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LABORATORY EVALUATION OF COMPACTABILITY AND PERFORMANCE OF WARM MIX ASPHALT

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ABSTRACT

Warm mix asphalt (WMA) is the term used to describe the set of technologies that allow fabrication of asphalt mixtures at lower temperatures than those specified for conventional hot mix asphalt (HMA). This temperature reduction leads to advantages, compared to construction of HMA, that include energy savings, reduced emissions, and safer working conditions. However, WMA is a relatively new technology and several aspects are still under evaluation. This paper assesses some of these aspects including laboratory compactability and its relation to mixture design, and performance of WMA (i.e., permanent deformation and cracking resistance) fabricated with three WMA additives, namely Advera®, Sasobit®, and Evotherm®. Corresponding results showed better or equivalent laboratory compactability for the WMA, as compared to that of the HMA used as reference (or control-HMA), leading to smaller optimum asphalt contents selected based on a specific target density (i.e., 96%). In terms of performance, inclusion of the WMA additives led to decrease the mixture resistance to permanent deformation, although the mixture resistance to cracking can remain similar or even improve as compared to that of the control-HMA.

KEYWORDS: warm mix asphalt (WMA); hot mix asphalt (HMA); compactability; mix design; performance; pavements.

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EVALUACIÓN DE LABORATORIO DE LA COMPACTABILIDAD Y EL DESEMPEÑO DE MEZCLAS ASFÁLTICAS TIBIAS

RESUMEN

Mezclas asfálticas tibias (MAT) es el término empleado para describir el conjunto de tecnologías que permiten la fabricación de mezclas asfálticas a menores temperaturas que las especificadas para mezclas asfálticas en caliente (MAC) convencionales. Esta reducción de temperatura conlleva ventajas, comparadas con la construcción de MAC, que incluyen ahorros de energía, menores emisiones y condiciones de trabajo más seguras. Sin embargo, las MAT son tecnología relativamente nueva y aun están en evaluación diferentes aspectos. Este artículo evalúa algunos de estos aspectos incluyendo compactabilidad y su relación con el diseño de mezcla y desempeño de MAT en laboratorio (i.e., deformación permanente y resistencia a la fisuración), fabricadas con tres modificadores tipo MAT, específicamente Advera®, Sasobit® y Evotherm®. Los resultados correspondientes mostraron que la compactabilidad en laboratorio para las MAT es equivalente o mejor que la obtenida para la MAC empleada como referencia (o mezcla de control), conllevando a menores contenidos óptimos de asfalto seleccionados con base en una densidad de diseño específica (i.e., 96%). En términos de desempeño, la inclusión de los aditivos tipo MAT generó la reducción de la resistencia de la mezcla ante deformación permanente, aunque su resistencia al agrietamiento podría permanecer igual o incluso mejorar en comparación con aquella de la MAC.

PALABRAS CLAVES: mezcla asfáltica tibia; mezcla asfáltica en caliente; compactabilidad; diseño de mezcla; desempeño; pavimentos.

AVALIAÇÃO DE LABORATÓRIO DA COMPACTABILIDADE E O DESEMPENHO DE MISTURAS ASFÁLTICAS QUENTES

RESUMO

Misturas asfálticas mornas (MAT) é o termo empregado para descrever o conjunto de tecnologias que permitem a fabricação de misturas asfálticas a menores temperaturas que as especificadas para misturas asfálticas em quente (MAC) convencionais. Esta redução de temperatura implica vantagens, comparadas com a construção de MAC, que incluem poupanças de energia, menores emissões e condições de trabalho mais seguras. No entanto, as MAT são tecnologia relativamente nova e ainda estão em avaliação diferentes aspectos. Este artigo avalia alguns destes aspectos incluindo compactabilidad e sua relação com o desenho de mistura e desempenho de MAT em laboratório (i.e., deformação permanente e resistência à fisuración), fabricadas com três modificadores tipo MAT, especificamente Advera®, Sasobit® e Evotherm®. Os resultados correspondentes mostraram que a compactabilidad em laboratório para as MAT é equivalente ou melhor que a obtida para a MAC empregada como referência (ou mistura de controle), implicando a menores conteúdos óptimos de asfalto seleccionados com base numa densidade de desenho específica (i.e., 96%). Em termos de desempenho, a inclusão do aditivos tipo MAT gerou a redução da resistência da mistura ante deformação permanente, ainda que sua resistência ao agrietamiento poderia permanecer igual ou inclusive melhorar em comparação com aquela da MAC.

PALAVRAS-CÓDIGO: quente de asfalto mix (WMA); mistura de asfalto quente (HMA); compactabilidade; design mix; performance; calçadas.

1. INTRODUCTION

Warm mix asphalt (WMA) are termed the technologies engineered to reduce the production and construction temperatures (i.e., compaction) of asphalt mixtures as compared to the temperatures required for these activities in conventional hot mix asphalt (HMA). The WMA technologies currently available permit temperature reductions in the range of 20 °C to 50 °C compared to the temperature of corresponding HMA (Button, Wimsatt and Estakhri, 2007; Yan *et al.*, 2010). Among other advantages, these temperature reductions have positive environmental effects (e.g., reduced fuel use, and generation of fumes and emissions during mixture production), engineering effects (less potential for asphalt aging), and economical effects (e.g., less plant wear and extended paving season) (Button, Wimsatt and Estakhri, 2007; Estakhri, Button and Alvarez, 2010; Haggag, Mogawer and Bonaquist, 2011; Silva *et al.*, 2010; You and Goh, 2008). During the last decade, these advantages have led to an important growth all around the world in the development of WMA technologies (Button, Wimsatt and Estakhri, 2007; Haggag, Mogawer and Bonaquist, 2011), research for evaluation of WMA produced in both the laboratory and field (Button, Wimsatt and Estakhri, 2007; Hurley and Prowell, 2006), and corresponding implementation of field projects (Button, Wimsatt and Estakhri, 2007; Yan *et al.*, 2010).

Despite these positive achievements, WMA is still a new technology and several aspects require further assessment to fully validating its application as an alternative to conventional HMA. Overall, the expected response and performance of WMA should be similar or better than that of HMA. Otherwise, the environmental and economical benefits pursued may not be truly obtained in the life-cycle period of the corresponding in service pavement structure.

In this context, previous research concluded that the addition of the WMA additives: Evotherm® (Hurley and Prowell, 2006), Sasobit® (Hurley and Prowell, 2005b), and Advera® (Aspha-Min®) (Hurley and Prowell, 2005a) led to improve the mixture compactability. This parameter was assessed in terms of the total air voids (AV) content of WMA specimens, compacted using the Superpave Gyratory Compactor (SGC), as compared to HMA specimens. This evaluation showed reductions of the total AV content in the range of 0.65 to 1.4% in WMA fabricated using the three WMA additives previously indicated. In addition, previous research (Hurley and Prowell, 2005a; Hurley and Prowell, 2005b; Hurley and Prowell, 2006) explored the possibility of decreasing the optimum asphalt content (based on the reduced total AV content exhibited by SGC compacted WMA specimens) of WMA as compared to HMA. However, additional research was suggested to better assess this possibility.

In addition, previous laboratory performance evaluations of WMA (i.e., Evotherm®, Sasobit®, and Advera®) (Hurley and Prowell, 2005a; Hurley and Prowell, 2005b; Hurley and Prowell, 2006; Zelelew, Paugh and Corrigan, 2011)—conducted using the Hamburg Wheel Tracking test (HWTT)—also suggested reduced resistance to permanent deformation of the WMA as compared to HMA. Despite these previous research efforts, there is still a need to explore the compactability, selection of optimum asphalt content, and performance of WMA to better support the application of these WMA technologies in future projects.

Consequently, this paper focuses on evaluating aspects related to the laboratory compactability, mixture design (i.e., selection of the optimum asphalt content), and laboratory performance (resistance to both permanent deformation and cracking) of WMA. The mixtures evaluated were fabricated with three WMA additives, namely Advera®, Sasobit®, and Evotherm®, and compared to a control-HMA (fabricated using the same asphalt and aggregate included in the WMA).

The Sasobit® corresponds to an asphalt modifier agent designed to reduce the asphalt viscosity, while the Advera®, as a synthetic zeolite hydro-thermally crystallized, is a foaming based technology (Button, Wimsatt and Estakhri, 2007). At temperatures above 85 °C to 182 °C the zeolite releases 21% water (by mass), which foams the asphalt to enhance the aggregate coating and increase workability. The Evotherm® (DAT—Dispersed Asphalt Technology—) corresponds to a chemical package, distributed as an emulsion type product with a high asphalt residue, that includes adhesion promoters and other chemical products to enhance aggregate coating (Estakhri *et al.*, 2009).

2. METHODS AND MATERIALS

Two asphalt mixtures, fabricated in the laboratory with limestone (Mixture 1) and sandstone (Mixture 2) aggregate type and a neat PG 6422 asphalt, were evaluated in this study. In addition, a plant-produced mixture (Mixture 3; fabricated with limestone and a PG 64-22 asphalt) was sampled and subsequently reheated to the compaction temperature —with no additional oven curing allowed— and immediately compacted in the laboratory. The mixtures complied with the current Texas Department of Transportation (TxDOT) mix design procedure for dense-graded HMA (TxDOT, 2011) and corresponding material specifications (TxDOT, 2004). The aggregates met the specifications for the dense graded Type C-HMA (mixtures 1 and 2) and Type DHMA (mixture 3). In this study, the mixtures 3 and 1 were used, respectively, to evaluate the mixture compactability and mixture design (i.e., selection of the optimum asphalt content). In addition, the mixtures 1 and 2 were used to analyze the WMA performance (i.e., permanent deformation and cracking resistance).

The mixtures were produced in the laboratory (Mixtures 1 and 2) and field (Mixture 3) as a conventional HMA (control-HMA) and using the three WMA additives (Advera®, Sasobit®, and Evotherm®). The three WMA additives were added as recommended by the manufacturers in the following proportions: Evotherm® at 0.5% by weight of the asphalt, Advera® at 0.5% by weight of the mix, and Sasobit at 3% by weight of the asphalt. Previous research reported details on the characteristics, properties, and handling of these WMA additives (Beltrán *et al*., 2011; Button, Wimsatt and Estakhri, 2007; Estakhri, Button and Alvarez, 2010; Silva *et al*., 2010).

In this study, the mixture compactability was assessed in terms of both the: (*i*) absolute value of the slope of the compaction curve determined using the SGC (or slope of compaction) and (ii) number of the SGC gyrations required to achieve the target total AV content (or AV content). The slope of compaction was computed as the ratio of the total change in the AV content (registered by the SGC) to the number of gyrations required to induce that change in the AV content. These indexes of compactability were evaluated for the plant mixtures (mixture 3: WMA and control-HMA) reheated in the laboratory and compacted at: 79 °C, 93 °C, 104 °C, and 121 °C. The first and last temperatures are indicative, respectively, of the cessation temperature and the specified temperature for field compaction of the control-HMA. The two intermediate temperatures (93 °C and 104 °C) are potential temperatures for field compaction of WMA. In addition, specimens of two heights (62 ± 2 and 115 ± 5 mm) were compacted at the four temperatures before specified to investigate the effect of the specimen height on the mixture compactability using the SGC.

The analysis of WMA mix design (selection of the optimum asphalt content) included assessment of the total AV content —or corresponding density— of specimens compacted using the Texas gyratory compactor (TxGC) in accordance with the test method Tex-206-F (TxDOT, 2011) as specified by TxDOT (TxDOT, 2011). This evaluation included TxGC specimens compacted at 89 °C, 104 °C, and 121 °C for both the control-HMA and each WMA.

The mixture laboratory performance was evaluated by applying both the HWTT —evaluation of permanent deformation resistance— and Overlay test (OT) —evaluation of cracking resistance— in accordance with the test methods Tex-242-F and Tex-248-F, respectively (TxDOT, 2011). Specific testing procedures are documented elsewhere (TxDOT, 2011). The specimens required for the evaluation of performance were compacted using the SGC (test method Tex-241-F (TxDOT, 2011)). The HWTT was conducted on mixtures fabricated in the laboratory under the following conditions: (*i*) 2 h oven curing at 121 °C for the control-HMA and at 104 °C for the WMA and (*ii*) 4 h oven curing at 135 °C for both the control-HMA and WMA. These conditions were applied to appraise the curing and short-term aging effect on the WMA performance. After these curing conditions, the SGC specimens were compacted at 121 °C and 104 °C for the control-HMA and WMA, respectively. The specimens used for the OT were compacted at 121 °C and 104 °C for the control-HMA and WMA, respectively, after oven curing the mixtures at the compaction temperature for 2 h.

3. RESULTS AND ANALYSIS

This section presents results in terms of the WMA compactability, mix design (i.e., selection of the optimum asphalt content), and laboratory performance.

3.1. Warm mix asphalt (WMA) compactability

Figure 1 shows four typical compaction curves obtained for the control-HMA and WMA based on the information registered by the SGC. In all cases, the target total AV content of the specimens was 7% and they were compacted to 62 ± 2 mm in height. This type of curves was used to subsequently computing the slope of compaction index. Higher slope of compaction values imply improved efficiency in the compaction process, i.e., higher reduction of the total AV content per SGC gyration.

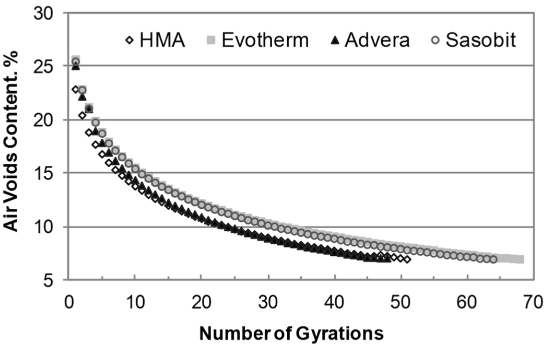
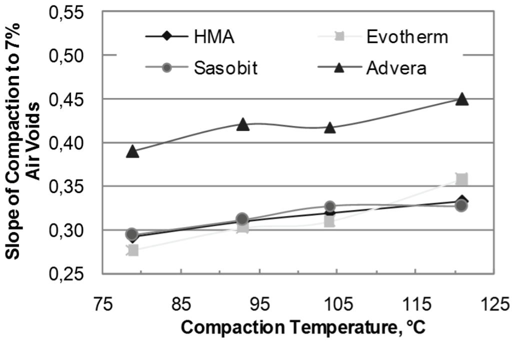
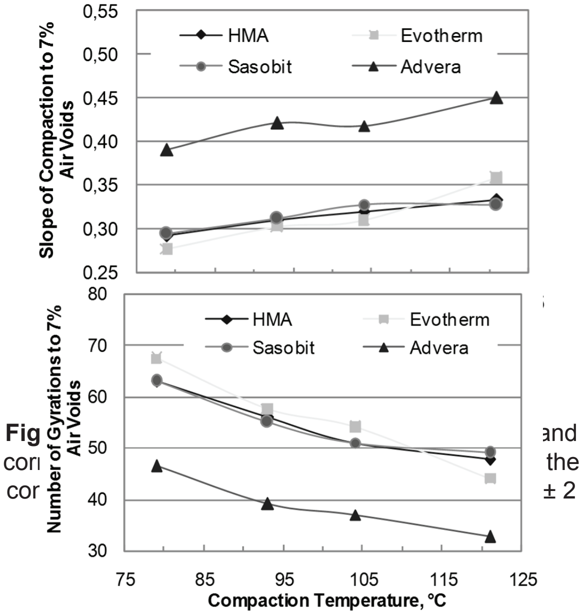


Figure 1. Typical compaction curves obtained from the SGC

Figure 2(a) and 2(b) show, respectively, the mean values of the slope of compaction and coefficient of variation (COV) calculated for three replicate specimens of each the control-HMA and WMA. Figure 3 shows the same statistics for the number of gyrations registered in the SGC for compaction of these specimens. In addition, for both indices of compactability (slope of compaction and number of SGC gyrations), the null hypothesis of equal means determined for the control-HMA, Advera®-, Sasobit®-, and Evotherm®-WMA was evaluated by applying Analysis of Variance (ANOVA) at a significance level of 0.05. In addition, the Tukey's honestly significant difference, Tukey's b, and Bonferroni *t* test for multiple comparisons between means were applied for identification of significantly different means. These analyses were performed using the SPSS Statistics 16.0 software.



(a)



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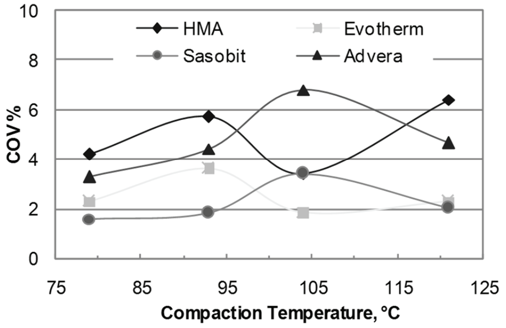


(b)

Figure 2. Mean values of number of gyrations (a) and corresponding coefficient of variation (COV) (b) for both the control-HMA and WMA compacted specimens 62 ± 2 mm in height

The statistical analysis conducted led to conclude that there are not significant differences for the mean values of both the slope of compaction and number of gyrations determined for the control-HMA, Sasobit®-WMA, and Evotherm®-WMA. However, significant differences were reported for the mean values (slope of compaction and number of gyrations) of the Advera®WMA as compared to the control-HMA, Sasobit®-WMA, and Evotherm®-WMA.

These results (Figures 2(a) and 3(a)) suggest better laboratory compactability for the Advera®-WMA as compared to the control-HMA and the other WMA studied and equivalent compactability for the control-HMA, Sasobit®WMA, and Evotherm®-WMA. This response was consistently obtained in the range of temperatures analyzed. The only exception corresponds to the number of gyrations for compaction at 121 °C, where the analyses showed equivalent mean values for the couples: (*i*) control-HMA and Sasobit®WMA and (*ii*) controlHMA and Evotherm®-WMA. However, significant differences in the mean values were reported again for the Advera®WMA as compared to the Control-HMA and the other two WMA.

A COV value of 10 % was arbitrarily used in previous research as the reference benchmark for the variability of total AV content of dense-graded HMA (Medani, Huurman and Molenaar, 2004). The same benchmark was adopted for the analysis of mixture compactability in this study. Consequently, data presented in the Figures 2(b) and 3(b) provide evidence of the reduced variability in the indexes selected to assess the mixture compactability. Comparable COV values for the slope of compaction of WMA and control-HMA were reported. In addition, the COV values obtained for the slope of compaction are comparable to those reported for the number of gyrations for compaction. For these two compactability indexes, the variability reported for both the Evotherm® and Sasobit® tend to be smaller than that of the control-HMA (Figures 2(a) and 3(b)).

Data shown in Figure 4 include the mean values of slope of compaction for: (*i*) two replicate specimens compacted to 115 ± 5 mm in height and a target total AV content of 7% and (*ii*) three replicate specimens compacted to 62 ± 2 mm in height and a target total AV content of 7% (previously reported in the Figure 2(a)). The comparison of the slope of compaction values presented in this figure suggests that the SGC compactability of the control-HMA and WMA is dependent of the compacted specimen height. The higher SGC specimens—115 mm—revealed to have better compactability as assessed in terms of the higher values of slope of compaction. These tall specimens are used for mix design purposes, whereas the short—62 mm in height—specimens are compacted for performance evaluation (i.e., HWTT).

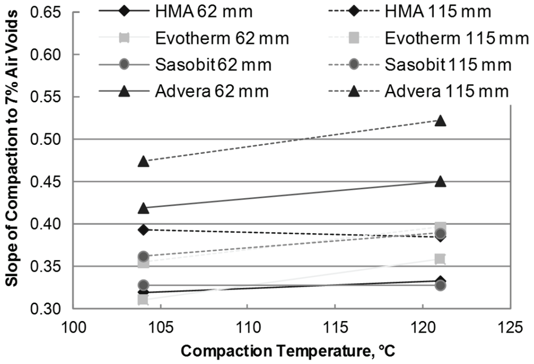


Figure 4. Mean values of slope of compaction for the control-HMA and WMA compacted specimens (62 ± 2 and 115 ± 5 mm in height)

These differences in compactability are consistent with some discrepancies in the mixture internal structure (i.e., vertical distribution of both total AV content and AV size) of WMA reported in previous research (Álvarez, Carvajal and Reyes, 2012; Álvarez, MacÍas and Fuentes, 2012). Based on the differences reported, the same research recommended avoiding direct compaction of SGC short specimens for laboratory performance evaluation (i.e., HWTT) and suggested production of this short (62 mm in height) specimens by cutting the top and bottom portions of the 115 mm in height compacted specimens.

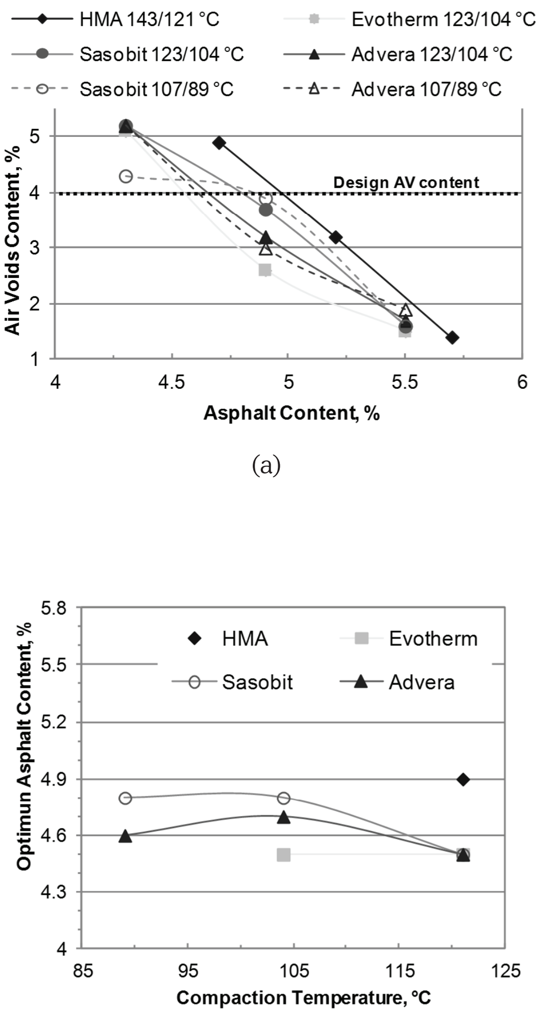
In summary, as compared to conventional HMA, the data presented in the Figures 1 to 4 supported the hypothesis of better compactability attained through the use of Advera®-WMA and equivalent compactability obtained through the use of both Sasobit®- and Evotherm®WMA. Thus, based on the laboratory mixture compactability evaluation conducted, reduction of the compaction temperature (as compared to the HMA compaction temperature) through incorporation of these WMA additives showed to be viable. Additional research should be conducted to further assess the three WMA additives in WMA mixtures fabricated using different asphalt sources and aggregate combinations to determine potential advantages in WMA mixture compactability as compared to the use of the conventional HMA.

3.2. Warm mix asphalt (WMA) mix design (selection of the optimum asphalt content)

Figure 5(a) shows the mixture design curves for the control-HMA and WMA mixed and compacted at different temperatures—as indicated in the legend—. The total AV content reported in this figure was assessed on TxGC compacted specimens. Based on the data reported in the Figure 5(a), Figure 5(b) shows the summary of corresponding optimum asphalt content values selected at a design total AV content of 4% (96% density) for all the mixtures. It should be noted that the Figure 5(a) does not include the data of WMA compacted at 121 °C to avoid losing readability in the figure.

Based on the Figure 5(a), at a constant asphalt content (e.g., 5%), the total AV content of all the WMA specimens is smaller than that obtained for the control-HMA, which reinforces the previous conclusion offered of better or equivalent compactability for the WMA —compacted at lower temperatures than the control-HMA— as compared to the control-HMA. In addition, the smallest total AV content values, for a specific asphalt content, were obtained for the Evotherm®-WMA, which suggests that this mixture exhibited the best compactability when compacted using the TxGC. Additional research shall be conducted to further explore the compactability of WMA using the TxGC and compare it with the mixture compactability evaluated using the SGC data.

An alternative analysis of Figure 5(a), based on a constant total AV content equal to the design AV content (i.e., 4%), leads to conclude that the optimum asphalt content selected for all the WMA is smaller than that obtained for the control-HMA (see Figure 5(b)). For the mixtures analyzed the reduction in the optimum asphalt content of WMA, as compared to that of the control-HMA, can range between 2% (for Sasobit®-WMA) and 8.2% (for Evotherm®-WMA).



(a)

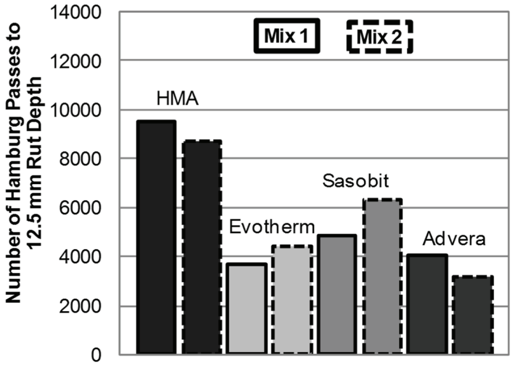
(b)

Figure 5. Mixture design curves (a) and selected optimum asphalt content (b) for the control-HMA and WMA

Therefore, selection of the optimum asphalt content of WMA based on volumetric properties (i.e., density or corresponding total AV content) can lead to smaller optimum asphalt content values than those used in the reference HMA. This can be contemplated as an additional advantage of WMA over HMA. However, this asphalt content reduction is not recommended without further analysis of the corresponding implications in terms of mixture durability and performance (i.e., fatigue resistance and moisture damage susceptibility). This analysis was out of the scope of this research.

3.3. Warm mix asphalt (WMA) laboratory performance

Results of the laboratory performance evaluation conducted based on both the HWTT and OT results are subsequently discussed. Figure 6 shows the HWTT results for mixtures subjected to 2 h and 4 h oven curing (on loose mixture). These results are expressed as the number of load passes required to accumulate a rut depth of 12.5 mm in the HWTT. A higher number of passes is, therefore, indicative of higher resistance to permanent deformation. In addition, current TxDOT specification for dense-graded HMA, fabricated using a PG-64 asphalt binder, is 10 000 load cycles for the HWTT conducted at 50 °C and 12.5 mm rut depth (TxDOT, 2004). A particular specification for evaluation of WMA using the HWTT is not available at this time.



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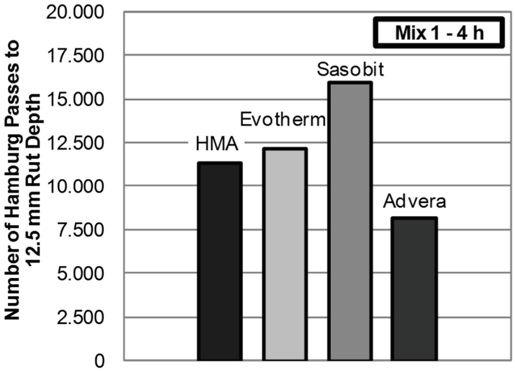

(b)

Figure 6. HWTT results for the control-HMA and WMA subjected to oven curing for 2 h (a) and 4 h (b)

Data presented in the Figure 6(a) suggests that oven cured (at 104 °C —compaction temperature—) WMA exhibit reduced resistance to permanent deformation as compared to the oven cured (at 121 °C —specified compaction temperature—) control-HMA. These results are coincident with those reported in previous research (Hurley and Prowell, 2005a; Hurley and Prowell, 2005b; Hurley and Prowell, 2006; Zelelew, Paugh and Corrigan, 2011) based on the assessment of other types of dense-graded asphalt mixtures. The ranking of resistance to permanent deformation for mixtures 1 and 2 also changed for the WMA as compared to that registered for the control-HMA. For example, the mix 1 showed higher resistance to permanent deformation than mix 2 for both the control-HMA and Advera®-WMA, while the opposite is true for both the Evotherm®- and Sasobit®-WMA. These results provide evidence of the particular response of each WMA additive that should be expected when using these additives with different aggregate and asphalt combinations.

Data presented in the Figure 6(b) suggest that oven curing the WMA at high temperature and for longer periods (4 h at 135 °C) resulted in higher resistance to permanent deformation. The relative increment in the number of HWTT passes to failure induced by this oven curing process, as compared to the 2 h conditioning process, was higher for the WMA than for the control-HMA. This modification in the HWTT results was expected based on the stiffening process generated on the asphalt due to accelerated oxidative aging induced by the curing process.

Figure 7 shows the results of the OT (cycles to failure) conducted on mixtures subjected to 2 h oven curing at the compaction temperature. A higher number of cycles to failure (i.e., longer cracking life) is indicative of higher resistance to fracture (Zhou and Scullion, 2006). Previous research (Zhou, Hu and Scullion, 2006)TX</pub-location><publisher>Texas Transportation Institute-Texas A&M University</publisher><isbn>Report No. FHWA/TX-06/0-5123-1</isbn><urls></urls></record></Cite></EndNote> proposed 300 cycles as pass/fail criterion for dense-graded HMA. As shown in the Figure 7, the WMA specimens of the evaluated mixes exhibited similar (i.e., Sasobit®) or better (i.e., Evotherm® and Advera®) cracking resistance than the control-HMA specimens. As previously discussed for the HWTT results, the relative ranking of cracking resistance for mixtures 1 and 2 also changed for the different WMA evaluated compared to the ranking registered for the control-HMA.

Results of both the HWTT and OT suggest that incorporation of the WMA additives to reduce the compaction temperature can lead to a reduction in the resistance to permanent deformation, as compared to the control-HMA, while the mixture resistance to cracking remains equivalent or even improves. As discussed by Alvarez et al. (Alvarez, Carvajal and Reyes, 2012), close internal structures (analyzed in terms of the AV characteristics) were computed for both WMA (Advera®, Sasobit®, and Evotherm®) and corresponding control-HMA specimens compacted using the SGC.

Therefore, the aforementioned discrepancies in performance for the WMA and control-HMA can be mainly related to differences in the properties, components, and addition technique of the different WMA additives that lead to differences in the asphalt binder rheological properties during mixing, after curing (i.e., during compaction), and probably along the mixture service life. Modification of the quality of adhesion for the aggregate-asphalt interfaces —with incidence on the mixture resistance to cracking— can also occur due to the incorporation of WMA additives. Therefore, additional research is recommended to address these aspects and further explain the differences in performance, macroscopically evaluated in terms of the HWTT and the OT, of HMA and WMA.

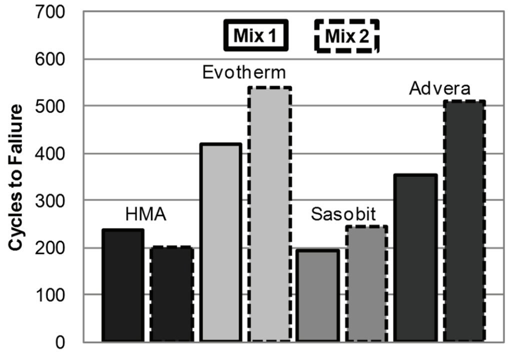

Figure 7. OT results for both control-HMA and WMA

4. CONCLUSIONS AND RECOMMENDATIONS

This paper assessed the mixture compactability, design (i.e., selection of the optimum asphalt content), and laboratory performance of warm mix asphalt (WMA) fabricated with three different types of WMA additives, namely Advera®, Sasobit®, and Evotherm®. Corresponding results were analyzed by comparison with a control-HMA mixture. Based on the results obtained and the analysis conducted the following conclusions can be offered:

Assessment of both the slope of compaction and number of SGC gyrations required to complete the laboratory compaction showed that, at reduced compaction temperature compared to that specified for the HMA, the WMA exhibited better or equivalent compactability than the control-HMA.

Selection of the optimum asphalt content of WMA based on volumetric properties (i.e., total AV content or corresponding density) led to smaller optimum asphalt content values than those determined for the control-HMA. These results were a consequence of the improved compactability exhibited by the WMA specimens produced using the TxGC. However, reduction of the optimum asphalt content for WMA was not recommended at this time. Additional research is still required to assess the convenience of using in WMA either the reduced optimum asphalt content obtained based on the volumetric criteria, or keep the optimum asphalt content determined for the HMA (i.e., without using the WMA additive).

The performance assessment conducted suggested that the incorporation of WMA additives to reduce the compaction temperature of the asphalt mixtures can decrease the mixture resistance to permanent deformation —as assessed by the HWTT—, although the mixture resistance to cracking, evaluated using the OT, can remain similar or can even improve. Additional research is still required to assess additional aspects related to the WMA performance and better characterize the expected performance.

The results obtained in this research are indicative of the response and performance of the WMA evaluated. Since the response and performance of WMA not only depends of the WMA additive used, but it is also a function of the asphalt mixture constituents, different results can be expected for different material combinations (asphalt, mineral filler, coarse aggregates, and WMA additives). Therefore, characterization of WMA should be specific and adjusted to the local conditions of the projected application. In addition, future research is required to assess the field performance of WMA and corresponding control-HMA mixtures to validate the laboratory responses gathered in this study.

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DISCLAIMER

The contents of this paper reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein and do not necessarily reflect the official views or policies of any agency or institute. This paper does not constitute a standard, specification, nor is it intended for design, construction, bidding, contracting, or permit purposes. Trade names were used solely for information and not for product endorsement.

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