Binder Rheology – Interaction between RA Binder and Added Binder

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1. Introduction

Current concerns about the scarcity of raw materials for the construction and maintenance of roads (and the increase in price that this implies), together with the potential shown by reclaimed asphalt (RA) to be successfully recycled in asphalt mixtures, are encouraging the increase of the use of this material to produce high RA content mixtures (Jimenez et al. 2017). However, to obtain good performance of high RA content asphalt mixtures (surfaces and base courses) depends on the individual RA properties and the selected mixture design used to account for the presence of the aged RA binder. The interaction and blending of the RA binder with new virgin binder is critical to the successful implementation and increased percentages of used RA in new asphalt mixtures.

Three marginally different approaches (methodologies) are currently used throughout the world (Europe, USA and Australia) in terms of this blending (interaction) between the aged RA binder and the new virgin binder. This paper described a new binder blend methodology that can be used with different types of RA, with or without rejuvenators, to more accurately predict the interaction between RA and virgin binder in increasingly high RA content asphalt mixtures. This methodology has been successfully used with a number of different RA contents, RA types, degrees of RA binder ageing and blending, and asphalt mixtures to increase confidence in the use and eventually pavement performance of high RA content mixtures (Lo Presti et al. 2016).
2. **Standard approaches to RA and virgin binder interaction**

The European blending models are based on penetration and softening point of the RA recovered binder and virgin binder. In addition, the determination of this interaction between these two binders is not required if the recycled mix design includes less than 10% RA for surfacing layers and less than 20% RA for base layers and binder courses (Jimenez et al. 2015). If higher proportions of RA are used, the penetration and softening point values of the binder blend need to be determined using Equations 1 and 2 respectively:

\[
a \log \text{pen}_1 + b \log \text{pen}_2 = (a + b) \log \text{pen}_{\text{mix}} [1]
\]

Where \( \text{pen}_1 \) = penetration of the binder recovered from the RA; \( \text{pen}_2 \) = penetration of the added virgin binder; \( \text{pen}_{\text{mix}} \) = calculated penetration value of the binder in the mixture containing RA and \( a, b = \) ratios by mass of the binder from the RA and of the virgin binder respectively (\( a+b=1.0 \)).

\[
T_{R&B \text{ mix}} = a T_{R&B 1} + b T_{R&B 2} [2]
\]

Where \( T_{R&B 1} \) = softening point of the binder recovered from the RA; \( T_{R&B 2} \) = softening point of the added virgin binder; \( T_{R&B \text{ mix}} \) = softening point of the binder in the mixture containing RA and \( a, b = \) ratios by mass of the binder from the RA and of the virgin binder respectively (\( a+b=1.0 \)).

In terms of the US approach, for high percentages of RA, the RA binder has to be recovered and a blend design undertaken based on critical temperatures of the different materials using the following prediction law:

\[
T_{\text{blend}} = T_{RA} \times \%RA + T_{VB} \times \%VB [3]
\]
Where $T_{\text{blend}}$ = critical temperature of the final blend of binders; $T_{\text{RA}}$ = critical temperature of the RA binder; $T_{\text{VB}}$ = critical temperature of the virgin binder used as rejuvenator; $\% \text{RA} = \text{percentage of RA in the blend and } \% \text{VB} = \text{percentage of virgin binder in the blend.}$

These critical temperatures relate to rheological parameters measured from dynamic shear rheometer (DSR) and bending beam rheometer (BBR) tests. The high critical temperature ($T_{c}\text{(High)}$) for unaged RA binder is determined as:

$$T_{c}\text{(High)1} = \left( \frac{\log(1.00) - \log(G_1)}{a} \right) + T_1$$  \[4\]

Where $G_1$ = the G*/sin\(\delta\) value in kPa at a specific temperature $T_1$ and $a$ = the slope of the stiffness-temperature curve determined as $\Delta \log (G*/\sin\delta)/\Delta T$. A second high critical temperature ($T_{c}\text{(High)}$) for RTFOT aged RA binder is determined as:

$$T_{c}\text{(High)2} = \left( \frac{\log(2.2) - \log(G_1)}{a} \right) + T_1$$  \[5\]

Where $G_1$ = the G*/sin\(\delta\) value in kPa at a specific temperature $T_1$ and $a$ = the slope of the stiffness-temperature determined as $\Delta \log (G*/\sin\delta)/\Delta T$. $T_{c}\text{(High)}$ is chosen between $T_{c}\text{(High)1}$ and $T_{c}\text{(High)2}$ as the most restrictive value (the lower one).

The intermediate critical temperature ($T_{c}\text{(Int)}$) is determined for the RTFOT RAP binder using Equation 6:

$$T_{c}\text{(Int)} = \left( \frac{\log(5000) - \log(G_1)}{a} \right) + T_1$$  \[6\]

Where $G_1$ = the G*/sin\(\delta\) value in kPa at a specific temperature $T_1$ and $a$ = the slope of the stiffness-temperature curve determined as $\Delta \log (G*/\sin\delta)/\Delta T$.

The low critical temperature ($T_{c}\text{(Low)}$) for the RTFOT RAP binder is determined using Equations 7 and 8:
\[
T_C(\text{Low})(S) = \left(\frac{\log(300) - \log(S_1)}{a}\right) + T_1 \tag{7}
\]

Where \( S_1 \) = the S value in MPa at a specific temperature \( T_1 \) and \( a \) = the slope of the stiffness-temperature curve determined as \( \Delta \log(S)/\Delta T \).

\[
T_C(\text{Low})(m) = \left(\frac{0.300-m_1}{a}\right) + T_1 \tag{8}
\]

Where \( m_1 \) = the m value at a specific temperature \( T_1 \) and \( a \) = the slope of the stiffness-temperature curve determined as \( \Delta m/\Delta T \). \( T_C(\text{Low}) \) is chosen between \( T_C(\text{Low})(S) \) and \( T_C(\text{Low})(m) \) as the most restrictive value (the higher one).

The Australian binder blend approach is based on the complex viscosity of the RA, the virgin binder and the rejuvenator (if required) measured in the DSR at 60°C and 1 rad/s. The viscosity of the binder blend is then determined using the following prediction law:

\[
\mu^{1/3} = w_A \mu_A^{1/3} + w_B \mu_B^{1/3} \tag{9}
\]

Where \( \mu \) = viscosity of the blend (cP); \( \mu_A \) = viscosity of component A (cP); \( \mu_B \) = viscosity of component B (cP); \( w_A \) = weight fraction of component A (cP) and \( w_B \) = weight fraction of component B (cP).

3. **Binder blend design methodology**

The proposed new binder blend methodology includes a combination of the different methodologies, presented in the previous section, as illustrated in Figure 1. The methodology consists of four stages, namely RA and virgin binder (plus rejuvenator if required) rheological characterization, production of blending charts and laws, design evaluation and recommendations and finally design validation.
Figure 1. Binder design methodology

The approach also uses the real percentage of RA binder that will be available for blending, defined as the Replaced Virgin Binder (RVB), which depends on several factors such as RA binder content, binder content in the final mixture and the degree of blending (DOB) between virgin and aged binders:

$$RVB\, (\%) = 100 \cdot \frac{RA \text{ in the mixture} \cdot DOB \cdot RA \text{ content}}{binder \text{ content in the mixture}}$$  \[10\]

Where RA content in the mixture is the total RA percentage to be added in the mixture; RA binder content is the binder content in the RA; binder content in the mixture is the designed final binder content in the mixture; DOB is the assumed degree of blending between RA and virgin binders (with values between 60 and 100%).

An example of a blending chart is shown in Figure 2 where 0% RVB represents the value of the rheological property of the virgin binder and 100% is the property of either the RA binder (or the rejuvenated RA binder).
4. Conclusions

The proposed binder blending methodology has been successfully used with a range of RA types and contents, RA binder rheological properties, with and without RA rejuvenators, and finally different degrees of blending to produce well-designed and sustainable recycled asphalt mixtures.

References

