RAS Binder Characterization and Blending with Virgin Binders

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ABSTRACT

In addition to reclaimed asphalt pavement (RAP), recycled asphalt shingles (RAS) has accepted and fairly used in different transportation agencies in recent years.. However, very limited information on RAS binder characterization and blending with virgin (and RAP) binders is available in the literature partially due to the limitations of regular dynamic shear rheometers (DSR) and bending beam rheometer (BBR) to test this type of materials. This paper first validated the applicability of the existing asphalt binder extraction and recovery procedures to extremely stiff RAS binders through comparing the binder properties before and after the extraction and recovery processes. Then a variety of tear-off asphalt shingles (TOAS) and manufacture waste asphalt shingles (MWAS) were extracted, recovered, and characterized using a high temperature DSR and a BBR. It was found that TOAS binders with an average of high temperature grade of 175 °C are much stiffer than MWAS binders which have an average of high temperature grade of 131 °C. Furthermore, this paper investigated the blending among virgin/RAP/RAS binders. The results indicated that the virgin/RAS binder blending was nonlinear, which is different from the well known virgin/RAP binders linear blending. However, for practical application, the linear blending chart can still be used for estimating continuous grade (high and low temperatures) of both virgin/RAS blended binders and virgin/RAP/RAS blended binders, if the RAS binder is limited within 30 % of the total binder. The applicability of the linear blending chart for virgin/RAP/RAS binders significantly reduces the DSR/BBR testing workload. Additionally, compared with TOAS binders, MWAS binders have much less impact on properties of blended virgin/RAS binders. The significant differences between TOAS and MWAS in terms of RAS binder properties and virgin/RAS binders blending characteristics imply that it is necessary to differentiate MWAS from TOAS in the mix design process and to have different upper limits on maximum RAS binder replacement for MWAS and TOAS.

Keywords: **Asphalt Binder, Recycled Asphalt Shingles, Blending Chart, Extraction and Recovery**

INTRODUCTION

With increases in the price of asphalt binder and subsequent price fluctuations, asphalt industry has further amplified its recycling efforts. In addition to reclaimed asphalt pavement (RAP), recycled asphalt shingles (RAS) has accepted and fairly used in different transportation agencies because of the environmental benefit and the reduction of asphalt pavement construction cost. Generally there are two basic types of RAS scraps: (a) tear-off asphalt shingles (TOAS), and (b) manufacture waste asphalt shingles (MWAS). In the United States, around 10 million tons of TOAS and 1 million tons of MWAS are available for recycling. Specifically, there are several national wide, large roof shingles manufacturers in Texas, such as Owens Corning, GAF, TAMKO, Certain Teed, etc. Significant markets of both TOAS and MWAS exist for both recycling and paving industries.

More than 30 years ago, some of the original pioneers established the first shingle recycling plants, investigated hot-mix asphalt (HMA) mix designs incorporating RAS, and then published the first technical literature in the late 1980s (*1-3*). More recently, several additional HMA producers, departments of transportation (DOTs), and researchers, have developed substantial expertise in shingle recycling in HMA (*4-16*). All these efforts paved the way for more and more DOTs to allow the use of RAS in HMA. In February 2009, the Texas Commission on Environmental Quality (TCEQ) issued an authorization memo to allow HMA plants to include either MWAS or TOAS under the TCEQ air quality standard permit for permanent HMA plants. Since then, RAS has been used in a variety of pavement constructions. Meanwhile, some concerns on the use of RAS, as listed below, were raised:

- Unknown stiffness of RAS binder: RAS binder is so stiff and beyond the high temperature range of regular dynamic shear rheomters (DSR) can measure;
- Unknown virgin/RAS binders blending: Is linear blending chart applicable?
- TOAS vs. MWAS: is it necessary to differentiate them in specification?

Apparently, it is critical to address these concerns in order to widely and better use RAS in HMA.

The objectives of this paper were to address these three concerns listed above. To achieve the objectives, the authors first validated the applicability of the existing asphalt binder extraction and recovery procedures to extremely stiff RAS binders through comparing with original shingles binder properties before and after the extraction and recovery processes in terms of binder performance grade (PG) and chemical components detected by Fourier transform infrared spectroscopy (FTIR). Then RAS binders were extracted and recovered from a variety of TOAS and MWAS, and then graded following the Superpave binder PG system. Furthermore, this paper discusses the non-linear blending characteristics between virgin and RAS binders. The differences between TOAS and MWAS in terms of PG temperatures and blending characteristics are identified in this paper. Additionally, the maximum binder replacement and the blending among virgin, RAP, and RAS binders are discussed as well. Finally, this paper concludes with the summary and findings.

VALIDATION OF ASPHALT BINDER EXTRACTION AND RECOVERY METHODS

Solvent-based asphalt binder extraction and recovery become necessary if one needs to characterize the recovered binder. However, there are always concerns especially about the solvent-based asphalt binder recovery process. One of the concerns is that the properties of the

recovered asphalt binder may be changed for two potential reasons: 1) some solvent left in the recovered asphalt binder (note that solvent often softens asphalt binders), or 2) the recovered asphalt binder is stiffened due to over-cooking for removing the solvent. To address this concern and validate the extraction and recovery methods used, this study compared both rheological properties and chemical components of one original shingles binder with the extracted/recovered binder from the MWAS produced with the same original shingles binder. The rheological properties were evaluated using DSR and BBR, and the chemical property was measured with FTIR. Note that the original shingles binder was directly received from binder supplier and no filler was added. Figure 1 shows the whole process. The solvent used in binder extraction is trichloroethylene. The extraction and recovery methods employed in this study are:

- Tex-210-F Determining Asphalt Content of Bituminous Mixtures by Extraction: Part I-Centrifuge Extraction Method Using Chlorinated Solvent
- ASTM D5404 Standard Practice for Recovery of Asphalt from Solution Using the Rotary Evaporator

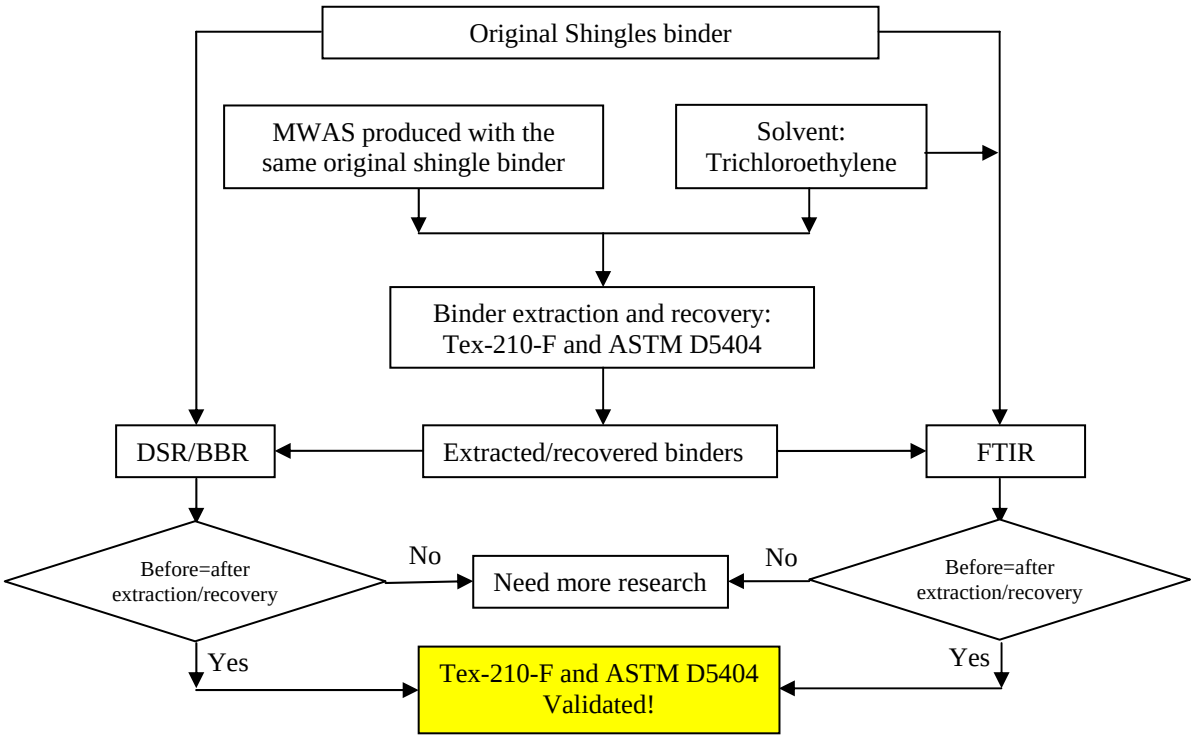


FIGURE 1 Flow Chart of Validation of Binder Extraction and Recovery Methods.

Figure 2a-c presents the FTIR test results of original shingles binder before and after the extraction and recovery. It is clear that the chemical components of the original shingles binder are exactly the same as those of the extracted and recovered shingles binder. Furthermore, Figure 2d also shows the FTIR test result of the trichloroethylene solvent itself. Apparently, the trichloroethylene itself has large absorbance when wavelength is less than 1000 (cm-1). If there is any trichloroethylene left, the absorbance values of the recovered shingles binder will be different from those of original shingles binder. Therefore, the trichloroethylene solvent was completely removed during the recovery process.

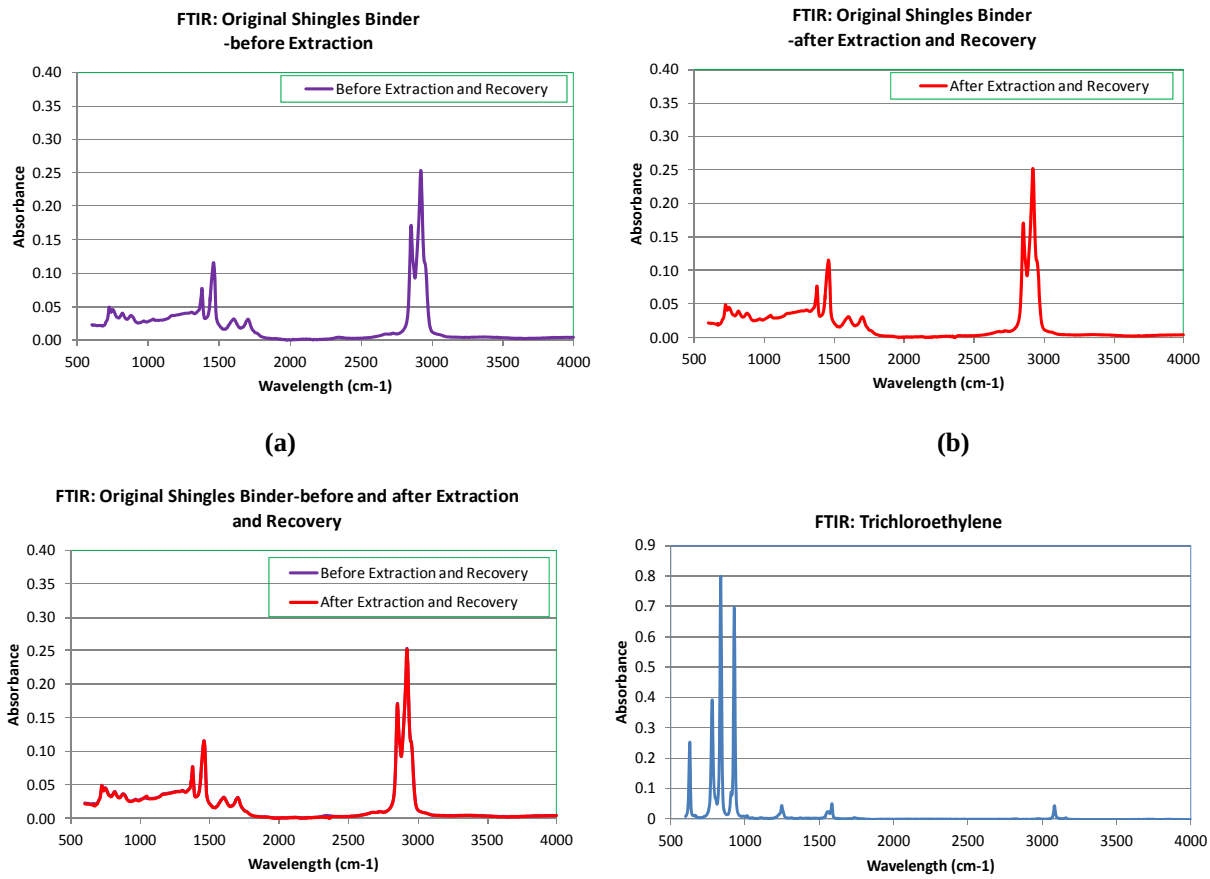


FIGURE 2 FTIR Test: Trichloroethylene and Original Shingles Binder before and after Extraction and Recovery.

Figure 3 illustrates the DSR and BBR test results of the original shingles binder before and after the extraction and recovery. Note that the BBR beams were prepared using the pressure aging vessel (PAV) aged asphalt binder residue. It is apparent that the rheological properties of the shingles binder, in terms of PG grade, have no change before and after the extraction and recovery. Note that the low temperatures grade of the PAV aged shingles binder are beyond the limits of BBR test so no data is available (more discussion in later section). Instead, the *S* and *m* values at 0°C were used for comparison. Again, the extraction and recovery process did not change the rheological properties of the shingles binder. With this validation, the authors conducted extensive shingles binder extraction and recovery following the Tex-210-F and ASTM D5404, and then evaluated the RAS binder properties, as discussed in next section.

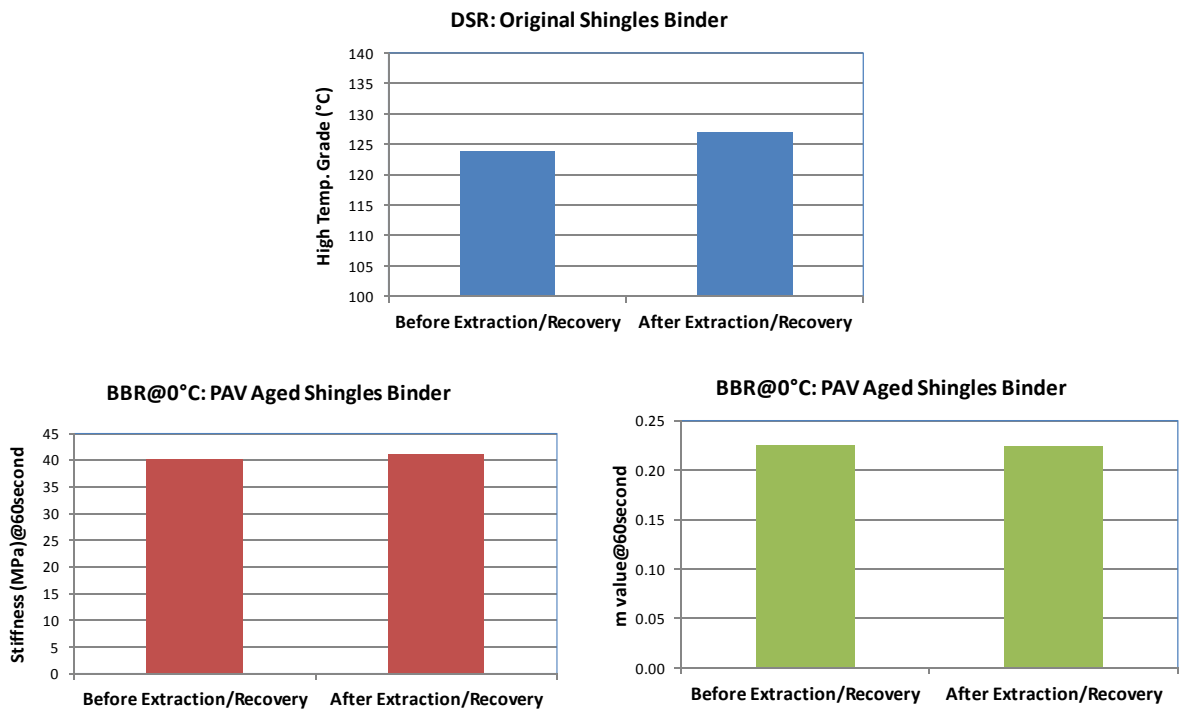


FIGURE 3 Shingles Binder: before and after Extraction/Recovery.

RAS BINDER CHARACTERIZATION

It is well known that the extracted/recovered shingles binders, regardless of MWAS or TOAS, are very stiff, and they are far stiffer than any PG76-22 binder. It is important to determine the true grade of the RAS binder since it has significant influence on virgin binder selection and the maximum amount of RAS allowed in the asphalt mixes. This study sampled, extracted, recovered, and characterized a variety of RAS binders. Detailed information is presented below.

Selection of RAS Samples

A variety of processed RAS including both MWAS and TOAS were collected from contractors and shingles recyclers. In Texas major shingles manufacturers are mainly located in Dallas-Fort Worth and Houston areas. The contractors in these areas have been using MWAS collected from those shingles manufactories in the last three years. Four types of MWAS often used in Texas were sampled from the processed MWAS stockpiles in this study, and are designated with MWAS-A, MWAS-B, MWAS-C, and MWAS-D. Additionally, six TOAS were also selected from different contractors and recyclers around Texas with the following designation: TOAS-A, TOAS-B, TOAS-C, TOAS-D, TOAS-E, and TOAS-F. In summary, a total of ten processed RAS were selected and evaluated under this study.

RAS Binder Extraction and Recovery

RAS binders were extracted and recovered from the ten processed RAS selected above, following the validated extraction and recovery methods (Tex-210-F Part I and ASTM D5404). There was some difficulty in “draining” out of the recovered TOAS binders which were so stiff that they just didn’t flow out of the beaker even at 165 °C after finishing the recovery process. In one case, the oven temperature was raised up to 200 °C in order to ‘drain’ out the TOAS binder.

RAS Binder Characterization

Both DSR and BBR were used to grade the 10 extracted/recovered RAS binders. As noted previously, the authors had difficulty in grading PAV aged shingles binder using BBR. There are two criteria (*S* and *m*) for determining the low temperature grade of asphalt binders. It is no problem for RAS binders to meet the *S* (<300 MPa) criteria, but the measured *m* values were always less than 0.3. The reason for having a small *m* value is that RAS binders including MWAS binders have much less capability to relax under force. Note that the original shingles binder are already substantially aged and often made through air-blown process. The authors even tried to run the BBR test at higher temperatures (i.e. 18 °C and even 24 °C), but the measured *m* values are still less than 0.3, and in some cases the beam deformation reaches the limit of BBR machine within a very short of period of time (in seconds). Therefore, no reliable results from BBR test were obtained for any one of the 10 recovered RAS binders. Alternative test (such as Asphalt Binder Cracking Device test) should be explored.

To measure the high temperature grades of those extremely stiff binders, a high temperature DSR was specifically purchased under this study. Nine of the 10 RAS binders were successfully graded following Superpave binder PG system. The high temperature grade of one TOAS binder is beyond the upper limit of the purchased DSR which is 200 °C, so that extrapolation was used to estimate its high temperature grade. For each extracted/recovered RAS binder, both original and rolling thin-film oven (RTFO) aged residue were evaluated. The high temperature grades of the 10 RAS binders are shown in Figure 4.

Several observations can be clearly made from Figure 4:

- TOAS binders with an average of high temperature grade of 175 °C are much stiffer than MWAS binders which have an average of high temperature grade of 131 °C.
- Compared to the TOAS varying from 159 °C to 214 °C, the MWAS has smaller variation in terms of the high temperatures grade.

These two observations clearly indicate that the MWAS is different from the TOAS. It is necessary and important to differentiate the MWAS from the TOAS when used in asphalt mixes. For example, DOTs may allow smaller amount of TOAS in the specification when compared with MWAS.

In summary, the RAS binders are very stiff, and regular DSR and BBR could not characterize rheological properties of these extremely stiff binders. Therefore it is critical to investigate the impact of these stiff binders on rheological properties of the combined binder after blending with virgin binders, which is discussed in next section.

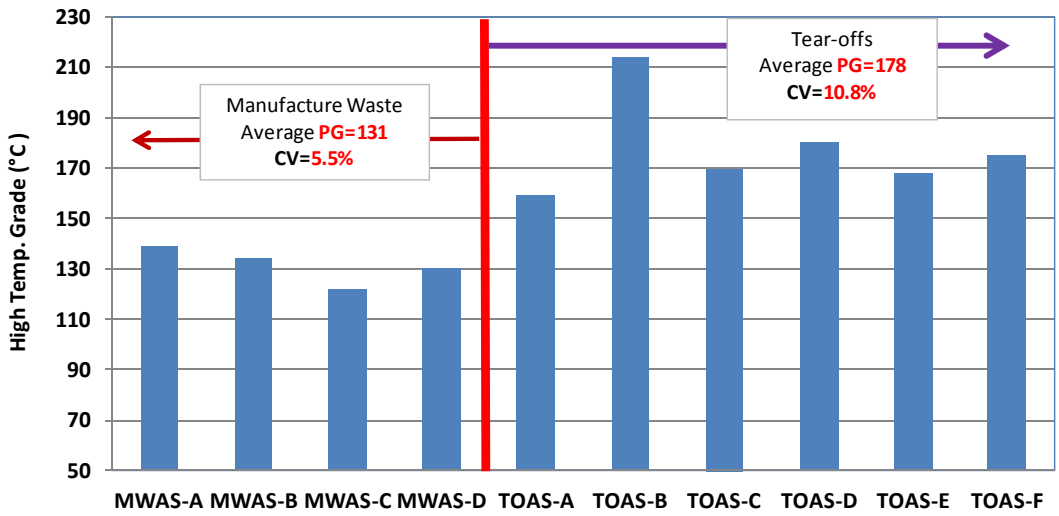


FIGURE 4 High Temperature Grades of RAS Binders: MWAS and TOAS.

INVESTIGATION OF BLENDING BETWEEN VIRGIN BINDER AND RAS BINDER

Many efforts have been made to evaluate the blending between virgin binders and RAP binders, and all results indicated that the RAP binders linearly blend with virgin binders. Compared to virgin/RAP binder blending, there was very little work done on virgin/RAS binders blending in the literature, although AASHTO PP53, *Standard Practice for Design Consideration when Using Reclaimed Asphalt Shingle (RAS) in New Hot-Mix Asphalt (HMA)*, recommends that the linear blending used for virgin/RAP binders blending also be used with virgin/RAS binders. One reason, as discussed previously, may be the difficulty in grading RAS binder using regular DSR and BBR. This study investigated the full blending charts for 3 virgin binders and 4 RAS binders extracted/recovered from both TOAS and MWAS. Detailed information is presented below:

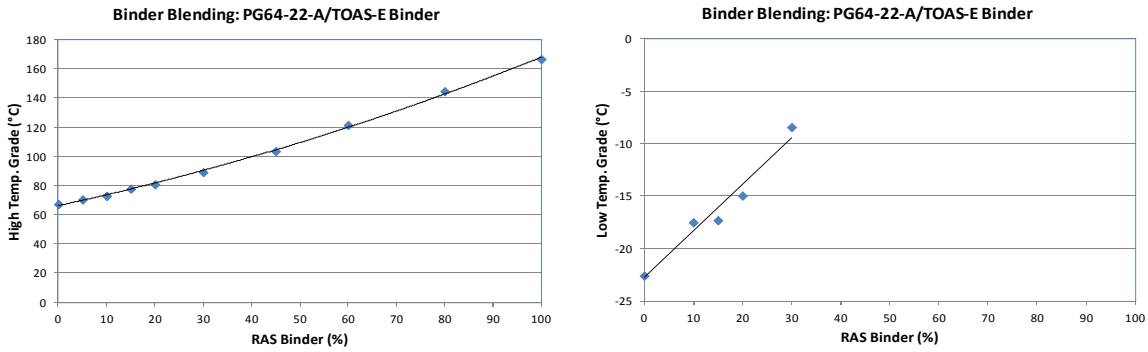
Virgin and RAS Binders

Three virgin binders selected for blending are 1) PG64-22-A, 2) PG64-22-B, and 3) PG64-28, and the four RAS binders are TOAS-A, TOAS-E, MWAS-A, and MWAS-C. With these selected binders, a total of 4 combinations of virgin/RAS binders, as listed below, were evaluated under this study. Note that these 4 combinations have been used in the field test sections.

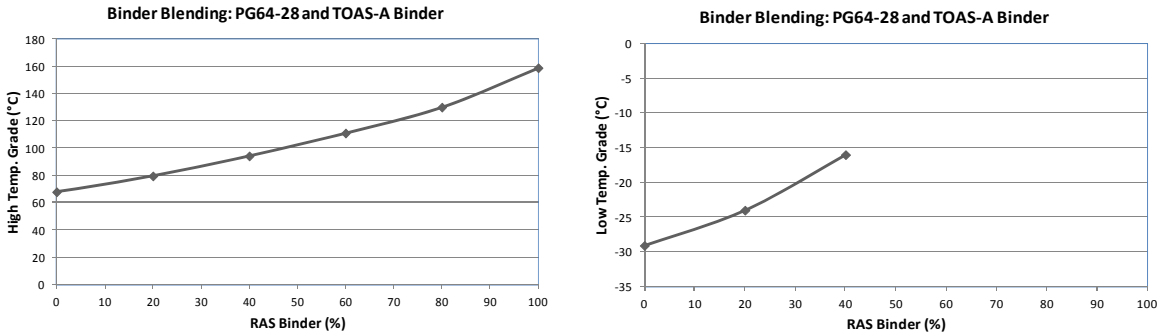
- Virgin Binder: PG64-22-A and RAS Binder: TOAS-E
- Virgin Binder: PG64-28 and RAS Binder: TOAS-A
- Virgin Binder: PG64-22-B and RAS Binder: MWAS-A
- Virgin Binder: PG64-22-B and RAS Binder: MWAS-C

Laboratory Testing, Results, and Analysis

For each combination, different percentages of virgin and RAS binders were blended and then evaluated through DSR and BBR testing in terms of the high and low PG temperatures. The test results for these four combinations are presented in Figures 5, and 6, respectively.

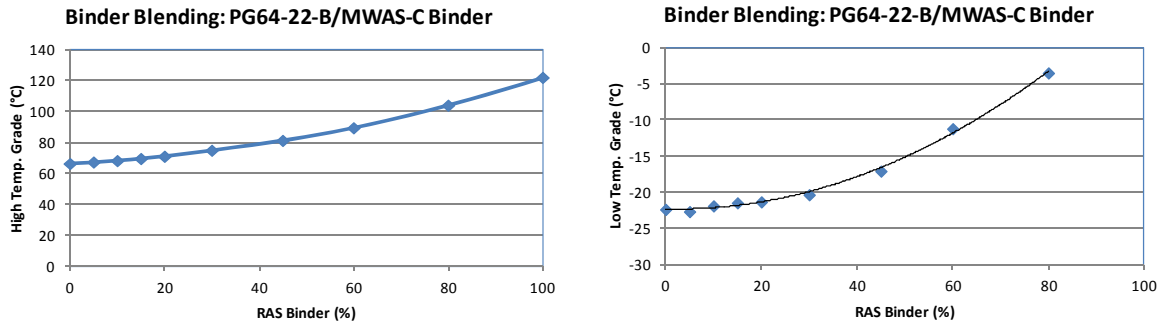


(a) Binder Blending between PG64-22-A and TOAS-E Binder.

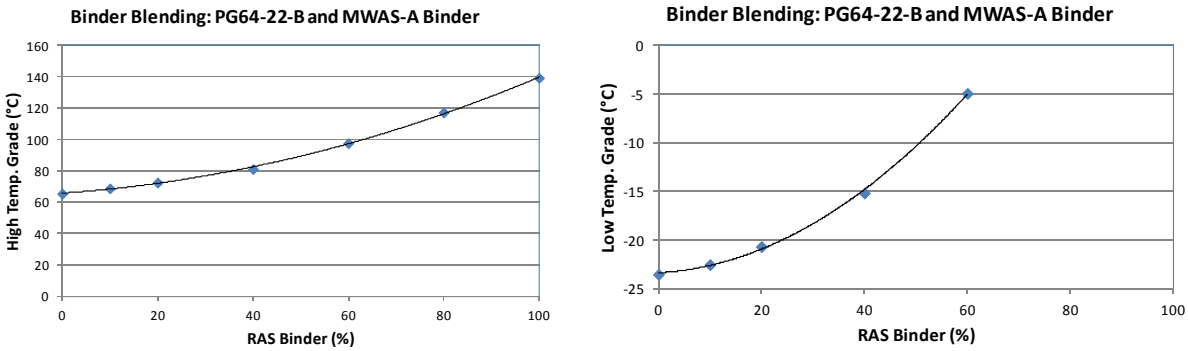


(b) Binder Blending between PG64-28 and TOAS-A Binder

FIGURE 5 Binder Blending: Virgin Binders/TOAS Binders.



(a) Binder Blending between PG64-22-B and MWAS-C Binder



(b) Binder Blending between PG64-22-B and MWAS-A Binder

FIGURE 6 Binder Blending: Virgin Binders/MWAS Binders.

The following observations are made from Figures 5 and 6.

- Generally the virgin and RAS binders blending is non-linear.
- For practical application, the linear blending chart can still be used if the RAS binder percentage is less than 30 %, which is consistence with the finding from a previous study conducted by Bonaquist (*17*). Within 30 % RAS binder, not only is the linear blending chart applicable, but the regular DSR and BBR can also be used to evaluate the high and low PG temperatures of the blended binders.
- Increasing the RAS binder amount will make the blended binder stiffer and accordingly, better rutting resistance but poorer cracking resistance. Adding 20 % RAS binder can make a PGxx-22 virgin binder become a PGxx-16 (or even a PGxx-10 shown in Figure 5a) blended binder. Additionally, the necessity of using the PGxx-28 virgin binder is clear if one targets to get a PGxx-22 blended binder when the 20 % RAS binder is added (Figure 5b). Note that the 20 % RAS binder is corresponding to 5 % RAS in weight of the total mix when assumed that the optimum asphalt content of a RAS mix is 5 % and the RAS contains 20 % asphalt binder in it.
- Impact of MWAS binders on the high and low PG temperatures of virgin binders is different from that of TOAS binders. Compared to the TOAS binders (Figure 5), the MWAS binders (Figure 6) have less impact on PG temperatures of virgin binders, which makes sense since TOAS binders are much stiffer than those MWAS binders (see Figure 4). Therefore, it is necessary to consider differentiating the MWAS from the TOAS when designing HMA containing RAS.

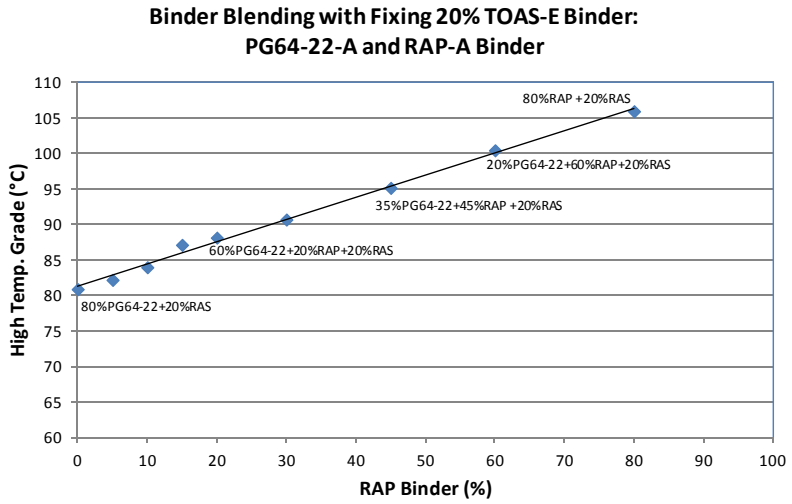
EVALUATION OF BLENDING AMONG VIRGIN, RAP AND RAS BINDERS

The use of both RAP and RAS in HMA has become a regular practice in asphalt industry, so this study also briefly explored the blending among virgin/RAP/RAS binders. The same two virgin binders (PG64-22-A and PG64-22-B), two RAS binders (MWAS-A and TOAS-E), and two RAP binders (RAP-A and RAP-B) were selected. Again, 4 combinations listed below were evaluated with different percentages of binder contents through DSR and BBR testing.

- TOAS-E RAS Binder (=20% of the total binder): varying PG64-22-A and RAP-A
- RAP-A Binder (=20% of the total binder): varying PG64-22-A and TOAS-E
- MWAS-A Binder (=5% of the total binder), varying PG64-22-B and RAP-B
- RAP-B Binder (=10% of the total binder), varying PG64-22-B and MWAS-A

The DSR and BBR test results of these 4 combinations are shown in Figures 7, 8, 9, and 10, respectively. From these figures the following observations are made:

- As long as RAS binder content is fixed in the blending process, the virgin/RAP binders follows linear blending line, as seen in Figures 7 and 9. Both high and low temperatures of PG of the combined binder increases linearly with adding RAP binder. When RAP binder content is fixed, the virgin/RAS binders blending, again, is non-linear (see Figures 8 and 10).
- When RAS binder is already blended with virgin binder, adding more RAP binder makes the blended binder even stiffer. For example, as shown in Figure 7, 20 % RAS binder itself already modified the PG64-22-A binder to a PG81-15 binder. Adding any RAP binder (even 5% RAP binder) will worsen the cracking resistance of the combined binder. The similar finding for fixing RAP binder but adding more RAS binder to the virgin binder can be observed in Figures 8, 9, and 10.



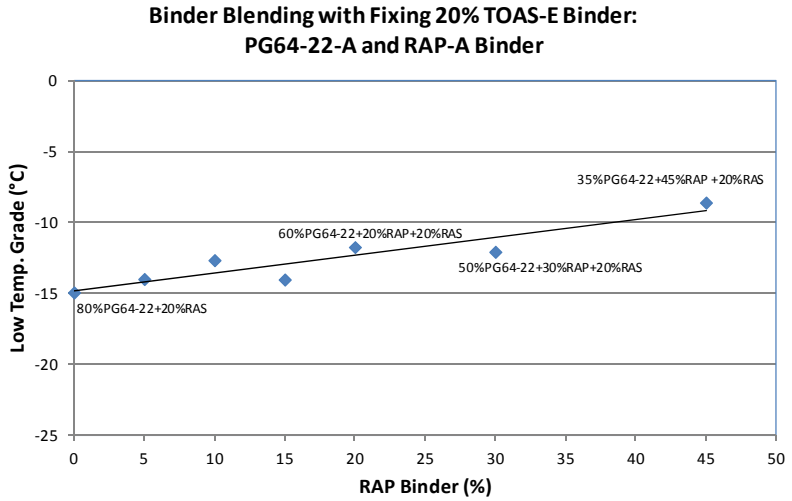
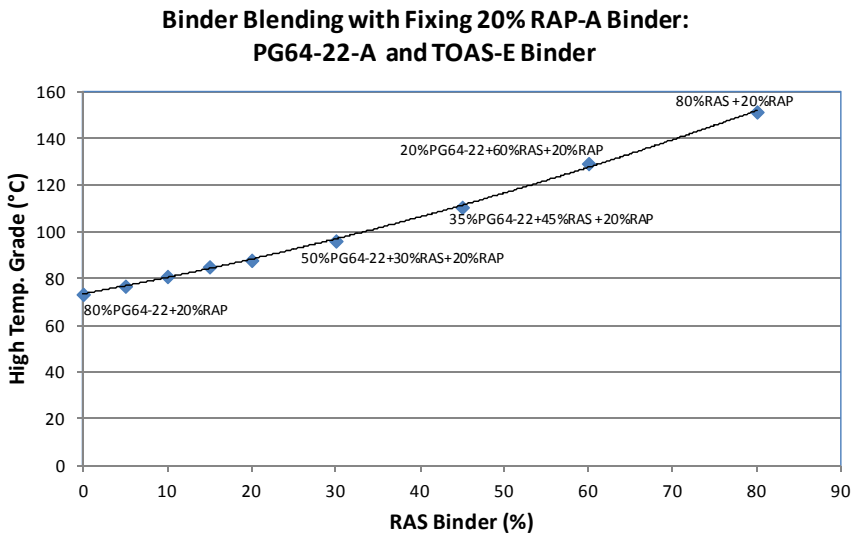


FIGURE 7 Binder Blending with Fixing 20 % TOAS-E Binder and Varying PG64-22-A and RAP-A Binder.



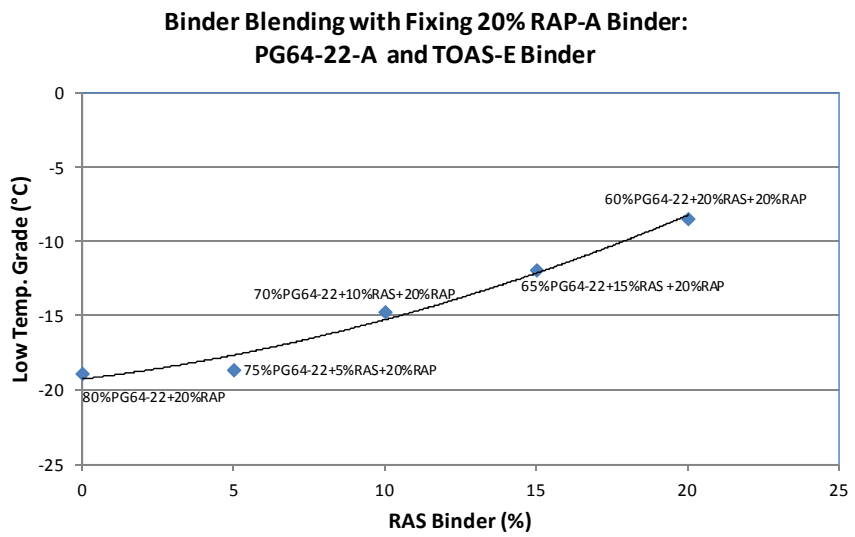
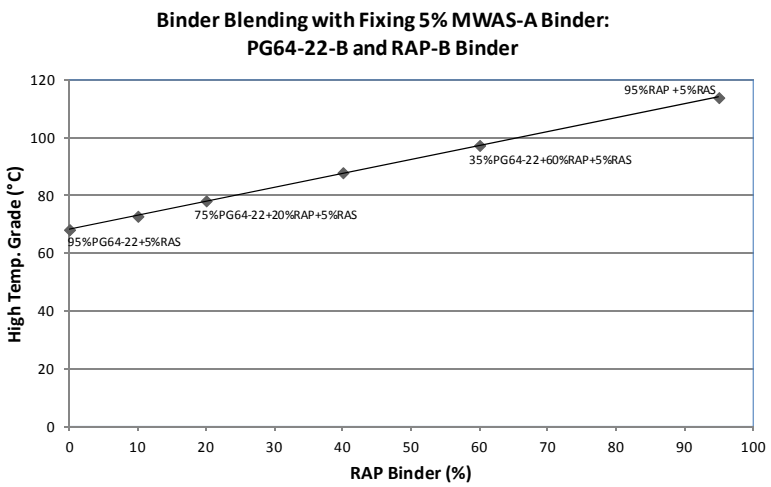


FIGURE 8 Binder Blending with Fixing 20 % RAP-A Binder and Varying PG64-22-A and TOAS-E Binder.



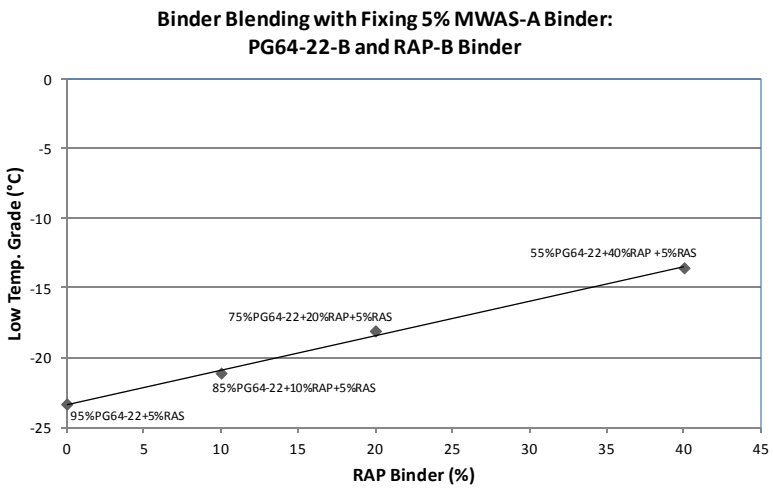
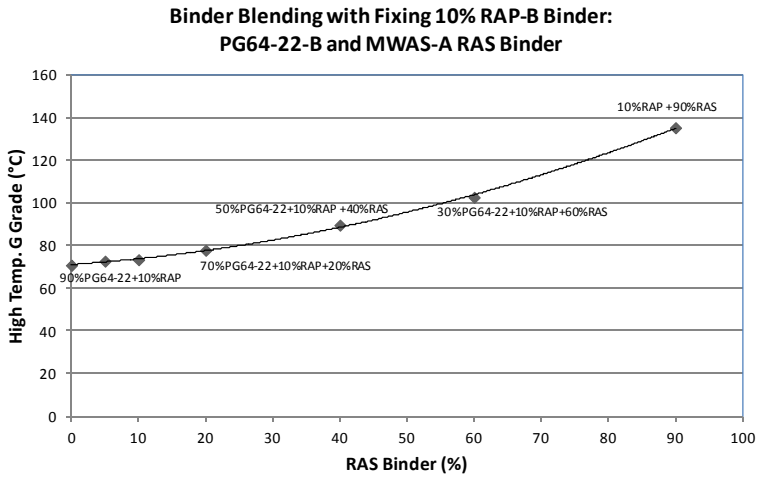


FIGURE 9 Binder Blending with Fixing 5 % MWAS-A Binder and Varying PG64-22-B and RAP-B Binder.



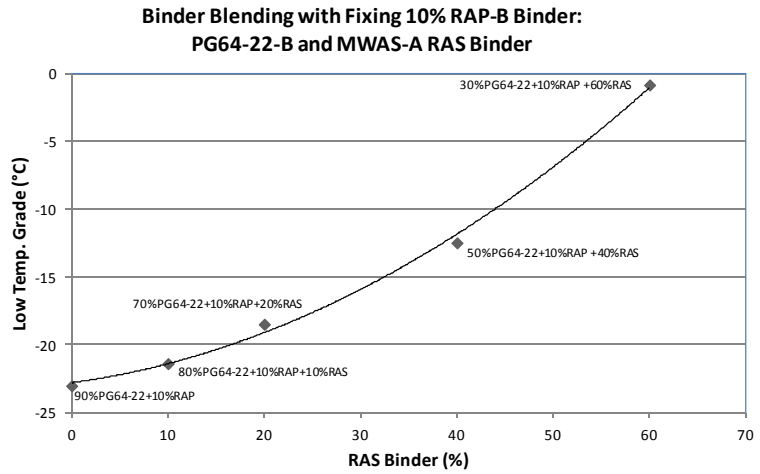


FIGURE 10 Binder Blending with Fixing 10 % RAP-B Binder and Varying PG64-22-B and MWAS-A Binder.

DISCUSSION ON MAXIMUM ALLOWABLE ASPHALT BINDER REPLACEMENT

The DSR and BBR test results presented above clearly indicated that RAS binders have significant influence on both high and low PG temperatures of the blended binder; positive effect on high temperature property (or rutting resistance) and negative effect on low temperature property (or cracking resistance). Thus the maximum allowable RAS binder replacement is controlled by the influence of RAS binder on the low temperature property of the blended binder. The virgin/RAS binders blending charts shown in Figures 5 and 6, clearly indicated that the maximum binder replacement allowed for MWAS should be different from TOAS. It seems OK to use MWAS with a maximum of 20 % binder replacement, but the maximum binder replacement allowed for TOAS should be significantly reduced.

When both RAP and RAS are used, the maximum allowable recycled binder (RAP binder plus RAS binder) replacement is influenced by many factors (such as virgin binder, RAP binder, RAS binder, pavement layers [surface or base layer], climate, traffic, etc.). It will be safe to

directly evaluate the blending chart for virgin, RAP, and RAS binders. Reviewing the impact of RAS binder on low temperature property of the blended binders shown in Figures 5, 6, 8, and 10, RAS binders, for practical applications, should be limited within 30 % of the total binder. If this is the case, the blending chart for virgin/RAP/RAS can be significantly simplified:

- Linear blending chart is practical applicable to estimate the high and low PG temperatures of the blended virgin/RAS binders or virgin/RAP/RAS binders, which significantly reduces the DSR/BBR testing workload, because only the properties of blended binders at two ends are required, and anything in between can be linearly interpolated.

  For virgin/RAS binders blending (see Figure 11a), one only needs to determine the PG temperatures of virgin binder and the 30 % RAS/70 % virgin binders, respectively. Then one can determine the continuous PG temperatures of any blending through linear interpolation. For virgin/RAP/RAS binders blending (see Figures 11b and 11c), similar approach can be used for 1) fixing RAS binder replacement (say 20 %) and varying virgin/RAP binders and 2) fixing RAP binder replacement (15 %) and varying virgin/RAS binders. Note that RAS/RAP binder replacements shown in Figure 12b/c are just for demonstration only, and can be replaced with real numbers.

- Additionally, the use of the linear blending chart and practical amount of RAP/RAS binders makes it possible to employ regular DSR and BBR test equipment to evaluate the properties of the blended virgin/RAP/RAS binders.

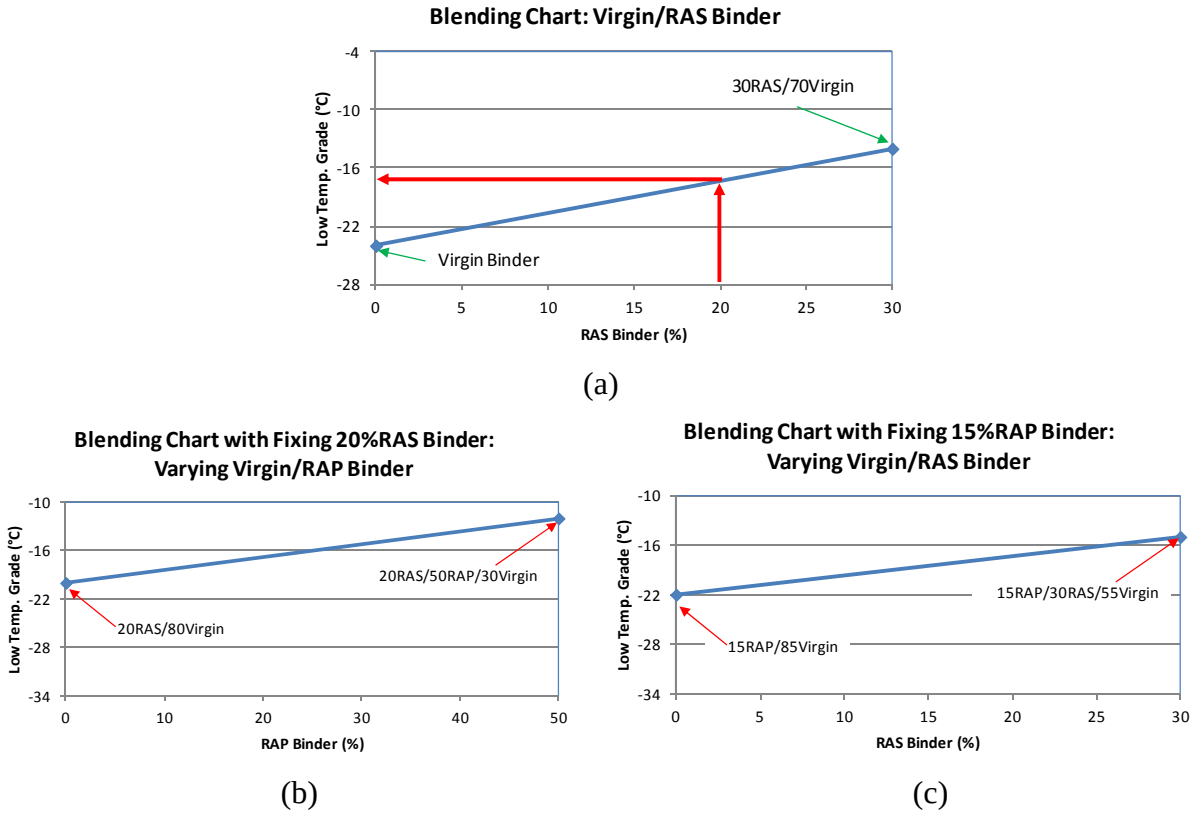


FIGURE 11 Illustration of Linear Blending Charts for Virgin/RAP/RAS Binders.

SUMMARY AND FINDINGS

Based on the data presented previously, the following summary and findings are offered:

- The asphalt binder extraction and recovery procedures (Tex-210-F Part I and ASTM D5404) are validated in this study. No solvent was detected through FTIR testing, and the binder rheological properties, in terms of PG high and low temperatures, were the almost same before and after going through the extraction and recovery processes.
- RAS binders are very stiff. TOAS binders with an average of high temperature grade of 175 °C are much stiffer than MWAS binders which have an average of high temperature grade of 131 °C. These observed significant differences indicate that it is necessary to differentiate MWAS from TOAS in the mix design process and to have different upper limits on maximum RAS binder replacement for MWAS and TOAS.
- Different from virgin/RAP binders blending, the virgin/RAS binder blending, in general, is nonlinear. However, for practical application, the linear blending chart can still be used for estimating continuous grade (high and low temperatures) of both virgin/RAS blended binders and virgin/RAP/RAS blended binders, if the RAS binder is limited within 30 % of the total binder. In such way, the DSR/BBR testing is significantly reduced. Furthermore, within 30 % RAS binder, not only is the linear blending chart applicable, but the regular DSR and BBR can also be used to evaluate the high and low PG temperatures of the blended binders.

It is worth noting that the work presented in this paper needs to be further verified and expanded to include more virgin, RAP, and RAS binders for blending. Additionally, all the binders blending done in the laboratory may not represent the actual blending in the plant during HMA production. The laboratory binder blending often is much higher when compared with HMA plant. Thus, it is important to tie the binder blending with engineering properties of mixes containing RAS, and ideally, field test sections.

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DISCLAIMER

The contents and opinions of this paper reflect the views of the authors, who are solely responsible for the facts and the accuracy of the data presented herein. The contents of this paper do not necessarily reflect the official views or the policies of any agencies.

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