Applied Rheology | DOI: 10.3933/APPLRHEOL-26-53830 | WWW.APPLIEDRHEOLOGY.ORG

High-temperature Properties and Modeling of Asphalt Binders Modified with SBR Copolymer and PPA in the Multiple Stress Creep and Recovery (MSCR) Test

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Received: 7.4.2016, Final version: 23.7.2016

Abstract:
The main objectives of this paper are to (i) study the rutting performance of asphalt binders modified with styrene butadiene rubber (SBR) copolymer, polyphosphoric acid (PPA) and SBR+PPA, (ii) quantify the percent recoveries *R* and the nonrecoverable compliances J_{nr} in the multiple stress creep and recovery (MSCR) test, and (iii) indicate the best formulations in terms of rutting performance. All these formulations have the same high-temperature performance grade in the Superpave® specification (PG 76-xx). The Burgers model was used to fit the laboratory data and the parameter G_V was obtained from the model. The degrees of improvement in the *R* and the J_{nr} values after binder modification are higher for the AC+SBR+PPA and the AC+PPA than for the AC+SBR and the results are slightly better for the AC+SBR+PPA. The use of longer creep and recovery times led to increases in the stress sensitivity of the modified asphalt binders and in their rutting potential (higher J_{nr} values and lower *R* values) and these effects are more pronounced for the AC+SBR. The AC+SBR+PPA was identified as the best formulation in terms of elastic response and susceptibility to rutting, followed by the AC+PPA and the AC+SBR.

Key words:
Asphalt binders, percent recovery, nonrecoverable compliance, SBR copolymer, PPA, Burgers model

1 INTRODUCTION

Polymer-modified asphalt binders have been commonly used for paving applications due to their great resistance to several pavement distress mechanisms such as permanent deformation (or rutting), fatigue cracking and thermal cracking. This is especially the case for streets and highways that are subjected to heavy traffic loads and extreme temperatures [1, 2]. Other techniques for improving the rheological properties of asphalt binders may be used instead of polymer modification. Some examples of these techniques include the selection of good crude sources and adjustments in the refinery process. Unfortunately, the number of crudes that can produce better asphalt binders is restricted and the course of actions that can be taken to control the refining process is limited [3, 4].

The polymers used most often in modifying asphalt binders are broadly grouped into two classes, i.e. elastomers (or thermoplastic elastomers) and plastomers. Elastomers typically have high elastic responses and resist rutting by deforming under loading and recovering their original shape when the load is removed. The thermoplastic elastomers include the styrene-butadiene-styrene (SBS), the styrene-isoprene-styrene (SIS) and the styrene butadiene rubber (SBR) copolymers. SBS has a wider application in the paving industry than the other elastomers probably due to its acceptable cost, relatively good dispersibility in the binder and rather excellent properties [3, 6]. Plastomers are characterized by forming a rigid three-dimensional network in the asphalt binder to resist rutting [2, 5, 6]. The ethylene vinyl acetate (EVA) copolymer and the polyethylene (PE) are common examples of plastomers.

Although the SBR copolymer is not widely used as a modifier when compared with SBS, it has also been attracting researchers' attention due to the benefits of its addition to the base material. The benefits include the formation of a reinforced network structure in the formulation, improvements in the low-temperature ductility, better adhesive and cohesive properties and increases in viscosity at high temperatures [1, 3, 5]. This modifier can be added to the asphalt binders in two forms: In the pure form and dispersed in water (latex

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higher rutting resistance than the AC+PPA for both parameters (G_v and J_{nr}) and the AC+SBR is the less rut resistant material among the modified ones. The change in the loading-unloading times decreased the G_v values by 40 – 55 %, whereas the increases in the nonrecoverable compliances (Figure 3) were of about 100 % for the same materials and test temperatures (64 and 70 °C).

4 CONCLUSIONS

With respect to the results reported in the present study and the analysis of the rutting performance of binders modified with styrene butadiene rubber (SBR), polyphosphoric acid (PPA), and a combination of both, the following conclusions can be reached:

- The added modifiers, used isolatedly or in combination, increased the percent recovery *R* values and decreased the nonrecoverable compliance J_{nr} values of the base asphalt binder at the typical highest pavement temperatures of 64 and 70 °C and both 0.1 and 3.2 kPa stress levels, which indicates that the AC+PPA, the AC+SBR and the AC+SBR+PPA are less susceptible to rutting than the base material. In a general context, the addition of SBR alone yielded the lowest degree of improvement (lower *R* values and higher J_{nr} values) in the rheological properties of the base asphalt binder and the addition of SBR+PPA and PPA yielded the highest degrees of improvement (higher *R* values and lower J_{nr} values) in the rheological properties of the base material.
- None of the modified asphalt binders showed percent differences in nonrecoverable compliances ($J_{nr,diff}$ values) above 75 %, the AC+SBR+PPA shows the highest $J_{nr,diff}$ values at 70 °C (highest degrees of stress sensitivity and nonlinearity), and the AC+SBR shows the highest ones at 64 °C. Also, the use of longer creep and recovery times increased the $J_{nr,diff}$ values of the modified asphalt binders and no substantial variations can be seen in the percent differences of the 50/70 base material.
- Longer creep and recovery times are detrimental to the rutting resistance of the asphalt binders in the extent that they lead to lower percent recoveries (R_P values greater than one) and higher nonrecoverable compliances (R_C values greater than one) at 2/18 s than at 1/9 s. In general, the greatest increases in the J_{nr} values can be seen in the AC+SBR followed by the base material and the two formulations with PPA (AC+PPA and AC+SBR+PPA).
- Ranking the formulations in terms of higher values for *R* and lower values for J_{nr}, i.e. higher rutting resistances, at the regular creep and recovery times (1/9 s), the AC+SBR+PPA is the best, followed by the AC+PPA, the AC+SBR and, as the last one, the pure AC. When the creep and recovery times are increased to 2/18 s, the general effect observed is reduction of %*R* and increase of J_{nr}, i.e. the formulation presents a lower rutting resistance, but the ranking is the same. In other words, longer creep and recovery times are harmful to the asphalt binders but it is possible to obtain the same ranking for the formulations at both creep and recovery times.
- The Burgers model fitted the strain data of the modified asphalt binders with very small deviations from the original values (average absolute errors lower than 2.7 %) and the higher elastic responses of the AC+SBR+PPA and the AC+PPA may be attributed to the presence of a lower amount of viscous strain (higher η_M values). The reductions in these elastic responses at longer creep-recovery times may be explained by the application of loads for 2 s rather than only 1 s (η_M values do not markedly differ from one loading-unloading condition to the other, which means that the viscous component of the binder is simply a function of the loading time applied in the test).

ACKNOWLEDGEMENTS

The first author would like to thank the Brazilian Federal Research Agency (CAPES) for supplying a scholarship. The second author would like to thank the Research Agency of the Sao Paulo State (FAPESP) for financial funds (FAPESP process number 2006/55835-6).

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