Recycling of Laboratory-Prepared RAP mixtures Containing Crumb Rubber Modified Binders in HMA

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ABSTRACT

The recycling of reclaimed asphalt pavements containing crumb rubber modified binder (CRM RAP) is an important issue to investigate because some of these types of pavements are more than 10-15 years old in some areas in the USA. In this study, a laboratory investigation was conducted on the possibility of recycling laboratory-prepared CRM RAP in Superpave mixtures by following a normal recycling practice. Six mixtures (three recycled mixtures containing laboratory-prepared CRM RAP and three control virgin mixtures) were designed and tested. Three types of aggregates and two types of CRM binders were used for the mixtures. The CRM RAP used in the study was artificially aged in the laboratory using an accelerated aging process. The percentage of the RAP incorporated into the recycled mixtures was 15%. Evaluation of all mixtures included the following testing procedures: indirect tensile strength (ITS), Asphalt Pavement Analyzer (APA), resilient modulus and gel permeation chromatography (GPC). The results from this study showed that 1) it is possible to incorporate 15% CRM RAP into HMA using normal recycling practices; 2) there is no significant difference in the properties (e.g., indirect tensile strength, rutting resistance, resilient modulus, and binder molecular size distribution) between the three virgin and the three recycled mixtures.

Key words: CRM binder, RAP, recycling, APA, GPC, resilient modulus

INTRODUCTION

Using crumb rubber modifier (CRM) to modify asphalt binder in pavement engineering began over four decades ago in the USA. The most important motivation behind this application of the CRM was the improvement of pavement performance including increased pavement life through resistance to cracking and rutting, decreased traffic noise, reduced maintenance costs and increased traffic safety through skid resistance and the reduction of vision impairing spray during inclement weather *(1), (2), (3)*. Currently, this application also provides a practical way to dispose of millions of scrap tires, a waste issue difficult to solve in many parts of the country. For example, an open graded friction course (OGFC) and stress absorbing membrane interlayer (SMAI) pavements use an average of 530 to 2000 scrap tires per lane per kilometer, respectively *(4)*. In 1991, the Intermodal Surface Transportation Efficiency Act (ISTEA) specified that all asphalt pavement projects funded by federal agencies must use certain percentages of scrap tires *(5), (6)*. However, in 1995, this Act was repealed. Currently, more and more countries have begun using CRM binders for these advantages *(7)*. A very few research organizations are available to promote the use of this material *(8)*.

A recycling method of reclaimed asphalt pavement (RAP) containing CRM binders (CRM RAP) is one of the technologies needed for the use of rubberized asphalt. This is very important and necessary research, because many of these pavements were built over 10-20 years ago. However, the recycling issue of CRM RAP has lagged behind other technologies, with only limited reports available dealing with the possibility of recycling this material. Shen et al. studied the effects of rejuvenating agents on aged CRM binders *(9)*. The results of the research indicated that traditional rejuvenating agents (i.e., a softer binder and a rejuvenator) were equally effective in rejuvenating aged CRM binders compared to conventional binders. These binders were rejuvenated to a target PG grade as easily as the aged SBS modified binder used as the control. Another research investigated the recycling process of aged CRM binders based on molecular sizes *(10)*. This study found that the molecular size distribution of the aged CRM binders approached that of the virgin binders as the contents of the rejuvenating agents increased.

Objective and Scope

This study investigated the possibility of recycling CRM RAP in Surperpave mixtures using recycling practices proposed for a typical RAP mixture *(11)*. Three mixtures with CRM RAP and three others without the CRM RAP, used as control, were designed using Supepave specifications. Several properties of these mixtures, including indirect tensile strength, rutting resistance, resilient modulus and binder molecular size distribution were evaluated. Three types of CRM RAP aged using an accelerated aging process were incorporated in the mixture. The virgin mixtures were produced with three different aggregates and two different CRM binders. A RAP percentage of 15% was used in this research.

MATERIALS AND TEST PROGRAM

The experimental flow chart of this study and test combinations are shown in Figure 1.

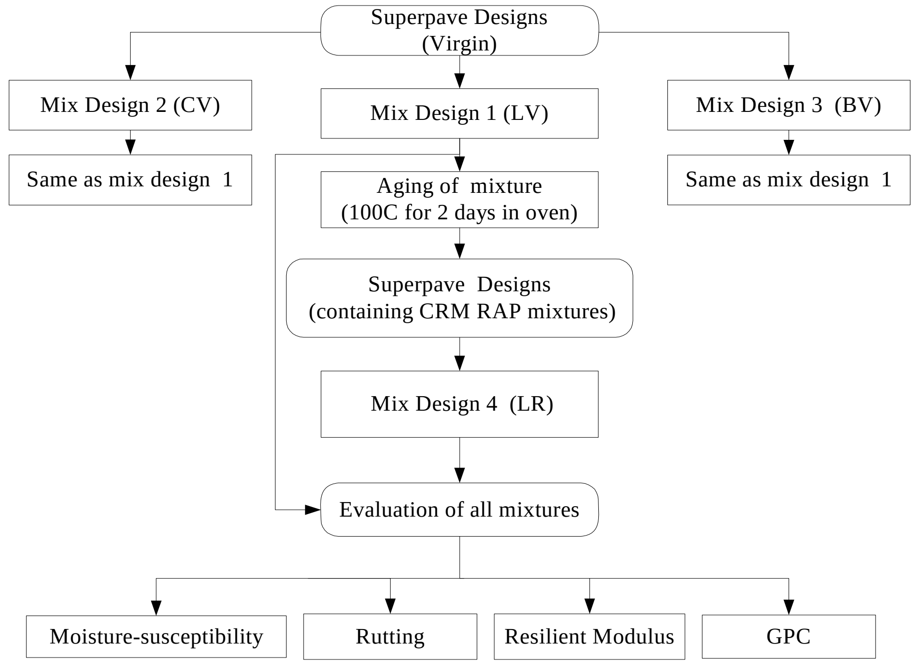


FIGURE 1 Flow chart and test combinations of this study (mixes prepared using aggregate sources B, C, and L made with virgin (V) and recycled (R) materials).

Aggregates

Three aggregate sources designated as B, C and L from three different locations in South Carolina were used to produce the six Superpave mixtures to distinguish the aggregate influence on the recycling of CRM RAP.

Binders

CRM binders from two different sources (I and T) were used to produce the six Superpave mixtures by mixing the two base binders (PG 64-22) with 10% (by weight of the binder) ambient CRM (-40 mesh). The properties of all the binders are listed in Table 1. The CRM binders were graded as either PG 70-22 or PG 76-22. These two CRM binders were produced using a high shear radial flow mixer (700 rpm) under the mixing condition of 177°C temperature and 30 minutes of mixing. This mixing condition matches the field practices used in South Carolina to produce field mixtures. The two CRM binders were used to make both the virgin and recycled mixtures.

CRM RAP mixtures

The three CRM RAP mixtures used as recycling materials were artificially produced using an accelerated aging process on virgin mixtures in the laboratory. Kliewer et al. concluded that oven aging at 85°C for 4 days was recommended to represent projects of about 10 years old and aging for 2 days at 100°C could be used for stiff mixes *(12)*. In this study, CRM binders were graded as PG 70-22 or PG 76-22, and therefore the aging process was conducted in an oven at 100°C for 2 days. The amount of CRM RAP used for the recycling for all three recycled mixtures

TABLE 1 Properties of base binders (PG 64-22) and CRM binders

Aging states	Test properties	Base I	Base T	CRM I	CRM T
No aging	Viscosity @ 135°C (Pa-s)	0.430	0.703	1.922	2.559
	G*/sin(delta)@64°C (kPa)	1.279	2.413	-	-
	G*/sin(delta)@76°C (kPa)	-	-	1.050	2.450
RTFO	G*/sin(delta)@64°C (kPa)	2.810	6.075	-	-
	G*/sin(delta)@76°C (kPa)	-	-	2.060	6.500
PAV	G*sin(delta)@25°C (kPa)	4074	3352	-	-
	G*sin(delta)@ 31°C (kPa)	-	-	4480	2305
	Stiffness @-12°C (MPa)	217	141	243	204
	m-value@-12°C	0.307	0.359	0.330	0.356
Note: "-" test was not done					

was 15%. This percentage was selected because most states use this percentage in recycling practices. Additionally, previous research concluded that, if 15% RAP is used, the Superpave PG grade of the new asphalt binders can be the same as that used in 100% virgin mixtures *(11)*.

Superpave mixture designs

The three virgin and three recycled Supepave mixtures were designed according to AASHTO M323-04 (Table 2). Both the virgin and recycled mixtures used an identical structure for each type of aggregate to distinguish the influence of the binders. A 9.5mm Superpave mixture aggregate gradation was used with a design gyration level of 75. Optimum asphalt contents were obtained from these designs and used to produce the virgin and recycled mixtures.

TABLE 2 Combinations of Superpave mixtures designed

Mixture	Virgin Aggregate		CRM RAP mixture		CRM binder
	Type	% of mixture	Type	% of mixture	
LV	L(1)	100	L	0	I
LR	L	85	L	15	I
CV	C(2)	100	C	0	T
CR	C	85	C	15	T
BV	B(3)	100	B	0	T
BR	B	85	B	15	T

(1) L: granite, (2) C: granite, (3) B: marble – schist
V: Virgin mix
R: Recycled mix

Indirect Tensile Strength (ITS)

The ITS test was used to evaluate the moisture susceptibility of the mixtures. Two sets of 3 samples each were tested at 25°C in wet and dry states. The samples were 100mm diameter having a height of 65mm and a void ratio of 7±1%. The ITS and TSR (tensile strength ratio) values were calculated.

Asphalt Pavement Analyzer (APA)

The APA test in this study was conducted on cylindrical samples with air voids of 4.0±1.0% and a height of 75mm and diameter of 150mm, which were compacted by a Surperpave Gyratory Compactor. The test temperature was 64°C, the hose pressure was 690kPa, and the wheel load was 445N. The rut depth was recorded and measured manually after 8,000 cycles.

Resilient Modulus (M_r)

The resilient modulus test is a repeated load indirect tensile test conducted at temperatures of 5, 25 and 40°C according to ASTM 4123. Four duplicate samples with 150mm diameter and 76mm thickness were compacted using a Surperpave Gyratory Compactor to a void ratio of 7±1%. One of the four samples was used to measure the indirect tensile strength by which the repeated load is determined, specifically 30, 15 and 5% of the ITS was used as the repeated load for the tests at 5, 25 and 40°C; respectively. The reported resilient modulus value is an average of three samples.

Gel Permeation Chromatography (GPC)

The GPC test is typically used to measure the molecular size distribution of a substance using silica gel porous columns through which the sample solution is pumped. The response obtained by the detector of the GPC was recorded as the elution time increased. Through an extensive laboratory research work, Kim et al. concluded that a sample mix could be utilized to obtain GPC information instead of extracting the binder and performing the test on the recovered materials *(13)*. In this present study, the same technique was used to obtain GPC results from the mixtures. A sample of asphalt mix was weighed and allowed to dissolve in a tetrahydrofuran (THF) solvent with the asphalt concentration in the solvent being adjusted to 1/400. Next, the solution was drawn using an injector and then filtered through a 0.45 μm filter to ensure the purity of the solution. Third, 0.5-ml of the solution was then immediately drawn and injected into the GPC system. The solution was pumped through the gel permeation columns and allowed to flow at a rate of 1 ml/min. This test was conducted at 35°C for 30 minutes for each injection, with 3 duplicate injections being used for each mixture.

RESULTS AND DISCUSSIONS

Superpave mixture design

Table 3 summarizes the primary Superpave mix design results. The optimum asphalt contents (OAC) were found to be 6.0, 6.1 and 5.1% for the recycled mixtures LR, CR and BR; respectively. These values are similar to those for the virgin mixtures LV, CV and BV. However,

TABLE 3 Results of Superpave mixture designs (aggregate sources L, C, and B made with virgin (V) or containing laboratory-prepared RAP (R))

Specification		Type of Superpave mixture					
Sieve	Limit	LV	LR	CV	CR	BV	BR
12.5mm	97-100	100	100	100	100	100	100
9.5mm	80-100	96	96	100	100	92	92
4.75mm	58-75	63	63	67	67	62	62
2.36mm	42-60	45	45	48	48	46	46
0.6mm	19-40	25	25	27	27	21	21
0.15mm	8-20	8.1	8.1	8.4	8.4	11.9	11.9
0.075mm	3-8	7.3	7.3	7.2	7.2	7.4	7.4
Test results							
Max specific gravity		2.419	2.413	2.386	2.371	2.591	2.557
%Max density at N_{des}	96	96.0	96.0	96.0	96.0	96.0	96.0
%VMA	Minimum 15.5	17.9	17.5	16.9	17.3	16.0	16.0
Optimum asphalt content (%)		6.2	6.0	5.9	6.1	5.0	5.1

based on the authors' experience with other projects, in general, the OAC for the CRM mixtures are approximately 1% higher than that obtained for mixtures using no CRM. The higher OAC for mixtures using the CRM binder is attributed to the thicker film of the CRM binder coating the aggregates due to the presence of the rubber particles.

Indirect Tensile Strength

Figure 2 shows the ITS values of the six Superpave mixtures in wet and dry states. Overall, the ITS values of the three recycled mixtures are slightly higher than those of the three corresponding virgin mixtures in both states. The addition of the laboratory-prepared CRM RAP to the HMA did not decrease the ITS values. In most cases, the mixtures made with aggregate source B and containing RAP produced the highest ITS in both the wet and dry states. This aggregate source is a non-strip prone aggregate and had the highest mixture specific gravity value compared to the other sources. All mixtures produced wet ITS values that met the requirements set forth by the South Carolina Department of Transportation (SCDOT) (455 kPa or 65 psi). Statistical analyses were performed to determine if there is a statistically significant difference between the ITS values of virgin and recycled mixtures within the same aggregate source. From the t test results, there was no significant difference, at α=0.05 level, between the ITS values of virgin and recycled mixtures in both dry and wet states.

Figure 3 shows the TSR values of all mixtures. Two of the three recycled mixtures (CR and BR) have higher TSR values than the corresponding virgin mixtures, CV and BV. For the LR case, the TSR was lower than that of the LV, but the TSR was still higher than 85%, the criterion specified by the SC DOT. However, these differences between virgin and recycled mixtures were not statistically significant at the 5% level. A visual observation was conducted on all ITS samples, and there were no visible signs of stripping.

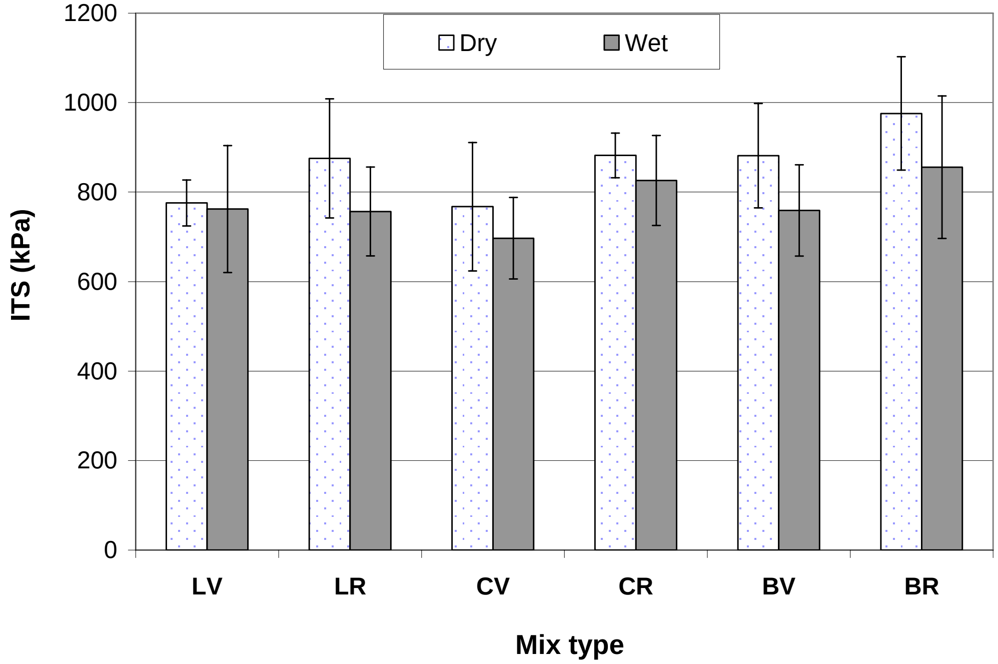


FIGURE 2 Indirect Tensile Strength (ITS) results of mixtures made with aggregate sources L, C, and B made with virgin (V) or laboratory-prepared RAP materials (R).

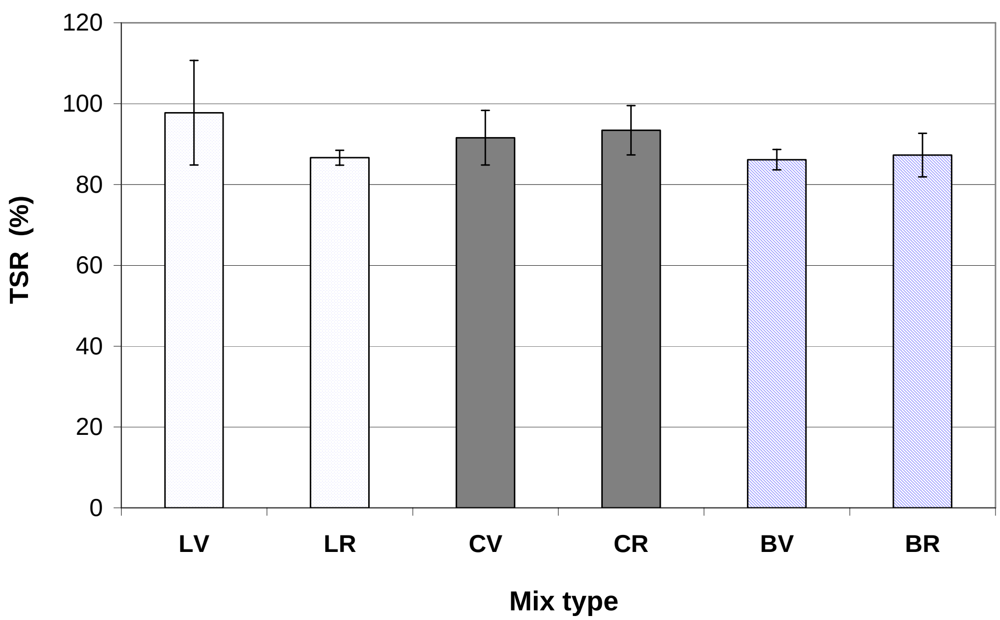


FIGURE 3 Tensile Strength Ratio (TSR) results of mixtures made with aggregate sources L, C, and B made with virgin (V) or laboratory-prepared RAP materials (R).

Asphalt Pavement Analyzer (APA)

Figure 4 shows the relationship between the deformation and the repeated load cycles for the six mixtures. A general trend that the deformation changed with the loading cycles in two phases can be observed for all six samples. The two phases, termed the primary and secondary phases in a rutting test for the asphalt mixture samples were observed in all the curves shown in Figure 4. The primary phase is thought to be associated with the compaction of the mixtures, while the second phase is caused by the plastic deformation or shear flow of the mixtures.

In this study, the deformation values in the primary phase were found to be 0.9, 1.2 and 1.3 mm for the three virgin mixtures BV, LV and CV, respectively. The slope of the primary phase depends on the type of the aggregate, with CV being the steepest and BV the flattest. For the recycled mixtures, the primary phase of BR was similar to that of the BV in both deformation and slope. A slightly higher deformation value (1.5mm) and a steeper slope was observed for recycled mixture LR compared to the virgin mixture LV. In addition, a smaller deformation value (0.9 mm) and a flatter slope for the recycled were found for the CR mixture compared to the virgin CV mixture. These differences between the recycled and the control in the primary phase could be regarded insignificant, depending on the aggregate types. In addition, the average void ratio was 4.1, 4.0, 3.5, 3.7, 4.8 and 4.7 for LV, LR, CV, CR, BV, and BR mixtures, respectively.

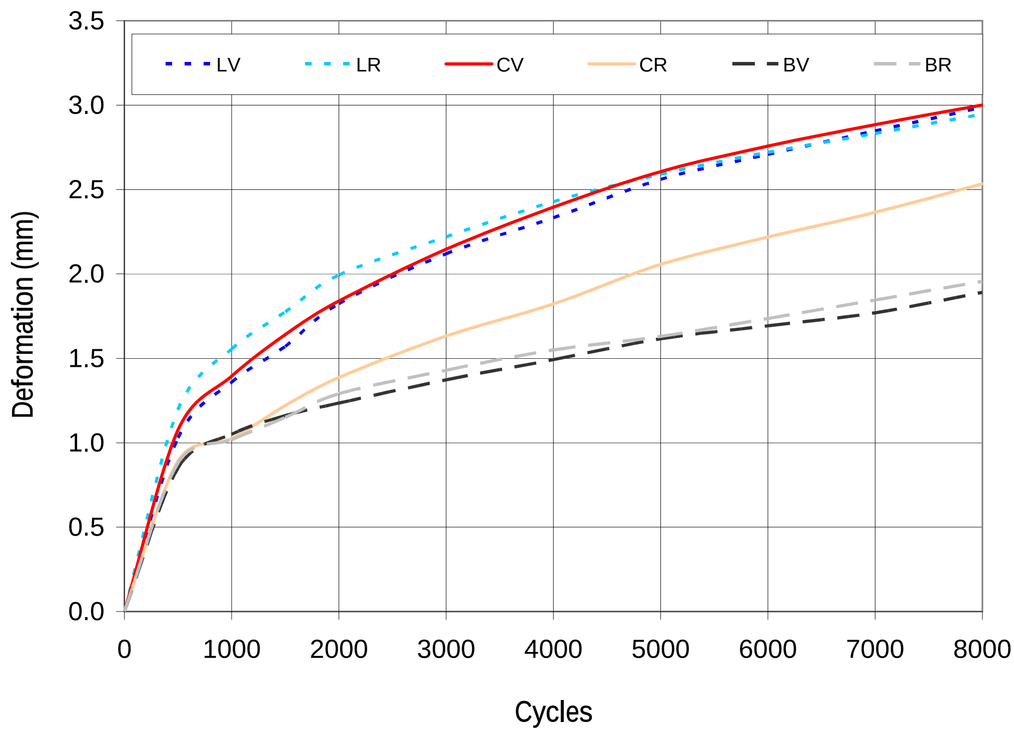


FIGURE 4 Asphalt Pavement Analyzer (APA) test results (aggregate sources L, C, and B made with virgin (V) or containing laboratory-prepared RAP (R)).

The difference of the void ratios between the recycled and the virgin mixtures was small. Because the primary phase of the mixtures reflects the properties of compaction on the mixture, it could be concluded that the effect of this process is not significant when comparing the recycled and the virgin mixtures.

The slope of the curves in the second phase is a good index of the influence of the stress-strain properties on the rutting resistance. The slopes of the three virgin and the three recycled mixtures are similar and dependent on the aggregate type. The slopes of the BV and BR are flatter than those of the other four mixtures, indicating that there is no difference between the recycled and the virgin mixtures regarding the rutting resistance.

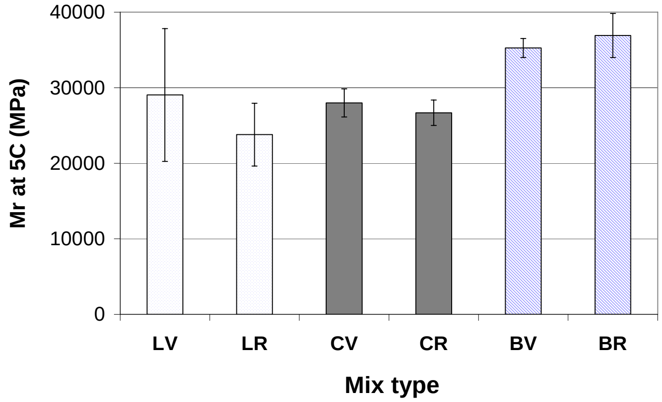
The difference of rutting values after 8,000 cycles of loading between the recycled and virgin mixtures is dependent on the aggregate source. It is very small for mixtures using L and B aggregate sources, and relatively large for the mixture using aggregate source C. The recycled CR mixture has a lower rut depth than the virgin CV. All of the rut depths are significantly below 8 mm, the recommended value *(14)*.

Resilient Modulus

Figure 5 shows the results of the resilient modulus test (n=3) obtained at 5, 25 and 40°C. The testing stress level was 30, 15 and 5% of the ITS values, which were obtained using samples prepared by Superpave Gyratory Compactor. Overall, the difference in the resilient modulus of the recycled mixtures compared to that of the virgin modulus is dependent on the type of the aggregate and the test temperature. The resilient modulus of the recycled mixtures LR and CR was lower than that of the virgin mixtures LV and CV, regardless of the test temperature. For the mixtures made with aggregate source B, the resilient modulus of the recycled mixture was higher than the virgin mixture at 5 and 40°C.

Gel Permeation Chromatography (GPC)

Figure 6 shows the GPC profiles for the six mixtures. The recycled mixtures have very similar molecular size distributions to the virgin regardless of the aggregate type. Moreover, the mixtures of CV and CR have similar profiles to those of BV and BR, because all four of these mixtures used the same CRM binder. The larger molecular size (LMS) distribution, an index related to the properties of CRM binders, was calculated according to its definition *(15)*. The LMS values of binders from six mixtures are shown in Figure 7. The LMS of the binders in the recycled and virgin mixtures is similar, regardless the type of the aggregate. Additionally, the long-term aging of the mixtures in the laboratory resulted in the average increase of 68% in the LMS ratios (LMS ratio = LMS value after aging / LMS value before aging).



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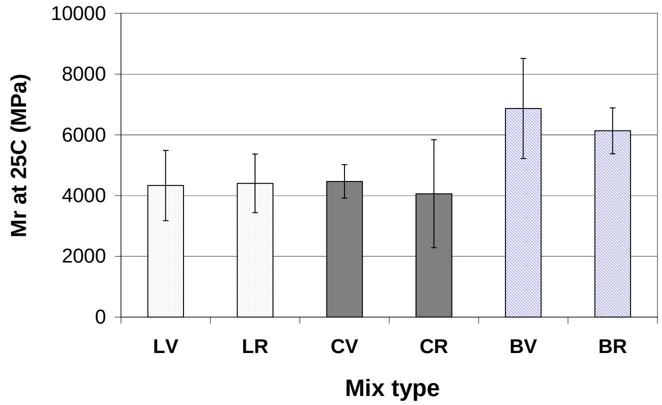

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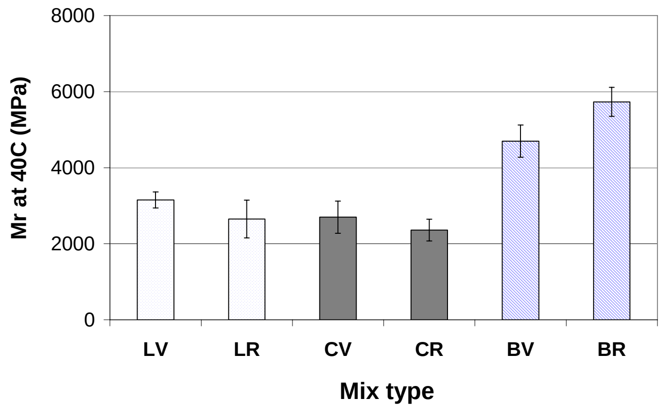

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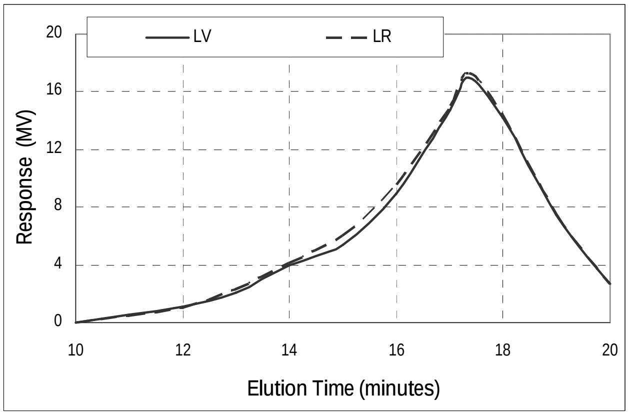
FIGURE 5 Indirect Tensile Resilient Modulus (M_r) test results a) at 5°C, b) at 25°C, and c) at 40°C.



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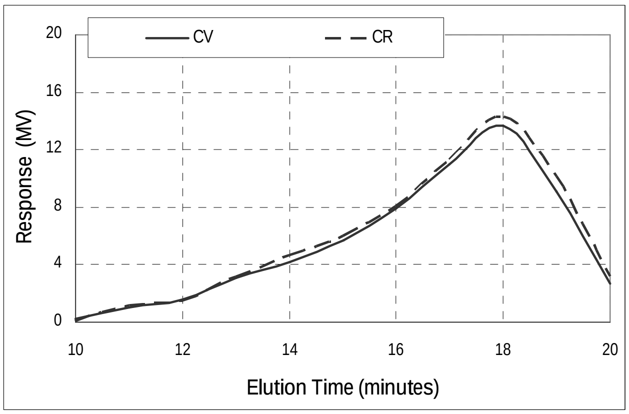

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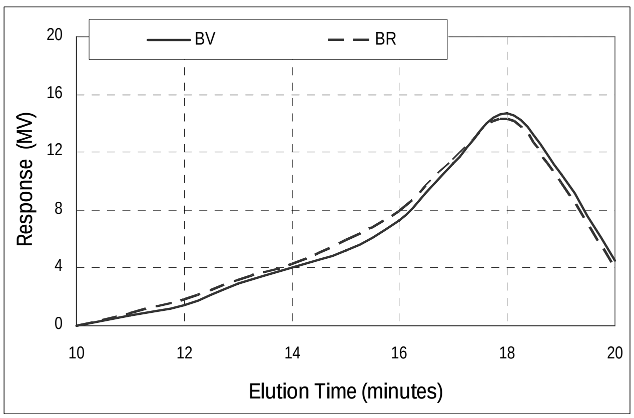

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FIGURE 6 Gel Permeation Chromatography test results (profiles) for mixes with aggregate types of a) L, b) C, and c) B.

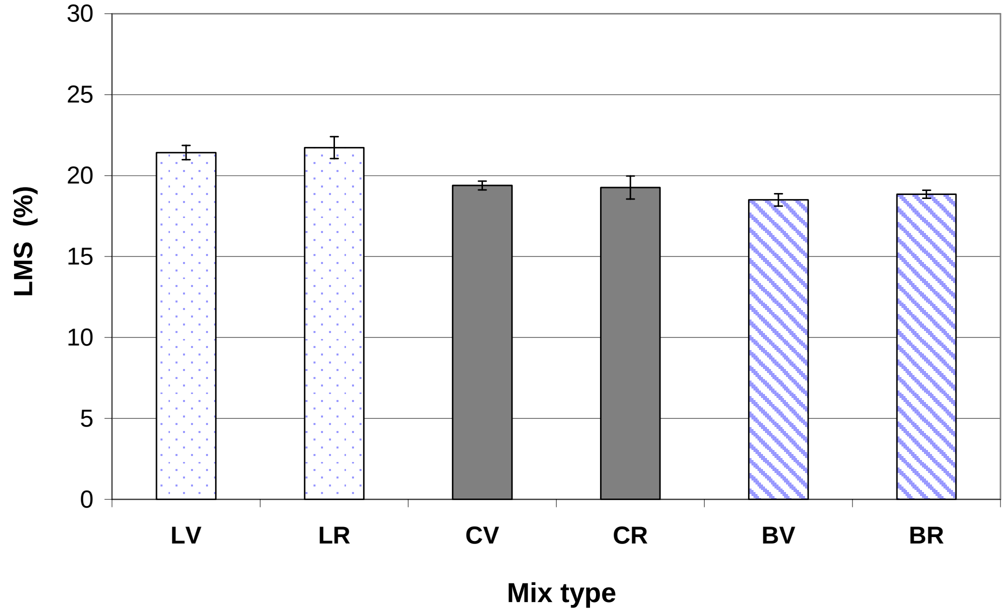

FIGURE 7 Gel Permeation Chromatography test results (LMS, %).

SUMMARY AND CONCLUSIONS

Three recycled mixtures containing laboratory-aged CRM RAP were incorporated into HMA designed with three different aggregate sources and two CRM binders. In addition, three virgin mixtures, used as control, were made using the same aggregate and the CRM binder sources. The CRM binders graded as PG 70-22 or PG 76-22 were produced using two base binders of PG 64-22 with 10% ambient CRM (-40 mesh) by weight of the binder. A series of tests were conducted using ITS, APA, resilient modulus and GPC to investigate the possibility of using laboratory-aged CRM RAP by following the recycling procedure for normal RAP. The properties of the recycled mixtures containing 15% CRM RAP were comparable to those of the control mixtures; thus 15% CRM RAP can be incorporated into the mixtures using the normal recycling process. The more specific findings are listed below:

1) Superpave mixture designs indicated that the optimum asphalt contents of the recycled mixtures were similar to those of the virgin mixtures regardless of the type of the aggregate. The recycled mixtures containing CRM RAP satisfied all the requirements, set forth by the SC DOT. The differences in the mix properties between the virgin and recycled mixtures were statistically insignificant at the 5% level.
2) The primary and secondary phases in the rutting tests for the recycled mixtures did not differ much from the controls. Therefore, the compaction effect and the shear flow properties of the recycled mixtures had no significant differences compared to the virgin mixes.

3) The difference in the total rut depths, measured by the APA, between the virgin and the recycled mixtures was found to be insignificant for L and B aggregates. For aggregate source C, the recycled mix had smaller rut depth than the virgin mix. The rut depths of all mixtures are much smaller than the requirements set forth by SC DOT. The results indicated that the difference in rutting resistance between the recycled and the virgin mixes was not significant.
4) The ITS values of the three recycled mixtures in both wet and dry states were higher than the required value specified by SCDOT. There was no significant difference at α=0.05 level between the ITS values of the virgin and recycled mixtures. Also, no visual stripping was observed in any of the mixtures.
5) The resilient modulus of the recycled mixtures showed no significant difference compared to the control regardless of the aggregate sources and the test temperatures.
6) The GPC results showed that the molecular size distribution profiles of the three recycled mixtures which a laboratory-aged RAP of 15% was used was similar to that of the three virgin mixtures. Further analysis of the three divisions of the profiles showed that the difference between the virgin and the recycled mixtures was small with regard to the LMS.
7) It is recommended to conduct another study with a higher RAP percentage than 15% and a more significant aging level.

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