Effects of Compaction Temperature on Volumetric Properties of Rubberized Mixes Containing Warm-Mix Additives

Chandra K. Akisetty[1]; Soon-Jae Lee[2]; and Serji N. Amirkhanian[3]

Abstract: The warm-mix asphalt (WMA) refers to technologies that allow a significant reduction of mixing and compaction temperatures of asphalt mixes through lowering the viscosity of asphalt binders. Several studies have been carried out evaluating the properties of WMA, and it is found that warm mix additives work in different ways either in reducing the viscosity of the binder or allowing better workability of the mix at lower temperatures. In terms of rubberized asphalt mixtures, they are generally produced and compacted at higher temperatures than conventional mixtures, based on the field experience. If the technologies of warm-mix asphalt are incorporated, it is expected to reduce the mixing and compaction temperatures of rubberized asphalt mixtures to those of conventional mixtures. This study was initiated to investigate the effects of compaction temperature on rubberized mixes containing the warm mix additives. For this, four Superpave mix designs for two asphalt binders and two aggregate sources were conducted to determine optimum asphalt contents. Warm rubberized mixes were produced using two of the available processes. A total of 192 specimens (4 mix types: control mix, rubberized mix, warm rubberized mix 1, and warm rubberized mix 2×2 aggregate sources $\times 4$ compaction temperatures: 97, 116, 135, and $154^\circ\mathrm{C} \times 6$ repetitions) were fabricated using Superpave gyratory compactor. Volumetric properties of the specimens were evaluated. The results showed that the warm mix processes were effective to improve the volumetric properties of rubberized mixes at a certain range of compaction temperatures.

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CE Database subject headings: Soil compaction; Temperature effects; Material properties; Rubber; Admixtures.

Introduction

Background

Approximately 300 million scrap tires are generated each year in the United States (Putman 2005; Shen et al. 2007). The disposal of these scrap tires has been a serious issue for many reasons (e.g., lack of landfill space, environmental issues, etc.). Previous studies indicated that rubberized binders could produce asphalt pavements that would result in decreased traffic noise, reduced maintenance costs, and improved resistance to rutting and cracking (Huang et al. 2002; Lee et al. 2008; Liang and Lee 1996; Ruth and Roque 1995; Shen et al. 2005). From these benefits, there is an increasing interest in using rubberized binders in hot-mix asphalt (HMA) pavements in some states in the United States and other countries (Bahia and Davies 1994; Lee et al. 2006).

The warm-mix asphalt (WMA) refers to technologies that allow a significant reduction of mixing and compaction temperatures of asphalt mixes through lowering the viscosity of asphalt binders. Reduced mix production and paving temperatures would decrease the energy required to produce hot-mix asphalt, reduce emissions and odors from plants, and make better working conditions at the plant and the paving site (Hurley and Prowell 2005a,b, 2006; Romier et al. 2006; Gandhi and Amirkhanian 2007; Kristjansdottir et al. 2007; Wasiuddin et al. 2007; Prowell et al. 2007).

Rubberized asphalt mixes are generally compacted at a higher temperature than conventional mixes based on the field experience (Amirkhanian and Corley 2004). With lower compaction temperatures, the rubberized mixes might result in several problems, such as inadequate volumetric properties (e.g., high % air void and low % VFA) and poor short- and long-term performance. If the technologies of warm-mix asphalt are incorporated into the mixes, optimum mixing and compaction temperatues of the rubberized mixes are expected to decrease and be comparable to those of conventional mixes.

Among a number of warm-mix additives, this study evaluated two additives, Aspha-min and Sasobit. Aspha-min is sodium–aluminum–silicate that is hydrothermally crystallized as a very fine powder. It contains approximately 21% crystalline water by weight. By adding it to an asphalt mix, the fine water spray is created as all the crystalline water is released, which results in volume expansion in the binder, therefore increasing the workability and compactability of the mix at lower temperatures (Eurovia Services 2008). Sasobit is a long chain of aliphatic hydrocarbons obtained from coal gasification using the Fischer–Tropsch process. After crystallization, it forms a lattice structure in the binder that is the basis of the structural stability of the binder containing Sasobit (Sasol Wax 2008). More detail information regarding the two additives can be found in other reports (Hurley and Prowell 2005a,b).

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Table 1. Crumb Rubber Gradation

	Ambient CRM		
Sieve No. (μm)	% retained	% cumulative retained	% cumulative passed
30 (600)	0	0	100
40 (425)	9.0	9.0	91.0
50 (300)	31.9	40.9	59.1
80 (180)	32.9	73.8	26.2
100 (150)	7.6	81.4	18.6
200 (75)	18.6	100.0	0

Research Objective and Scope

This study investigated the volumetric properties of crumb rubber-modified (CRM) asphalt mixtures containing warm mix additives as a function of compaction temperature using the Superpave gyratory compactor (SGC). Four mixtures, including control (PG 64-22) and 10% rubber-modified binders and two aggregate sources, were designed using Superpave specifications. The mixtures were compacted at four temperatures of 97, 116, 135, and 154°C. The volumetric properties of these mixtures were evaluated.

Materials and Test Program

Materials

Two binders (control PG 64-22 and CRM binders) were used in this study. The control binder was a mixture of several sources that could not be identified by the supplier. One type of rubber, which was produced by mechanical shredding at ambient temperature, was used with a gradation as shown in Table 1. To ensure that the consistency of the rubber was maintained throughout the study, only one batch of crumb rubber was used in this study. CRM binders were made by adding a specified amount of rubber (10% by binder weight) to the control binder, mixing with a stirrer (700 rpm) at 177°C for 30 min (Shen et al. 2006; Lee et al. 2008). This mixing condition matches the field practices used in South Carolina to produce field CRM mixtures. The properties of all the binders are listed in Table 2.

Two aggregate sources were used for preparing samples (Table 3). Hydrated lime, used as an antistrip additive, was added at a rate of 1% by dry mass of aggregate. The experimental flowchart of this study and test combinations are shown in Fig. 1.

Table 3. Aggregate Properties

Properties	Standard method	Aggregate A[a]	Aggregate B[b]
Apparent specific gravity	AASHTO T 85	2.800	2.810
Bulk specific gravity	AASHTO T 85	2.750	2.780
Absorption (%)	AASHTO T 85	0.70	0.40
LA abrasion (%)	AASHTO T 96	49	32
Soundness (%)	AASHTO T 104	0.4	1.9

[a] Aggregate A: granite.

[b] Aggregate B: marble Schist.

Superpave Mix Designs

A nominal maximum size 12.5-mm Superpave mixture was used for the mix design in this study. The procedures described in AASHTO T 312 (2004) regarding the preparation of HMA specimens were followed. All mixtures within each aggregate source used an identical aggregate structure to distinguish the influence of the binders and the warm mix additives (Fig. 2). Optimum asphalt contents were obtained and used to produce specimens at four different compaction temperatures.

Compaction as a Function of Temperature in SGC

The mixing of the aggregates with the asphalt binders was conducted at temperatures recommended by the manufacturers of asphalt binder and warm mix additives. The loose asphalt-aggregate mixtures were oven aged at the compaction temperatures for 2 h prior to the compaction. The four compaction temperatures used were 97, 116, 135, and 154°C. This range was selected based on the temperatures (135 and 154°C), which are commonly used as short-term oven-aging temperatures in the laboratory to simulate binder aging and absorption during the construction of HMA pavements (The Asphalt Institute 2003). The compaction temperatures of 97 and 116°C were selected to evaluate the effect of warm mix additives at relatively lower temperature.

The specimens were manufactured to the target air void content of 4 ± 1% using 75 gyration of SGC. Each specimen was 150 mm in diameter and 110 ± 5 mm in height. A total of 192 specimens (4 binder types ×4 compaction temperatures ×2 aggregate sources ×6 repetitions) were prepared and tested.

Analysis Method

Statistical analysis was performed using the Statistical Analysis System program to conduct analysis of variance and Fisher's

Table 2. Binder Properties

Aging states	Test properties	Control PG 64-22	10% CRM[a]	10% CRM with Aspha-min[a]	10% CRM with Sasobit[a]
Unaged binder	Viscosity at 135°C (Pa-s)	0.405	1.600	1.477	1.438
	$G^*/\sin\delta$ at 64°C (kPa)	1.243	—	—	—
	$G^*/\sin\delta$ at 76°C (kPa)	—	0.934	1.196	1.402
RTFO aged residue	$G^*/\sin\delta$ at 64°C (kPa)	3.295	—	—	—
	$G^*/\sin\delta$ at 76°C (kPa)	—	2.450	3.289	3.325
RTFO+PAV aged residue	$G^*\sin\delta$ at 25°C (kPa)	2,970	1,705	2,042	2,160
	Stiffness at −12°C (MPa)	183	129	148	151
	m value at −12°C	0.311	0.320	0.330	0.290

[a] DSR: with the plate gap adjusted to 2 mm. The plate gap adjustment was used to eliminate the influence of rubber particle size.

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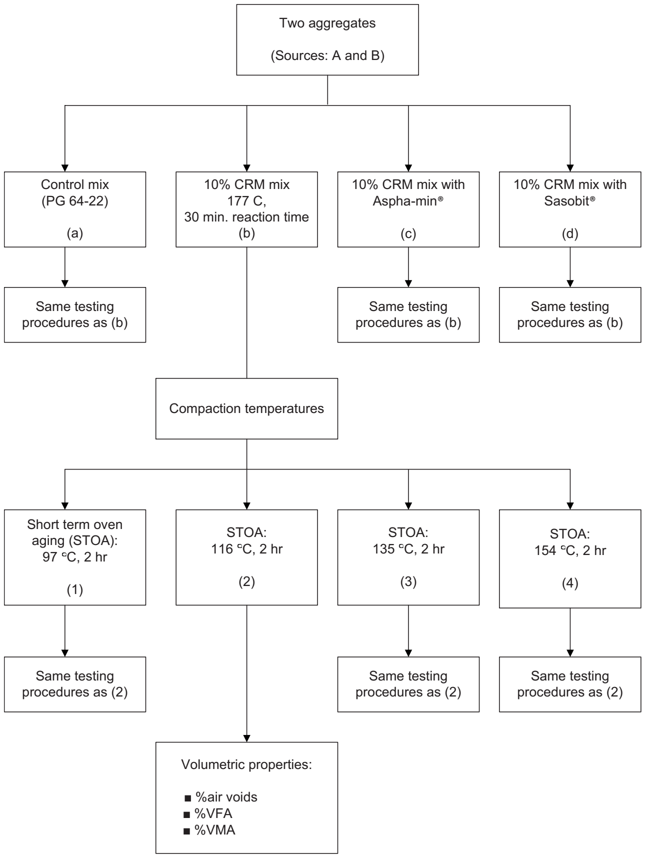


Fig. 1. Flowchart of experimental design procedures

least-significant difference (LSD) comparison with an $\alpha=0.05$. The primary variables included the binder types (control binder, 10% CRM binder, 10% CRM binder with Aspha-min, and 10% CRM binder with Sasobit) and the compaction temperatures (97, 116, 135, and 154°C).

Table 4. Results of Superpave Mix Designs

	Aggregate Source A		Aggregate Source B	
Property	Control (PG 64-22)	10% CRM modified	Control (PG 64-22)	10% CRM modified
OAC (%)	5.7	6.2	4.2	5.0
MSG	2.472	2.477	2.627	2.583
BSG	2.373	2.379	2.524	2.482
%Air void	4.0	4.0	3.9	4.0
%VMA	17.0	18.1	14.1	15.8
%VFA	76.6	77.9	72.2	74.7

Note: OAC=optimum asphalt content; MSG=maximum specific gravity; and BSG=bulk specific gravity.

Results and Discussions

Superpave Mix Design

Table 4 summarizes the optimum asphalt content (OAC), maximum specific gravity (MSG), bulk specific gravity (BSG), and other related data of the mix designs with four different mixes. As expected, the mixes with CRM binder seemed to have higher OAC than the conventional mixes. The previous study reported that the higher OAC for mixtures made with the CRM binder is considered to be attributed to the thicker film of the CRM binder coating the aggregates due to the presence of the rubber particles (Shen et al. 2006). In terms of the effect of aggregate source, the mixes made with Aggregate A was found to have approximately 1.2–1.5% higher OAC than those with Aggregate B, when compared within the same mix type. However, it should be mentioned that both aggregate types and gradation have an effect to cause the increased variability of mix design results.

Volumetric Properties as a Function of Compaction Temperature in SGC

The air void contents of 192 specimens fabricated at four compaction temperatures were calculated. Fig. 3 depicts the air void

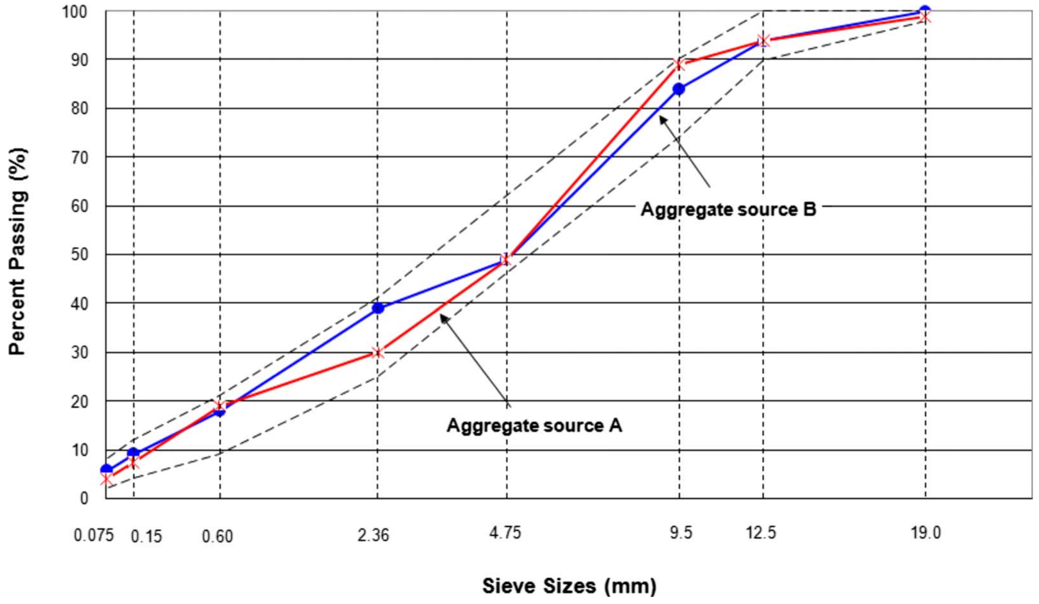
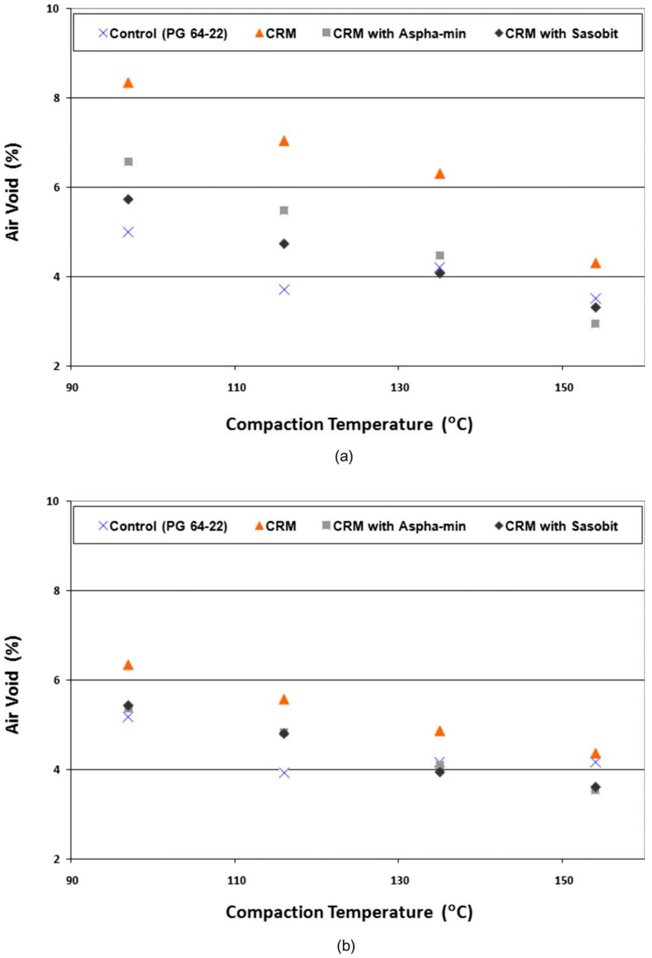


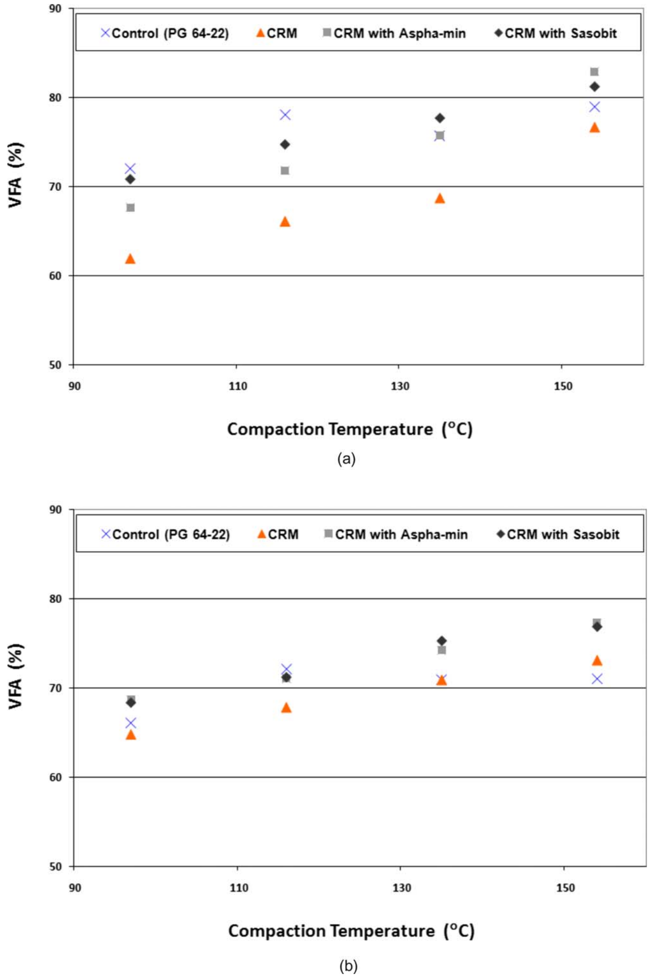
Fig. 2. Gradation chart of 12.5-mm asphalt mixtures



(a)

(b)

Fig. 3. Change in %air voids as a function of compaction temperature with respect to Aggregate Sources: (a) A; (b) B



(a)

(b)

Fig. 4. Change in %VFA as a function of compaction temperature with respect to Aggregate Sources: (a) A; (b) B

contents of the mixtures as a function of the compaction temperature. Similar to the previous research (Lee et al. 2007), the air void contents of CRM mixtures significantly decreased with an increase in the compaction temperature. Both warm mix additives were found to have an effect in decreasing the air void contents of CRM mixtures at each compaction temperature used in this study. However, specimens made with control binder of PG 64-22 had almost the same air void contents over a range of compaction temperatures (116–154°C). This result is also consistent to the findings of previous studies (Azari et al. 2003; Bahia 2000; Stuart 2000).

For Aggregate Source A, the range of compaction temperatures to satisfy the target air void content of 4 ± 1% was found to be 122–157°C and 113–158°C for the CRM mixtures with Aspha-min and with Sasobit, respectively. The results indicated that the addition of Aspha-min into the CRM mixture had an effect in decreasing the compaction temperature needed to get the air void content of 4% from 158 to 140°C. With respect to the CRM mixture containing Sasobit, the compaction temperature for the air void content of 4% was decreased to 136°C. The CRM mixtures produced with Aggregate Source B showed that the compaction temperature could be decreased to 139°C (for Aspha-min) and 133°C (for Sasobit). In general, the warm mix additives resulted in approximately 20–30°C reduction of compaction temperature required for the target air void content, indicating that the compaction temperatures of CRM mixtures containing the additives can be reduced to those of conventional control mixtures.

Using one-way analysis of variance, the statistical significance of the change in the air voids with the increase in compaction temperature was examined and the results are shown in Table 5. A general trend is found from the results that air void contents of the CRM mixtures are affected significantly by the compaction temperature, irrespective of the warm mix additives. With respect to the control mixtures containing PG 64-22 asphalt binder, there was no significant difference, at $\alpha = 0.05$ level, among the air void contents of three compaction temperatures (116, 135, and 154°C) for the mixtures made with Aggregate Source B. In addition, the difference of air void contents between the CRM mixtures containing Aspha-min and Sasobit was statistically insignificant at each compaction temperature, especially for the aggregate source B. When compared within each mixture, the lowest compaction temperature of 97°C was observed to have a significant difference at the 5% level in the air void content for all other compaction temperatures (116, 135, and 154°C).

Figs. 4 and 5 illustrate the change of %VFA and %VMA of the specimens with an increase in the compaction temperature from 97 to 154°C, respectively. Similar to the air void contents, as expected, the %VFA and %VMA of specimens produced with

Table 5. Statistical Analysis Results of % Air Voids of Specimens Fabricated at Different Compaction Temperatures ($\alpha = 0.05$)

		Control (PG 64-22)				10% CRM				10% CRM with Aspha-min				10% CRM with Sasobit			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Aggregate Source A																	
Control (PG 64-22)	1	—	S	S	S	S	S	S	S	S	N	S	S	S	N	S	S
	2		—	N	N	S	S	S	S	S	S	S	S	S	S	N	N
	3			—	S	S	S	S	N	S	S	N	S	S	S	N	S
	4				—	S	S	S	S	S	S	S	S	S	S	S	N
10% CRM	1					—	S	S	S	S	S	S	S	S	S	S	S
	2						—	S	S	N	S	S	S	S	S	S	S
	3							—	S	N	S	S	S	S	S	S	S
	4								—	S	S	N	S	S	N	N	S
10% CRM with Aspha-min	1									—	S	S	S	S	S	S	S
	2										—	S	S	N	S	S	S
	3											—	S	S	N	N	S
	4												—	S	S	S	N
10% CRM with Sasobit	1													—	S	S	S
	2														—	S	S
	3															—	S
	4																—
Aggregate Source B																	
Control (PG 64-22)	1	—	S	S	S	S	N	N	S	N	N	S	S	N	N	S	S
	2		—	N	N	S	S	S	N	S	S	N	N	S	S	N	N
	3			—	N	S	S	S	N	S	S	N	S	S	S	N	S
	4				—	S	S	S	N	S	S	N	S	S	S	N	S
10% CRM	1					—	S	S	S	S	S	S	S	S	S	S	S
	2						—	S	S	N	S	S	S	N	S	S	S
	3							—	S	S	N	S	S	S	N	S	S
	4								—	S	S	N	S	S	N	N	S
10% CRM with Aspha-min	1									—	S	S	S	N	S	S	S
	2										—	S	S	S	N	S	S
	3											—	S	S	S	N	S
	4												—	S	S	N	N
10% CRM with Sasobit	1													—	S	S	S
	2														—	S	S
	3															—	N
	4																—

Note: Compaction temperature 1: 97°C; 2: 116°C; 3: 135°C; and 4: 154°C. N=nonsignificant; and S=significant.

control PG 64-22 binders were found to be almost the same values over the compaction temperatures, except for the lowest temperature of 97°C. In terms of the CRM mixtures, the general trends of %VFA and %VMA were also similar to the change in the air void contents of the CRM mixtures. Still, the %VMA values of the CRM mixtures were relatively higher than those of the control mixtures with the same air void contents. This is thought to be associated to the higher OAC of the CRM mixtures, increasing the effective asphalt contents of the mixtures (Lee et al. 2007).

In general, the warm-mix additives used in this study were observed to have an effect to increase the %VFA values and decrease the %VMA values for all compaction temperatures, compared to the conventional CRM mixtures. On the other hand, Aspha-min and Sasobit were generally found to have insignificantly different influences on the CRM mixtures regarding the %VFA and %VMA values, especially for the Aggregate Source B.

Summary and Conclusions

To investigate the volumetric properties of warm rubberized asphalt mixtures depending on compaction temperatures, two warm mix additives of Aspha-min and Sasobit were incorporated into CRM mixtures designed with two aggregate sources. Control mixtures were produced with control binder (PG 64-22) using the same aggregate source and gradation, and used for comparison purposes. A total of 192 specimens were fabricated using the Superpave gyratory compactor at four compaction temperatures of 97, 116, 135, and 154°C. The volumetric properties of the mixtures were measured and evaluated using the statistical analysis method. From these results, the following conclusions were drawn:

1. As expected, the CRM mixtures were found to have higher optimum asphalt contents than the control mixtures, regardless of the aggregate source used.

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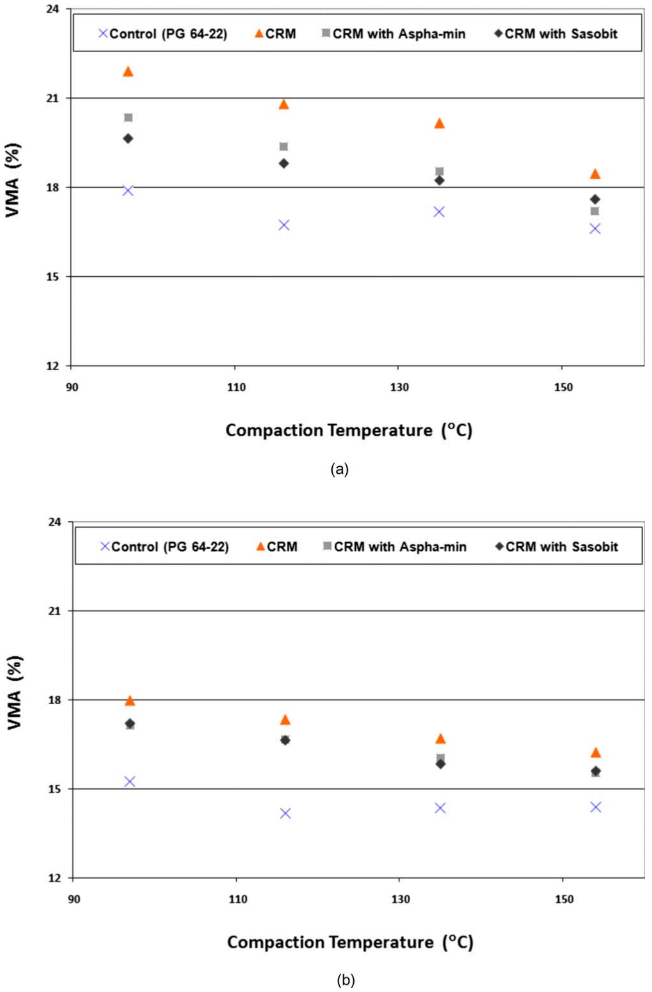

Fig. 5. Change in %VMA as a function of compaction temperature with respect to Aggregate Sources: (a) A; (b) B

2. For the specimens compacted using the Superpave gyratory compactor, the difference in the air void contents as a function of the compaction temperatures was generally found to be statistically insignificant for the control mixtures at the 5% level, except for the compaction temperature of 97°C.
3. Irrespective of the warm mix additives, the air void contents of the mixtures with CRM binders decreased as the compaction temperature increased from one temperature to the next consecutive temperature. From statistical analysis, it was observed that the compaction temperature significantly affected the air void contents of the mixtures.
4. Generally, the compaction temperatures of CRM mixtures containing the warm mix additives can be decreased to those of the control mixtures, with the target air void contents satisfied.
5. Regardless of the compaction temperature, the addition of warm mix additives into CRM mixtures resulted in the increase of %VFA values and the decrease of %VMA values.
6. In general, the two warm mix additives, Aspha-min and Sasobit, were found to have statistically insignificant difference on the volumetric properties of CRM mixtures, compared within each compaction temperature.
7. It is recommended to conduct a study to investigate the engineering properties of CRM mixtures containing the warm mix additives. Also, further study with many other aggregate and binder sources is needed to generalize these findings.

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