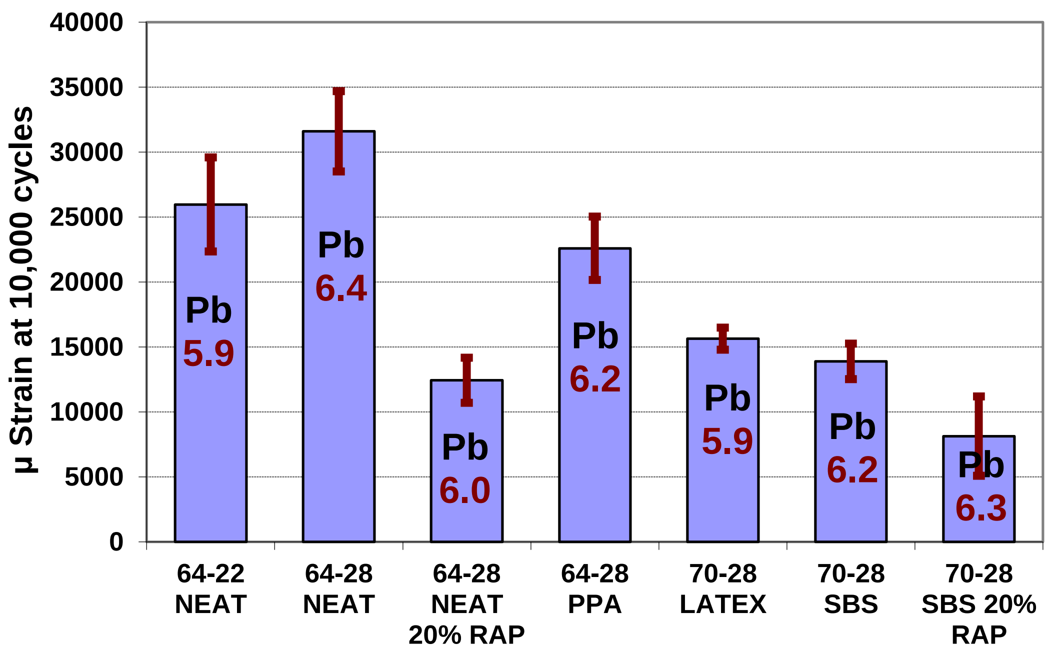

Figure 14 Total Strain at 10,000 cycles for Pike Mixtures

MMLS3 Testing

Testing of SGC specimens fabricated by Pike Industries, Inc. was performed using the MMLS3 at UNH. Specimens were cut to the appropriate specimen geometry for MMLS3 testing and the bulk specific gravities of the final test specimens were measured. Table 5 summarizes the calculated air void contents for each specimen and mixture type. The average air void content for all mixtures are within 4.5%-5.2%, with a few individual specimens falling outside this range. Specimens were tested in the MMLS3 at 50C under wet conditions. Figure 15 shows the average rut depth as a function of number of cycles for each mixture. Each curve represents the average of the seven individual specimens.

All mixtures exhibited rut depths of less than 2.5 mm over the course of the test. The mixture containing PPA shows the greatest amount of rutting. With the exception of the SBR Latex mixture, the mixtures with PG 64-xx binder have greater rut depths than those with PG 70-28 binder, as would be expected. The 20% RAP mixture with the PG 70-28 binder has less rutting than the comparable mixture with only 15% RAP. The 20% RAP mixture with PG 64-28 binder actually shows more rutting than the companion 15% RAP mixture. This may be explained by the higher average air void contents of the 20% RAP specimens as compared to the 15% RAP specimens.

Table 5. MMLS3 Specimen Air Void Contents

Mixture	Specimen							Avg
	1	2	3	4	5	6	7	
64-22 Neat Pike 15% RAP	4.6	5.2	4.8	4.7	4.9	4.8	4.8	4.8
64-28 Neat Trigeant 15% RAP	4.6	4.1	4.1	4.4	5.1	4.5	4.9	4.5
64-28 Neat Trigeant 20% RAP	5.3	5.3	5.2	5.3	5.2	5.2	5.0	5.2
64-28 PPA Irving 15% RAP	4.7	4.7	5.0	5.6	5.3	4.8	4.8	5.0
70-28 SBR Latex 15% RAP	5.3	5.4	5.1	5.2	5.2	5.2	5.0	5.2
70-28 SBS Hudson 15% RAP	5.1	4.7	4.8	5.2	4.8	4.9	4.7	4.9
70-28 SBS Hudson 20% RAP	5.5	5.1	5.2	5.1	5.1	5.1	4.9	5.1

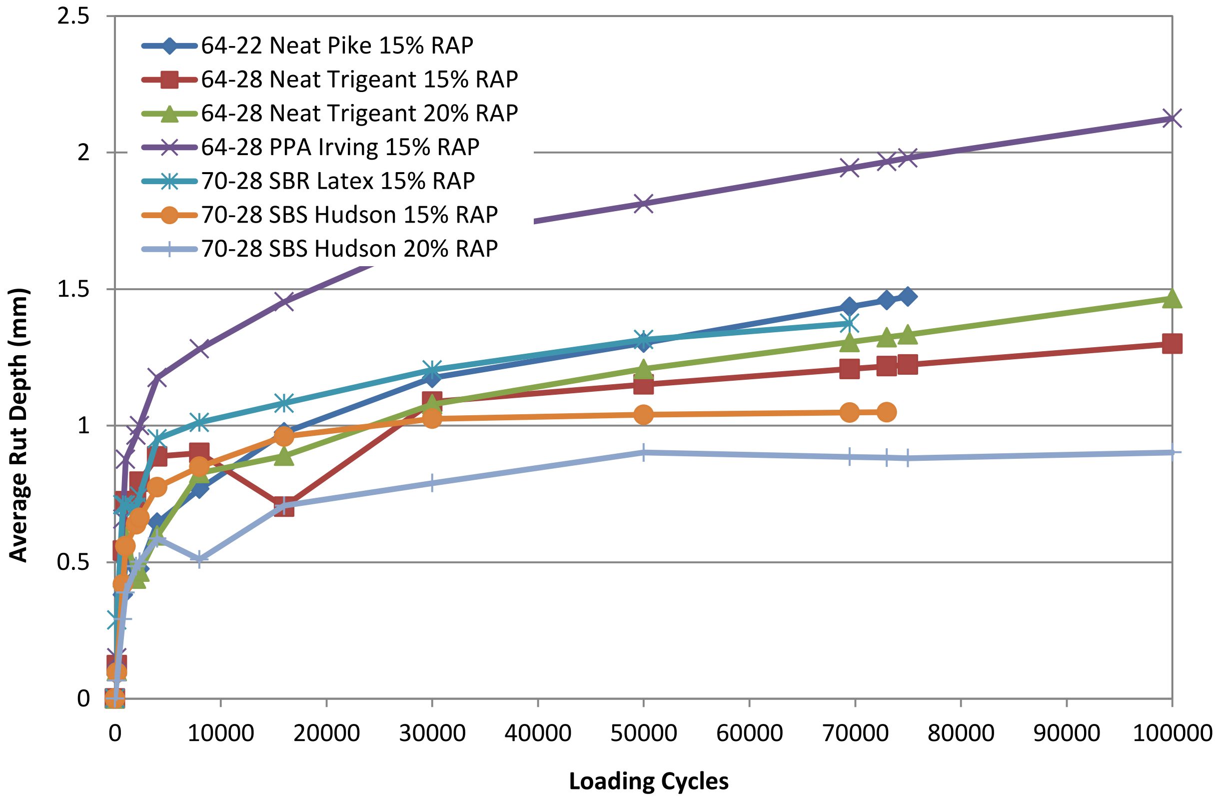

Figure 15. Average Rut Depths for MMLS3 Tests

Summary

Binder Testing

- All PG XX-28 binders have similar CCT values, with NHDOT test results showing that the SBS Pike mixture is the best and FHWA test results showing the Continental SBR mixture as the best
- The addition of PPA causes a slight decrease in the low PG temperature and a stiffer |G*| at the higher frequencies (which corresponds to low temperature).
- The SBR modifier for the PG 70-28 binders shows slightly better performance than the SBS modifier at the low PG temperature. The SBS modified binder is stiffer at the higher frequencies (low temperatures)
- In summary, the PPA may slightly decrease the low temperature performance and the SBR modified binder would perform better at low temperatures than the SBS modified binder. With respect to rutting, the MSCR results indicate the PPA binder may increase rutting susceptibility and the SBR modified binder would perform better than the SBS modified binder.

Mixture Testing

- The addition of PPA causes an increase in stiffness and a more elastic response at high frequencies (low temperatures). Flow tests indicate the PPA mixture will perform better with respect to rutting, but the MMLS3 tests show the opposite. Air void content differences for the MMLS3 specimens could be affecting the results.
- Increasing the amount RAP creates a stiffer and more elastic mixture response. Flow tests indicate the virgin mixtures perform better with respect to rutting, but the MMLS3 tests show the opposite. Air void content differences for the MMLS3 specimens could be affecting the results.
- SBR increases the stiffness of the mixture at high frequencies (low temperatures), but does not change the relative elastic/viscous response. Flow test results for SBS and SBR mixtures are similar, while the MMLS3 testing indicates the SBR mixture will perform better.
- In summary, the differences in fatigue performance will be dependent on the pavement structure – a stiffer mixture is generally better for thicker pavements, but may not be for thinner structures.