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Performance Analysis of Resilient Modulus and Fatigue Resistance of AC-BC Mixture with Full Extracted Asbuton and Reclaimed Asphalt Pavement (RAP)

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Abstract

One way to be developed to overcome challenges in providing flexible pavement materials is to apply the green roads principle by reusing some or all of the old road pavement material or Reclaimed Asphalt Pavement (RAP) as a material for new road pavement, which if reused will affect the performance of the mixture, such as decreasing the level of durability and premature pavement damage, so an effort must be made to improve the performance of the recycled material, namely by adding full extracted Asbuton and rejuvenating materials. The RAP material was obtained from scratching the asphalt of the Jagorawi Toll Road. The mixture used was asphalt concrete-binder course (AC-BC) layer using 30%, 40%, and 50% RAP material, using full extracted Asbuton at 6%, and Nichireki rejuvenating material. Then, on mixtures with RAP material, Marshall Test, Resilient Modulus test with UMATTA, and resistance to fatigue with four points loading test with strain control were conducted. The use of RAP material with modified asphalt in the form of an addition of full extracted Asbuton into the Pen 60/70 Asphalt can increase the asphalt stiffness. Marshall test results showed that a mixture with 6% full extracted asbuton content and 0% RAP material content (A6RAP0) gave the highest stability value. The results of the Resilient Modulus test showed that the mixture with 6% full extracted asbuton content and 50% RAP material content (A6RAP50) gave a high Resilient Modulus value at a test temperature of 45°C. The results of the fatigue resistance test showed that the mixture with 6% full extracted asbuton content and 50% RAP material content (A6RAP50) at a strain level of 300 $\mu\varepsilon$ gave the longest fatigue life.

Keywords: Reclaimed asphalt pavement (RAP), full extracted asbuton, asphalt concrete -binder course, modified asphalt, resilient modulus, fatigue life.

Abstrak

Salah satu cara dikembangkan untuk mengatasi tantangan dalam penyediaan material perkerasan lentur adalah menerapkan prinsip greenroads dengan memanfaatkan kembali sebagian atau keseluruhan material perkerasan jalan lama atau Reclaimed Asphalt Pavement (RAP) sebagai material untuk perkerasan jalan yang baru, dimana jika digunakan kembali akan mempengaruhi kinerja dari campuran seperti penurunan tingkat durabilitas dan kerusakan dini perkerasan, sehingga harus dilakukan suatu upaya untuk memperbaiki kinerja dari material daur ulang tersebut, yaitu dengan penambahan Asbuton murni dan bahan peremaja. Material RAP didapatkan dari hasil garukan aspal Jalan Tol Jagorawi. Campuran yang dipakai adalah Laston Lapis AC-BC menggunakan kadar material RAP sebanyak 30%, 40%, dan 50%, dengan penggunaan Asbuton murni sebesar 6%, serta bahan peremaja Nichireki, dan kemudian selanjutnya pada campuran dengan penggunaan material RAP dilakukan pengujian Marshall, Modulus Resilien dengan alat UMATTA dan ketahanan terhadap kelelahan (fatigue) metode four points loading test dengan kontrol regangan. Penggunaan material RAP dengan aspal modifkasi berupa penambahan Asbuton murni kedalam Aspal Shell Pen 60/70 dapat meningkatkan kekakuan aspal. Hasil pengujian Marshall menunjukkan campuran dengan kadar Asbuton murni 6% dan kadar material RAP 0% (A6RAP0) memberikan nilai stabilitas tertinggi. Hasil pengujian Modulus Resilien menunjukkan campuran campuran dengan kadar Asbuton murni 6% dan kadar material RAP 50% (A6RAP50) memberikan nilai Modulus Resilien yang tinggi pada temperatur pengujian 45°C. Hasil pengujian ketahanan terhadap kelelahan menunjukkan campuran dengan kadar Asbuton murni 6% dan kadar material RAP 50% (A6RAP50) pada regangan 300 $\mu\varepsilon$ memberikan umur kelelahan yang paling panjang.

Kata-kata kunci: Reclaimed asphalt pavement (RAP), Asbuton murni, laston lapis antara, aspal modifikasi, modulus resilien, umur kelelahan.

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1. Introduction

1.1 Background

The provision and improvement of the performance of road infrastructure currently face several major challenges, one of which is the limited material for flexible pavement in the form of aggregate and asphalt. Limited resources for new non-renewable materials and continuous use are one of the reasons why natural materials are increasingly scarce and their prices continue to increase, so it is necessary to consider the application of methods of providing materials in the construction and handling of road pavement damage that is more environmentally friendly and more economical.

One way which is currently being developed to overcome challenges in providing flexible pavement materials is to apply the greenroads principle by reusing parts or all old pavement materials or Reclaimed Asphalt Pavement (RAP) as material for new road pavement. The recycled asphalt mixture material can be obtained from the raking or demolition of the road pavement layer that has completed its service life.

Recycled pavement materials, both aggregate and asphalt, have decreased physical properties as well as rheological changes due to traffic loads and environmental conditions during their previous service life, which if reused will affect the performance of the mixture such as decreased durability and premature pavement damage due to increased stiffness of the asphalt mixture so that an effort must be made to improve the performance of the recycled material. Improving the basic rheological properties of asphalt can be done by adding additives, such as soft asphalt, polymers, and/or rejuvenating materials. For recycled asphalt materials that have undergone aging, it is necessary to mix them with soft asphalt or a rejuvenating material. The rejuvenating material will restore the physical and chemical properties of the RAP asphalt.

One of the added ingredients that is expected to improve the performance of asphalt mixtures is Buton Stone Asphalt (Asbuton) which is starting to be widely used as a substitute or as an additive to hard asphalt. One of the uses of Asbuton in asphalt mixtures is full extracted asbuton as a result of extraction from Granular Asbuton (Buton Granular Asphalt). The addition of full extracted asbuton which is stiff as an additive to Pen 60/70 hard asphalt can improve the rheology of hard asphalt which is viscoelastic so that it will increase the performance of the durability (strength) of the asphalt mixture. Modified asphalt using full extracted asbuton in the AC-BC mixture with the use of RAP material and rejuvenating material can be a solution to produce a mixture that results in an increase in Resilient Modulus value, is resistant to fatigue crack and groove damage due to high traffic loads, and produces environmentally friendly pavement.

One of the parameters that can analyze the performance of the pavement mixture is by analyzing the response of the pavement to traffic loads or more commonly referred to as the Resilient Modulus using the Universal Materials Testing Apparatus (UMATTA) test tool. In addition, the resistance of a pavement to fatigue can also interpret pavement performance through testing with the Four Loading Fatigue Test.

1.2 Scope of research

a. Type of mixture used was Asphalt Concrete-Binder Course (AC-BC).
b. The test referred to 2010 Bina Marga General Specifications (Rev.3), SNI, ASTM, and AASHTO.
c. Materials used:
   - Reclaimed Asphalt Pavement (RAP) from Jagorawi Toll Road maintenance;
   - Shell Pen 60/70 Asphalt;
   - Full extracted asbuton from the extraction of the Buton Granular Asphalt;
   - Nichireki rejuvenating material;
d. The percentage of RAP material used in the mixture was 0%, 30%, 40% and 50% with full extracted asbuton at 6%.
e. The asphalt mixture planning used the Marshall method and Absolute Density Approach to obtain the Optimum Asphalt Content (OAC).
f. Laboratory testing under OAC condition consisted of:
   - Marshall immersion test;
   - Resilient Modulus test using UMATTA test tool;
   - Resistance to fatigue crack test using Four Point Loading Test.

2. Research Methodology

The flowchart for the research work plan can be seen in **Figure 1**.

3. Data Presentation

3.1 RAP material extraction test results

Before using the RAP material in the mixture, it is necessary to determine the asphalt content and the asphalt characteristics of the RAP material. The results of the test of asphalt content in the RAP material are shown in **Table 1**.

The results of the test of asphalt physical characteristics of the RAP Material are shown in **Table 2**.

On the aggregates extracted from the RAP material, the physical properties of the aggregates were tested and the sieve analysis was tested. The results of the sieve analysis test will determine whether to add aggregate to meet the AC-BC mixture gradation specifications. The results of the sieve analysis test of the aggregates extracted from the RAP Material are shown in **Table 3**.

The results of the sieve analysis of the RAP material aggregate show that the percentage passing is greater than the specifications, as shown in **Figure 2**, so that

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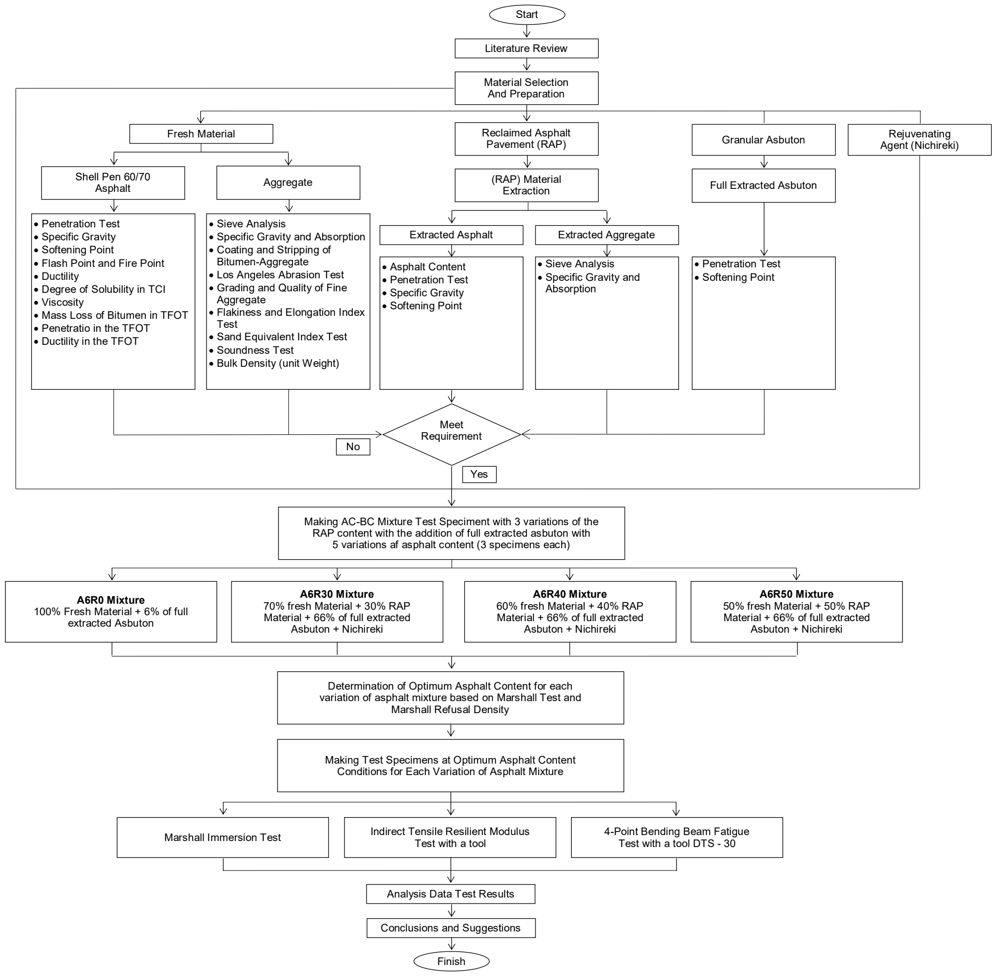

Gambar 1. Research flowchart

Table 1. RAP material asphalt content calculation

Sample	Weight (gr)			Asphalt Content (%)
	Sample	Aggregate	Asphalt	
(1)	(2)	(3)	(4) = (2) – (3)	(5)
I	500	468,90	31,10	6,22
II	500	465,20	34,80	6,96
RAP Material Average Asphalt Content				6,59

Table 2. RAP material asphalt characteristics

No	Test Type	Test Result
1	Asphalt Penetration (dmm)	10,80
2	Asphalt Specific Gravity	1,142
3	Softening Point (^{o}C)	75,50
4	Flash Point (^{o}C)	332

for the making of asphalt mixtures, new aggregates will be added to several aggregates sizes.

From the results of the RAP material aggregate physical properties test, it is known that the specific gravity of coarse aggregate is 2.59 with an absorption of 2.30% while the specific gravity of fine aggregate is 2.61 with an absorption of 0.81%.

Table 3. RAP material aggregate gradation

Sieve Size		% Passing Specification		Cumulative % Passing	
ASTM	(mm)	Upper	Lower	I	II
1”	25	100	100	100	100
3/4”	19	100	90	100	100
1/2"	12,5	90	75	95,54	95,03
3/8”	9,5	82	66	91,26	88,93
No. 4	4,75	64	46	71,04	68,55
No. 8	2,36	49	30	45,96	46,04
No. 16	1,18	38	18	32,46	32,59
No. 30	0,6	28	12	25,34	25,17
No. 50	0,3	20	7	20,71	20,25
No. 100	0,15	13	5	12,41	12,49
No. 200	0,075	8	4	6,87	6,17

3.2 Full extracted asbuton Test Results

Physical test of full extracted asbuton was conducted to determine the characteristics of full extracted asbuton to be used in the AC-BC mixture. The results of the full extracted asbuton physical properties test are shown in **Table 4**.

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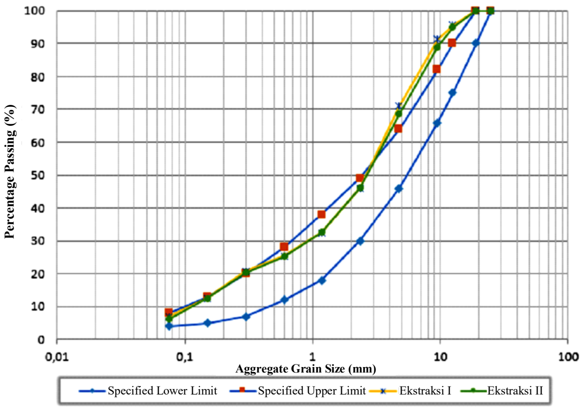

Figure 2. Comparison of specifications for mixture gradation and aggregate gradation of RAP material

Table 4. Test results for full Extracted asbuton properties

Test Type	Test Result
Penetration (dmm)	13,50
Softening Point (°C)	73,00
Asphalt Specific Gravity	1,055

3.3 The addition of Full extracted asbuton and Pen 60/70 Hard Asphalt to RAP Material Extracted Asphalt and Rejuvenating Material

Determination of the content of Nichireki rejuvenating material used was conducted based on the penetration value approach. Asphalt extracted from the RAP Material was heated up to 120°C and then was added with rejuvenating material based on the weight ratio. The asphalt extracted from the RAP material was heated to 120°C and then a rejuvenating material was added based on the weight ratio. The penetration value refers to the basic asphalt requirements, namely Pen 60/70 hard asphalt from the 2010 Bina Marga General Specifications (rev. 3). Along with the increase in the content of Nichireki in the RAP material asphalt, the penetration value will also increase. Based on the test results, it is known that the addition of Nichireki of 42% of weight of RAP material asphalt will provide a penetration value that is in accordance with Shell Pen 60/70 Asphalt.

To determine the physical properties of the combination of Shell Pen 60/70 Asphalt and full extracted asbuton with asphalt extraction of RAP and Nichireki, a test of the physical properties of asphalt from the mixture of these materials was conducted,

Table 5. Relationship of nichireki content with RAP asphalt penetration

Content Nichireki (%)	RAP Asphalt Penetration Value (dmm)
0	10,80
10	18,63
20	27,00
30	39,79
40	58,75
42	61,90
50	78,60

Table 6. Asphalt mixing physical properties test results

Test Type	Specifications		Test Result			
	Min	Maks	A6RAP0	A6RAP30	A6RAP40	A6RAP50
Asphalt Penetration	60	79	55,38	63,60	66,50	67,10
Softening Point	48	-	52,25	50,75	50,25	49,25

where the composition of full extracted asbuton was 6%, RAP Material asphalt content were at 0%, 30 %, 40%, and 50%, and Nichireki was 42% of the test sample weight.

Table 6 shows that the addition of full extracted asbuton to the Shell Pen 60/70 Asphalt shows that this asphalt mixture is stiffer and has the ability to resist better surface temperatures. Asphalt mixture with the use of RAP and Nichireki materials of 42% results in a higher penetration value and lower softening point temperature along with the addition of RAP material content and the addition of Nichireki making the asphalt mixture softer.

The results of test and analysis of kinematic viscosity data show that the addition of full extracted asbuton to the Shell Pen 60/70 Asphalt and the use of RAP asphalt will make the mixture thicker, resulting in an increase in the mixing temperature and the temperature of the asphalt mixture, where the mixing temperature and compaction temperature range on the Pen 60/70 Shell Pen Asphalt (150-156°C and 142-147°C) was lower compared to the mixture of Shell Pen 60/70 Asphalt and the addition of full extracted asbuton (153,2-159,1°C and 141-146,4°C) and the addition of full extracted asbuton to the Shell Pen 60/70 Asphalt and the use of RAP Asphalt and Nichireki generated the highest mixing temperature and compaction

Table 7. Marshall parameter values under OAC_{Ref} condition for each mixture variation

Criteria	A6RAP0	A6RAP30	A6RAP40	A6RAP50
OAC (%)	5,25	5,40	5,44	5,70
Stability (kg)	2.135,67	1.446,31	1.410,99	1.348,54
Flow (mm)	3,62	5,10	6,41	6,92
VIM (%)	3,64	3,30	3,06	3,11
VMA (%)	14,34	14,68	14,16	14,18
VFA (%)	74,08	76,56	77,64	77,23
MQ (kg/mm)	589,96	283,59	220,12	194,88

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temperature of Shell Pen 60/70 Asphalt (155-159°C and 147-151°C).

3.4 AC-BC mixture test

In this test, the mixtures used were:

a. A6RAP0 Mixture is a mixture with 0% RAP Material with an addition of 6% of full extracted asbuton;
b. A6RAP30 Mixture is a mixture with 30% RAP Material with an addition of 6% of full extracted asbuton;
c. A6RAP40 Mixture is a mixture with 40% RAP Material with an addition of 6% of full extracted asbuton;
d. A6RAP50 Mixture is a mixture with 50% RAP Material with an addition of 6% of full extracted asbuton.

3.4.1 Marshall test and absolute density approach

Marshall test was conducted to obtain the Optimum Asphalt Content (OAC) from each mixture variation. OAC was obtained based on asphalt content that met the Marshall parameter specifications and mixture volumetrics, namely stability, flow, VIM, VMA, and VFA based on Marshall test results to obtain Marshall OAC and Absolute Density Approach to obtain OAC_{Ref} according to the 2010 Bina Marga General Specifications (rev. 3). The OAC value of each mixture is presented in **Table 7**.

3.4.2.Marshall immersion test

The Marshall Immersion test was conducted to determine the durability of the asphalt mixture against water damage by immersing the specimens in water at a temperature of 60°C for 24 hours, then comparing them with the specimens immersed in standard condition (immersion for 30 minutes). The percentage of stability comparison is called the Residual Strength Index (RSI). The test specimen used for this test was a mixture of asphalt under OAC_{Ref} condition. Marshall immersion test results are shown in **Table 8**.

3.4.3 Resilient modulus test with UMATTA

Resilient Modulus Test was conducted using the UMATTA tool, where the test specimen used was diametrically shaped like the Marshall test specimen and made under OAC_{ref} condition. The test method referred to AASHTO TP31 and ASTM D 4123-82 with test temperatures of 35°C and 45°C. The results of the Resilient Modulus test for each mixture variation are shown in **Table 9**.

3.4.4 Resistance to fatigue test with the four point loading test method

This test was conducted on every mixture variation under OAC_{Ref} condition. The test object was a beam where each mixture variation was tested at two levels of strain, namely 300 and 500. According to AASHTO T 321-07, the fatigue test temperature was 20±0.5°C. Fatigue test results can be seen in **Table 10**.

4. Data Analysis

4.1 RAP material extraction test analysis

The asphalt in the RAP material had undergone an oxidation process which caused the evaporation of the light fraction in the asphalt and the change in the liquid fraction (maltenes) to solid (asphaltenes) so that the asphalt became harder or stiffer, as seen from the average penetration value of 10.80 dmm and softening point at a temperature of 75.50°C, so a higher temperature or the addition of a rejuvenating material was needed to make the asphalt softer.

While for the aggregate of RAP material, the results of the sieve analysis show that the gradation of the aggregate of RAP material tended to be smooth, because the aggregate experienced wear due to friction with traffic loads and due to the asphalt stripping process using a recycler machine (milling machine)

Table 8. Marshall immersion test Results

Mixture Property	Specification	Mixture Variation			
		A6RAP0	A6RAP30	A6RAP40	A6RAP50
Standard Immersion Stability (kg), A	>1.000	1749,4	2.164,4	2.198,6	1.947,8
24-hour Immersion Stability (kg), B	-	1632,0	2.094,7	2.172,8	1.925,6
RSI (%) =B/A	>90	93,30	96,80	98,80	98,90

Table 9. Resilient modulus test with UMATTA tool

Mixture Type	Test Temperature (°C)	Total Horizontal Deformation (μm)	Peak Load (N)	Resilien Modulus (RM) (MPa)	RM Standar Deviation	MR *Coefficient of Variance*
A6RAP0	35	10,54	1.501	1.535	36,13	2,35
	45	14,13	1.406	1.090	44,01	4,04
A6RAP30	35	15,62	1.474	1.037	19,97	1,93
	45	18,84	1339	780	31,33	4,02
A6RAP40	35	9,14	1525	1.861	20,77	1,12
	45	15,71	1336	950	29,75	3,13
A6RAP50	35	12,32	1506	1.381	32,29	2,34
	45	20,71	1340	734	21,55	2,93

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Table 10. Fatigue test with four point loading test method results

Mixture Type	Strain Level (με)	*Flexural Stiffness* (MPa)			Load Repetition (*Cycles*)
		Initial	*Current*	*Termination*	
A6RAP0	300	5499	1953	2750	185200
	500	7002	3450	3501	2090
A6RAP30	300	3560	1690	1780	111680
	500	7362	3599	3681	6170
A6RAP40	300	5334	2270	2667	86310
	500	4732	2365	2366	16760
A6RAP50	300	5472	767	2736	180790
	500	4829	1997	2415	12680

which broke the aggregate into finer fractions. The results of the test of specific gravity of the RAP material aggregate and absorption show that the aggregate of the RAP material was quite good and could be reused in the makingof asphalt mixtures.

4.2 Full extracted asbuton test analysis

The test results of the average penetration value of full extracted asbuton of 13.50 dmm indicated that full extracted asbuton had stiffer properties. This can also be seen from the softening point test of full extracted asbuton at a temperature of 73.0°C.

4.3 Analysis of addition of full extracted asbuton and pen 60/70 hard asphalt with RAP extraction asphalt and rejuvenating material

The addition of full extracted asbuton would increase the hardness of Shell Pen 60/70 Asphalt where the penetration value was 52.55 dmm, and the softening point at 52.25°C was higher than the softening point of Shell Pen 60/70 Asphalt, this indicated the addition of full extracted asbuton to the Shell Pen 60/70 Asphalt could be used in high temperature conditions.

The results of the test on RAP asphalt with the addition of Nichireki, based on the results of the penetration test approach, show that 42% of Nichireki was required to add to the weight of RAP asphalt.

The increase in the percentage of RAP asphalt was also in line with the amount of Nichireki rejuvenating material used and consistently increased the penetration value and lowered the softening point. This shows that the use of Nichireki in asphalt mixing could make the asphalt mixture softer so that it could increase elasticity and give an effect on the performance of the AC-BC mixture.

4.4 Marshall test results analysis

The mixture of A6RAP0 produced the highest maximum stability value of 2,124.57 kg because the asphalt mixture of Pen 60/70 asphalt with full extracted asbuton was stiffer. In a mixture of A6RAP30, A6RAP40, and A6RAP50 the stability value decreased with the addition of asphalt content, where the maximum stability value was obtained at the minimum asphalt content of 1,933.65 kg, 1,955.44 kg, 2,094.57 kg, this indicates the higher the asphalt content, the higher the amount of rejuvenating material, allowing the asphalt in the AC-BC mixture to become softer so that the strength of the mixture to carry the load decreased.

The results of the flow test, in all variations of the mixture, the value increased with the addition of asphalt content, where the A6RAP0 mixture has the lowest flow value due to the higher stiffness of the asphalt, while the mixture containing RAP, the mixture of asphalt and Nichireki rejuvenating material became soft, so that the flow value was higher. This allows the A6RAP0 mixture to receive a greater load than the mixture containing RAP material before undergoing deformation.

A6RAP0 mixture produced a higher MQ value, in accordance with the results of stability and flow tests. While in the variation of the mixture with RAP material, the resulting MQ value decreased with increasing asphalt content, where as asphalt content increased, the resulting stability value decreased, and the yield value increased.

The VIM value in the A6RAP0 mixture shows a higher value, due to the asphalt mixture being stiffer and causing the asphalt to not be able to fully fill the void in mix. Meanwhile, in all variations of the mixture with RAP material, the VIM value was smaller because the asphalt mixture had a fairly good elasticity, and the greater the asphalt content, the more VMA filled with asphalt.

The VMA value tended to increase with the addition of asphalt content in each variation of the mixture. The high VMA value was because the modified asphalt in the A6RAP0 and A6RAP30 mixture was stiffer and did not completely cover the aggregate voids. Meanwhile, the A6RAP50 mixture had the lowest VMA value. This was possible because, on the mixtures with RAP material, the asphalt was softer and able to fill the aggregate pores quite well.

The A6RAP0 mixture had a lower VFA value than the mixtures with RAP material, due to the lower asphalt content, so it could not fill the mixture voids optimally. While the mixture with RAP material, in general, the VFA value was higher, where the asphalt content was higher which indicates that the mixture using RAP material caused the asphalt to be more capable of filling aggregate voids and has a thicker asphalt blanket.

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4.5 Mixture analysis under OAC condition

The comparison between OAC_{Ref} values for each mixture variation can be seen in **Figure 3**.

The KAO value in the A6RAP0 mixture was smaller than the mixture using RAP material. In a mixture using RAP material, the OAC_{Ref} value increased with the addition of the percentage of RAP material because in a mixture using RAP material, the increasing content of RAP material would require more asphalt to cover the aggregate in the mixture.

4.6 Marshall immersion test analysis

Residual Strength Index (RSI) on the A6RAP0 mixture was the lowest (93,29%). This shows that water infiltration and temperature were quite influential in reducing the stability value. In addition, the thickness of the asphalt blanket that was not optimal could also be one of the factors that caused the durability of the mixture to decrease against the influence of water. In the mixture with RAP material, the RSI value obtained was >95%, and increased with the addition of the percentage of RAP material in the mixture. This shows that the mixture using RAP material had better adhesion between aggregate and asphalt and had good resistance to the influences of water and temperature and caused the mixture to become watertight and more durable because it was not prone to stripping.

4.7 Resilient modulus test analysis

Resilient modulus test results using UMATTA tool at temperatures of 35^{o}C and 45^{o}C can be seen in **Figure 4**.

At the test temperature of 35^{o}C and 45^{o}C, the A6RAP0 mixture produced quite high Resilience Modulus values of 1,535 MPa and 1,090 MPa, these values were influenced by asphalt modification of Shell Pen 60/70 Asphalt with the addition of full extracted asbuton which had high stiffness, which was also in accordance with the stability value and yield value so that it had good deformation resistance.

In mixtures with RAP material, at the test temperature of 35^{o}C and 45^{o}C, the A6RAP40 mixture had the highest Resilient Modulus value compared to the A6RAP30 and A6RAP50 mixtures, which were 1,861 MPa and 950 MPa. The A6RAP40 mixture had a higher Resilient Modulus value because it had a smaller void in mix and had a higher OAC than the A6RAP0 mixture so that there was an adequate asphalt film layer to cover the aggregate to maintain the bond between the aggregates when given a load at low and high temperatures. While the A6RAP30 and A6RAP50 mixtures, at test temperatures of 35^{o}C and 45^{o}C, produced a high Resilient Modulus of 1,037 MPa and 780 MPa, respectively, and 1,381 MPa and 734 MPa.

4.8 Resistance to fatigue test result

In the test with a strain of 300 με, the A6RAP0 mixture produced the longest fatigue life of 185,200 cycles, which shows that the mixture containing modified Asphalt Shell Pen 60/70 and full extracted asbuton has better fatigue resistance.

In the test with a strain of 500 με, the A6RAP0 mixture produced the shortest fatigue life of 2,090 cycles, which shows the high stiffness of the A6RAP0 mixture, prone

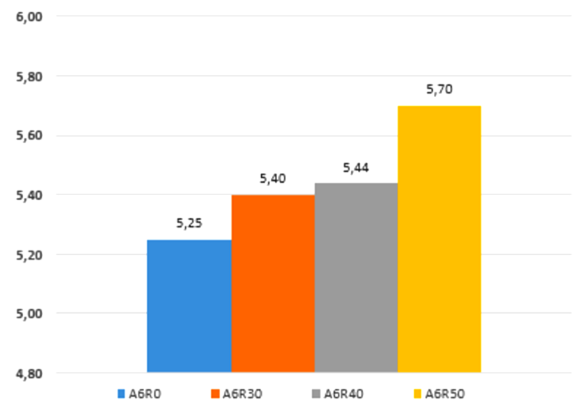

Figure 3. OAC_{Ref} values comparison for each variation of mixture

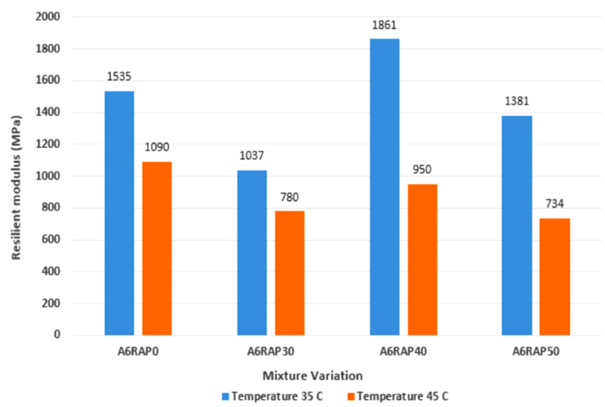

Figure 4. Comparison between resilient modulus values using UMATTA test tool

Table 11. Marshal parameters of each mixture variation under OAC condition

Marshall Parameter	Specification	A6RAP0	A6RAP30	A6RAP40	A6RAP50
OAC (%)	-	5,25	5,40	5,44	5,70
Stability (kg)	min. 1000	2.135,67	1.446,31	1.410,99	1.348,54
Flow (mm)	2 - 4	3,62	5,10	6,41	6,92
VIM (%)	3 – 5	3,64	3,30	3,06	3,11
VMA (%)	Min 14	14,34	14,68	14,16	14,18
VFA (%)	Min 65	74,08	76,56	77,64	77,23
MQ (kg/mm)		589,96	283,59	220,12	194,88

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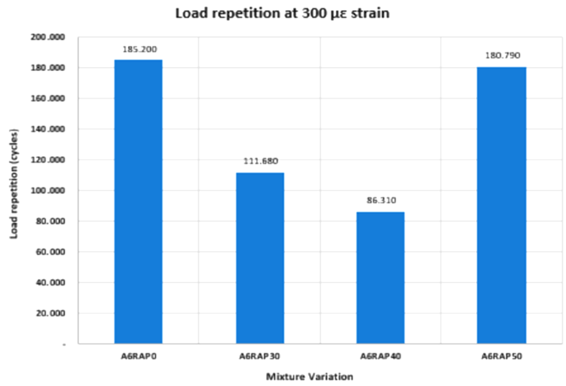

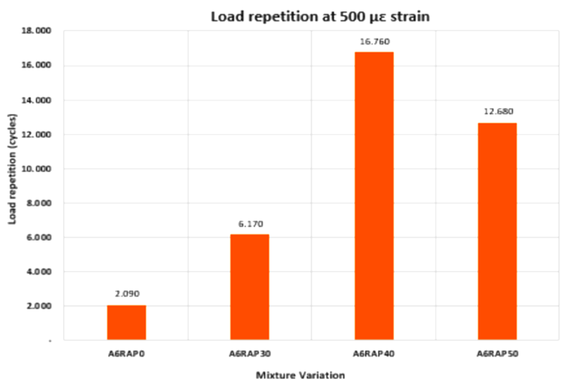

Figure 5. Fatigue life at 300 με and 500 με strains for each mixture variation

to high strain, because the greater the stress generated and the faster failure is achieved.

In the mixtures with RAP material at a strain of 300 με, the longest fatigue life was produced in the A6RAP50 mixture of 180,790 cycles. While for the mixture of A6RAP30 and A6RAP40 they were 111,680 cycles and 86,310 cycles or 60.30%, 46.60%, and 97.62% compared to the fatigue life of the A6RAP0 mixture. This shows that the mixture using RAP has a fairly high Resilient Modulus, so that the mixture tends to get fatigued more quickly.

At a strain of 500 με, the mixtures with RAP material produced a fairly long fatigue life, where the A6RAP30, A6RAP40, and A6RAP50 mixtures' fatigue life was 6,170 cycles, 16,760 cycles, and 12,680 cycles or equal to 295.22%, 801.91%, and 606.70% compared to the A6RAP0 mixture's fatigue life. It is possible that the mixture using RAP material has a composite asphalt that has high elasticity, so that at high strain, the mixture with the use of RAP material is more flexible, so it is resistant to fatigue.

5. Conclusions and Suggestions

5.1 Conclusions

Based on the presentation and analysis of the data, it can be concluded that:

1. The test results on the extracted RAP material showed that the RAP asphalt material has undergone aging so that it becomes stiffer, where with the addition of 42% Nichireki, the RAP asphalt material may become softer so that it can be used in asphalt mixtures. While for the RAP material aggregate, it is necessary to add several new aggregate sizes to maintain the planned gradation to meet specifications.
2. The addition of full extracted asbuton to Shell Pen 60/70 Asphalt without RAP asphalt has a lower penetration value and higher melting point temperature than mixtures with RAP asphalt and Nichireki. The increase in RAP asphalt content in the combination of Pen 60/70 Shell asphalt and full extracted asbuton with RAP asphalt and Nichireki indicates that the asphalt mixture becomes softer, indicated by the greater penetration value and lower softening point temperature.
3. Under OAC_{Ref} condition, the stability and MQ values in the mixture without RAP material (A6RAP0) resulted in the highest values and the lowest flow value. On mixtures using RAP material, the RSI obtained were higher than 95%.
4. At the test temperature of 35°C and 45°C, the A6RAP0 mixture produced a fairly high Resilient Modulus value of 1,535 MPa and 1,090 MPa, while for the mixtures with RAP material, at the test temperature of 35°C and 45°C, the A6RAP40 mixture had the highest Resilient Modulus value of 1,861 MPa and 950 MPa. The A6RAP50 mixture also had a Resilient Modulus value of 1.381 MPa and 734 MPa.
5. At a strain of 300 με, the A6RAP0 mixture produced the longest fatigue life (185,200 cycles), while at a strain of 500 με, the fatigue life was the shortest (2,090 cycles). For mixtures using RAP material, at a strain of 300 με, the longest fatigue life was produced by A6RAP50 mixture, 97.62% of A6RAP0's fatigue life. While at a strain of 500 με, it was 606.70% of A6RAP0's fatigue life. This was probably because mixtures using RAP material are more flexible and resistant to fatigue.
6. Overall Test Conclusion
   Generally, based on the results of tests and analysis, for the suitability of the use of full extracted asbuton with the performance of the AC-BC mixture with the use of RAP material, the use of full extracted asbuton content of 6% is recommended in the AC-BC mixture with a RAP content of 50% because it increases the strength of the mixture in the form of stability and Resilient Modulus, and provides long fatigue life.

5.2 Suggestions

Based on the results of the research, here are some suggestions that are proposed:

1. At the mixture-making stage, full extracted asbuton and Shell Pen 60/70 Asphalt should be mixed first before being added to the aggregate.

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2. Further research on the percentage of Nichireki rejuvenating material to improve the rheological properties of asphalt for the use of high-grade RAP material is necessary.
3. Further research on the asphalt content of the RAP material that can be activated in the RAP mixture is necessary.
4. It is necessary to test the rheological properties of asphalt using a Dynamic Shear Rheometer (DSR) on RAP asphalt with the addition of a rejuvenating material in order to determine its effect on the performance of a mixture using RAP material.
5. It is necessary to conduct a fatigue test with large variations in loading in accordance with the loading in the field.

References

AASHTO (2010): Standard Specifications for Transportation Materials and Methods of Sampling and Testing. American Association of State Highway and Transportation Officials, Washington.

Affandi, F. (2006): Jurnal, Ekstraksi Aspal Asbuton Untuk Campuran Beraspal Panas, Puslitbang Jalan dan Jembatan, Bandung.

Azka, A. (2020): Analisis Kinerja Campuran Lapis Antara (AC-BC) dan Hot Rolled Asphalt Menggunakan Asbuton Murni (Full Ekstraksi), Tesis Program Magister, Institut Teknologi Bandung.

Direktorat Jenderal Bina Marga (2010): Spesifikasi Umum (Rev.3), Kementerian Pekerjaan Umum, Jakarta.

Djunaedi, R.O. (2015): Kajian Karakteristik Reologi Campuran Lataston (HRS-WC) Berdasarkan Spesifikasi Kementerian Pekerjaan Umum Menggunakan Aspal Pen 60/70 Dengan Penambahan Asbuton Murni, Tesis Program Magister, Institut Teknologi Bandung.

Huang, Y.H. (2004): Pavement Analysis and Design Second Edition, Prentice Hall, Inc. New Jersey.

Indriyati, E.W (2012): Kajian Perbaikan Sifat Reologi Visco-Elastic Aspal dengan Penambahan Asbuton Murni Menggunakan Parameter Complex Shear Modulus, Tesis Program Magister, Institut Teknologi Bandung.

Kurniadjie (2008): Modifikasi Aspal Keras Standar Dengan Bitumen Asbuton Hasil Ekstraksi, Pusat Litbang Jalan dan Jembatan, Bandung.

Maha, I., Subagio, B.S., Furqon, E., and Rahman, H (2015): Performance of Warm Mix Asphalt Concrete Binder Course (AC-BC) with Reclaimed Asphalt Pavement, Journal of the Eastern Asia Society for Transportation Studies, Vol. 11, 1745 – 1753.

Nirwan, E. (2015): Kajian Karakteristik Modulus Dinamis Dan Modulus Resilien Pada Campuran Lapis Pengikat (AC-BC) Dengan Menggunakan Material Daur Ulang (RAP), Tesis Program Magister, Institut Teknologi Bandung.

Nofriza, E. (2016): Evaluasi peningkatan kinerja campuran Laston Lapis Aus (AC-WC) dengan perbaikan sifat reologi visco-elastic aspal ditambah asbuton murni, Tesis Program Magister, Institut Teknologi Bandung.

Nono. (2015): Pengaruh Bahan Peremaja Terhadap Kinerja Campuran Beraspal Panas Bergradasi Menerus Menggunakan Daur Ulang Perkerasan Beraspal, Pusat Litbang Jalan dan Jembatan, Bandung.

Pradipta, W. (2016): Kinerja Modulus Resilien Dan Deformasi Permanen Dari Campuran Lapis Antara (AC-BC) Yang Menggunakan Material Hasil Daur Ulang (RAP) dan BNA Blend 75/25 Dalam Aspal Campuran Panas, Tesis Program Magister, Institut Teknologi Bandung.

Primadiyanti, S.P (2014): Evaluasi Perbaikan Sifat Reologi Visco-Elastic Aspal Dengan Penambahan Asbuton Murni Untuk Meningkatkan Kinerja Campuran Laston Lapis Pengikat (AC-BC) Bergradasi Kasar, Tesis Program Magister, Institut Teknologi Bandung.

Rahman, H. (2010): Evaluasi Model Modulus Bitumen Asbuton dan Model Modulus Campuran yang Mengandung Bitumen Asbuton, Disertasi Program Doktor, Institut Teknologi Bandung.

Suaryana, N., Susanto, I., Sembayang, I.R. (2018): Evaluasi kinerja campuran beraspal dengan bitumen hasil ekstraksi penuh dari Asbuton, Media Komunikasi Teknik Sipil, 24, 62 - 70.

Subagio, B.S., Rahman, H., Sinuhaji, C.A.V. (2018): Kinerja Modulus Resilien dan deformasi permanen dari campuran Lataston gradasi senjang (HRS-WC) dengan bahan aspal modifikasi Starbit E-55, Jurnal Teknik Sipil, 23, 149 – 158.

Wanudyaningrum, A (2019): Analisis Pengaruh Kadar Fine Aggregate Dari Reclaimed Asphalt Pavement Terhadap Kinerja Campuran Panas AC - BC Recycled, Tesis Program Magister, Institut Teknologi Bandung.

Yoder, E.J., Witczak, M.W. (1975): Principles of Pavement Design 2nd Edition, John Wiley & Sons, Inc, USA.

Zaumanis, M and Mallick, R.B (2015): Review of very high-content reclaimed asphalt use in plant-produced pavements: state of the art, International Journal of Pavement Engineering, 16:1, 39-55.Yoder, E.J., Witczak, M.W. (1975) : Principles of Pavement Design Second Edition, USA: John Wiley & Sons, Inc.

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Diterima 15 November 2021, Direvisi 27 November 2021, Diterima untuk dipublikasikan 7 Desember 2021