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Evaluating the Performance of Recycled Concrete Aggregate in AC-BC Mixture Using Marshall Immersion and Cantabro Loss Tests

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Abstract Solid waste is increasing throughout the world due to rapid population growth and the need for infrastructures. Reports have shown that Indonesia contributes 3% to this solid waste due to the demolition of highways constructed using concrete pavement and others. However, the waste can be processed into recycled concrete aggregate (RCA) which has the potential to be reused as an alternative for new pavement materials to reduce the use of natural aggregate (NA) and achieve environmental sustainability. Therefore, this study aimed to discuss the application of RCA with concrete grade Fs 4.5 on Asphalt Concrete Binder Course (AC-BC) mixture. RCA with 12.5 mm and 9.5 mm thickness was applied as a 45%, 50%, and 55% substitute for NA in AC-BC mixture. Marshall Immersion and Cantabro Loss tests were later conducted to analyze the residual strength and grain release resistance. The results showed that the application of RCA had a positive effect on AC-BC mixture with the sample containing 55% observed to have a stability of 1909.79 kg. The Marshall Immersion test also showed that the sample with 50% RCA had the largest residual strength of 94.41%. Furthermore, the use of RCA as a substitute for NA in AC-BC mixture led to an increase in Marshall stability in the range of 0.41% to 29.24% compared to the application of 100% NA. Cantabro Loss test results for mixture with RCA replacement were observed to have increased by 6.46% to 7.26% when compared to a mixture with 100% NA. The highest Cantabro Loss value was recorded for 45% RCA at 7.26% while the lowest was for 55% RCA at 6.46%. However, the required Cantabro Loss value was less than or equal to 20% which pointed the ability of the proposed asphalt mixture to resist degradation against wear usually caused by vehicle tire friction. In conclusion, Marshall and Cantabro Loss test results showed that the proposed mix was resistant to wear and could withstand traffic loads effectively by distributing the loads to the underlying layers to support the pavement as a whole.

Keywords Recycled Concrete Aggregate, AC-BC, Marshall, Cantabro Loss

1. Introduction

Construction is the most rapidly growing sector in the country with a significant contribution to economic development. This is due to the increasing urbanization and population growth which require a lot of resources in the form of construction [1]. Countries usually use infrastructural development to accommodate the growing population and compete globally. This shows that the strength of the construction sector is directly proportional to the population growth [2]. For example, the observations and predictions made showed that Indonesia contributed up to 3% to the global construction sector. The trend could be associated with the increasing global desire to move into the future and implement sustainability efforts for aging building structures (PBC Today et al. 2019). However, the rapid population growth and need for infrastructure have led to an annual increase in different types of solid waste related to construction and demobilization or demolition. The waste has also led to an increase in the volume of landfills due to the inability to break the structure down into simpler components. The efforts to address this problem require reusing the materials to ensure environmental and economic benefits [3-5].

Road networks constructed globally mostly require pavements with 90 - 95% natural aggregate (NA) while the remaining constituents are asphalt binder [6]. This phenomenon has led to an increase in the demand for NA, thereby requiring alternative materials such as construction waste [7-9]. An example is the waste from demolished highways developed using concrete pavement with 85% identified to have the potential to be reused as aggregates in new pavement construction to ensure sustainability [1,10]. Aggregate derived from this construction waste is known as recycled concrete aggregate (RCA) and has been applied in concrete mixes to produce compressive strengths ranging between 2.1 and 37 MPa depending on the composition [11].

RCA was observed to have several positive impacts but the usage in pavement construction had not been fully studied. Therefore, further studies were required to determine the optimal composition to obtain the best results [9]. Tang et al. [12] used RCA obtained from demolished building concrete and rigid pavements at a ratio of 0-50% to NA. The results showed that the substitution of 0-50% led to an 11.8-17.9% and 6-9.8% reduction in compressive and flexural strength respectively compared to the usage of only NA. Meanwhile, the samples were observed to have environmental benefits considered important to achieving sustainable development of rural highways. Another study by Mikhailenko et al. [13] used 2/4 mm RCA as coarse and 0.125/2 mm for sand at a percentage of 50% while the filler was replaced by 100% of the weight of NA in asphalt mixture using semi-dense asphalt gradation. The results showed that RCA aggregate absorbed a large amount of asphalt binder and required more energy for compaction. It was also observed that there were certain limitations to the usage of RCA in asphalt mixture but it was considered potentially useful when a volume-based replacement percentage was recommended.

Nwakaire et al. [14] studied the performance of asphalt mixture produced using RCA in the form of concrete block waste as 20% to 100% replacement for granite stone aggregate. The Marshall stability, fatigue, effect strength, and abrasion resistance tests conducted showed that RCA mixture performed better than those with granite aggregates. It was also observed that all the mixtures performed effectively based on skid resistance for highways and lanes with heavy traffic. The observation led to the conclusion that RCA could be effectively used in asphalt mixture with 40% recommended for optimum pavement performance. Another study replaced NA with 25%, 35%, 50%, and 75% RCA, and the results showed a decrease in modulus of elasticity and tensile strength [15,16]. It was stated that the mixtures with RCA could be useful on roads with minimal traffic because 75% RCA was below the requirements.

The studies recommended the usage of RCA as a partial replacement for NA but further tests were required to determine the optimal composition, specifically in asphalt mixture. Therefore, RCA was proposed in this study to be used at quantities less than 75%, including 45%, 50%, and 55 to obtain complete information on the performance, specifically in AC-BC asphalt mixture. The effort was considered necessary because most previous studies have focused on RCA materials derived from rigid pavement to be reapplied in constructing roads while lesser attention has been placed on flexible pavement. RCA used in this study was obtained from the demolition of high-quality concrete pavement waste and is believed to have the potential to be reused in flexible pavement roads.

2. Materials and Methods

2.1. Materials

The materials used in this study were asphalt, coarse and fine aggregates, as well as filler. The asphalt used was type 60/70 with the physical properties presented in Table 1. Tests on properties of asphalt include penetration test, softening point test, specific gravity and ductility that refer to American Standard Testing and Material (ASTM) and Indonesian National Standard (SNI).

Table 1. Results for physical properties of asphalt

Parameter Testing	Unit	Result	Spec.	Test Method
Penetration at 25 ℃	0.1 mm	67.4	60 - 70	ASTM D 5-05 / SNI 2456:2011
Softening Point	℃	49.7	Min. 48	ASTM D-36 / SNI 2434:2011 /
Specific Gravity	-	1.003	Min. 1.0	ASTM D 70-03 / SNI 2441:2011 /
Ductility	cm	146.25	Min. 100	ASTM D113-99 / SNI 2432:2011

Coarse aggregate was produced by mixing NA RCA based on the composition presented in Table 2. Moreover, RCA was obtained from demolishing the rigid pavement of the Toll Road with Concrete Quality Fs 4.5 in South Sumatra, Indonesia [17], where the RCA is taken in chunk form as shown in Figure 1.

Table 2. Composition of aggregate mixture

Aggregate Mix	% Natural Aggregate (NA)	% Recycled concrete aggregate (RA)
Control (NA)	100	0
Mix-45NA-55RA	45	55
Mix-50NA-50RA	50	50
Mix -55NA-45RA	55	45

Figure 1. Recycled concrete chunks

The chunks were broken first and aggregates with a size of ½" (12.5 mm) and 1-1 (9.5) mm were obtained as shown in Figure 2. The results of characteristics of coarse and fine aggregates determined through tests are presented in Table 3. Tests on each aggregate include specific gravity, content weight and abrasion refer to ASTM, American Association of State Highway and Transportation (AASHTO) and SNI.

2.2. Design of AC-BC Hotmix Asphalt Mixture

Design of AC-BC hotmix asphalt mixture using the 2018 Bina Marga specifications (Revision 2). Bina Marga is a specification that regulates road pavement construction in Indonesia. The AC-BC mixture used has a maximum aggregate size of ¾" (19 mm). The design of the hot asphalt mixture was determined by first producing a design mix formula (DMF) to identify the planned asphalt binder content. This was followed by the calculation of the job mix formula to determine the composition of aggregate. The range of planned asphalt content used was 5%, 5.5%, 6%, 6.5%, and 7% while the aggregate composition consisted of 14.98% sand, 11.04% coarse size at 9.5 mm, 31.22% at ½" (12.5 mm), 38.66% stone ash and the remaining 4.09% was filler. The gradation plan used and included in AC-BC mixture specification was plotted in the following Figure 3.

Figure 2. RCA at ½" (12.5 mm) and 1-1 (9.5 mm) sizes

Table 3. Physical properties of coarse and fine aggregates

Test Type	Average Test Result					Spec.	References
	Natural aggregate (NA)	Recycled concrete aggregate (RA)		Sand	Stone ash		
		½” (12.5 mm)	1-1 (9.5 mm)				
Dry Specific gravity	2.648	2.171	2.040	2.481	2.53	2.5 – 2.7	ASTM-C127-88-2001 AASHTO T85-45 SNI 1969:2008
SSD Specific gravity	2.663	2.341	2.246	2.538	2.67	2.5 – 2.7	
Apparent Specific gravity	2.690	2.615	2.569	2.632	2.73	2.5 – 2.7	
Water Absorption (%)	0.588	7.829	10.084	2.510	3.52	Max 3	
Content Weight (gr/cm^3)	1.514	1.315	1.229	1.372	1.321	-	ASTM C29/C 29M-97 AASHTO T 19M/T 19-14 SNI 03-4804-1998
Abrasion (%) 500 revolutions of Los Angeles Machine	20.342	42.924	42.468	-	-	Max 40	ASTM D 1559-76 AASHTO T96-22 SNI 03-4804-1998

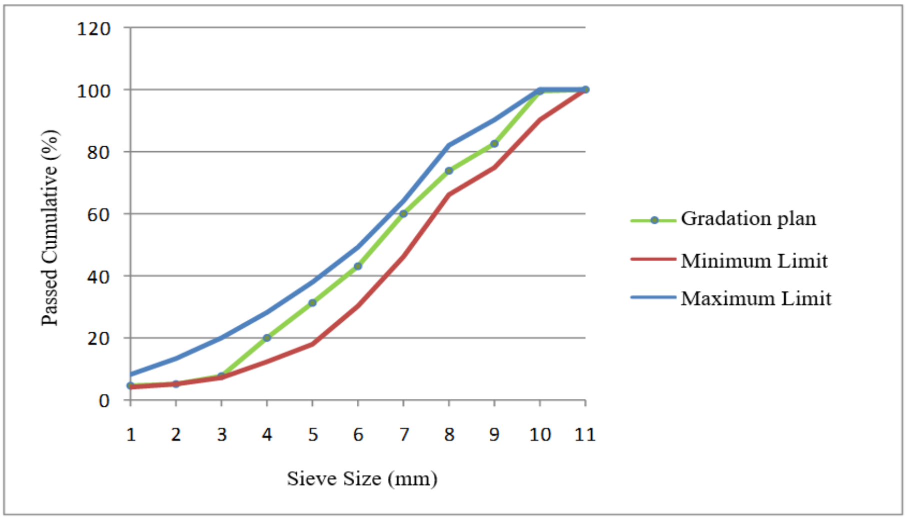

Figure 3. AC-BC hot mixture gradation plan

Table 4. Number of Marshall testing samples

No.	Variation	Aggregate Mixture	Asphalt Content					Total
			5%	5.5%	6%	6.5%	7%	
1	Control	Control	3	3	3	3	3	15
2	M-45-55	Mix-45NA-55RA	3	3	3	3	3	15
3	M-50-50	Mix-50NA-50RA	3	3	3	3	3	15
4	M-55-45	Mix-55NA-45RA	3	3	3	3	3	15
After obtaining KAO								
1	Control	Control	KAO of Control sample					6
2	M-45-55	Mix-45NA-55RA	KAO of M-45-55 sample					6
3	M-50-50	Mix-50NA-50RA	KAO of M-50-50 sample					6
4	M-55-45	Mix-55NA-45RA	KAO of M-55-45 sample					6

2.3. Testing of AC-BC Hot Asphalt Mixture

The design plan of AC-BC hot asphalt mixture was evaluated using Marshall testing without soaking and with soaking based on SNI 06-2489-1991 or AASHTO T 245-90. To perform the Marshall Immersion test, weigh each test object in both air and water, then determine each test object's specific gravity. Each test item collection is split into two groups, each of which is made up of the average specific gravity of the test objects in group 1, which is equal to the average specific gravity of the test objects in the group overall. The average Marshall stability of the test objects in group 1 is evaluated. After being submerged in water for 24 hours at 60 ℃, the test specimens from Group 2 were promptly subjected to a Marshall Average stability test.

The samples used included planned asphalt binder content and optimum asphalt binder content (KAO), as shown in Table 4. Moreover, each planned asphalt content of 5 - 7% had 15 samples for each variation [18]. KAO value was also obtained according to Marshall parameter limit using 3 samples each with and without soaking, leading to a total of 6 for 1 variation. The resistance of asphalt mixtures to disintegration was assessed through Cantabro Loss test with Los Angeles Machine of 300 rounds based on ASTM C131-06 using 3 samples for each variation. To conduct this test, the specimen is placed in an oven or temperature chamber for a sufficient amount of time to ensure a constant temperature of 77 ±2 ℉ (25 ±1 ℃) before testing. The Los Angeles testing apparatus was filled with the test specimen. On a Los Angeles machine, the test object was rotated 300 revolutions at a speed of 30-33 rpm. Weigh the specimen and remove any loose materials after 300 cycles.

3. Result and Discussion

The physical characteristics of the proposed aggregate mixture were tested with a focus on the specific gravity, moisture content, water absorption, weight, and wear [19], as shown in Table 5. The tests were conducted because aggregate was partly derived from the breakdown of used concrete through a crusher which could affect the pore connectivity with subsequent effect on water absorption [20, 21]. The analysis conducted showed that the water absorption of aggregate Mix-45NA-55RA, Mix-50NA-50RA, and Mix-55NA-45RA was greater than for NA, and Mix-50NA-50RA was found to have the highest. Moreover, the specific gravity of the proposed aggregate mixture was found to be lower than for NA because RCA had a lower value due to the presence of residual mortar which led to a more porous and rough surface texture as well as a less dense attribute compared to NA [22, 23]. The wear test further showed that the proposed aggregate mixture had 26.78% to 27.70% considered to have satisfied the requirements. The range was greater than the value obtained for NA because RCA had weak mortar parts considered more prone to wear [14,24].

Marshall test was used to analyze the optimum asphalt content obtained in each proposed aggregate mixture based on the designated parameters. Void in Mix (VIM) is the volume of voids between aggregate grains covered with asphalt or the volume of voids in solid asphalt concrete. Void in Mineral Aggregate (VMA), which is the number of voids between the aggregate grains in solid asphalt concrete, expressed as a percentage of the bulk volume of solid asphalt concrete, while Void Filled with Asphalt (VFA) is part of the voids that are between mineral aggregates. (VMA) filled with asphalt. The results presented in Table 6 showed that the stability, flow, and VMA control samples designed using NA met specifications. However, some VIM and VFA parameters were observed not to have met the required specifications.

Table 5. Results for aggregate mixture characteristics

No	**Test Type**	**Average Testing Results**							**Spec.**	**Method**
		Control (NA)	**Mix-45NA-55RA**		**Mix-50NA-50RA**		**Mix -55NA-45RA**			
			½” (12.5 mm)	**1-1 (9.5 mm)**	**½” (12.5 mm)**	**1-1 (9.5 mm)**	**½” (12.5 mm)**	**1-1 (9.5 mm)**		
1	Dry Specific Gravity	2.648	2.507	2.530	2.510	2.501	2.501	2.505	2.5 – 2.7	ASTM-C127-88-2001 AASHTO T85-45 SNI 1969:2008
2	SSD Specific Gravity	2.663	2.561	2.578	2.574	2.557	2.560	2.562		
3	Apparent Specific Gravity	2.690	2.650	2.658	2.682	2.649	2.657	2.656		
4	Effective Specific Gravity	2.669	2.579	2.594	2.596	2.575	2.579	2.580		
5	Moisture Content (%)	1.056	2.096	2.302	1.958	2.239	1.921	2.486	-	ASTM-C566-97 AASHTO T 255-00 (2004) SNI 03-1971-1990
6	Water Absorption (%)	0.588	2.158	1.837	2.557	2.239	2.352	2.275	Max. 3	ASTM-C127-88-2001 AASHTO T85-45 SNI 1969:2008
7	Content Weight (gr/cm^3)	1.514	1.415	1.445	1.474	1.457	1.400	1.401	Min. 1.2	ASTM C29/C 29M-97 AASHTO T 19M/T 19-14 SNI 03-4804-1998
8	Abration Test (%)	20.342	27.13		26.78		27.70		Max. 40	ASTM D 1559-76 AASHTO T96-22 SNI 03-4804-1998

The results presented in Table 6 showed that the highest stability was at an asphalt binder content of 6.5%. However, several VIM parameters did not meet the required specifications at 5% to 6.018% and VFA at 5% and 5.5% did not meet the required specifications. Hence, the KAO obtained for the control samples ranged from 6.018% to 6.94% and this led to the middle value of 6.48% being chosen as the optimum value.

The results of Marshall test conducted on M-45-55 mixture for KAO based on the 2018 Revision 2 Bina Marga General Specification for modified asphalt concrete layers are presented in Table 7. The mixture was observed to have a better stability value than the control sample and this showed that RCA had a higher aggregate strength than NA because RCA was produced from demolished concrete pavement with Quality Fs 4.5. Meanwhile, the flow did not meet the specifications required when the planned asphalt content was 6.5%. The results presented in Table 7 showed that KAO ranged from 5.0% to 6.18% and this led to the selection of the middle value, 5.59%, as the optimum.

M-50-50 Marshall test for the planned asphalt content of 5% to 7% showed that the flow of 6.5% and 7% did not meet the requirement while the stability values were greater than those of the control sample as presented in Table 8. It was further observed that the flow range was shorter than the other parameters, leading to the selection of the range 5.0% to 6.123% with a center value of 5.56% as the KAO.

Table 6. Marshall results for Control sample (NA)

Marshall characteristics	Plan asphalt content					Specification
	5%	5.5%	6%	6.5%	7%	
Stability	1067.90	1203.41	1243.67	1401.57	1235.71	Min.800 kg
Flow	2.81	3.62	3.77	3.65	3.27	2 - 4 mm
VIM	7.98	6.41	5.03	4.16	2.74	3 - 5 %
VFA	56.70	64.37	71.83	77.39	84.46	Min. 65%
VMA	18.41	17.97	17.70	17.89	17.60	Min. 14%
Marshall Quotient (M-Q)	380.13	332.10	329.57	384.38	377.35	-

Table 7. Marshall test results of sample M-45-55

Marshall characteristics	Plan asphalt binder content					Specification
	5%	5.5%	6%	6.5%	7%	
Stability	1710.98	1589.59	1714.70	1781.3	1866.60	Min 1000 kg
Flow	3.55	3.91	3.72	4.71	3.78	2 – 4 mm
VIM	4.55	4.68	4.71	4.57	4.25	3 – 5%
VFA	68.28	69.66	71.28	73.46	76.21	Min. 65%
VMA	14.34	15.43	16.41	17.22	17.85	Min. 14%
Marshall Quotient (M-Q)	482.37	407.01	460.51	378.38	493.42	-

Table 8. Marshall test results of sample M-50-50

Marshall characteristics	Plan asphalt binder content					Specification
	5%	5.5%	6%	6.5%	7%	
Stability	1623.13	1756.40	1605.03	1806.58	1659.28	Min 1000 kg
Flow	3.54	3.83	3.87	4.61	4.80	2 – 4 mm
VIM	4.59	3.71	3.88	3.40	3.05	3 – 5%
VFA	67.93	74.53	75.66	78.98	81.91	Min. 65%
VMA	14.30	14.49	15.60	16.13	16.75	Min. 14%
Marshall Quotient (M-Q)	458.90	458.51	414.84	392.08	345.44	

Table 9 shows Marshall test results for sample M-55-45 and the flow at 6.5% and 7% as well as VMA at 5% were found not to have met the required specifications. Meanwhile, VIM and VFA satisfied the general specifications of Bina Marga 2018 Revision 2 for stability. The results to determine KAO in Table 9 showed the range was from 5.446% to 6.357% and the middle value was 5.9%. KAO values obtained from each proposed mixture are presented in Table 10 and the lowest is 5.56% at M-50-50 while the highest is 5.9% at M-55-45. The trend showed the ability of RCA to reduce asphalt usage compared to the Control (NA) sample. It was further observed that the flow of M-55-45 did not meet the specifications of 4.32 mm and the sample also had the least stability and Marshall Quotient values due to the lesser quantity of RCA compared to M-45-55. Meanwhile, M-45-55 sample had the largest flow value compared to the control sample. RCA used had a higher aggregate strength than NA and this led to a higher stability or stiffness as shown in Marshall Quotient value.

Marshall immersion test was conducted to analyze the residual strength of the proposed mixture by immersing the sample in water for 24 hours at 60ºC. Figure 4 shows the KAO sample used to test Marshall immersion. The results presented in Table 11 showed 97.63% for the Control (NA) sample, 93.76% for M-45-55, 94.41% for M-50-50, and 92.65% for M-55-45 sample. This showed that all samples satisfied the minimum of 90% required but RCA samples tended to have lower values compared to NA due to the existence of pore mortar. The trend showed that mixtures with RCA absorbed more water leading to the reduction of the bonding structure between asphalt with aggregate and consequently the stability value. Moreover, Marshall immersion showed the adhesion behavior between aggregate grains and asphalt in the mixture. The values above 90% pointed to a lesser release of the grains in the mixture which led to resistance to changes in temperature and traffic loads when used as a highway pavement.

Table 12 shows Cantabro Loss test results conducted using Los Angeles machine with 300 revolutions to determine the percentage of the mixture to grain release for the proposed mixture. It was observed that the mixture with RCA had a greater Cantabro Loss value than the Control sample and this pointed to a higher susceptibility of the mixture to grain release. The largest value was recorded for M-55-45 sample at 7.26% while the smallest was in M-45-55 sample at 6.46%. These values met the required specifications of ≤ 20%, meaning the proposed asphalt mixture could withstand degradation against vehicle tire friction and resistance. The values further showed the ability of the mixture to withstand and distribute good traffic loads to the underlying layers in order to support the pavement as a whole and be used for heavy traffic. Furthermore, the application of RCA in AC-BC mixture was based on the ability to reduce the asphalt content and potentially increase Marshall stability values. It can also reduce the amount of concrete waste from the demolition of concrete road pavements through the subsequent reapplication of other road pavement constructions.

Table 9. Marshall test results of sample M-55-45

Marshall characteristics	**Plan asphalt binder content**					**Specification**
	5%	**5,55**	**6%**	**6,5%**	**7%**	
Stability	1553.24	1890.08	2311.44	1738.51	1638.24	Min 1000 kg
Flow	3.41	3.26	3.47	4.26	4.88	2 – 4 mm
VIM	3.39	3.32	4.37	4.41	3.99	3 – 5%
VFA	74.45	76.61	72.96	74.57	77.34	Min. 65%
VMA	13.28	14.20	16.08	17.05	17.61	Min. 14%
Marshall Quotient (M-Q)	455.56	580.58	665.64	408.15	335.98	

Table 10. Marshall test results for KAO samples

Marshall characteristics	**Control (NA)**	**M-45-55**	**M-50-50**	**M-55-45**	**Specification**
KAO	6.48%	5.59%	5.56%	5.9%	-
Stability	1477.71	1909.79	1794.12	1483.71	Min 1000 kg
Flow	3.69	3.69	3.33	4.32	2 – 4 mm
VIM	4.01	4.39	4.67	4.63	3 – 5%
VFA	77.44	72.29	69.96	71.38	Min. 65%
VMA	17.72	15.45	15.46	16.13	Min. 14%
Marshall Quotient (M-Q)	400.28	517.84	538.72	343.77	-

Figure 4. KAO sample produced

Table 11. Marshall Immersion test results

Testing Parameters	Control (NA)	M-45-55	M-50-50	M-55-45	Specification
KAO	6.48%	5.59%	5.56%	5.9%	-
Stability of the Test Piece soaked for 30 minutes.	1477.71	1909.79	1794.12	1483.71	Min. 1000 kg
Stability of Test Objects soaked 24 hours.	1442.66	1790.66	1693.91	1374.66	Min. 1000 kg
Marshall Immersion.	97.63%	93.76%	94.41%	92.65%	Min. 90%

Table 12. Cantabro Loss test results

Parameter	Control (NA)	M-45-55	M-50-50	M-55-45
KAO	6.48%	5.59%	5.56%	5.9%
Weight of Initial Test Object (gr)	1182.47	1184.67	1169.8	1159.60
Weight of Test Object After Cantabro Testing (gr)	1163.9	1108.13	1091.8	1075.27
Cantabro Loss (%)	1.57	6.46	6.67	7.27

4. Conclusions

In conclusion, the use of RCA in AC-BC mixture had a positive effect through the production of smaller optimum asphalt content than samples with NA. Marshall test showed that the sample with 55% RCA had a stability value of 1909.79 kg, 50% RCA had 1813.59 kg, and 45% RCA had 1483.71 kg, with a flow of 3.69 mm, 3.57 mm, and 4.32 mm, respectively. Moreover, Marshall immersion test showed that RCA mixtures had a lower value than those containing NA with 50% RCA observed to have the highest residual strength of 94.41%. Cantabro Loss test showed that RCA mixtures experienced higher grain release than those containing NA with 45% RCA reported to have the smallest Cantabro Loss value. Therefore, Marshall and Cantabro Loss test results showed that using RCA at 45% - 55% levels could positively affect AC-BC pavement mixture by producing high stability values and good wear resistance, specifically for pavements with heavy traffic.

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