Assessing the validity of blending charts for rejuvenated reclaimed asphalt pavements (RAP) binders

Mohamed Elkashef[1], Joseph H. Podolsky[1], Nacu Hernandez[2], R. Christopher Williams[1], Eric W. Cochran[2]
（[1] Iowa State University, Civil, Construction and Environmental Engineering Department，
394 Town Engineering, Ames, Iowa, 50011, USA, mkashef@iastate.edu, podolsky@iastate.edu, rwilliam@iastate.edu）
（[2] Iowa State University, Chemical, and Biological Engineering Department，2114 Sweeney Hall, Ames, Iowa, 50011, USA, nacu23@iastate.edu, ecochran@iastate.edu）

ABSTRACT

Rejuvenators are becoming more common in mixtures containing reclaimed asphalt pavement (RAP). Rejuvenators are added to RAP binders to reduce their stiffness and improve their low temperature properties thus higher content RAP mixtures are possible. For RAP mixtures utilizing more than 25% RAP, blending charts are often used to determine the proportions of the virgin and RAP binders based on their respective performance grades. Introducing rejuvenators into the blend changes the overall physical properties of the blend, hence the need to assess the validity of blending charts when rejuvenators are present. In this paper, the rheological properties of a soybean-derived rejuvenator are studied using a rotational viscometer. Asphalt blends made with an extracted RAP, a virgin PG58-28S, and a soybean-derived rejuvenator are prepared using different proportions. The performance grades of the extracted RAP and the resulting rejuvenated RAP blends are determined and the impact of the rejuvenator's viscosity on the viscosity of the blend is studied. Mixing rules to predict viscosity are assessed to determine their validity for binders and blends containing rejuvenators.

Keywords: Rejuvenators; Reclaimed asphalt pavements (RAP); blending charts; viscosity.

1. INTRODUCTION

The current guidelines for designing RAP mixtures determines the performance grade (PG) of the virgin binder based on the amount of RAP by percentage dry weight of the mixture as outlined in AASHTO M323-13. These guidelines were based on the recommendations of the NCHRP 9-12 study which were published in the NCHRP Report No. 452 [1] . A three-tier system was introduced where mixtures are classified based on their RAP content. The original three-tier system presented in the NCHRP Report No. 452, accounted for the low temperature grade of the RAP binder. For example, a RAP binder having a low temperature PG of -22 can be added at 20% content without any change in the virgin binder grade, however this percentage would drop to 10% for a stiffer RAP binder with a low temperature grade of -10. The guidelines adopted in AASHTO M323-13 ignored the low temperature grade of the RAP binder and provided a set of limiting values that are independent of the PG of the RAP binder. A note was however added to indicate that these limiting values could be modified at the discretion of the agency based on the findings of the NCHRP Report No. 452. The tiers and limiting values defined in AASHTO M323-13 were as follows: 1) Low RAP content mixtures, defined as having less than 15% RAP, where the influence of the RAP is considered negligible and thus no change in the PG of the virgin binder is required. 2) Intermediate RAP content mixtures, containing 15-25% RAP, where the PG of the virgin binder must be dropped by one grade to offset the effect of the RAP binder. 3) High RAP content mixtures, above 25%, for which the use of blending charts to determine the PG of the virgin binder is deemed necessary. In practice, the implementation of the middle tier requiring the use of a softer virgin binder was difficult to implement. This difficulty often arises from the frequent unavailability of a softer virgin binder in addition to the need to make changes to asphalt mix plants by adding an additional tank along with the associated pipes, heating and controls to accommodate the softer binder.

The idea of using the RAP content by weight of the mixture to specify the tiers was met with a lot of reservations. It was argued that a more accurate system should use the RAP binder content in lieu of the RAP content based on the premise that the effect of RAP is determined largely by the properties of the RAP binder and its content. In NCHRP Report 752, the RAP binder replacement ratio was introduced as a binder selection criterion [2]. The RAP binder ratio is defined as the ratio of the RAP binder to the total binder content of the mixture. The new criterion use a two-tier system where the grade of the virgin binder is kept unchanged for mixtures with RAP binder ratio of less than 0.25 whereas blending charts are used for mixtures having a RAP binder ratio above 0.25. Blending charts assume that the overall properties of a blend can be estimated using a weighted average of its constituents' properties based on their proportions. To develop a blending chart for a virgin and RAP binder blend, the property of interest is obtained for both the virgin and RAP binder. With the virgin binder considered as 0% RAP and the RAP binder being 100% RAP, a line connecting between the two can then be used to estimate the value of that specific property at different percentages of RAP. In the Superpave method, blending charts are plotted for the critical high, intermediate and low temperatures. The purpose of these charts is to either estimate the grade of the virgin binder or the percentage of RAP to be used to obtain a specific grade of the blend.

Blending charts can also be used to predict properties such as viscosity, penetration, and softening points. The European specifications apply blending models to estimate penetration and softening points. The Australian guidelines uses a blending equation based on viscosity. The viscosity relation used in Austroads Asphalt Recycling Guide was derived based on earlier work by Epps et al. [3]. With the growing trend to use higher amounts of RAP in mixtures, the use of softening agents or rejuvenators is increasing. Rejuvenators have different physical and chemical properties which makes it more complicated to predict the properties of the resulting blends. In this paper, a rejuvenator derived from soybean oil is added in different proportions to a blend of both RAP and virgin binders. In previous research, the soybean-derived rejuvenator was successfully used to restore the properties of reclaimed asphalt pavement (RAP) binders [4-6]. The accuracy of different models to predict the viscosity of the resulting blends will be compared.

This paper uses two different viscosity models to predict the properties of binder blends. The prediction capability of both models will be evaluated for blends with and without rejuvenators.

2. MATERIALS AND METHODS

A neat PG58-28S was used in this study along with a reclaimed asphalt pavement (RAP) binder that was extracted from a recycled pavement in the State of Iowa, USA. Extraction of the RAP binder followed ASTM D2172-Method A. The toluene used in the extraction process was removed using a rotary evaporator to recover the RAP binder according to ASTM D5404. A flow of Nitrogen gas was used during the recovery process to prevent oxidation of the RAP binder.

Rolling thin-film oven (RTFO) aging and PAV aging were conducted as per ASTM D2872 and ASTM 6521, respectively. A dynamic shear rheometer (DSR) was used to determine the critical high temperature of the binders as per AASHTO T315 while a bending beam rheometer (BBR) was performed to obtain the critical low temperature as per AASHTO T313.

The rejuvenator used is derived from soybean oil and will be referred to as SB. The rejuvenator was added to a PG58-28S binder at a ratio of 3% and 6% by total weight of the binder. The RAP binder was then blended with the rejuvenated PG58-28 binder resulting in a blend with 24% RAP and 76% rejuvenated PG58-28S. Blending of the binders and the rejuvenator was done using a shear mill at 140°C and 2000 rpm for 1 hour. Viscosity measurements using a rotational viscometer were done according to AASHTO T316. All viscosity measurements were done at a temperature of 135°C.

3. RESULTS AND DICUSSION

3.1 Performance grade (PG)

The binder blends were tested to determine their performance grades. The critical high temperature was determined as per AASHTO T315 based on the criteria $G^*/\sin\delta \geq 1.0$ KPa and $G^*/\sin\delta \geq 2.2$ KPa for unaged and RTFO-aged conditions, respectively. To determine the critical low temperature, PAV-aged binder blends were tested in the BBR to satisfy the criteria $S \leq 300$ and $m \geq 0.300$. The RAP and PG58-28S blend produced a performance grade of PG64-28. The rejuvenated blends with 3% and 6% dosage lowered the performance grade down to PG58-28 and PG52-28, respectively. The addition of the rejuvenator caused a slight increase in the mass loss however the mass loss remained within acceptable limits. The low temperature continuous PG improved slightly from -29.0°C for the unrejuvenated blend to -32.4°C for the 6% rejuvenated blend.

TABLE 1 Properties of the binder blends

Binder	RAP +PG58-28S	RAP +PG58-28S +3%SB	RAP +PG58-28S +6%SB
Unaged (High Temp.), °C	66.6	59.5	54
RTFO (High Temp.), °C	65.7	60.8	57.9
PAV (Low Temp.), °C	-29.0	-30.8	-32.4
Performance Grade (PG)	64-28	58-28	52-28
Mass loss (%)	0.6	0.75	0.98

3.2 Viscosity

The viscosity of asphalt can be described by the CROSS model where a Newtonian region is observed at very low shear rates followed by a shear thinning non-Newtonian region before the behavior returns to being Newtonian again at very high shear rates. The CROSS model is expressed as:

$$\frac{\eta_o-\eta}{\eta-\eta_\infty} = (k\dot{\gamma})^m \qquad (1)$$

where η is viscosity at a given shear rate $\dot{\gamma}$, η_o is zero shear viscosity, η_∞ is infinite shear viscosity, and k and m are material constants. The above equation can be simplified by considering $\eta_\infty = 0$. The viscosity measurements of the binders and the blends were fitted using the simplified CROSS model.

ASTM D4887 uses a linear log-log model to predict blend viscosity of binders. A linear model proved less accurate for blends containing low viscosity oils [7]. The Chevron model was shown to provide good precision to predict the viscosity of blends [8]. The model calculates a viscosity blending index for each component in the blend. A total viscosity blending index for the whole blend is then determined based on the volume fraction of each component. The total viscosity blending index can then be used to obtain the viscosity of the blend. The equations used in the model are as follows:

$$VBI_i = \frac{\log(\eta_i)}{3+\log(\eta_i)} \quad (2)$$

$$VBI_T = \sum_{i=1}^{n} r_i\, VBI_i \quad (3)$$

$$\log(\eta_T) = \frac{3VBI_T}{1-VBI_T} \quad (4)$$

where VBI_i, η_i, and r_i are the viscosity blending index, viscosity in cP, and volume fraction of the i^{th} component of the blend. VBI_T and η_T are the viscosity blending index and viscosity in cP of the total blend.

Another viscosity model that is being used for ideal fluids is also be evaluated. The model was developed by Kendall and Monroe [9]. The model is expressed as shown in equation (5).

$$\eta_T{}^{1/3} = \sum_{i=1}^{n} r_i \eta_i{}^{1/3} \quad (5)$$

Figure 1 shows the viscosity plot for the RAP and neat PG58-28S binders and the resulting blend. The viscosity plots for the RAP and neat PG58-28S binders were obtained by fitting the measured data using the CROSS model. Both the Chevron model and the Kendall and Monroe model were used to predict the viscosity of the blend. Both models yielded very close estimates however the Kendall and Monroe model showed slightly better predictive performance. The viscosity plots of the blends made of RAP binder and both 3% and 6% rejuvenated PG58-28S binders are shown in Figures 2 and 3, respectively. The Kendall and Monroe model also provided a slight improvement over the Chevron model, however the two models showed good predictive ability.

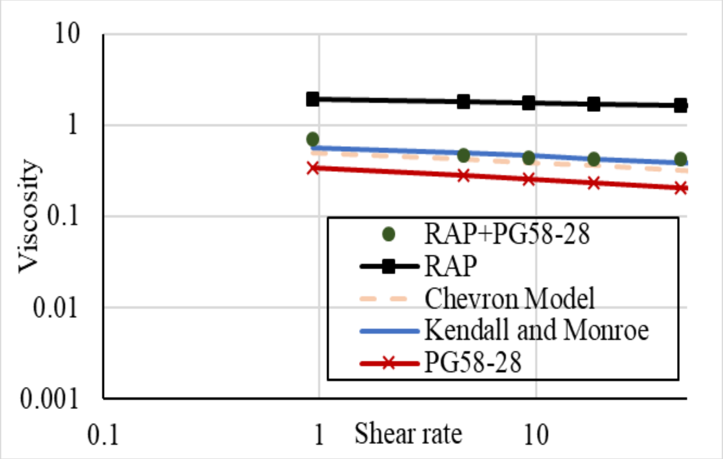

FIGURE 1 Viscosity plot for the RAP and neat PG58-28 blend

The ability of the two models to predict blends made using the soybean-derived rejuvenator was also assessed. The viscosity of the rejuvenator was determined and the models were used to estimate the viscosity of the rejuvenated PG58-28S blends as shown in Figures 4 and 5. The predictive models provided a good estimate of the viscosity of the 3% rejuvenated binder however none of the models could adequately describe the behavior of the 6% rejuvenated binder.

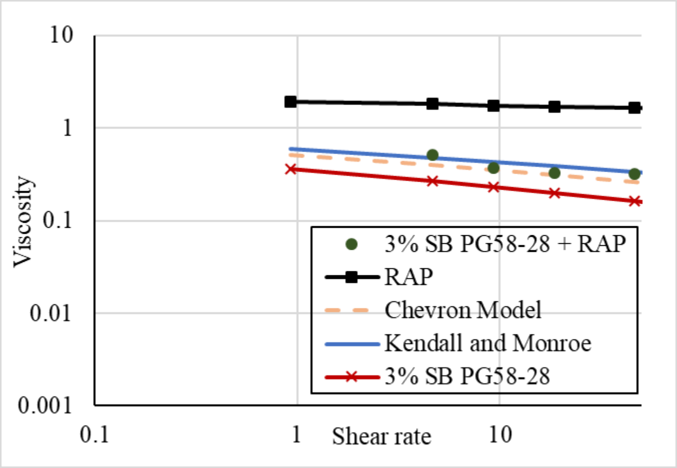

FIGURE 2 Viscosity plot for the RAP and 3% rejuvenated PG58-28 blend

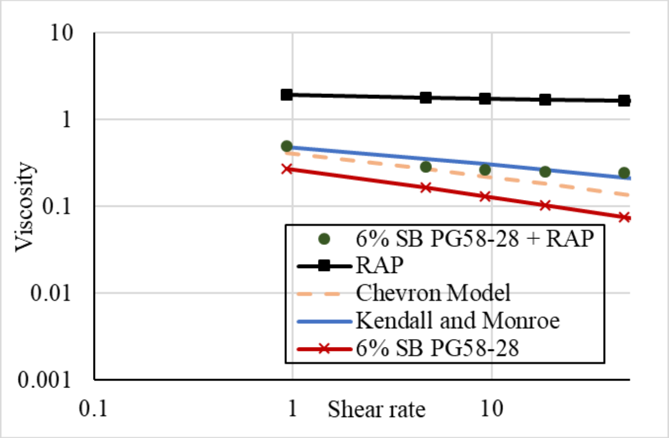

FIGURE 3 Viscosity plot for the RAP and 6% rejuvenated PG58-28 blend

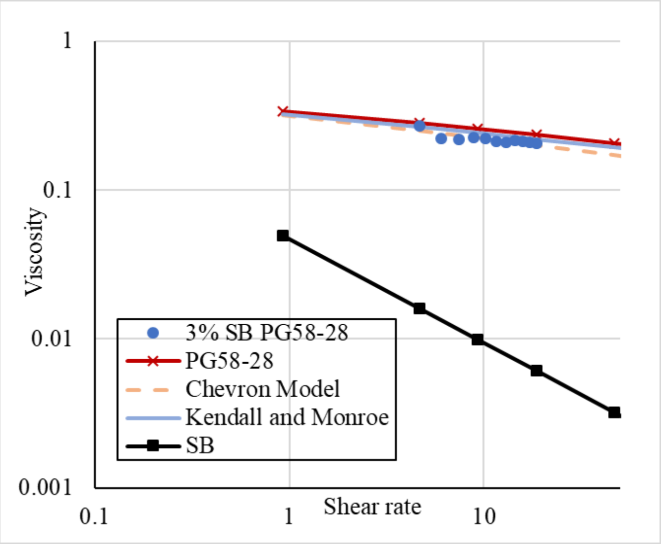

FIGURE 4 Viscosity plot for the 3% rejuvenated PG58-28 blend

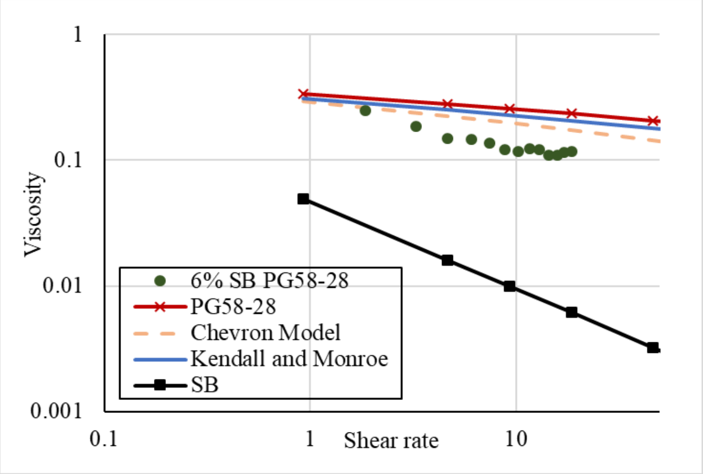

FIGURE 5 Viscosity plot for the 6% rejuvenated PG58-28 blend

3. SUMMARY AND CONCLUSIONS

In this paper, a soybean-derived rejuvenator is added to a PG58-28S binder at a dosage of 3% and 6% by weight. The rejuvenated PG58-28S was blended with an extracted reclaimed asphalt pavement (RAP) binder. The percentage of the RAP binder in the total blend was 24%. A control blend made of RAP and neat PG58-28S was also prepared. The performance grade of the control RAP and neat PG58-28S blend was determined to be PG64-28, while that of the 3% and 6% rejuvenated blends was PG58-28 and PG52-28, respectively.

Two viscosity models, namely the Chevron model and the Kendall and Monroe model were used to predict the viscosity of the resulting blends at a temperature of 135^{o}C. Both models provided satisfactory prediction for the binder blends, with the Kendall and Monroe showing slightly better predictive performance. For the blends made of PG58-28S and the soybean-derived rejuvenator, the two models were not able to predict the viscosity of the blend particularly at a higher dosage of the rejuvenator. The results of this study showed that the mixing rules available for predicting performance of binder blends may not be suitable for rejuvenators. This could be attributed to the nature of the interaction between the rejuvenator and the binder which may involve chemical as well as physical changes. Hence, simple mixing rules, as the one outlined in the NCHRP Report No. 452, may not be sufficient to describe the blend properties. Further research needs to be done to investigate other existing models and their relation to blend properties at different temperatures.

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