Effect of Modification on Rut Susceptibility of Asphalt Binders and Mixtures

N. Tabatabaee & P. Teymourpour
Department of Civil Engineering, Sharif University of Technology, Tehran, Iran

ABSTRACT: Rutting is a primary cause of premature deterioration of asphalt pavements and modifying asphalt binders is a common way to improve binder characteristics and field performance. Two types of parameters are used to characterize asphalt rutting. One type includes binder parameters such as zero-shear viscosity and the Superpave rutting resistance index ($G^*/\sin\delta$) derived from oscillatory loading tests such as the dynamic shear rheometer. The other type is derived from static and repeated loading creep tests on mixtures and binders. Researchers have pointed out that these parameters may rank modified binder and mixture rut susceptibility differently. In this study, the rutting resistance of mixtures made with two unmodified binders, three mixed aged binders and eight modified binders, including low and high percentages of styrene-butadiene-styrene, ethylene-vinyl-acetate, crumb rubber and poly-phosphoric acid was evaluated. Asphalt binder properties were determined according to Superpave specifications. Asphalt concrete specimens were then fabricated for each binder and the rut susceptibility of the mixtures was evaluated by conducting unconfined static and repeated loading creep tests. The results were used to present a ranking of rutting resistance of mixes with different modifiers and also evaluate the suitability of the Superpave rutting resistance index ($G^*/\sin\delta$) in predicting the rut susceptibility of modified binders by correlating the results of the two parameters.

KEY WORDS: Superpave specifications, rutting, modified binders.

1 BACKGROUND

Rutting is one of the most common distresses in asphalt mixtures. In asphalt pavements, rutting is defined as the progressive accumulation of longitudinal depressions in a wheel path under repetitive loading (Faheem and Bahia 2004). Modifying asphalt binders enhances their performance characteristics, including rutting resistance. A wide range of modifiers, such as crumb rubber and polymers, are used to improve the performance parameters of asphalt mixtures. These binders are produced by adding different modifiers under different mixing conditions (Brule 1997).

Rutting is mainly evaluated by tests such as the static and dynamic creep test. Superpave, developed by the Strategic Highway Program (SHRP), introduced $G^*/\sin\delta$ as a measure of a binder's ability to resist rutting (Bahia and Anderson 1995). However, since the SHRP asphalt research was carried out almost exclusively with unmodified asphalt binders, the applicability of Superpave specifications and test methods to modified binders has not been validated. Although research has shown that, according to Superpave performance parameters, modified asphalt binders show marked improvements in selected performance characteristics, such as rutting, compared to unmodified binders, concern exists that the Superpave specification does not fully measure the performance improvements from modification (Bahia et al. 2001).

Determining the applicability of Superpave performance grading specifications for rutting to modified binders is of great importance. Previous research has primarily concentrated on polymer modified binders; thus, crumb rubber modifier and polyphosphoric acid have generally been excluded from the scope of these studies. It was for this purpose, as well as to evaluate the rutting performance of different modifiers, that the present study was carried out.

Unmodified binders and binders modified with various percentages of different modifiers were examined. The asphalt binders were tested using a dynamic shear rheometer (DSR) to measure G*/sinδ. Asphalt mixture specimens were then fabricated using the binders tested and the specimens were subjected to performance related tests. The ranking of the modifiers and the suitability of the Superpave performance grading protocol was then evaluated by the comparing the results of the mixture tests with the performance grading parameters derived during the Superpave binder tests.

2 MATERIALS

Two types of asphalt binders, PG 58-22 (85/100 pen grade) and PG 70-22 (40/50 pen grade), were selected for this study. Different percentages of styrene-butadiene-styrene (SBS), ethylene-vinyl-acetate (EVA), crumb rubber modifier (CRM) and poly-phosphoric acid (PPA) were added to the PG 58-22 base binder.

To compare the effect of the dosage of the modifiers, one high percentage and one low percentage of each modifier was added to the base binder. The high percentage was that at which viscosity reached the Superpave maximum viscosity limit for sufficient workability (3 Pa.s). Roughly half the high percentage was defined as the low percentage. Unmodified PG 58-22 and PG 76-22 specimens were also tested for comparison with the modified binders. The binders used in this study are shown in Table 1.

Table 1: Binder types used in the study.

Code	A	B	S-high	S-low	E-high	E-low	C-high	C-low	P-high	P-low
Binder Type	PG 58-22	PG 70-22	PG 58-22 +7% SBS	PG 58-22 +4% SBS	PG 58-22 +10% EVA	PG 58-22 +6% EVA	PG 58-22 +18% CRM	PG 58-22 +9 % CRM	PG 58-22 +2.5% PPA	PG 58-22 +0.5% PPA

The aggregate used in this research was limestone obtained from a quarry near the city of Saveh in central Iran. The physical characteristics of the aggregate are shown in Table 2.

Table 2: Characteristics of the aggregate used in the study.

Test	**Measured Value**	**Limiting Value**
Density (kg/m^3)	2650	>1120
One face fractured (%)	100	>40
Los Angeles abrasion (%)	18	<40

A dense-graded aggregate was selected for this study. The gradation had a nominal maximum size of 19 mm (3/4 in) and was selected in accordance with the ASTM D3515. The gradation curve (Figure 1) was set near to the Superpave restricted zone, which generally indicates less rutting (Kandhal and Mallick 2001).

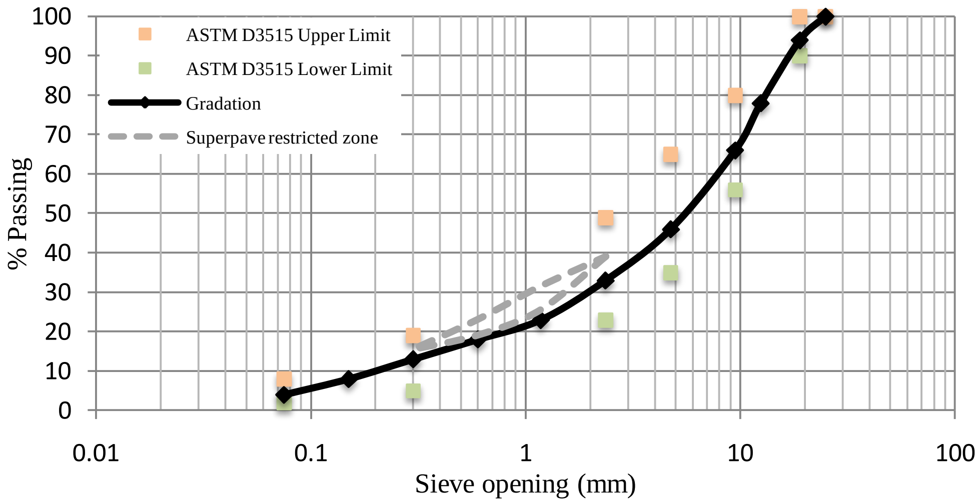

Figure 1: Aggregate gradation curve (19 mm maximum nominal size).

3 BINDERS AND MIXTURE FABRICATION

SBS and EVA were added to the base binder at 180°C and mixed for 2 h at a high shear rate (5000 rpm). Crumb rubber was added in the same way except that it was mixed for 1 h. The PPA was mixed with the PG58-22 binder at a low shear rate (350 rpm) for 30 min at 165°C.

Mixture specimens in this study were compacted using a Marshal hammer. The diameter of the specimens was 150 mm (6 in) with thicknesses of 63.5 and 150 mm (2.5 and 6 in).

4 TESTING PROCEDURE

4.1 Binder Characterization

G* and δ are the parameters corresponding to rutting performance according to the Superpave standard. They were measured at high temperatures using a DSR.

4.2 Unconfined Static Creep Test

The unconfined static creep test was used to evaluate rut susceptibility. In this test, specimens 150 mm (6 in) in diameter and 150 mm (6 in) in thickness were tested at 40°C. According to British standard BS 598-111:1995, the specimens were subjected to a preload of 0.01 MPa for 2 min, followed by a constant static load of 0.1 MPa for 1 h, after which the specimen was unloaded and allowed to recover for 1 h (Ahmedzadeh and Yilmaz 2008). During the test, the axial deformation was constantly measured using three potentiometers placed at 120° angles around the specimen.

4.3 Confined Dynamic Creep

This test was carried out on 150 mm (6 in) diameter, 63.5 mm (2.5 in) thick specimens using a 100kN Dartek universal testing machine. The tests were conducted in a thermostatic chamber at 40°C. The specimens were kept in the chamber for 4 h and then a preload of 10 kPa was applied for 10 min (600 s). Immediately after the preloading time ended, a periodic load of 100 kPa was applied with a 1 s loading time and 1 s rest period for each pulse. A total of 3600 pulses were applied to each specimen over a 2 h period. The cumulative axial deformation and vertical permanent strain were measured constantly during the test period. The results were used to demonstrate rutting resistance of the specimens.

5 RESULTS AND DISCUSSION

5.1 Binder Characterization

G*/sinδ is used at high performance temperatures as a measure of binder contribution to resistance of rutting in pavements in accordance with ASTM D7175-05e1 standard. It is computed at a frequency of 10Hz for unaged and RTFO aged asphalts. The test was carried out using a 25 mm spindle on binder samples 25 mm in diameter and 1 mm in thickness. Figures 2 and 3 show the values of G* and δ, respectively, for the binders used in this study.

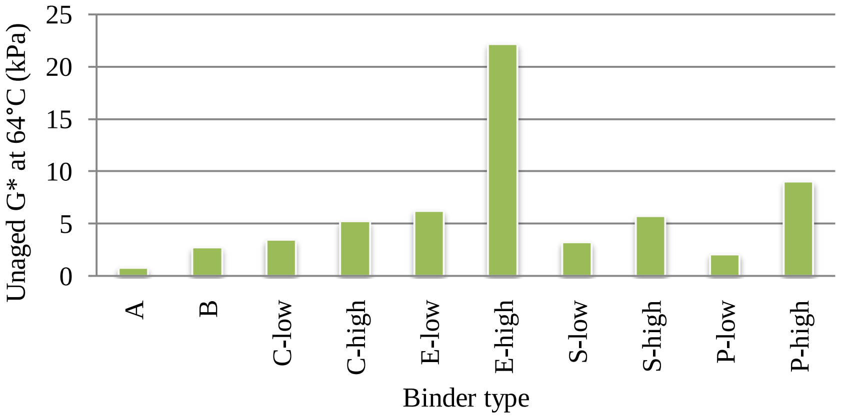

Figure 2: Variation of complex shear modulus at 64°C for different unaged binders.

Figure 2 shows that mixing EVA with asphalt greatly increased the stiffness. PPA is shown to be the most effective modifier after EVA. Figure 3 demonstrates that increasing the percentage of EVA caused a noticeable decrease in phase angle. This led to a phase angle of less than 45 degrees at 64°C for the E-high binder. Therefore, despite other binders showing viscous behavior at 64°C, E-high has a more elastic performance at this temperature. The behavior of the G* and δ parameters indicate that an increase in the value of G*/sinδ for these binders should be expected.

Figures 4 and 5 show high performance grades and the values of G*/sinδ for this study. It can be seen that, as predicted, G*/sinδ increased as modifiers were added to the base binder. If this parameter is indicative of binder contribution to rutting resistance (Bahia and Anderson 1995), the observed trend would indicate a significant increase in rut resistance up to a temperature of about 88°C. Asphalts modified with 10% EVA and 2.5% PPA had the highest performance grades.

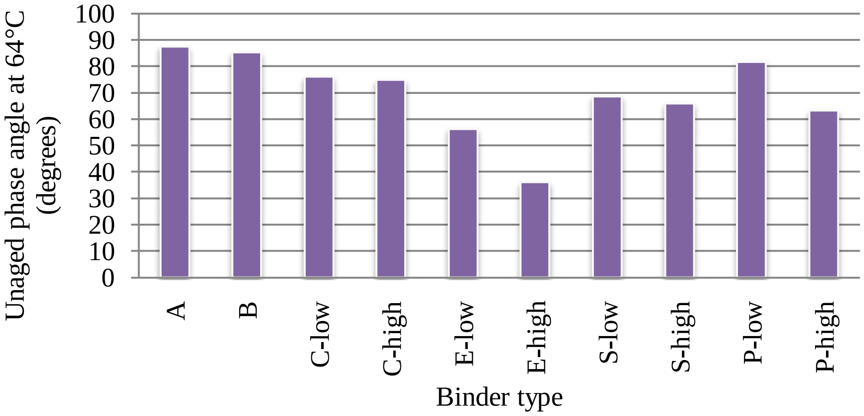

Figure 3: Variation of unaged phase angle at 64°C.

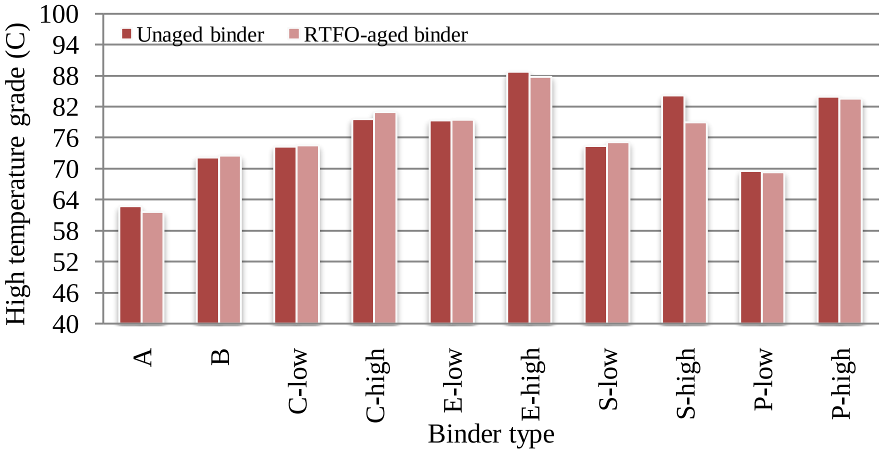

Figure 4: High performance grade of binders.

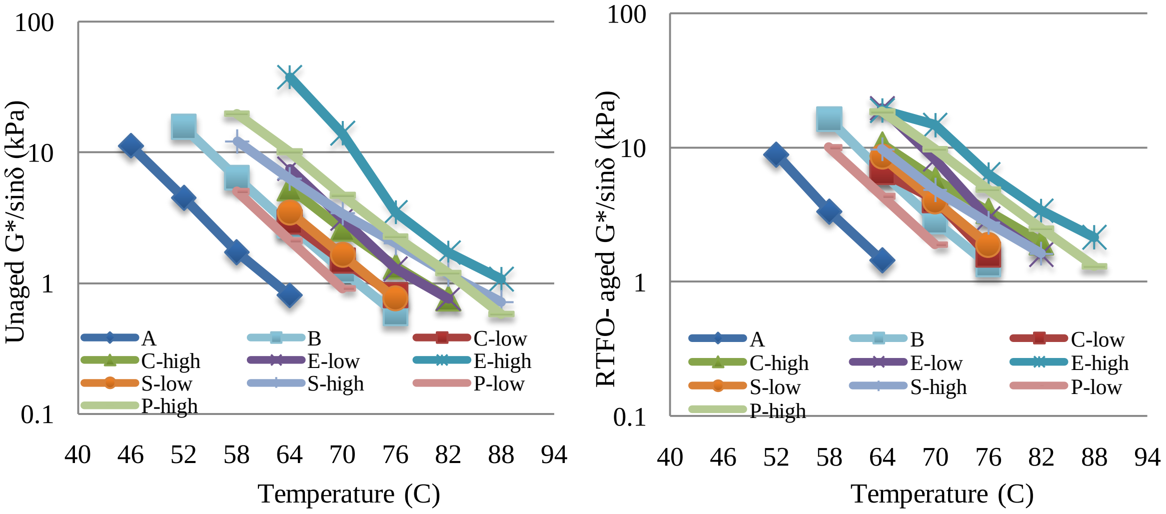

Figure 5: Variation of unaged and RTFO-aged G*/sinδ by temperature.

From the values of G* and δ at 64°C, the E-high binder was expected to show a high performance grade, but such behavior was not seen at higher temperatures. As seen in Figure 5, the unaged G*/sinδ decreased with a uniform logarithmic trend as the temperature increased, except for the E-high binder, for which G*/sinδ started out with a steeper slope, followed by a drop as the temperature exceeded 70°C and then became parallel to the other ones with a flatter slope. EVA is a plastomer and, according to the percent of acetate, has a melting point of between 55°C and 95°C (Gaucher et al. 2002). The EVA used in this study had 18% acetate and a melting point of approximately 70°C. This drop appeared to be caused by reaching the melting point of EVA, which resulted in a sudden decrease of strength. Similar trends were observed for the RTFO-aged binders, except for the E-high, which started out with a flatter slope that became steeper after 70°C.

The values obtained for G*/sinδ, G* and δ in high performance temperatures indicate that all the modifiers enhanced the rutting resistance of the unmodified binder, with EVA being definitely the most effective modifier for improving the rutting resistance of binders.

5.2 Unconfined Static Creep Test

The results of the unconfined static creep test are shown in Figure 6. For many decades, the unconfined static creep test has been a fundamental test for evaluating rutting susceptibility of asphalt mixtures (Witzack et al. 2002, Kim and Sargand 2003, Bhasin et al. 2005). Rutting is mainly caused by plastic shear deformation under traffic loading; therefore, permanent strain can accurately show the rutting potential of binders (Kim and Sargand 2003.

In this test, after unloading, the specimens were allowed to rest for one hour, which led to recovery of a portion of the deformation. This unloading phase was done because creep deformation under static loading cannot truly reflect the performance of modifiers that improve the elastic recovery of materials (Tayfur et al. 2005).

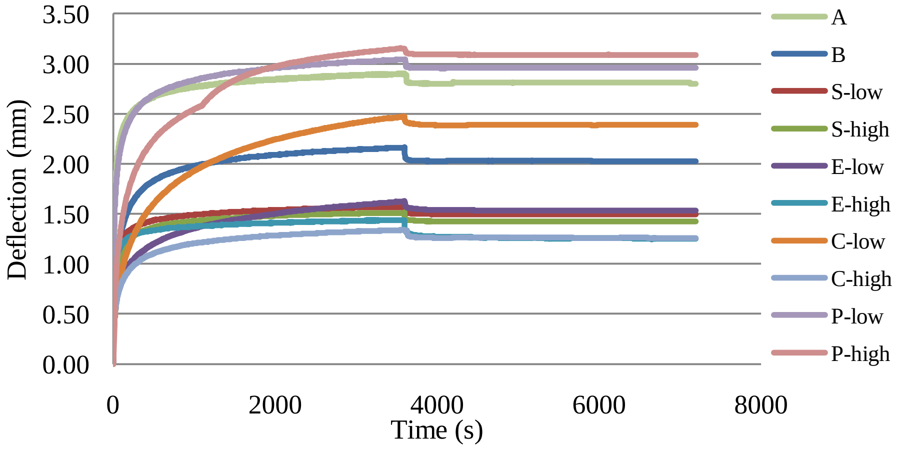

Figure 6: Time versus deformation in static creep test for all binders.

Figure 7 shows the permanent strain of binders tested in the static creep test. The results showed that modified binders are more resistant to permanent deformation than are unmodified base binders. A decrease in both deformation and permanent strain of mixtures containing greater amounts of modifiers was observed. The mixture test showed that E-high and C-high enhanced rutting resistance the most, as was also shown by the G*/sinδ. Figure 7 also shows that lower crumb rubber content does not improve the rutting resistance of the mix. This agrees with the previous results obtained by Tabatabaee et al. (2009). They observed that higher rubber contents behave much more effectively to improve the permanent deformation performance of CRM mixtures when tested with the unconfined static creep procedure at 40°C.

A noteworthy phenomenon was observed in mixtures containing PPA. This modifier made mixtures more sensitive to permanent deformation compared to the mixture containing no additive. This effect is the exact opposite of that seen using the Superpave measure of binder ability to resist rutting.

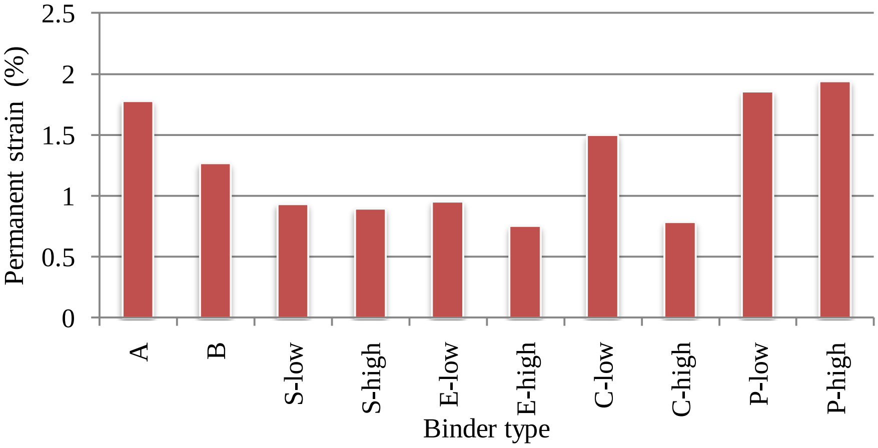

Figure 7: Permanent strain determined from unconfined static creep test.

Figure 8 shows the percentage of recovered deformation at the end of the unconfined static creep test. As seen, most of the modifiers enhanced rutting resistance. PPA once again showed performance deterioration with the amount of deformation recovery decreasing as PPA content increased compared to the unmodified base binder

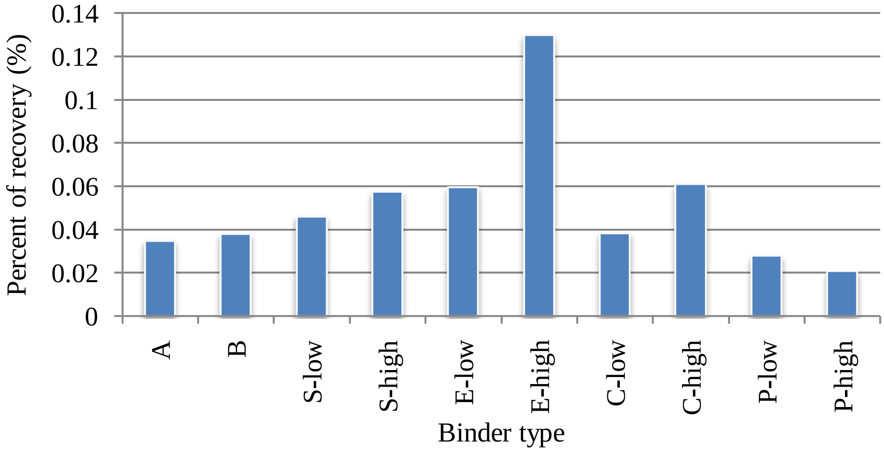

Figure 8: Percent of recovery determined from unconfined static creep.

5.3 Confined Dynamic Creep Test

The confined dynamic creep test to determine rutting resistance of asphalt mixtures was performed on two specimens for each type of binder. In order to observe the creep behavior of the mixtures, instantaneous deformation was omitted from the calculations and corresponding figures. The results are summarized in Table 3 and Figure 9.

Table 3: Dynamic creep results for asphalt mixtures.

Binder Type		**A**	**B**	**S-low**	**S-high**	**E-low**	**E-high**	**C-low**	**C-high**	**P-low**	**P-high**
Axial strain (με)	Mean	4699	4233	3949	2879	3449	2042	2879	3287	6955	14612
	CV (%)	10	6	8	4	1	8	12	1	3	5
Creep rate (με/pulse)	Mean	0.5	0.6	1.2	0.4	1.3	0.3	0.3	0.5	0.8	3.2
	CV (%)	6	13	1	6	1	4	8	10	6	9

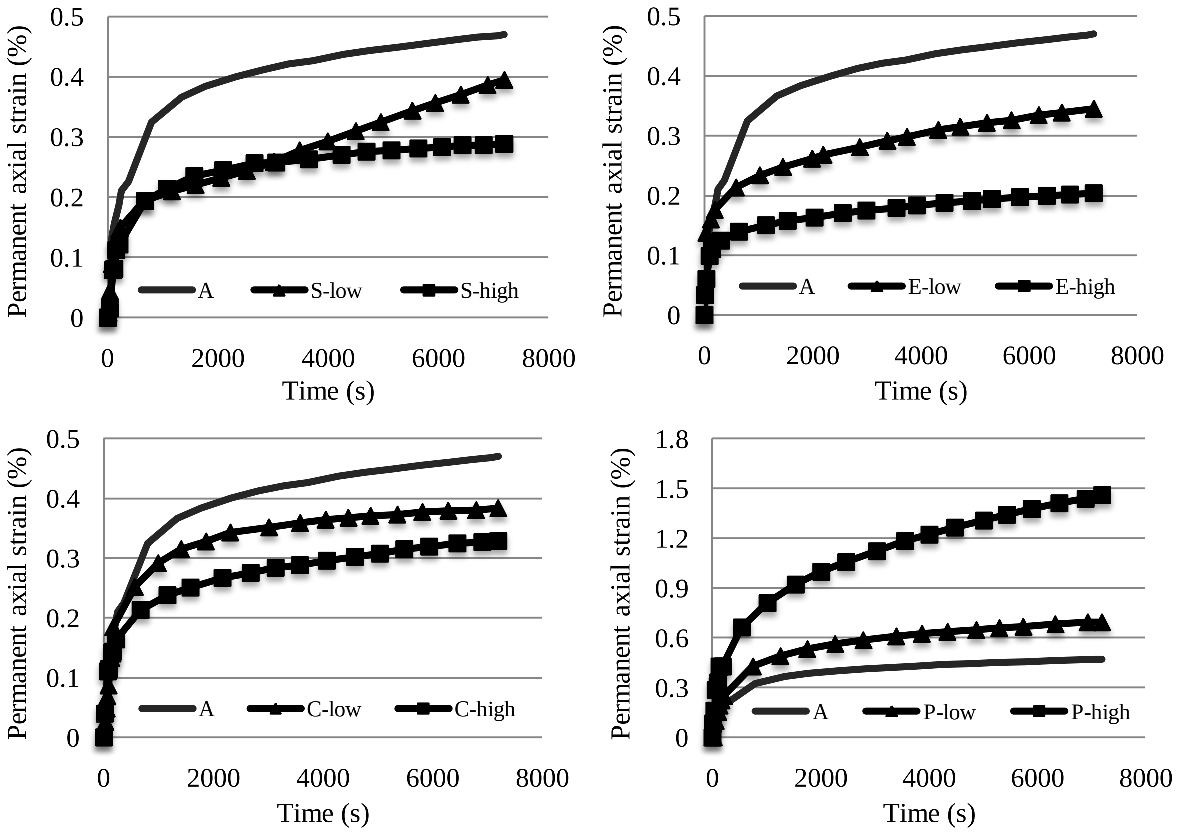

Figure 9: Results of dynamic creep test for each modifier.

The results showed that binders containing EVA, especially at a high content, showed smallest strain, which means that they are much more resistant to rutting compared to other binders tested. Figure 9 shows that high percentages of all modifiers except PPA significantly decreased the permanent axial strain of the mixes. Binders modified with PPA once again decreased the rutting resistance of mixtures in comparison with unmodified binder. A previous study done on PPA showed a similar trend in the dynamic creep test (Edwards et al. 2006). They reported an increase in permanent deformation in asphalt mixtures containing PPA in comparison with mixtures that had no additives, as was observed in the present study.

6 CONCLUSIONS

Table 4 shows that the ranking of the rut resistance of binders according to the Superpave binder criterion for rutting, the unconfined static and the confined dynamic creep tests on the mixtures.

Table 4: Ranking of rutting resistance of modified binders.

Test	A	B	S-low	S-high	E-low	E-high	C-low	C-high	P-low	P-high
Superpave binder	10	8	7	4	3	1	6	5	9	2
Static creep	8	7	5	4	3	1	6	2	9	10
Dynamic creep	8	7	6	2	4	1	5	3	9	10
Cumulative rank	26	22	18	10	10	3	17	10	27	22

Based on the test results and the analysis presented, the main findings of this study are:

1. The static and dynamic creep tests showed the same ranking for most binders. The effect of modifications as shown by the Superpave rutting index varied with the mixture test results. Some revision in this criterion for modified binders seems to be required.
2. The values obtained for G*/sinδ, G* and δ at high performance temperatures indicated that all the modifiers enhanced the rutting resistance of the unmodified binder. EVA is definitely the most effective modifier for improving rutting resistance of binders.
3. Adding EVA, CRM and SBS had a great effect on the high temperature performance grades of binders according to the Superpave specification. The high content of these modifiers improved the unmodified binder up to 3.5 grades.
4. The results of the unconfined static creep test showed that modified binders are more resistant to permanent deformation compared to unmodified base binders. Higher contents of each modifier resulted in greater recovery of deformation during unloading, except for PPA, which showed an adverse effect on mixture rutting.
5. Modifying asphalt mixtures with low crumb rubber content did not improve the rut resistance of the mix according to the results of the unconfined static creep test. The unconfined dynamic creep results showed a somewhat better performance for this binder.
6. The results of the confined dynamic creep test showed that binders containing additives, especially EVA, showed smaller strain after 3600 cycles of loading, compared to the unmodified binders, demonstrating much more resistance to rutting.
7. According to the results of the tests conducted on mixtures containing PPA, this modifier made mixtures more sensitive to permanent deformation compared to the mixtures containing no additive. This effect could not be seen using the Superpave measure of binder ability to resist rutting. These results indicate that the Superpave method is not suitable for characterizing the rutting performance of modified binders.
8. The cumulative ranking in Table 4 shows that binders modified with high percentages of EVA rank best in all laboratory measures evaluated in this research, followed by those with high percentages of CRM and SBS and a low percentage of EVA.

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