Determine the Impact of Degree of Blending and Quality of Reclaimed Asphalt Pavement on Predicted Pavement Performance using Mechanistic-Empirical Design Guide (MEPDG)

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ABSTRACT: Past studies have indicated binder from reclaimed asphalt pavement (RAP) aggregates do not fully blend within the hot mix asphalt (HMA), resulting in a partial degree of blending (DOB). The degree of blending is defined as the percentage of RAP binder that is effectively mobilized within the mix. Most state agencies assume full blending, which is an assumption that may lead to under asphalting or a relatively stiffer mix. However, it is unclear how this will affect the predicted pavement performance. Quality of RAP is yet another parameter that affects performance and DOB. This study focuses on determining the impact of DOB and RAP quality on predicted pavement performance using MEPDG level I analysis of 25% RAP mixes with three RAP sources. Dynamic complex modulus tests were conducted on each RAP source with two conditions: full blending and a calculated "Actual" DOB. MEPDG level I analysis was conducted using typical structures, climate, and traffic conditions for the state of New Jersey. Also rutting and fatigue cracking performance between the two DOBs were compared for each of the RAP sources. The results indicate that DOB has a negligible effect on fatigue and rutting performance for the three RAP sources tested, all of which had actual DOB values greater than 85%. Therefore, with hot mix asphalt consisting of RAP with such high DOB values, the full blending assumption would be cost effective and would not compromise the pavement performance. RAP with a uniform gradation would further reinforce this; however, it does not necessarily correspond to better performance, other RAP properties are at play.

KEY WORDS: RAP, Rutting, Fatigue, DCM, MEPDG

1. INTRODUCTION

The asphalt industry, which is under pressure to cut cost and produce a more environmentally sustainable product, is increasingly incorporating reclaimed asphalt pavement (RAP) into hot mix asphalt (HMA). With more mixes including RAP and at higher percentages it has become imperative to understand the impact of RAP on performance, yet little is known. RAP quality as well as how well the RAP blends with the new mix may be impacting performance. Many state agencies assume full blending, which may lead to under asphalting or a relatively stiffer mix. However, it is unclear how this will affect the predicted pavement performance. While RAP quality can affect the degree of blending (DOB), RAP quality can impact performance and can be classified separately. There is a need to conduct a level I analysis to determine the impact of DOB and RAP quality on predicted pavement performance.

2. OBJECTIVE

The objective of this study is to determine the impact of RAP quality and degree of blending, in a 25 % RAP hot mix asphalt (HMA), on predicted rutting and fatigue performance using MEPDG level I analysis. The research methodology to achieve the objective is shown in Figure 1 below for each RAP source. Each sample will be labeled by a mix label as follows: Mix-X-X-X (as shown in Table 1).

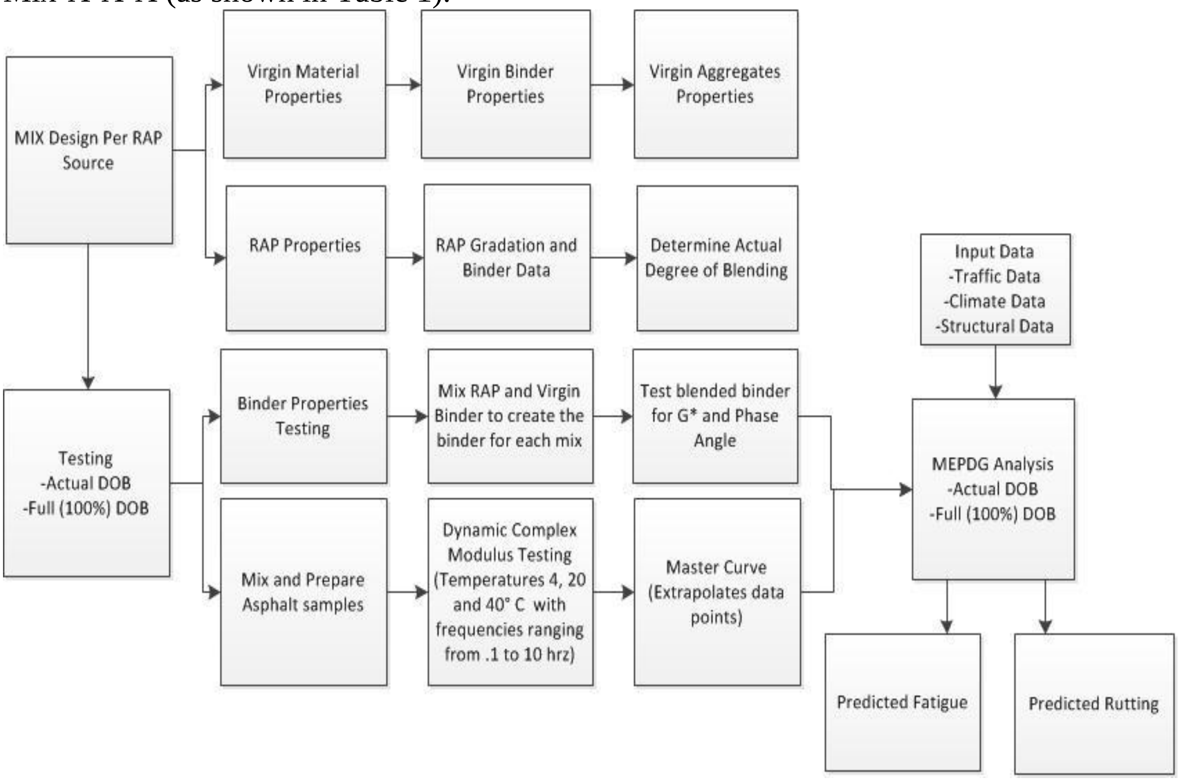

Figure 1: Research methodology for each of the three RAP sources

Table 1: Mix and Analysis Designation

RAP Source	Degree of Blending	Mix ID
1	Full	Mix-1-F
	Actual	Mix-1-A
2	Full	Mix-2-F
	Actual	Mix-2-A
3	Full	Mix-3-F
	Actual	Mix-3-A

3. BACKGROUND INFORMATION

3.1 Degree of Blending

Degree of blending (DOB) represents the percentage of the total RAP binder that is mobilized in an asphalt mix. Degree of blending (DOB) is dependent on binder content and properties, as well as gradation; therefore, samples were prepared under the "Actual" and full blending conditions to assess the impact of the DOB (Coffey, Mehta, and Kehr 2012). Many state agencies assume the full blending condition, where all of the RAP binder mobilizes and contributes to the total binder of the mix. However, in actuality, the DOB falls somewhere between 0 and 100%, depending on the RAP and mix properties, and is referred to as the "actual" DOB (Mehta and Nolan 2011). DOB is significant as it has an impact on the binder content and the stiffness of the final mix. If an incorrect DOB is assumed, it could result in under asphalting or over asphalting. Under asphalting can occur if the DOB is expected to be higher than it actually is, leading to a lower then intended binder content and usually a stiffer mix; while over asphalting is the leads to higher then intended binder content. Under-asphalting can lead to fatigue and thermal cracking, while over asphalting can lead to rutting (Al Qadi et al. 2009).

3.2 Dynamic Complex Modulus (DCM)

The new AASHTO Mechanistic-Empirical (M-E) Design Guide uses the dynamic complex modulus as the primary test protocol to characterize the modulus response of hot mix asphalt. Dynamic complex modulus or E* is the ratio of stress to strain under dynamic conditions, refer to equation 1.

$$|E^*| = \frac{\sigma}{\varepsilon} \qquad [1]$$

Where σ = the amplitude of stress
ε = the amplitude of strain

The test was conducted at three temperatures 4, 20, and 40 °C, as well as multiple frequencies ranging from 0.1 to 10 Hz. Subsequently, a master curve was developed using the procedure in AASHTO PP-62, (AASHTO PP-62 2010) developed to extrapolate more data points.

4. METHODS AND MATERIALS

The product of milling an old road, reclaimed asphalt pavement (RAP) is composed of aggregates, aged binder known as RAP binder and anything else that has worked its way into the pavement over its lifetime. Unlike virgin aggregates which usually come from a single source with little variability, RAP aggregates usually come from multiple sources with plants amassing large stock piles that range in variability.

RAP was obtained from three separate asphalt plants to assess the impact of RAP quality. The RAP was collected by sampling from five different locations within each of the plant's RAP stockpiles, which ensured a more representative sample of the entire stockpile. All virgin aggregates were from a single source, and a virgin binder of Performance Grade (PG) 70-28 was used.

To assess the impact of the DOB of each RAP source the mixes were prepared to the full and "actual" blending conditions. The full blending condition was used, since most state agencies assume this condition; therefore, this condition represents what is done in practice. An earlier study conducted by the authors (Coffey et al. 2012) showed that the "actual" DOB condition depends on the gradation of RAP aggregates, the RAP binder content, and the difference in the stiffness of the virgin binder and the RAP binder. Therefore, the different characteristics of each RAP supply determine the DOB condition that occurs. The degree of blending was experimentally determined using the following procedure:

Step 1: Prepare hot mix asphalt with ignited RAP aggregates composing 25% of the mix to determine the necessary binder content to achieve a 4% Superpave mix at the design gyrations of 75.

Step 2: Prepare the mix with RAP, working under the assumption of 70% blending. The 70% was selected based on a study conducted by Shirodkar et al. 2010 (Shirodkar, Sonpal, Mehta, Nolan, Norton, Tomlinson, Dubois, and Sauber 2010). If the volumetrics do not meet the 4 percent air voids at the design gyrations, the virgin binder is adjusted until the mix achieves 4% air voids. If no adjustment is necessary then the assumed DOB is correct. However, if the binder content needs to be adjusted, the difference in the effective binder content between the mixes prepared in step 1 and step 2 determines how much the actual DOB differs from the assumed DOB of 70%.

Step 3: The actual DOB is calculated based on the equation shown below:

$$DOB = 100 * \frac{Weight\ of\ binder\ expected\ with\ 70\%\ DOB + (weight\ of\ mix * \frac{difference\ of\ P_{be,est}}{100})}{Total\ weight\ of\ binder\ on\ the\ RAP}$$

The detailed analysis to determine DOB is beyond the scope of this paper. Once the DOB is determined the DCM is determined by preparing samples by following AASHTO T-342 (AASHTO T-342 2011). After the samples are prepared they are aged according to AASHTO R30 (AASHTO R 30 2006). They are then tested by following another part of AASHTO T-342 (AASHTO T-342, 2011). Once the data is compiled the master curves are developed following AASHTO PP-62 (AASHTO PP-62 2010).

5. RESULTS

5.1 RAP Source Properties

The gradation of the entire mix was kept the same to prevent the gradation from becoming a variable between mixes, such that the significance of the gradation of each RAP source could be analyzed. A representative sample from the stockpile was collected. Fifteen samples of RAP from the stockpile were also collected to determine the variability of the RAP sources. RAP sources 1 and 2 had a max coefficient of variation of 2.25% on the ½" sieve and a max coefficient of variation of 1.11% on the #8 sieve. RAP source 3 was highly variable, with half of the sieves having standard deviations over 3%. RAP source 2 and 3 had mostly fines in the mixes while RAP source 1 had a well blended mix due to fractionation.

RAP binder from source 1, 2, and 3, all had a high PG grade of 82°C. The RAP sources 1, 2, and 3 were mixed with virgin binder PG 70-28, and their DOB were 89.6%, 90.0%, and 84.7%, respectively. A recent study by authors (Coffey, Mehta, and Kehr 2012) regarding DOB from five RAP sources in the state of New Jersey showed that four of the five had DOB of around 85% and greater. Therefore, the DOB values above are typical of what is observed in the state.

5.2 Mixture Properties

All attempts were made of maintaining a similar gradation for each mix. Figure 2 shows gradation for each of the mixes.

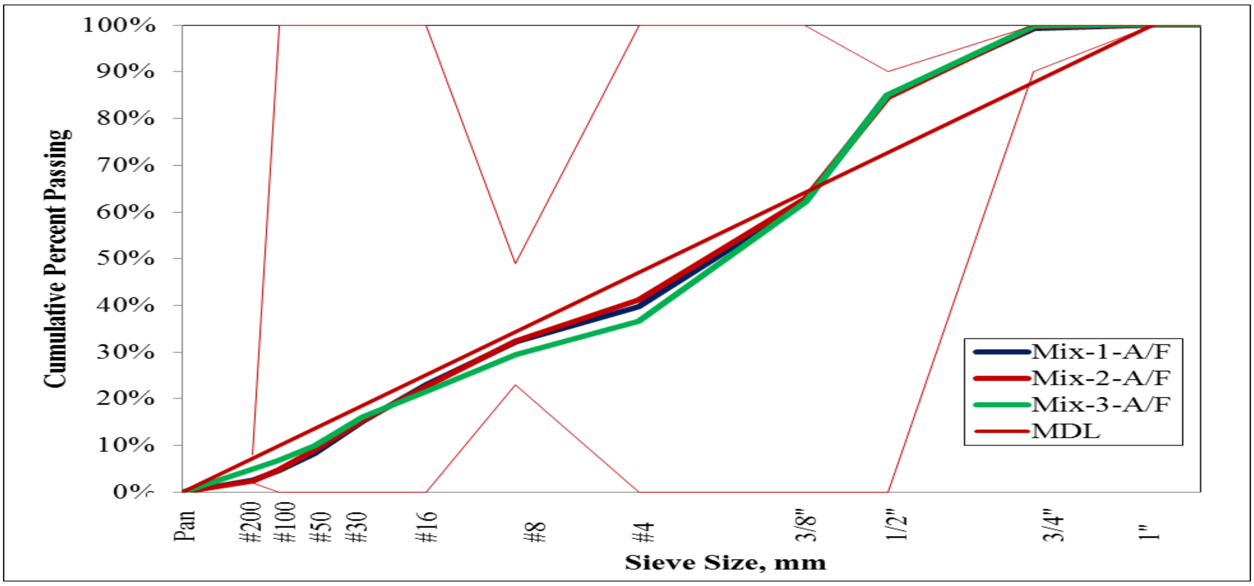

Figure 3: Gradation for the three mixes versus Maximum Density Line (MDL)

5.3 Master Curve

The following equation can model the master curve to allow data to be extrapolated beyond the testing range.

$$Log(E^*) = \delta + \frac{\alpha}{1+e^{\beta+\gamma(\log \text{red.}[freq])}} \qquad [2]$$

The terms δ and δ+α represent Log (E*)'s range and the terms β and γ shape the curve to fit the given situation

5.3.1 Mix 1

For lower temperatures or high frequencies, the actual DOB had higher E* values than in the full blending condition. At roughly 1.5 Hz, the master curve of actual DOB starts to be stiffer than that of full blending. As the frequencies go up, Mix-1-A is 18% stiffer than Mix-1-F. At the higher temperatures of the master curve the Mix-1-F is stiffer by 2%. Mix-1-A is stiffer at intermediate to lower temperatures.

5.3.2 Mix 2

Figure 3 shows the master curves of Mix 2 for actual and full DOB condition. At high frequencies, Mix-2-F is only 6% stiffer than Mix-2-A. At the intermediate frequencies Mix-2-A is stiffer, though Mix-2-F becomes stiffer again for the high temperatures.

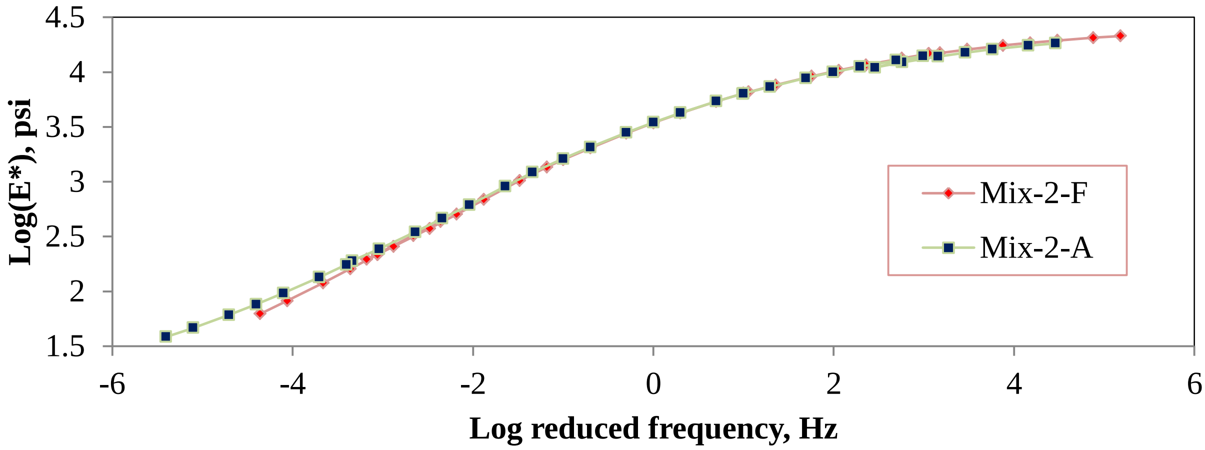

Figure 3: Master Curves for Mix-2-A and Mix 2-F at Reference Temperature of 20°C

5.3.3 Mix 3

The master curve for Mix-3-F is consistently above the master curve for Mix-3-A through the entire curve. The maximum difference between the stiffness values was at lower frequencies where Mix-3-A is about 20% lower than Mix-3-F.

6. MECHANISTIC EMPIRICAL PAVEMENT DESIGN GUIDE (MEPDG)

MEPDG software evaluates the major flexible pavement distresses, permanent deformation (rutting), and fatigue cracking (alligator and longitudinal cracking). The software uses traffic data, climatic data, and the structure of the pavement and asphalt layer properties to predict performance (ARA 2012). For the asphalt layer properties data, MEPDG has three levels of inputs with level 3 using default values for Performance Grades, level 2 using some binder properties and level 1 using dynamic complex modulus test results and binder information (ARA 2012).

As mentioned earlier, MEPDG will be used to predict pavement performance using measured dynamic complex modulus values to evaluate actual and 100% degree of blending. There are three design inputs in this program: traffic data, climate data, and structure design. The traffic data used for the MEPDG analysis was as follows:

- an initial two-way AADTT of 1700, operational speed is set at 60 mph
- 2 design lanes, 50% of trucks in the design direction and 25% of the trucks in the design lane.
- NJ-Newark Liberty International Airport climatic data and

- Water table depth of 20 feet will be used to represent New Jersey conditions.

The structure selected for analysis was determined from the four LTPP sections in New Jersey. The structure consists of four layers.

Layer 1: A 3” overlay. Level 1 analysis will be conducted.
Layer 2: A 6 inch asphalt concrete layer. The asphalt concrete layer uses a PG 76-22 binder with a basic gradation with: ¾”sieve with 0% CPR, 3/8” sieve with 17% CPR, #4 sieve with 36% CPR, and the #200 sieve with 8% CPP
Layer 3: A 7 inch crushed gravel layer, (default modulus values)
Layer 4: Semi-infinite A-1-a material subgrade layer (default modulus values)

6.1 Property of the Binder within the HMA Prepared in the Laboratory

MEPDG requires G* and phase angle binder properties for testing at level 1 or 2 analysis. To determine the properties of the binder in the hot mix asphalt with actual DOB, the binder could not be extracted and recovered from the mix itself because the extraction and recovery process would have blended all the RAP binder with the virgin binder. Therefore, instead the RAP binder was extracted and recovered separately then blended with the virgin binder according to their respective Degrees of blending using AASHTO T319 (AASHTO T319 2008). Table 2 is the blending ratios necessary to create the binder for each mix. Table 3 contains the G* and phase angle data at three temperatures required in MEPDG for the binders that were blended in the laboratory according to their respective DOB.

Table 2: Binder blending conditions for binder testing

RAP source	**DOB Condition**	**RAP Binder %**	**Virgin Binder %**
1	Actual (89.6)	20	80
	100%	22	78
2	Actual (90.0)	23	77
	100%	26	74
3	Actual (84.7)	19	81
	100%	21	79

Table 3: Binder testing results

Mix-DOB	**Mix-1-A**		**Mix-1-F**	
Temperature	G*	Phase Angle	G*	Phase Angle
70°C	5.84	69.9	5.59	70.4
76°C	3.07	72.4	2.89	72.7
82°C	1.63	75.2	1.56	75.6
Mix-DOB	Mix-2-A		Mix-2-F	
Temperature	G*	Phase Angle	G*	Phase Angle
70°C	5.54	71.0	7.04	69.9
76°C	2.90	73.5	3.63	72.2
82°C	1.54	76.3	1.98	74.8
Mix-DOB	Mix-3-A		Mix-3-F	
Temperature	G*	Phase Angle	G*	Phase Angle
70°C	5.75	70.3	6.03	70.2
76°C	3.02	72.7	3.12	72.6
82°C	1.60	75.5	1.69	75.3

6.2 MEPDG Predicted Performance

6.2.1 Mix 1

Figure 4 and 5 shows the predicted rutting and fatigue performance for Mix 1, and Table 4 summarizes the fatigue and rutting prediction at 10 years and 20 years, respectively. For both fatigue cracking and rutting, Mix-1-A performed better than Mix-1-F.

For fatigue cracking, the difference at 20 years was only 0.20%. The actual blend mix had less fatigue damage overall compared to the full blend mix. With only a 0.20% difference the effect on fatigue cracking between the two mixes is minimal. For rutting, the actual blend mix had less rutting then the full blend mix. The actual blend mix had about 0.01 inches less rutting when compared to the full blend mix. Overall, the effect on rutting is negligible for mix 1.

Table 4: Summary of Fatigue Cracking and Rutting at 20 years for Mix 1, 2 and 3

	Mix-1-A	**Mix-1-F**	**Diff. in Performance**	**Mix-2-A**	**Mix-2-F**	**Diff. in Performance**	**Mix-3-A**	**Mix-3-F**	**Diff. in Performance**
Fatigue Cracking, Maximum % Damage	6.13	6.33	-0.20	5.23	3.99	1.24	5.33	4.23	1.10
Rutting, Inches	0.17	0.17	-0.01	0.15	0.11	0.04	0.15	0.12	0.03

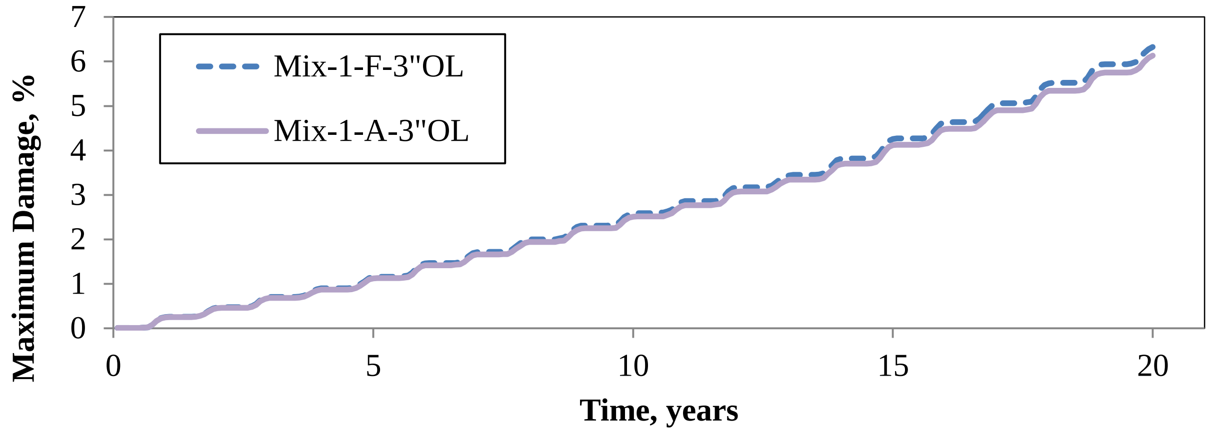

Figure 4: Predicted fatigue cracking performance for Mix 1.

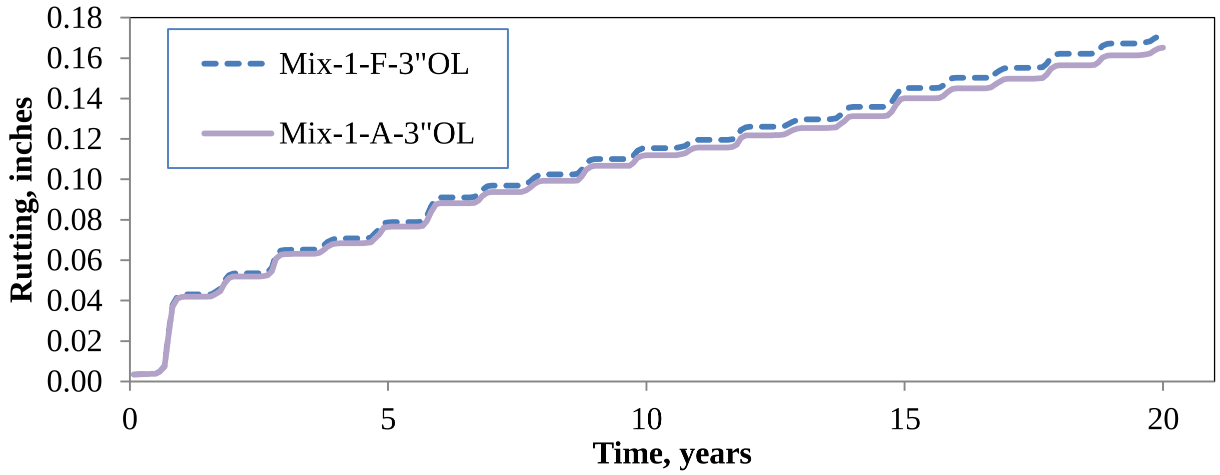

Figure 5: Predicted rutting performance for Mix 1

6.2.2 Mix 2

Table 4 summarizes the fatigue and rutting prediction at 20 years, respectively for Mix 2. For both fatigue cracking and rutting Mix-2-F performed better than the average Mix-2-A. The fatigue rutting difference was 1.24 between actual and full blending of Mix 2. The full blending outperformed the actual blending. The rutting difference had a max of 0.04 inches. Similar to mix one the rutting difference is minimal and is negligible. The analysis for Mix-2-A was an average where one sample performed worse than average and the other sample performed similarly to Mix-2-F. When the performance between the full and actual was compared, the full blending condition performed better.

6.2.3 Mix 3

Table 4 summarizes the fatigue and rutting prediction at 20 years for Mix 3. The fatigue cracking difference was 1.1%. The difference was about the same as it was for Mix 2 with a difference just over 1%. The full blending outperformed the actual blending for Mix 3. For rutting the maximum difference in rut depth was 0.03 inches, which is negligible in difference as it was for Mix-1.

6.2.4 Comparison between mixes

Using Table 4 to compare the predicted performance of each mix, Mix-2 performed the best with the least fatigue cracking and rutting, followed by Mix-3 and Mix-1 performing the worst. The three mixes can be ranked in order of quality with Mix-1 of the highest quality, as it had the tightest gradation amongst the three and was fractionated by the plant, followed by Mix-2, which had the next tightest gradation but was not fractionated, and Mix-3, with the most variable gradation and the plant did not fractionate. No trend developed between performance and DOB, possible because the DOB of each mix were similar. Quality of RAP as measured by sieve analysis and plant handling, either the plant fractionated or did not fractionate its RAP, once again did not show a trend among mixes. However, it was noticed that the difference in performance between full and actual blending conditions was less with the higher quality of RAP, following the quality rank mentioned previously.

7. SUMMARY OF FINDINGS

The findings based on the analysis at the 20 year mark are as follows

- RAP source 1, 2, and 3 were mixed with virgin binder PG 70-28, and the DOB was 89.6%, 90.0%, and 84.7%, respectively.
- RAP source 1 fractionated and had an overall well blended mix compared to sources 2 and 3 which had much finer gradations. Ranking Mix-1 of the highest quality among the 3 mixes, followed by Mix-2 and the Mix-3.
- Mix-1 had actual blending outperformed the full blending for both fatigue cracking and rutting.
- Mix-2 had the highest difference for fatigue cracking and rutting but the full blending performed better.
- Mix-3 followed a similar pattern to Mix-2 but had a small decrease in difference between the two blending assumptions.
- Rutting difference was minimal for all the Mixes and is overall negligible.

- The difference between blending conditions was minimized as quality of RAP increased, in regards to gradation uniformity.
- DOB and Quality of RAP showed no significant trends between mixes.

8. CONCLUSIONS

The conclusions based on the summary of findings above are:

1) Rutting is not significantly impacted by the assumed DOB
2) Fatigue cracking showed some significance between the Mixes.
3) DOB and Quality of RAP showed no significant trends between mixes.
4) However, as the quality of RAP, as measured by gradation uniformity, increases the difference between the full and actual blending conditions is minimized.

9. RECOMMENDATION

If the degree of blending is about 85% or higher, full blending could be assumed without compromising performance. This is especially true as the RAP gradations are more uniform and the RAP is fractioned. Classifying RAP by gradation uniformity may be a useful tool to determine if the DOB of a mix should be calculated; however, other parameters should be considered to determine the direct impact quality of RAP has on mix performance.

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