The Effect of Utilization of RCA on Volumetric Properties of Asphalt Mixtures

Farzaneh Tahmoorian[1], Bijan Samali[2] and Chin Leo[3]

[1]PhD Candidate, Centre for Infrastructure Engineering, Western Sydney University, Kingswood, Australia
[2]Director, Centre for Infrastructure Engineering, Western Sydney University, Kingswood, Australia
[3]Professor, School of Computing, Engineering and Mathematics, Kingswood, Australia

Corresponding author's E-mail: F.Tahmoorian@westernsydney.edu.au

Abstract

The need for sustainable asphalt mixture design is becoming a priority within pavement industry. This trend is necessitated by high rate of construction and demolition waste, pressing demand on landfill sites. Recycled Construction Aggregate (RCA) is one of the potential options for utilization in pavement construction. Therefore, the feasibility of partial substitution of virgin aggregate in hot-mix asphalt (HMA) with RCA is investigated in this research project. RCA differs from virgin aggregate because of the cement paste which is attached to the surface of the virgin aggregates as well as the variety in its composition. This highly porous cement paste and the variation in quality of RCA results in the lower particle density and higher porosity, and subsequently higher bitumen absorption and wet/dry strength variation.
However, the test results demonstrate that some parameters such as flakiness Index and particle shape have a smaller value in RCA compared to virgin aggregates. These parameters are two dominant characteristics which have significant impact on asphalt mixture strength and stability. This paper presents some of the results of an investigation on the feasibility of utilization of RCA in asphalt mixtures. For this purpose, firstly, a preliminary experimental study is conducted to evaluate the properties of RCA as an alternative for natural aggregate in asphalt mixture under different combination and percentages with virgin aggregates. The aggregate properties studied in this preliminary level were flakiness index, particle shape, water absorption and particle density, wet/dry strength variation, crushing value, and weak particles.
Based on the results obtained from the aggregate specification tests on unbound RCA, in the second step, different asphalt mixtures incorporating substitutions of coarse virgin aggregate with 25% and 50% RCA were prepared and evaluated through gyratory compaction method; the optimum bitumen contents were found to be 5.1%, 5.8 and 6.2% of C320 bitumen, respectively.

Keywords: Asphalt, Bitumen, Pavement, Recycled Aggregate, RCA, Volumetric Properties.

1. INTRODUCTION

With rising disposal related costs and depleting virgin aggregate sources, utilization of RCA in asphalt mixtures is being investigated worldwide to determine its suitability as an alternative aggregate.
The applicability of substituting natural aggregates with RCA has been shown to be promising by many researchers in different parts of the world. These research works obtained some encouraging results which indicate the feasibility of RCA in asphalt mixtures.
Referring to available literature (Arulrajah et al., 2012; Bennert et al., 2000; Blankenagel, 2005; Conceicao et al., 2011; Jayakody et al., 2014; Jimenez et al., 2012; Jr et al., 1998; Nataatmadja and `

Tan, 2001), RCA has been used effectively in base course and subbase course of pavements. However, few research studies (Berthelot et al., 2010; Celauro et al., 2010; Hossain et al., 1993; Pereira et al., 2004; Rebbechi and Green, 2005) have reported the use of RCA in HMA. To this end, this research investigates the properties of RCA through a series of tests. The results of these tests have showed that RCA has some shortcomings in terms of some properties such as absorption and wet/dry strength variation to satisfy design requirements for aggregate in asphalt mixtures. Accordingly, the application of RCA in asphalt mixture on its own may result in asphalt mixtures with less efficiency. Therefore, it is required to consider the combination of RCA with some other acceptable waste materials in certain percentages for designing the asphalt mixture. To this point, RCA have been considered in this research as coarse aggregate in combination with basalt, and hence several tests have been conducted on each aggregate individually and in combination as well as the asphalt mixtures composed of different combination of basalt and RCA. This paper will present the results of these tests leading to the selection of most acceptable combination of these aggregates for asphalt mixture design.

2. LABORATORY TESTING PROGRAM

All tests carried out in this research followed the Australian Standards procedures. Three specimens were tested in each test and following sections describe tests conducted in the laboratory in the Centre for Infrastructure Engineering (CIE) laboratory at Western Sydney University. The findings of the experimental work are presented in two main sections including the mechanical and physical characteristics of coarse aggregates (i.e. RCA and basalt), and volumetric performance of asphalt mixtures containing RCA.

2.1. Materials

In the present study, RCA and basalt have been used as aggregates and the original bitumen studied in this research corresponds to C320, which is the most common binder for wearing courses subjected to heavy loading and/or in hot climates. The fillers considered in this research are hydrated lime and Portland cement. Using the correct amount of hydrated lime, approximately 2% by weight, in mix designs will improve the durability of mixtures and will minimize the problem of stripping.

2.2. Aggregate Specification Tests

The basic properties of materials are essential factors in any asphalt mixture design. To evaluate the fundamental properties of RCA and compare them with virgin aggregates, the aggregate specification tests were conducted on RCA and virgin materials. A summary of all the aggregate specification tests on coarse and fine aggregates as well as fillers and the results are presented in Table 1.

The results of flakiness index test show that RCA has less flakiness index than basalt. Less flakiness index improves the inter-particle interlock in asphalt mixture. In addition, based on test results, basalt materials have more misshapen particles than RCA. Furthermore, the test results show that RCA and basalt meet the standard’s requirements in terms of percentage of weak particles. For particle density and water absorption test on RCA and basalt, the results, as presented in Table 1, indicate the high absorption of RCA compared to basalt. The water absorption of RCA exceeds the limit set by the Australian Standard. In addition, as the results of wet/dry strength variation test shows that RCA has substantially more wet/ dry strength variation than basalt, therefore, as mentioned previously, further investigation on the feasibility of the utilization of RCA with basalt in asphalt mixtures appears plausible.

Accordingly, the particle density and water absorption test and wet/dry strength variation test are also conducted on the mix of RCA and coarse basalt at different percentages of these materials in order to get a better understanding of an acceptable range of mix proportions. The results of two tests of water absorption, and wet/dry strength variation on the mix of coarse aggregates are presented in Table 2.

The results of these tests showed that RCA increase results in an increase in water absorption and a decrease in wet and dry strength. However, the result for wet strength of all mix of RCA and basalt meet the standard's requirements. This will emphasize on the optimum combination of RCA and the proper selection of other aggregates for combining with RCA to enhance the water absorption property.

Table 1: Results of Aggregate and Filler Specification Tests

Test		Aggregate		Specification	Remarks/ Comments
		RCA	Basalt		
Coarse Aggregate	**Flakiness Index Test**	6.91	19.03	25% (max)	passes specification
	Particle Shape Test	6.16	18.34	35% (max)	passes specification
	Water Absorption	**6.30**	1.64	2% (max)	unsatisfactory
	Particle Density	2.570	2.640	-	satisfactory
	Particle Density on Dry Basis	2.212	2.530	-	satisfactory
	Particle Density on SSD Basis	2.351	2.571	-	satisfactory
	Aggregate Crushing Value	29.21	8.91	35% (max)	passes specification
	Weak Particles	0.23	0.23	1% (max)	passes specification
	Wet/Dry Strength Test	26.6	8.5	35% (max)	passes specification
	Wet Strength	**119.7**	359.2	150 kN (min)	unsatisfactory
	Dry Strength	163.1	392.9	-	satisfactory
Fine Aggregate	**Water Absorption**	-	2.35	3% (max)	satisfactory
	Particle Density	-	2.879	-	satisfactory
	Particle Density on Dry Basis	-	2.610	-	satisfactory
	Particle Density on SSD Basis	-	2.668	-	satisfactory
Filler	**Particle Density of Hydrated Lime**	2.330		-	satisfactory
	Particle Density of Portland Cement	3.130		-	satisfactory

Based on the available references (e.g. Austroads, 2014), aggregates typically absorb binder 0.3 to 0.7 times of their water absorption. According to this standard, the samples with water absorption of between 2% and 4% of their mass should be carefully examined by other tests. In addition, if the sample absorbs more than 4% of its mass, it will rarely be an adequate aggregate for asphalt production.

Table 2: Summary of Tests Results for Evaluation of Mix of Coarse Aggregates Properties

Aggregate Property	Test Method	Basalt (75%), RCA (25%)	Basalt (50%), RCA (50%)	Basalt (25%), RCA (75%)
Water Absorption (%)	AS1141.6.1	**2.93**	**3.71**	**4.62**
Particle Density (gr/cm^3)	AS1141.6.1	2.590	2.527	2.476
Particle Density on Dry Basis (gr/cm^3)	AS1141.6.1	2.407	2.310	2.222
Particle Density on SSD Basis (gr/cm^3)	AS1141.6.1	2.477	2.396	2.324
Wet/Dry Strength Variation (%)	AS 1141.22	14.1	17.6	20.5
Wet Strength (kN)	AS 1141.22	250.4	204.1	167.2
Dry Strength (kN)	AS 1141.22	291.4	247.6	210.4

From the water absorption test results, it can be observed that the water absorption of mix of 25% RCA and 75% basalt is 2.93%, and also the combination of 50% RCA and 50% basalt would provide the water absorption of 3.71%, which are still in the water absorption range of aggregate that suggest further research. Therefore, in this research, basalt is substituted with RCA at the rate of 25% and 50% and the asphalt mixtures are then assessed using asphalt volumetric specifications.

2.3. Sample Preparation for Tests on Asphalt Mixtures

In this study, the samples were produced from material mixed in the laboratory. About 4 kg of materials were used to produce three batches of laboratory asphalt mixtures for a finished specimen of diameter 100 ± 2 mm and height of 65 ± 5 mm, in accordance with AS2891.2.1 (2014) and AS2891.2.2 (2014). Based on the results of aggregate specification tests, the basalt and RCA are combined at the rates of 50% and 25% to produce a design gradation similar to control mix. Therefore, the following asphalt mixtures were prepared in this investigation:

- **Mix I:** Control mix containing virgin basalt aggregates with 4.5%, 5% and 5.5% bitumen.
- **Mix II:** Basalt-RCA mix containing basalt (0-4.75 mm), and 75% basalt and 25% RCA (4.75-20 mm) with 5%, 5.5%, 6% and 6.5% bitumen.
- **Mix III:** Basalt-RCA mix containing basalt (0-4.75 mm), and 50% basalt and 50% RCA (4.75-20 mm) with 5%, 5.5%, 6% and 6.5% bitumen.

Control mixtures only contain virgin aggregates and basalt-RCA mixtures contain RCA as coarse aggregates. Portland cement and hydrated lime were used in mixtures as filler (passing 0.075 mm sieve).

2.4. Evaluation of Volumetric Properties of Asphalt Mixture

It is generally recognized that the volumetric composition of mixtures greatly influence their performance. Volumetric properties evaluation of asphalt mixtures is the basis of asphalt mix design and largely determines the performance of asphalt mixture. The asphalt mixture volumetric properties including void content, voids in mineral aggregate (VMA) and voids filled with binder (VFB) have been identified as important parameters for the durability and performance of asphalt pavements (Roberts et al., 1996). The minimum values are typically required for volumetric parameters depending on the type of asphalt mixture.

Table 3: Volumetric Parameters Requirements for DGA AC14 (AS2150-2005)

Parameter	Range	Typical Value	Description
Air void	3% - 6%	5%	Mixtures prepared in accordance with RMS T662
VMA	13% - 20%	≥ 15	Mixtures prepared in accordance with RMS T662
VFB	65% - 80%	-	Mixtures prepared in accordance with RMS T662
Filler-Binder Ratio	0.8 – 1.2	-	Mixtures prepared in accordance with RMS T662
Binder Film Index	-	≥ 7.5 *microns*	Determined in accordance with Test Method Austroads AG:PT/T237 or AS 2891.8

As mentioned previously, all asphalt mixes in this research are dense graded asphalt (DGA) with nominal size of 14 (AC14) which are prepared in accordance with Test Method RMS T661 and RMS T662 (120 cycles of compaction) which are identical to AS2891.2.1(2014) and AS2891.2.2 (2014), respectively. The requirements for volumetric parameters of this type of mixture are summarized in Table 3.

The volumetric properties of the basalt-RCA asphalt mixtures was determined and compared accordingly with the standards specifications. According to Austroads (2014), the essential parameters in the level 1 of mix design (Figure 6) include air voids in total mix, voids in mineral aggregate (VMA), and voids filled with binder (VFB). The volumetric mixture design standards require that for the structural design level of 5×10^6 ESAs to 2×10^7 ESAs, a nominal maximum aggregate size of 14 mm, VMA should be 15% minimum while the VFB specification range is between 60% and 80%. Table 4 presents the properties obtained for asphalt mixtures with different bitumen content at selected level of gyrations (120 cycles).

Table 4: Properties of Asphalt Mixtures

Design Mix	Air Void (%)	VMA (%)	VFB (%)	Binder Film Index (µm)	Filler-Binder Ratio	Bulk Density (gr/cm^3)	Water Absorption (%)	Height (mm)
B100-4.5	7.2	16.4	59.6	6.9	1.2	2.398	0.46	69.0
B100-5	5.4	15.4	69.0	7.5	1.1	2.439	0.17	67.0
B100-5.5	4.1	15.8	78.6	8.7	1.0	2.441	0.11	66.3
B75-5	6.7	15.3	59.7	6.4	1.1	2.398	0.43	69.7
B75-5.5	5.4	15.3	68.7	7.4	1.0	2.410	0.23	67.6
B75-6	4.8	15.7	73.8	8.2	0.9	2.411	0.15	67.0
B50-5	7.3	15.3	55.3	5.9	1.1	2.355	0.56	73.6
B50-5.5	6.0	15.1	64.0	6.8	1.0	2.371	0.31	71.0
B50-6	5.4	15.5	69.1	7.5	0.9	2.373	0.24	68.9
B50-6.5	4.5	16.5	77.1	9.0	0.9	2.359	0.16	68.2

In order to determine the optimum bitumen content and to study the effect of binder content on compacted asphalt containing RCA and control samples, the procedure indicated by Australian standards, AGPT04B-14, was followed in this research. Three specimens at each bitumen content (4.5, 5, 5.5, 6, and 6.5%) were tested for maximum density, bulk density, and subsequently air voids and VMA calculations.

As presented in Table 4, the general trend indicates that as the RCA percent in asphalt mixtures increases, the air void increases while VMA decreases. It is believed that RCA increase results in high binder absorption of the mixture due to porous nature of RCA. The high binder absorption reduces the effective binder content in the asphalt mixture, and subsequently reduces the VMA. In addition, the binder absorption increases with increasing RCA resulting in reduction in the binder available for coating the aggregate particles, and subsequently decreasing the BFI. According to the results obtained from volumetric evaluation tests on different asphalt mixtures and the air voids, VMA, and BFI trends with respect to the RCA percent in asphalt mixture, and taking into account the typical limits specified in available standards and references, it can be concluded that asphalt mixtures containing 20% to 22% RCA will meet the volumetric requirements.

Table 5: Volumetric Parameters Requirements for DGA AC14

Design Mix	B100 (Control Sample)	B75	B50	Standard Specification
Optimum Bitumen Content (%)	5.1	5.8	6.2	-
Air Void (%)	5.1	5.0	5.0	3% - 6%
VMA (%)	15.5	15.6	15.9	15% (min)
VFB (%)	71.5	72.0	72.2	60% - 80%
Bulk Density (gr/cm^3)	2.442	2.411	2.368	-
Binder Film Index	7.8	7.9	8.2	7.5µm (min)
Filler-Binder Ratio	1.1	0.9	0.9	0.8 – 1.2

The results of volumetric properties of asphalt mixtures were used to select the optimum bitumen content with:

- the air voids within the specified limits
- the minimum value for VMA as specified in standards
- the maximum values for bulk density

The results of volumetric analysis together with applicable limits are presented in Table 5.

3. RESULTS AND DISCUSSION

The research project was aimed at determining the optimum content of RCA as an alternative for coarse aggregates in asphalt mixtures. The test results on aggregates as well as asphalt mixtures containing RCA have shown that:

1) RCA has lower value of flakiness index and misshapen particles compared to basalt implying that asphalt mixtures containing RCA in a certain amount can provide better workability, compaction and deformation resistance.
2) RCA have considerably more absorption and wet/dry strength variation in comparison with virgin aggregate due to cracks and adhering mortar and cement paste. The results of tests conducted on RCA showed that RCA still meets the requirements for aggregate in asphalt mixtures while the high water absorption of RCA needs to be compensated.
3) Asphalt mixtures containing RCA have lower bulk density, VMA, VFB and BFI than control mixes, whereas the air voids are higher for specimens containing RCA. Lower bulk density of RCA will result in cost reduction, as asphalt jobs are mostly measured in cubic metre and materials are purchased in tonnes.
4) The results of tests on different asphalt mixtures containing different percentages of RCA revealed that a RCA increase will increase optimum bitumen content of the mixtures. Therefore, the selection of optimum combination of RCA and other aggregates is required to satisfy the relevant requirements.
5) The results show that asphalt specimens containing up to 22% RCA provide properties which are within the acceptable limits recommended by Australian Standards. Higher substitution of virgin aggregates with RCA beyond 22% will lead to a failure of the specification criteria and higher bitumen absorption.

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