Investigation of Warm Mix Asphalt (WMA) Technologies and Increased Percentages of Reclaimed Asphalt Pavement (RAP) in Asphalt Mixtures

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Introduction

The objective of this research project was three-fold:

1. Evaluate the performance of SCDOT mixtures made with WMA technologies.
2. Evaluate the effect of increased RAP contents on SCDOT asphalt mixtures.
3. Evaluate the influence of WMA technologies on SCDOT asphalt mixtures made with RAP.

To accomplish the research objectives, the research was divided in to three separate phases, each addressing one of the three specific objectives. Additionally, an extensive literature review was conducted to establish the state-of-the-practice related to the use of WMA and RAP in asphalt mixtures.

The effects of WMA technologies on asphalt mixtures were evaluated for binders and mixtures. Two different WMA technologies (Evotherm™ and foaming) were selected for this study. Standard binder testing procedures were employed to characterize the effects of Evotherm™ on the binders. Only Evotherm™ was used for the binder portion of the study because Evotherm™ modifies the binder, while foaming does not modify the binder properties—it only adds micro-bubbles which are not a long-term effect on the binder.

Following the binder evaluation, SCDOT Surface Type B mix designs were conducted for HMA and each WMA technology using two binders and two aggregates. Once the mix designs were complete, the performance of each mixture was determined by testing the indirect tensile strength, tensile strength ratio, rutting resistance, and resilient modulus. In addition, the effect of the WMA technologies on the relative compactibiliy of the mixtures was also quantified as the number of gyrations required to achieve the specified height of 95 mm for the ITS specimens.

The effect of RAP content on asphalt mixtures was also investigated by studying the binders and the mixtures. Five different RAP contents were included in this research (0, 20, 30, 40, and 50% by weight of mixture). The properties of composite binders (virgin and RAP blends) were characterized using viscosity and $G^*/\sin\delta$ testing. Mix designs were also conducted for each of the 20 combinations included in the study. The performance properties (indirect tensile strength, tensile strength ratio, rutting resistance, and resilient modulus) of each mix design were then evaluated.

Finally, the combined effects of WMA and RAP were evaluated. This involved the testing 60 different mix designs in the same manner as the previous two phases.

Conclusions

Based on the results of this multi-faceted study, the following conclusions have been made related to the influence of WMA technologies and RAP on asphalt mixtures.

Warm Mix Asphalt

- ✓ The WMA additive Evotherm™, did not have a significant effect on the properties of the virgin binders (PG 58-28, PG 64-22, and PG 76-22) included in this study.
- ✓ The use of the WMA technologies included in this study (Evotherm™ and foaming) did not have a significant impact on the optimum binder content determined from the asphalt mix designs. Therefore, a WMA mix can be designed using the same binder content as an equivalent HMA mixture. This has also been concluded by others (Bonaquist 2011). The mixing and compaction temperatures for all WMA mixtures used in this portion of the study were 50°F lower than the HMA mix counterparts. This was based on the manufacturer's recommendation for Evotherm™.
- ✓ The WMA technologies generally decreased the indirect tensile strength of the mixtures compared to the HMA mixtures, but all of the mixtures exceeded the minimum allowable wet ITS value of 65 psi.
- ✓ The Evotherm™ additive had a compactibility enhancing effect on the mixtures compared to the other mixes.
- ✓ The rutting resistance of mixtures made with the WMA technologies included in this study was aggregate source dependent. The WMA mixes exhibited similar rut depths as the HMA mixes for one aggregate, while the WMA mixes had higher rut depths than the HMA mixes for the other.
- ✓ The effects of the WMA technologies on the resilient modulus were also aggregate source dependent. The foamed WMA mixtures generally had higher resilient modulus values for one aggregate source and the Evotherm™ WMA mixes generally had higher values for the other aggregate.

Mixtures Made with Reclaimed Asphalt Pavement (RAP)

- ✓ The addition of RAP binder to virgin binders had a stiffening effect on each of the binders and the trend was linear with respect to RAB binder content. When the high PG failure temperatures were plotted against RAP content, the slopes of the curves for the two PG 64-22 binders were nearly identical indicating that the RAP binder increased the stiffness of the composite binders in a similar fashion

regardless of the virgin binder source. It should be noted, however, that only two binder sources were used in this study. The replacement of the PG 64-22 binder with a softer PG 58-28 resulted in approximately a 4-5°C reduction of the upper PG failure temperature and the slope of this curve was steeper.

- ✓ The effects of RAP content on mix design properties are aggregate, binder, and RAP specific meaning that the mixture must be designed for each combination of materials to understand the effect of a particular RAP source on the mix properties. The reason for this is the variable nature of RAP materials, namely the RAP binder properties and the gradation of the RAP. In this research, the addition of higher RAP contents resulted in finer mixes which required a higher binder content to ensure that the dust-to-binder ratio was kept within the specified range. While this practice could increase the cost of the asphalt mix, it is possible to adjust the virgin fine aggregate contents to control the dust-to-binder ratio without increasing the mix cost.
- ✓ As the RAP content increased, the mixing and compaction temperature of the mixtures also increased to ensure adequate mixing and compaction of the mix.
- ✓ The RAP content did not have a distinct effect on the indirect tensile strength of the mixtures as the effect appears to be aggregate or RAP specific. When PG 58-28 binder was substituted for the PG 64-22 for the 40 and 50% mixtures, the ITS values did decrease, but the decrease was not detrimental. All of the mixtures had a wet ITS well above the minimum specified value of 65 psi.
- ✓ Susceptibility of the RAP mixtures to moisture induced damage was not an issue with the mixtures evaluated in this study as all of the mixes exhibited a TSR of greater than 85%. However, the mixtures with 0% RAP generally had higher TSR values than the RAP mixes. Additionally, no evidence of visible stripping was observed in any specimens.
- ✓ The rutting resistance of the mixes improved with the addition of RAP, but not necessarily with increasing RAP contents. The use of PG 58-28 binder in place of PG 64-22 binder in high RAP mixes (40 and 50% RAP) resulted in higher rut depths, but the rut depths were still significantly lower than the virgin mixes.
- ✓ An increase in RAP content generally increased the resilient modulus of the asphalt mixtures. The substitution of PG 58-28 for the PG 64-22 binder for the higher RAP mixes reduced the resilient modulus.

Mixtures Made with WMA and RAP

- ✓ The Evotherm™ WMA additive generally reduced the stiffness of the composite binders as indicated by the reduction in the upper PG failure temperature. The effect was more pronounced as the RAP content increased for the RTFO aged binders. It should be noted that the Evotherm™ composite binders were conditioned at a lower RTFO temperature (135°C) compared to the HMA binders (163°C), but this change was made to simulate the difference in actual production temperatures.
- ✓ The WMA technologies had no significant effect on the mix design properties indicating that the optimum binder content used for HMA mixes could also be used for identical WMA mixes. However, it would be advantageous to conduct the mix design for the WMA mixes and have field verification.
- ✓ There was no distinct effect of WMA technology on the indirect tensile strength of the mixtures made with RAP and the results appeared to be aggregate specific. For mixtures from aggregate source B, the Evotherm™ WMA mixtures had 3 out of 10 mixtures that had TSR values below than 85% and for the aggregate C mixtures, the foamed WMA mixes had 2 out of 10 mixes with TSR values below 85%. The lowest TSR value recorded in the study was 78% and there were no visible signs of stripping for any of the mixes. Additionally, all of the wet ITS values were well above the minimum value of 65 psi.
- ✓ WMA technologies may improve the compactibility of asphalt mixture at WMA temperatures when RAP is added, but the effect was significant for only one of the two RAP sources included in this study. This effect was quantified using the number of gyrations of the Superpave gyratory compactor to achieve the desired height and density of ITS specimens in the lab, which has not been correlated to field compaction.
- ✓ The effect of WMA technology on the rutting resistance of mixtures containing RAP was dependent on the aggregate source, RAP properties, and binder source. No significant trend was noticed across all mixtures. However, as the RAP content increased, the rut depth of WMA and HMA mixtures generally decreased.
- ✓ The resilient modulus of WMA mixtures containing RAP generally followed a similar trend as for HMA mixtures—the resilient modulus increased as the RAP content increased. Additionally, the WMA mixtures generally had similar or lower resilient modulus values than the HMA mixtures for a given RAP content with a few exceptions.

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