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The effects of compaction temperature on CRM mixtures made with the SGC and the Marshall compactor

Soon-Jae Lee [a,*], Serji N. Amirkhanian [a], Seung-Zoon Kwon [b]

[a] *Department of Civil Engineering, Clemson University, Clemson, SC 29634-0911, United States*
[b] *Department of Civil Engineering, Kangwon National University, Samcheok 245-711, Republic of Korea*

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Abstract

The compaction temperature of crumb rubber modifier (CRM) asphalt mixes needs to be determined cautiously because the viscosity and the amount of the CRM binder affects the compactability of the mixtures. In this study, a laboratory investigation was carried out on the volumetric properties of CRM mixtures fabricated using the Superpave gyratory compactor (SGC) and the Marshall compactor as a function of compaction temperature. Two CRM binders were incorporated into HMA mixtures. Two other mixtures were produced with the control binder (PG 64-22) and SBS-modified binder (PG 76-22) and used for comparison purposes. The CRM binders were produced using one base binder (PG 64-22) with 10% or 15% ambient CRM (−40 mesh) by weight of the binder. For this research, the Superpave and the Marshall mix designs for four different asphalt binders were conducted to determine the optimum asphalt contents (OAC). A total of 128 specimens were manufactured using the SGC and the Marshall compactor at various compaction temperatures (116, 135, 154, and 173 °C). The volumetric properties were obtained and analyzed using the statistical methods. The results from this study indicated that (1) the compaction temperatures used in this study significantly affected the volumetric properties of the CRM mixtures, regardless of the compaction methods (the SGC and the Marshall compactor); (2) the CRM mixtures in both the SGC and the Marshall compactor showed the higher VMA values than the control and SBS-modified mixtures; (3) a general trend of the volumetric properties as a function of compaction temperature and compaction method was found for the CRM mixtures used in this study.

Keywords: Crumb rubber modifier; Compaction temperature; Volumetric properties

1. Introduction

Approximately 300 million scrap tires are annually generated in the United States, and about the same amount is produced in Europe [2]. This is becoming a problem in many Asian countries due to several factors (e.g., lack of landfill space, environmental issues, etc). There are many applications in civil engineering area that this by-product could be utilized to enhance the properties of the existing materials. For example, crumb rubber modifier (CRM) can be used to make asphalt pavements that exhibit increased pavement life, decreased traffic noise, reduced maintenance costs, and resistance to rutting and cracking [11,10,7]. At present, this application provides a practical way to dispose of millions of scrap tires, a waste issue difficult to solve in many parts of the country and the world. Currently more and more countries have begun using CRM pavements.

In general, the compaction temperature influences workability, which is related to achieving the proper density of the mixture. The compaction temperature for conventional asphalt mixtures is defined as the range of temperatures where an unaged binder has a kinematic viscosity of 280 ± 30 mm^2/s [3]. On the other hand, these requirements were determined based on experience with unmodified asphalt binders. Based on the field experience, CRM mixtures are compacted at a higher temperature than unmodified mixtures [2]. Nonetheless, the properties of the CRM mixtures depending on compaction temperature is considered to be rather unclear and few studies have been done in this area [8,9].

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[*] Corresponding author. Tel.: +1 864 650 5838.
E-mail addresses: soonjae93@gmail.com (S.-J. Lee), kcdoc@clemson.edu (S.N. Amirkhanian), szkwon@kangwon.ac.kr (S.-Z. Kwon).

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The objective of this study is to evaluate the volumetric properties of CRM asphalt mixtures as a function of four different compaction temperatures using two compaction methods in the laboratory and suggest a range of compaction temperature to satisfy the properties required in the mix designs.

2. Materials and test program

2.1. Materials

Four binders (control PG 64-22, 3% SBS-modified PG 76-22, 10% and 15% rubber-modified binders) were used in this study. The control and 3% SBS-modified binders were collected from one source. 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. Rubber-modified binders were made by adding a specified amount of rubber (−40 mesh) to the control binder, mixing with a stirrer (700 rpm) at 177 °C for 30 min [12]. This mixing condition matches the field practices used in South Carolina, USA, to produce field CRM mixtures. The properties of all the binders in unaged state are listed in Table 2. One granite aggregate source was used for preparing samples (Table 3). Hydrated lime, used as an anti-strip additive, was added at a rate of 1% by dry mass of the aggregate. The experimental flow chart of this study and test combinations are shown in Fig. 1.

2.2. Mix designs

A nominal maximum size 9.5 mm Superpave mixture was used for the mix design in this study. The procedures described in AASHTO T 312 [1] regarding the preparation of HMA specimens were followed. All mixtures used an identical aggregate structure to distinguish the influence of the binders (Fig. 2). The same aggregate gradation as Superpave mix design was used for Marshall mix designs which were carried out using the procedures in ASTM D 1559. Optimum asphalt contents were obtained and used to produce specimens at four different compaction temperatures (Tables 4 and 5).

Table 1
The gradation of crumb rubber used in this study

Sieve no. (μm)	Ambient CRM	
	% Retained	% Cumulative retained
30 (600)	0	0
40 (425)	9.0	9.0
50 (300)	31.9	40.9
80 (180)	32.9	73.8
100 (150)	7.6	81.4
200 (75)	18.6	100.0

Table 2
Properties of four binders in unaged state

Test properties	Control PG 64-22	SBS-modified PG 76-22	10% Rubber[a] modified	15% Rubber[a] modified
Viscosity @135 °C (Pa-s)	0.430	1.475	1.226	2.308
$G^*/\sin\delta$ @64 °C (kPa)	1.279	–	–	–
$G^*/\sin\delta$ @76 °C (kPa)	–	1.338	0.742	1.294

Note: Dashes indicate a test was not done.

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

Table 3
Properties of aggregate

Properties	Standard method	Aggregate
Apparent specific gravity	AASHTO T 85	2.670
Bulk specific gravity	AASHTO T 85	2.650
Absorption	AASHTO T 85	0.6
LA abrasion	AASHTO T 96	50
Soundness	AASHTO T 104	0.7

2.3. Compaction as a function of temperature using the SGC and the Marshall compactor

The mixing of the aggregates with the asphalt binders was conducted at temperatures determined using a plot of viscosity versus temperature. 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 116, 135, 154, and 173 °C. This range was selected based on the temperatures (135 and 154 °C) which are commonly used as short-term oven aging (STOA) temperatures in the laboratory to simulate binder aging and absorption during the construction of HMA pavements [15].

The specimens were fabricated to the target air void content of 4 ± 1% using 70 gyrations of SGC and 50 blows of Marshall compactor. Each specimen for the SGC was 150 mm in diameter and 100 ± 5 mm in height, and that for the Marshall compactor was 100 mm in diameter and 63 ± 3 mm in height. A total of 128 specimens (4 binders × 4 compaction temperatures × 2 compaction methods × 4 repetitions) were prepared and tested.

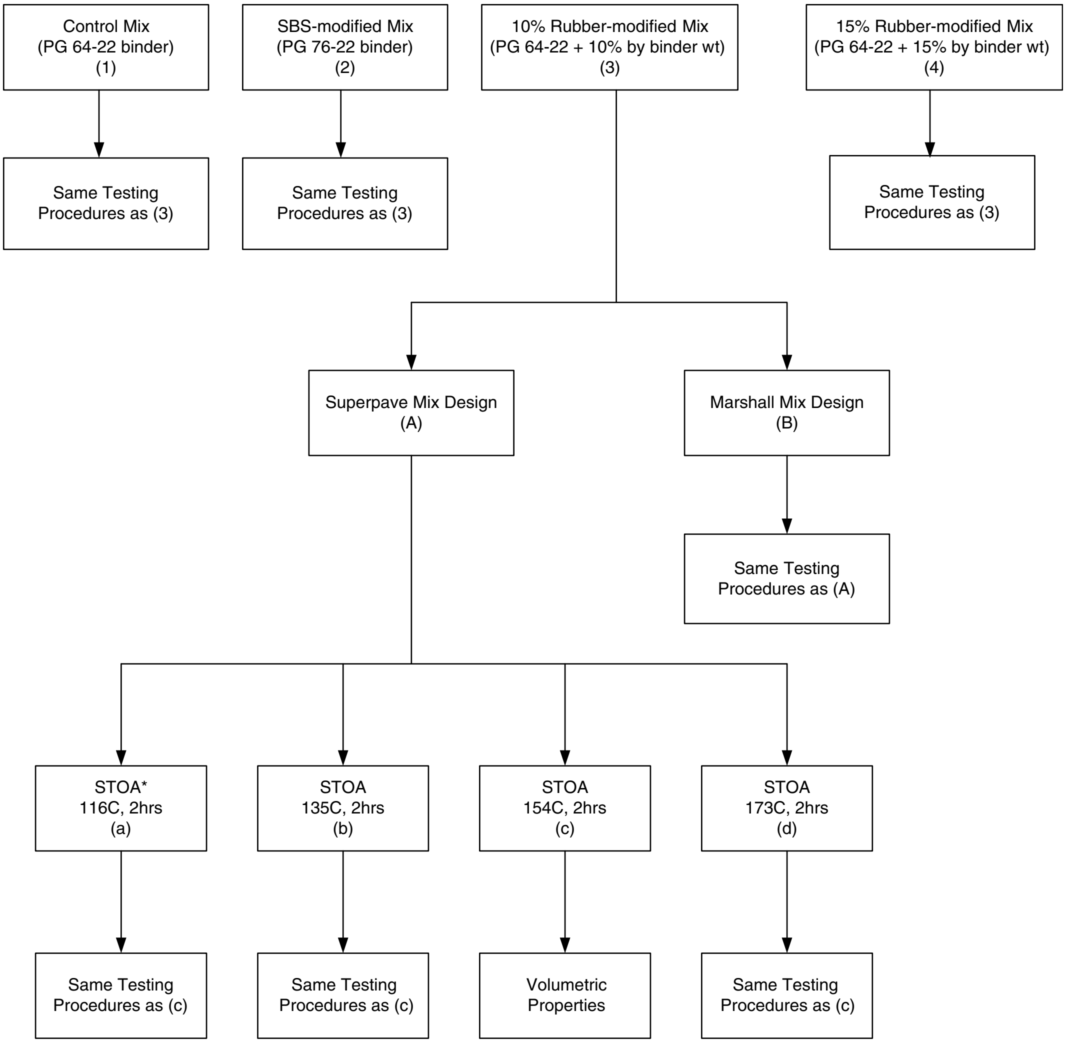
2.4. Analysis method

Statistical analysis was performed using the statistical analysis system (SAS) program to conduct analysis of variance (ANOVA) with an $\alpha = 0.05$. The primary variables included the binder types (control, SBS-modified, 10% and 15% rubber modified binders), the compaction temperatures (116, 135, 154 and 173 °C), and the compaction methods (the SGC and the Marshall compaction).

3. Results and discussions

3.1. Mix design

Table 4 shows Superpave mix design results of mixtures made with four different binders. The optimum asphalt



*STOA: Short Term Oven Aging

Fig. 1. Flow chart of experimental design procedures.

contents of control, SBS-modified, 10% and 15% rubber modified binders were found to be 4.6%, 4.7%, 6.0% and 6.2%, respectively. Previous research has indicated that, in general, the OAC for the CRM mixtures is approximately 1% higher than that obtained for mixtures made without CRM. The higher OAC for mixtures using the CRM binder is attributed to the thicker film of the CRM

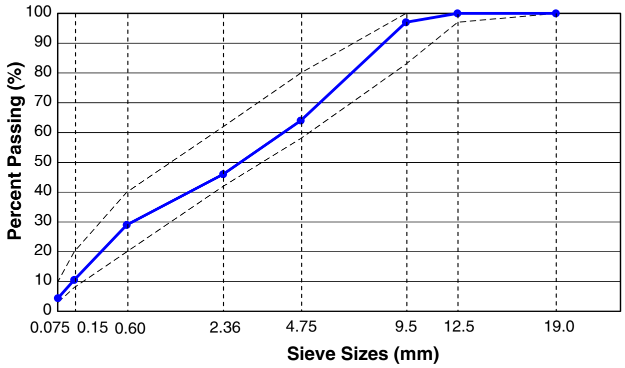


Fig. 2. Gradation chart of 9.5 mm mixture.

Table 4
Results of Superpave mix designs

Property	Mixtures			
	Control	SBS-modified	10% Rubber modified	15% Rubber modified
OAC (%)	4.6	4.7	6.0	6.2
MSG[a]	2.438	2.433	2.387	2.375
BSG[a]	2.331	2.336	2.291	2.269
Air void (%)	4.0	4.0	4.0	4.0
VMA (%)	15.2	15.1	19.4	19.9
VFA (%)	71.5	72.5	73.4	73.1

OAC, optimum asphalt content; MSG, maximum specific gravity; BSG, bulk specific gravity.

[a] No unit.

binder coating the aggregates due to the presence of the rubber particles [13].

The Marshall mix design results for four different asphalt mixtures are shown in Table 5. The OACs of control, SBS-modified, 10% and 15% rubber modified binders were found to be 5.2%, 5.4%, 6.0% and 6.4%, respectively. Like the previous study [6], the OACs of the mixtures with control and SBS-modified binder were higher than those determined from Superpave mix design. However, when it comes to the CRM mixtures used in this study, there was little difference of the OACs between two design methods.

Table 5
Results of Marshall mix designs

Property	Mixtures			
	Control	SBS-modified	10% Rubber modified	15% Rubber modified
OAC (%)	5.2	5.4	6.0	6.4
MSG[a]	2.417	2.410	2.387	2.368
BSG[a]	2.309	2.307	2.295	2.272
Air void (%)	4.4	4.3	3.9	4.1
VMA (%)	16.1	16.3	17.1	18.1
VFA (%)	71.9	72.9	77.4	77.6

OAC, optimum asphalt content; MSG, maximum specific gravity; BSG, bulk specific gravity.

[a] No unit.

3.2. Volumetric properties as a function of compaction temperature

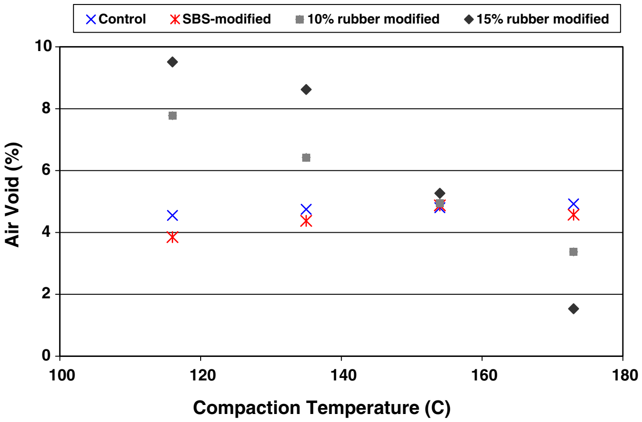


Fig. 3. Change in air void contents as a function of compaction temperature with 70 gyration level of the SGC.

Fig. 3 shows the air void contents of the specimens fabricated with the SGC as a function of the compaction temperature. In general, specimens made with control or SBS-modified binders had almost the same air void content over a very wide range of compaction temperatures (116–173 °C). This means that it is possible to satisfy the target air void contents of 4 ± 1% using 70 gyrations, at all compaction temperatures used in this study. However, in the case of CRM mixtures, the air void contents significantly decreased with an increase in the compaction temperature. The range of compaction temperature to satisfy the target air void content of 4 ± 1% was 152–173 °C and 153–167 °C for 10% and 15% rubber-modified mixtures, respectively.

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 6. The data indicated that air void con-

Table 6
Statistical analysis results of air void contents of specimens fabricated using the SGC at different compaction temperatures

70 Gyrations		Control				SBS-modified				10% Rubber modified				15% Rubber modified			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Control	1	–	N	N	N	N	N	N	N	S	S	S	N	S	S	S	S
	2		–	N	N	N	N	N	N	S	S	S	S	S	S	S	S
	3			–	N	S	N	N	N	S	N	N	S	S	S	S	S
	4				–	N	N	N	N	S	S	S	S	S	S	S	S
SBS-modified	1					–	N	N	N	S	S	S	N	S	S	S	S
	2						–	N	N	S	S	S	N	S	S	S	S
	3							–	N	S	S	S	S	S	S	S	S
	4								–	S	S	S	N	S	S	S	S
10% Rubber modified	1									–	S	S	S	S	N	N	S
	2										–	N	S	S	S	N	S
	3											–	S	S	S	N	S
	4												–	S	S	S	S
15% Rubber modified	1													–	N	S	S
	2														–	S	S
	3															–	S
	4																–

Compaction temperature: (1) 116 °C, (2) 135 °C, (3) 154 °C, and (4) 173 °C.
N, non-significant; S, significant.

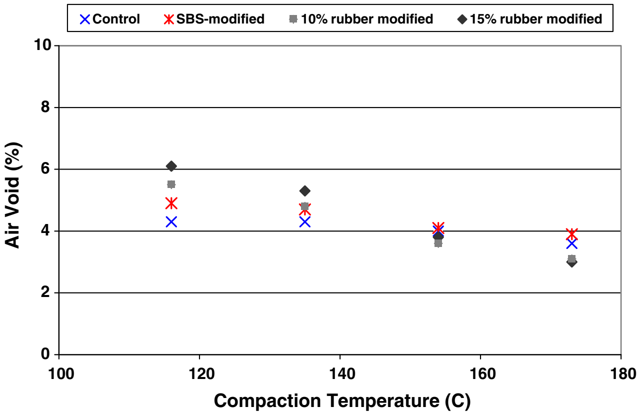


Fig. 4. Change in air void contents as a function of compaction temperature with 50 blow of the Marshall compactor.

tents of the CRM mixtures were affected significantly by the compaction temperature. Similar to the previous research [4,5,14], there was no significant difference, at $\alpha = 0.05$ level, among the air void contents of four compaction temperatures within both control and SBS-modified mixtures. Also, the difference of air void contents between control and SBS-modified mixtures was statistically insignificant in most cases.

Fig. 4 depicts the change of air void contents of the specimens manufactured using the Marshall compactor with an increase in the compaction temperature from 116 to 173 °C. A general trend is that the higher compaction temperature seemed to lead to lower air void contents, especially in the CRM mixtures. However, it should be mentioned that the change of air void contents of the CRM mixtures as a function of compaction temperature was relatively smaller, compared to the mixtures compacted with the SGC. For instance, the air void change of 15% CRM mixture produced with the Marshall compactor and the SGC was 3% (6.1% at 116 °C ~ 3.1% at 173 °C) and 8% (9.5% at 116 °C ~ 1.5% at 173 °C), respectively. In addition, the range of compaction temperature to satisfy the target air void content of 4 ± 1% was 127–173 °C and 137–172 °C for 10% and 15% rubber-modified mixtures, respectively.

The statistical significance of the change in air void contents depending on the compaction temperature was examined (Table 7). The statistical results showed that the air void contents of the CRM mixtures were significantly different in the four compaction temperatures within both 10% and 15% CRM mixtures. Moreover, the difference of air void contents between 10% and 15% CRM mixtures was statistically significant in most cases at the 5% level. Regarding the control and SBS-modified mixtures, it was difficult to find a consistency from a statistical standpoint.

Figs. 5 and 6 show the change of VMA (voids in the mineral aggregate) values of the specimens made using the SGC and the Marshall compactor with an increase in the compaction temperature from 116 to 173 °C, respectively. Similar to the air void contents, the VMA values of specimens produced with control or SBS-modified binders were found to be almost the same values over the four compaction temperatures. Regardless of the compaction methods, the specimens containing the two CRM binders produced the VMA values that were similar to the trends observed for air void contents at the same compaction temperature. However, it was noticed that the VMA values of the CRM mixtures were relatively higher than those of the control and SBS-modified mixtures, which had the same air void contents. This is probably attributed to the higher

Table 7
Statistical analysis results of air void contents of specimens fabricated using the Marshall compactor at different compaction temperatures

70 Gyrations		Control				SBS-modified				10% Rubber modified				15% Rubber modified			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Control	1	–	N	N	S	S	S	N	N	S	S	S	S	S	S	S	S
	2		–	N	S	S	S	N	N	S	S	S	S	S	S	S	S
	3			–	N	S	S	N	N	S	S	S	S	S	S	N	S
	4				–	S	S	S	N	S	S	N	S	S	S	N	S
SBS-modified	1					–	N	S	S	S	N	S	S	S	N	S	S
	2						–	S	S	S	N	S	S	S	S	S	S
	3							–	N	S	S	S	S	S	S	N	S
	4								–	S	S	N	S	S	S	N	S
10% Rubber modified	1									–	S	S	S	S	N	S	S
	2										–	S	S	S	S	S	S
	3											–	S	S	S	N	S
	4												–	S	S	S	N
15% Rubber modified	1													–	S	S	S
	2														–	S	S
	3															–	S
	4																–

Compaction temperature: (1) 116 °C, (2) 135 °C, (3) 154 °C, and (4) 173 °C.
N, non-significant; S, significant.

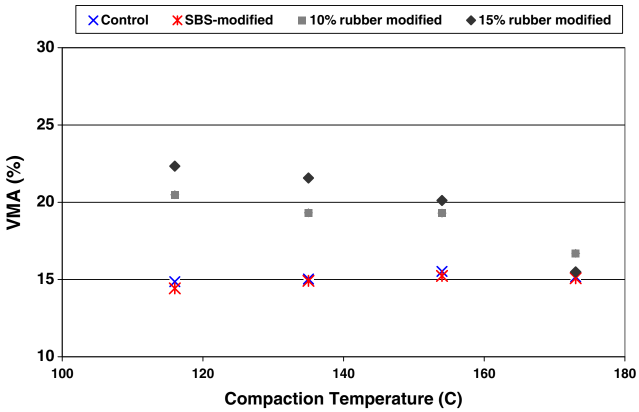


Fig. 5. Change in VMA values as a function of compaction temperature with 70 gyration level of the SGC.

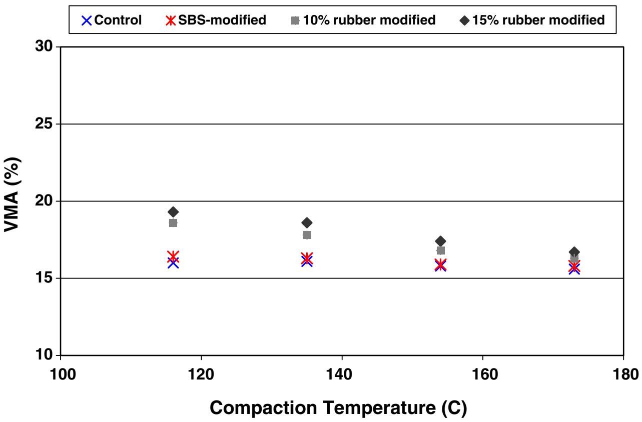


Fig. 6. Change in VMA values as a function of compaction temperature with 50 blow of the Marshall compactor.

OACs of the two CRM mixtures; therefore, increasing the effective asphalt contents of the mixtures [9].

4. Summary and conclusions

(1) From the Superpave mix design method, the optimum asphalt contents of the CRM mixtures were approximately 1.5% higher than the control mixture, depending on the CRM content used.

(2) The optimum asphalt contents of the control and the SBS-modified mixtures from the Marshall method were 0.6–0.7% higher than those from the Superpave method. However, there was little difference in optimum asphalt contents of the CRM mixtures between the Superpave and Marshall methods.

(3) For the specimens manufactured using the Superpave gyratory compactor, the difference in the air void contents as a function of the compaction temperatures was found to be statistically insignificant for the control and SBS-modified mixtures at the $\alpha = 0.05$ level. The specimens had almost the same volumetric properties at a very wide range of compaction temperatures from 116 to 173 °C.

(4) The CRM mixtures showed high air void contents at low compaction temperature; especially the mixtures compacted with the Superpave gyratory compactor. The change of air void contents of the CRM mixtures with compaction temperature was relatively smaller in the Marshall compactor.

(5) The air void contents of the CRM mixtures decreased as the compaction temperature increased from one temperature to the next consecutive temperature. From statistical analysis, it was shown that the compaction temperature significantly affected the total air void contents of the mixtures, regardless of the compaction methods.

(6) Because of the higher optimum asphalt contents of CRM mixtures, the VMA values of the two CRM mixtures in both the SGC and the Marshall compactor were found to be higher than those of the control and SBS-modified mixtures, which had the same air void contents.

(7) The range of compaction temperature to satisfy the target air void content of 4 ± 1% was found for two CRM mixtures used in this study. However, the point stressed in this paper is not to specify the observed number at each compaction temperature, but to show a general trend of the volumetric properties depending on compaction temperatures and compaction methods. Also, further study with many other aggregate and CRM sources is needed to generalize these findings.

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