The Resilient Modulus and Plastic Deformation Performance of Hot Mix Recycling Asphalt (HMRA) using Modified Binder Elvaloy®

Bambang Sugeng SUBAGIO[a], Rahmi ZURNI[b], Harmein RAHMAN[c], Eri Susanto HARIYADI[d]

[a]*Professor, Graduate School of Highway Engineering and Development, Institut Teknologi Bandung, Jalan Ganeca 10, Bandung, Indonesia*
[b]*Assistant, Graduate School of Highway Engineering and Development, Institut Teknologi Bandung, Jalan Ganeca 10 Bandung, Indonesia*
[c,d]*Lecturer, Faculty of Civil Engineering and Environment, Institut Teknologi Bandung, Bandung, Jalan Ganeca 10 Bandung, Indonesia*
[a]*E-mail: bsugengs@si.itb.ac.id*
[b]*E-mail: my_en_in@yahoo.com*
[c]*E-mail: rahman@trans.si.itb.ac.id*
[d]*E-mail: erisdi@yahoo.com*

Abstract: Due to the demand of road infrastructure increases in Indonesia, it needs an alternative technology of road construction having economically, effectively and efficiently method. Reused (recycled) the existing old pavement materials may be one solution. It is expected repairing and improving structural capacity of pavement. This study is intended to reuse the recycled asphalt (RAP) in the Hot-mix Recycled Asphalt, namely HMRA. The recycled asphalt (RAP) used in HRMA was restricted to 7.5% and 10% by weight. In each HMRA mix an asphalt Pen60/70 and polymer Elvaloy® was added. The main laboratory works consist of Marshall Standard, Marshall Immersion test, Resilient Modulus Test and Wheel Tracking test. In General, the results of this research showed that the RAP materials can be used as alternative materials in Hot-mix Recycled Asphalt (HMRA), but the percentage of RAP was varied depend on the RAP's quality.

Keywords: *Recycling Asphalt, Modified Binder "Elvaloy", Stiffness Modulus, Permanent Deformation*

1. INTRODUCTION

Due to the demand of road infrastructure increases in Indonesia, it needs an alternative technology having economically, effectively and efficiently results. Reused or recycled the existing old pavement materials may be one solution. It is expected repairing and improving structural capacity of pavement. (Subagio et al., 2011).

Many reasons have been put forward for asphalt recycling. As the overall condition of road pavements continues to deteriorate, the standard of road network continues to decline. The situation is getting worse as the volume of traffic continues to grow. This requires increasing effort to maintain and rehabilitate the existing pavements. Since most of road agencies face budget constrains, the focus is on achieving more with the same expenditure. Recycling is one of the most effective methods to achieve these goals. Recycling also reduces the impact of pavement construction on environment by reusing depleting natural resources, reducing energy consumption and reducing green house emission (Uzarowski, et.al., 2008)

Since raw materials are becoming more expensive, it is becoming more important to find ways to reuse the materials already in-place in the roadway. The use of in-place materials saves energy because the materials are processed in-situ, which greatly reduces the trucking required to haul away old pavement materials as waste (Subagio, et al., 2010).

Therefore, modification of the recycled asphalt by adding an “original” asphalt that has been modified with polymer(elastomer) is expected to improve the properties of the recycled material (RAP) and can synergize well with the continuously graded asphalt mixture, that is Asphaltic Concrete Binder Course (AC - BC) mix. (Subagio, 2011).

The standard method used in this study is the Indonesian Specification for Hot-mix Asphalt Mixture (Dept.Public Works, 2010). Another standard methods, for example SNI (Indonesian Standard), British Standard, ASTM and AASHTO were used when appropriate.

2. EXPERIMENTAL PROGRAM

2.1. Reclaimed Asphalt Pavement (RAP)

The Indonesian specification for RAP materials states that: the reclaimed asphalt pavement (RAP) must be free from all unexpected material, it has certain toughness and it should not be clotted. The RAP which will be immediately used should be stacked in a protected place and it has to be free from the influence of rainy water and direct sunlight (Dept. Public Works, 2010).

Before the RAP materials were used in HMRA mixture, an Extraction test should be conducted, in order to determine the percentage of RAP’s Bitumen and its characteristics, which is presented in Table 1. The results showed that the Penetration was too low and its Softening Point was too high. It can be concluded that the quality of RAP materials was not good, probably due to long time of Hardening or Aging process.

Table 1.Characteristics of RAP’s Bitumen

No	Type Test	Result
1	Penetration , 25°C (dmm)	11,1
2	Softening Point, °C	68,5
3	Specific Gravity	1.078
4	Ductility (cm)	5,2

Considering the results of bitumen blend between Shell bitumen Pen 60/70, RAP’s bitumen and modified bitumen Elvaloy®, as presented in Table 2, it was decided that the percentage of RAP’s bitumen used in the HMRA (AC-BC mix) was 7,5% and 10%.

Table 2.Characteristics of RAP and Bitumen blend

	25% RAP		**15% RAP**		**10% RAP**		**7,5% RAP**	
	Shell & RAP	Elvaloy & RAP	Shell & RAP	Elvaloy & RAP	Shell & RAP	Elvaloy & RAP	Shell & RAP	Elvaloy & RAP
Penetration	39	23.8	44.6	34	**56.2**	44.8	**59.6**	46.4
Softening Point (^oC)	52	56	50	54	50	59	51	60

2.2. Polymer Modified Bitumen

Polymers have been widely used as an ingredient to enhance the robustness and temperature sensitivity of asphalt. One of the prime roles of a bitumen modifier is to increase its resistance to permanent deformation by stiffening the bitumen so that the total visco-elastic response of the asphalt is reduced. On the other hand, increasing the Stiffness of the bitumen will improve the load spreading ability of the material and increase also its cracking resistance due to fatigue. (SHELL, 1990). .

Polymer Modified Binder Elvaloy® is a modification of the asphalt by mixing or blending the Pen 60/70 conventional asphalt with Elvaloy® from Dupont which are elastomer, by using the RET (Reactive Elastomers Terpolymer) technology. Then there is no separation or precipitation of the polymer binder, because the chemical reactions have occurred.

The conventional asphalt used in this research is Shell bitumen Pen 60/70, and its properties are shown in Table 3.

Table 3. Properties of Shell Bitumen Pen 60/70

No	Type Test	Result	Specification	
			Min	Maks
1	Penetration , 25°C (dmm)	66,3	60	70
2	Softening Point, °C	50	48	-
3	Specific Gravity	1.04	1	-
4	Ductility (cm)	>100	100	

Regarding the characteristics of RAP's bitumen, as shown in Table 1, a bitumen mix between Shell bitumen and modified binder Elvaloy® should be determined. After some tests have been carried out, a bitumen mix with 50% of Pen 60/70 and 50% of polymer Elvaloy® was chosen, namely "Elvaloy-bitumen blend". The properties of this mixing bitumen (50% and 50%) are shown in Table 4.

Table 4. Properties of "Elvaloy-bitumen blend" (50% to 50%)

No	Type Test	Result	Specification	
			Min	Maks
1	Penetration , 25°C (dmm)	61.2	40	-
2	Softening Point, °C	56	54	-
3	Specific Gravity	1.046	1	-
4	Ductility (cm)	>100	100	

2.3 Gradations

The aggregate grading used in this study was the aggregate grading for Indonesian's Asphaltic Concrete Binder Course (AC-BC), as shown in Figure 1. It is shown that the RAP's Gradation was moved before and after Extraction, which the later one was laid "outside" the upper limit of the Gradation's envelope. This condition confirmed that the RAP's Bitumen changed its functions from coarse aggregates to fine aggregates, after the extraction process. Therefore, in this research, the RAP's bitumen was considered as coarse or fine aggregates instead of "aged" bitumen in the HMRA's mixture.

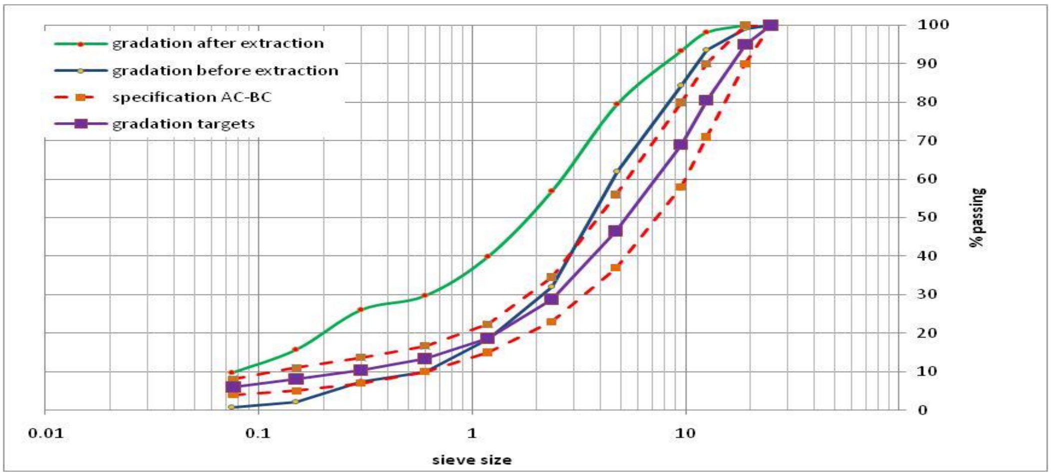

Figure 1. Gradation curve of RAP materials

2.4. Mix preparation

In this research, 4(four) types of mix were prepared, those are :

- A1 is a mixture AC-BC combined between 7.5% of RAP materials (by weight) and 92.5% of new materials with Shell Pen 60/70 plus Elvaloy Bitumen blend.
- A2 is a mixture AC-BC combined between 7.5% of RAP materials (by weight) and 92.5% of new materials with (only) Shell Pen 60/70.
- B1 is a mixture AC-BC combined between 10% of RAP materials (by weight) and 90% of new material with Shell Pen 60/70 plus Elvaloy bitumen blend.
- B2 is a mixture AC-BC combined between 10% of RAP materials (by weight) and 90% of new material with (only) Shell Pen 60/70.

2.5. Calculation of Stiffness Modulus

Resilient or Stiffness Modulus of bituminous mix is defined as the ratio of stress to strain under given conditions of loading time and temperature (McElvaney, 1988) Some formula was proposed in order to predict the Bitumen Stiffness (S_{bit}), as well as the Mix Stiffness (S_{Mix}).

Considering some bitumen characteristics i.e. loading time (t) and temperature difference ($T-T_{800\ Pen}$), the Van der Poel's monograph can be used to predict the Bitumen Stiffness. Alternatively, a formula proposed by Ullidtz (Ullidtz,1979) could be used to simplify the use of Van der Poel's monograph, as follows :

$$S_{bit} = 1.157 \times 10^{-7} \times t^{-0.368} \times \exp^{-PIr} \times (SP_r - T)^5 \quad (MPa) \tag{1}$$

where : PI_r : Recovered Penetration Index
SP_r : Recovered Softening Point (^oC)
T : Bitumen Temperature (^oC)
t : time of loading (second)

Before using that formula, some requirements should be accomplished, that is :

$$SP_r - T = 20^oC \text{ to } 60^oC$$

t = 0.01 second to 0.1 second
PI_r = -1 to +1

Following the simplified Ullidtz's formula, Brown (Brown, 1980) proposed one formula to predict the Mix Stiffness, that is :

$$S_{mix} = S_{bit} \left[1 + \frac{257.5 - 2.5 \times VMA}{n \times (VMA - 3)} \right]^n \quad (2)$$

where :

$$n = 0.83 \times \log \left[\frac{4 \times 10^5}{S_{bit}} \right] \quad (3)$$

and : VMA : Voids in the mixed aggregate (12% ≥ VMA ≥ 30%)

Shell (McElvaney, 1988) introduced the monograph to predict the Stiffness Modulus of asphalt mixture in function of the Bitumen Stiffness (S_{bit}) and aggregate volume concentration in the mixture. This study was followed by Bonnaure (Bonnaure et.al 1977) which introduced the equation of the Stiffness Modulus of asphalt mixture (with condition of the Bitumen stiffness (S_{bit}) ≥5 MPa) as follows :

$$\log S_m = \left(\frac{S_w + S_x}{2} \right) (\log S_b - 8) + \left(\frac{S_w - S_x}{2} \right) \left| \log S_b - 8 \right| + S_y \quad (4)$$

for : $5 \times 10^6 Pa < S_b < 10^9 Pa$

$$\log S_m = S_y + S_w + (S_z - S_y - S_w)(2{,}096(\log S_b - 9)) \quad (5)$$

for : $10^9 Pa < S_b < 3{,}0 \times 10^9 Pa$

with :

S_w = $0{,}76\ (S_z - S_y)$

S_z = $10{,}82 - 1{,}342 \left(\frac{100 - Va}{Va + Vb} \right)$

S_y = $8{,}0 + (5{,}68 \times 10^{-3} \times Va) + (2{,}135 \times 10^{-4} \times Va^2)$

S_x = $0{,}6 \log \left(\frac{1{,}37\ V_b^2 - 1}{1{,}33\ V_b - 1} \right)$

where :

V_a = Volume of aggregate, %
V_b = Volume of binder, %
S_b = Bitumen Stiffness, Pa

3. EXPERIMENTAL RESULTS

3.1 Marshall Test

Some parameters in the Volumetric analysis are VIM, VMA, VFB and VIM_{Ref} (VIM at Refusal condition). In order to determine the Optimum Bitumen Content (OBC), those all parameters and another value, i.e. Stability, Flow and Marshall Quotient, were considered and analyzed. The Marshall parameters for all specimens can be seen in Table 5.

Table 5. Marshall Characteristics of HMRA (AC-BC) Mixture

Mix Types	OAC (%)	VIM (%)	VMA (%)	VFA (%)	Stability (kg)	Flow (mm)	MQ (kg/mm)
A1	5,9	3,650	15,540	70,00	1255,7	3,98	334,5
A2	5,8	3,220	15,120	71,530	1300	4,12	312,75
B1	6,0	3,550	15,800	69,150	1265,1	3,88	328,25
B2	5,8	3,210	15,420	69,54	1319,15	3,98	337,62
Specification (*) :							
Asphalt Pen 60/70	-	2,5	□ 14	□ 63	□ 800	□ 3	□ 250
Asphalt Modification					□ 1000		□ 300

Source : Zurni, 2013, (*) (Dept. PW, 2010).

3.2 Marshall Immersion Test

The Marshall Immersion test was conducted for specimens prepared at OBC (optimum bitumen content). The objective of this test was to measure its durability or its water resistance after an immersion test for 24 hours at 60^{o}C. The specimens prepared for this test were 4x3x1 = 12 samples and the results of Immersion test are presented in Table 6.

Table 6. Results of Marshall Immersion test

Properties Mix Design	Result				Specification
	A1	A2	B1	B2	
Optimum Bitumen Content; (%)	5.9	5.8	6	5.8	-
Stability after Immersion (S1);(kg)	1277.98	1361.55	1189.79	1255.28	-
Standard Stability (S2); (kg)	1378.71	1485.83	1229.88	1316.04	min 1000
IRS (S1/S2); %	92.69	91.64	96.74	95.38	min 90

3.3 Resilient Modulus Test

The Resilient Modulus of all specimens, prepared at OBC, was measured by UMATTA equipment, for 2(two) temperatures i.e. 35°C and 45^{o}C. This test refers to the ASTM D 7369-09(2010) i.e. “Standard test method for Determining the Resilient Modulus of Bituminous Mixtures by Indirect Tension Test”. The total specimens for this test were 2x4x1 = 8 samples. (Zurni, 2013). The result of UMATTA Resilient Modulus test is shown in Table 7.

Table 7. Result of Resilient Modulus Test

Type of Mix	OBC (%)	Test Temperatur (^{O}C)	Result of UMATTA			
			Peak Load (N)	Time of Loading (dt)	Total Deformasi Horizontal (µm)	Stiffness Modulus (MPa)
A1 (Mod. Asp + RAP7,5 %)	5.9	25	1671	0.1034	4.96	3593
		35	457	0.1054	4.86	989
A2 (Shell + RAP 7,5%)	5.8	25	1225	0.1013	4.96	2581
		35	423	0.0936	4.94	910
B1 (Mod. Asp + RAP 10 %)	6	25	1278	0.0967	4.94	2745
		35	444	0.0979	4.66	982
B2 (Shell + RAP 10%)	5.8	25	1207	0.0996	5.05	2545
		35	324	0.0994	4.82	695

3.4 Wheel Tracking Test

The purpose of Wheel Tracking test was to measure the resistance of HMRA mixture on plastic deformation (SHELL, 1990). This test was conducted for 4 (four) types of specimens (A1, A2, B1, B2) at 3(three) temperature levels i.e. 35^{o}C, 45^{o}C and 60^{o}C. Each specimen was prepared at OBC (optimum bitumen content) and the test results at temperature 35^{o}C, 45^{o}C and 60^{o}C, are presented in Figure 2, Figure 3 and Figure 4 respectively.

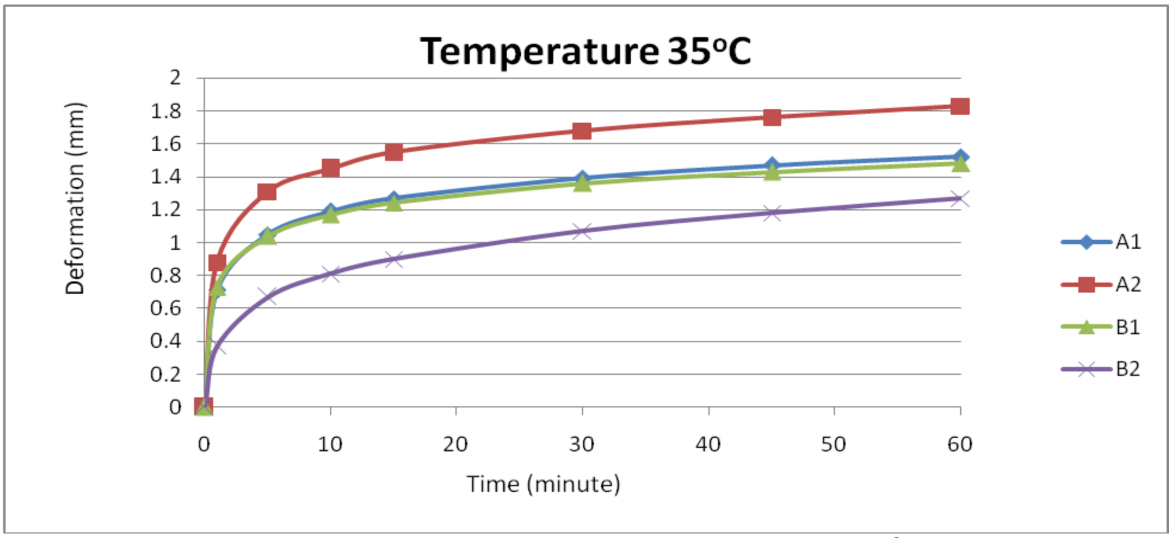

Figure 2. Result of Wheel Tracking Test at T = 35^{o}C

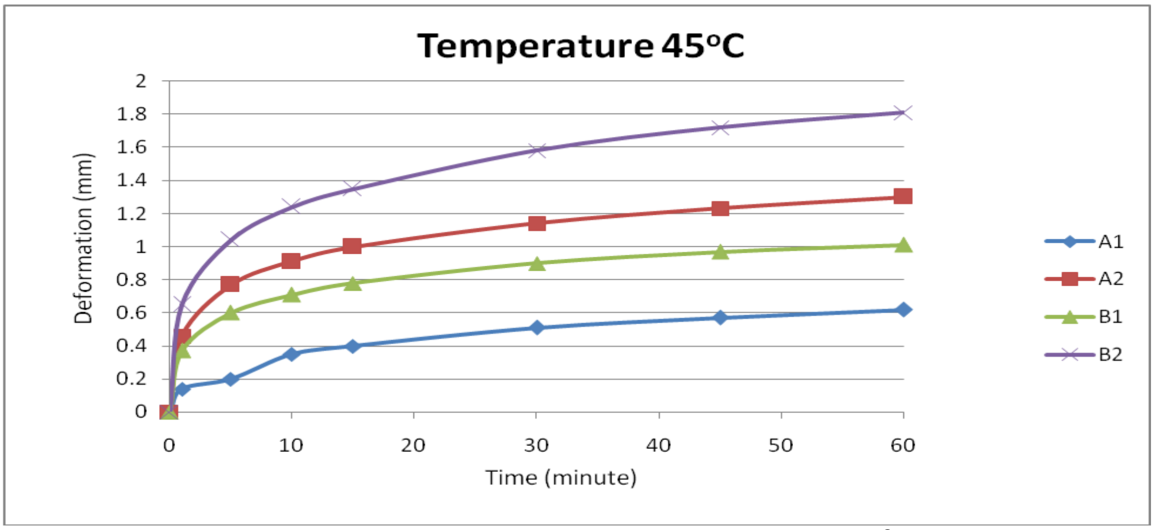

Figure 3. Result of Wheel Tracking Test at T = 45°C

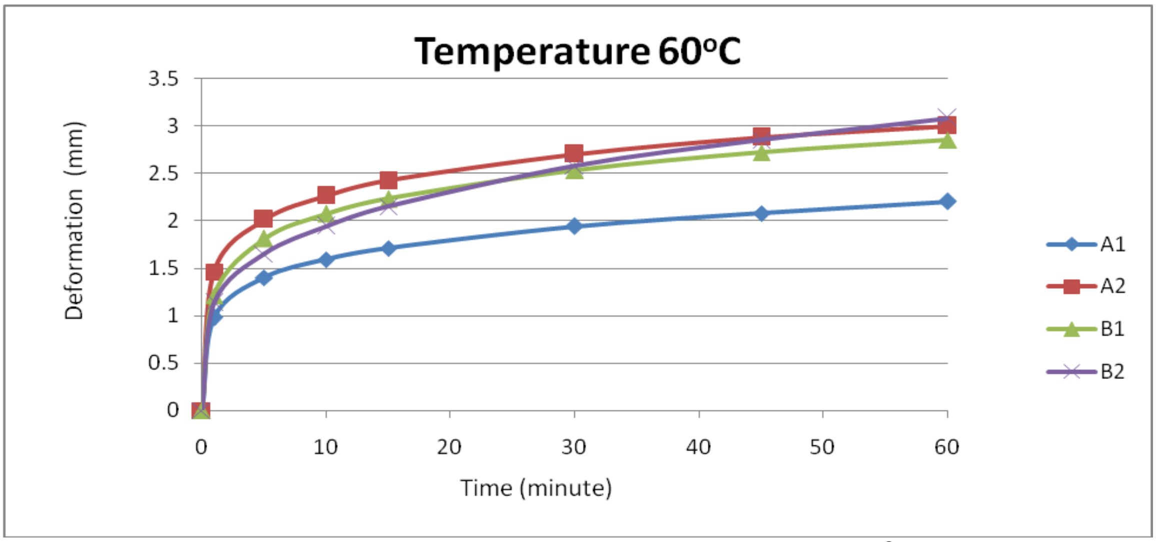

Figure 4. Result of Wheel Tracking Test at T = 60°C

4. ANALYSIS AND DISCUSSION

4.1. Optimum Bitumen Content (OBC)

The result of OBC (Optimum Bitumen Content) values for each specimen, determined by using the Indonesian criteria (Dept.PW, 2010), is shown in Figure 5.

Regarding those results, it can be seen that the highest OBC value was obtained by the specimen B1, prepared at 10% RAP and Elvaloy Bitumen blend. This result is confirmed with the result of Marshall Immersion test (see Table 5 above).

It is shown also that the specimen with Modified Asphalt "Elvaloy Bitumen blend" (A1 and B1) required more bitumen in the asphalt mix (HMRA – ACBC) than the other specimen without Modified Asphalt (A2 dan B2).

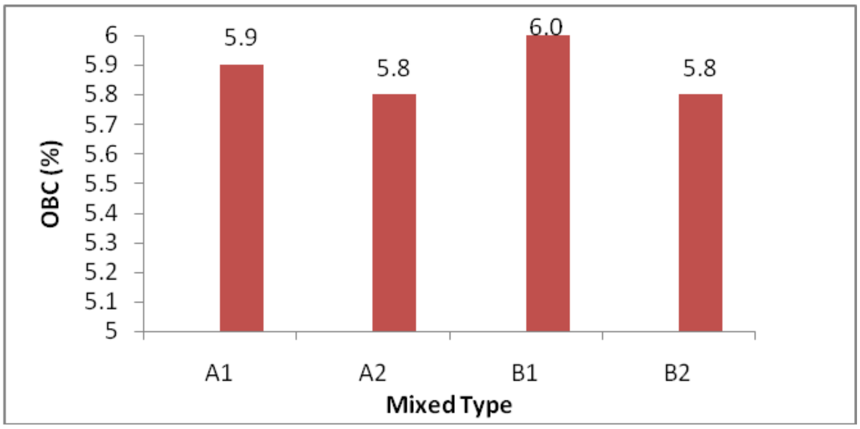

Figure 5.Comparison of Optimum Bitumen Content

4.2. Marshall Stability and Flow

Stability is an empirical parameter to determine the ability of pavement to receive traffic loads without its permanent deformation occurred in the form of a wave, plot, and bleeding. Two factors that affect the Marshall stability are the aggregate gradation and the bitumen content. The result of Marshall stability test is shown in figure 6. It can be seen that almost all values were greater than the minimum value (1000 kg) (Dept. PW, 2010).

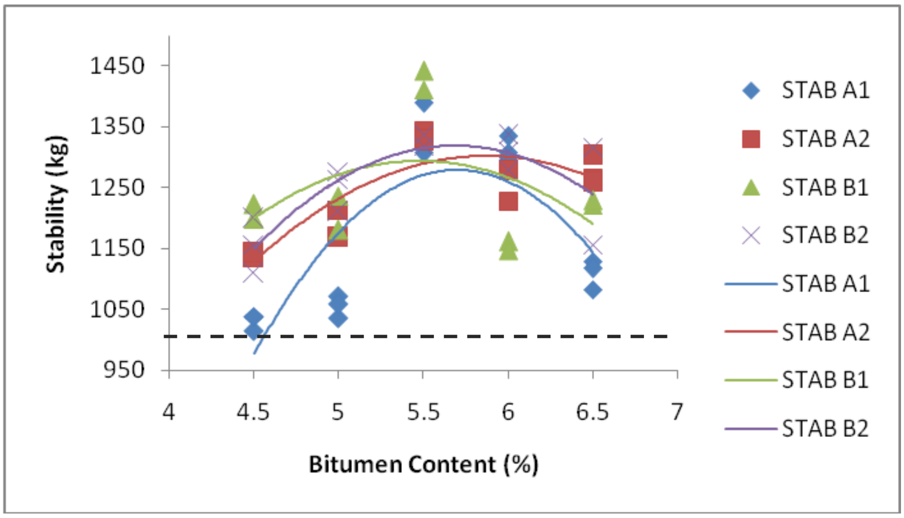

Figure 6. Result of Marshall Stability

Flow is an empirical parameter which is an indicator of the flexibility of asphalt mix due to plastic deformation which caused by the traffic load. The melting asphalt mixture is affected by the level of the mix, temperature, viscosity of the bitumen and shape of aggregate particles. The mixture that has a relatively low melting value at Optimum Asphalt Content has a better resistance to deformation. The result of Marshall Flow is shown in Figure 7. It can be seen also that almost all values were greater than the minimum value (3 mm) (Dept. PW, 2010).

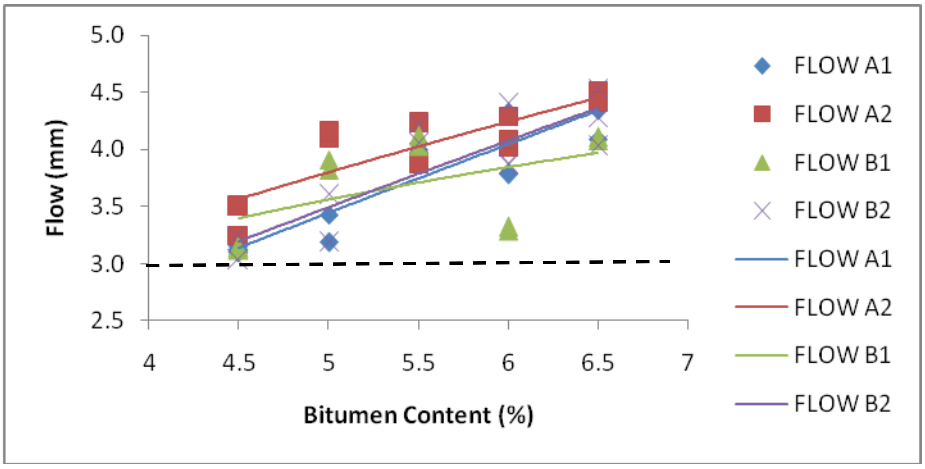

Figure 7. Result of Marshall Flow

4.3. Marshall Immersion

The calculation results of IRS (Index of Retained Stability) were presented in Figure 8 and all values were higher than the minimum value (90%), required in the Indonesian's Specification. (Dept.PW, 2010). It is shown that the specimen B1 (10% RAP and Elvaloy Bitumen blend) has the highest value of IRS, which conformed with the highest OBC value.

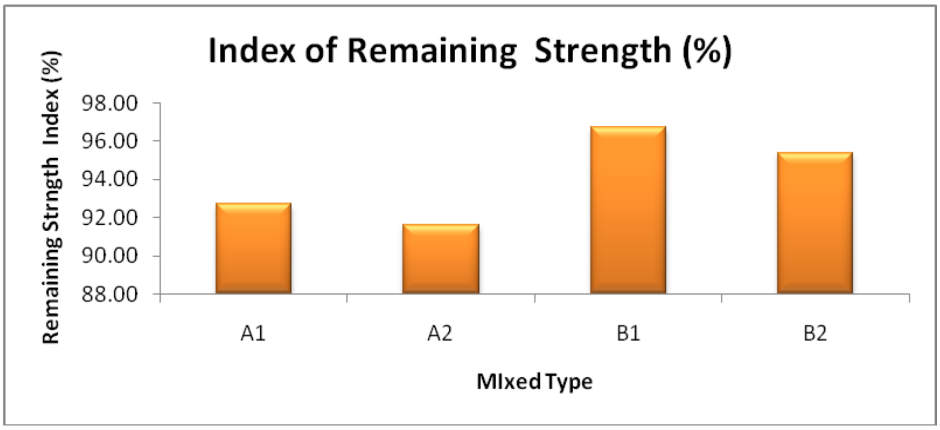

Figure 8.Comparison of Index Retained Strength (IRS)

4.4. UMATTA Resilient Modulus

The results of Resilient Modulus test were presented in Table 7 and Figure 8. It is shown that the highest Resilient Modulus at 25^{o}C and 35^{o}C was obtained by A1-mix. It is meaning that the Asphalt mixes (AC-BC) using 7.50% RAP materials and Shell Bitumen could achieve the highest strength, compared with the others.

At temperatures of 25^{o}C, the other specimen (A2, B1 and B2) has a relatively same value of Resilient Modulus, i.e. about 2600 MPa. While at temperatures of 35^{o}C, the 2(two) specimens have a relatively same value of Resilient Modulus, i.e. about 900 MPa, but 1(one) specimen has a lower value (less than 700 MPa).

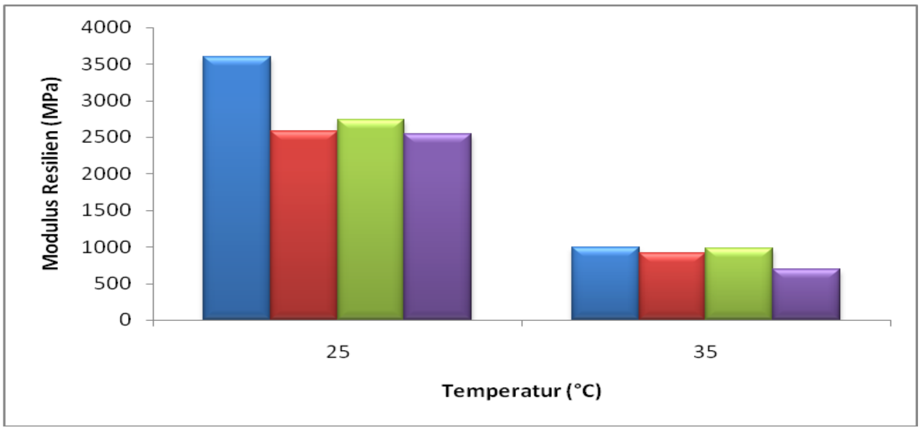

Figure 9. Comparison of UMATTA Resilient Modulus

4.5. Comparison of Resilient Modulus

In this study, the Shell and Nottingham formulas (Subagio et al., 2009) were used to calculate the Bitumen Stiffness and Mix Stiffness of HMRA (AC-BC) mixes containing RAP materials (A1-mix, A2-mix, B1-mix and B2-mix), at 2 (two) temperatures i.e. 25^{o}C and 35^{o}C. The result was presented in Table 8 and Figure 10 and 11.

It is shown that the average Ratio of Resilient Modulus measured by UMATTA compared to the Mix Modulus calculated by Shell formula was 1.23. It is shown also that the average Ratio of Resilient Modulus measured by UMATTA compared to the Mix Modulus calculated by Nottingham formula was 0.94. It is evident that the Nottingham formulas could give a relatively “small” difference to the experimental results.

Table 8. Comparison of Stiffnes Modulus

Type of Mix	Specimen Code	Temp. Specimen	Sbit Ullidtz Formula		UMATTA	Shell	Nottingham	Ratio	
					Smix			UMATTA/Shell	UMATTA / Nottingham
		^{o}C	Pa	MPa	MPa				
a	b	c	d	e	f	g	h	i	j
Mod. Asphalt + RAP 7,5%	A1-1	25	1.05E+07	10.47	3593	1725.00	3251.33	2.08	1.11
	A1-2	35	1.51E+06	1.51	989	1293.37	941.10	0.76	1.05
Shell + RAP7,5%	A2-1	25	9.25E+06	9.25	2581	1737.78	3824.59	1.49	0.67
	A2-2	35	1.29E+06	1.29	910	1200.37	1125.23	0.76	0.81
Mod. Asphalt + RAP 10%	B1-1	25	1.07E+07	10.73	2745	1663.53	2969.68	1.65	0.92
	B1-2	35	1.55E+06	1.55	982	1228.51	844.68	0.80	1.16
Shell + RAP 10%	B2-1	25	9.31E+06	9.31	2545	1539.23	2887.23	1.65	0.88
	B2-2	35	1.26E+06	1.26	695	1135.87	788.49	0.61	0.88
							Average :	1.23	0.94

At the temperature of 25^{o}C, it is shown that the average Ratio of UMATTA’s Resilient Modulus compared to the Mix Modulus calculated by Shell/Nottingham formula was about 1.31, while at high temperatur (35 ^{o}C) the average Ratio of UMATTA’s Resilient Modulus compared to the Mix Modulus calculated by Shell/Nottingham formula was about 0.85. It is obvious that the differences of Resilient Modulus (RM) ratio at high temperatur (35^{o}C) is greater than 1.0, but the RM ratio is less than 1.0 at low temperature (25^{o}C).

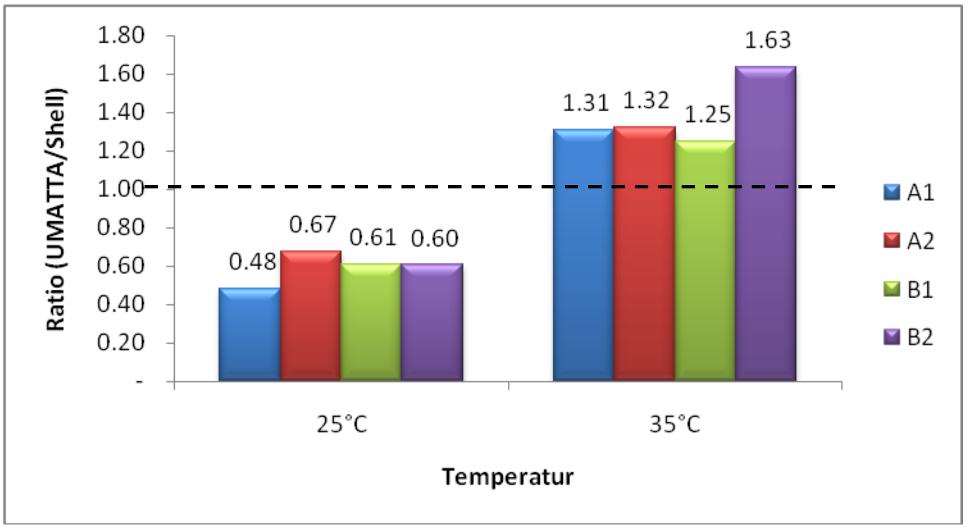

Figure 10. Ratio of Stiffness Modulus UMATTA vs Shell

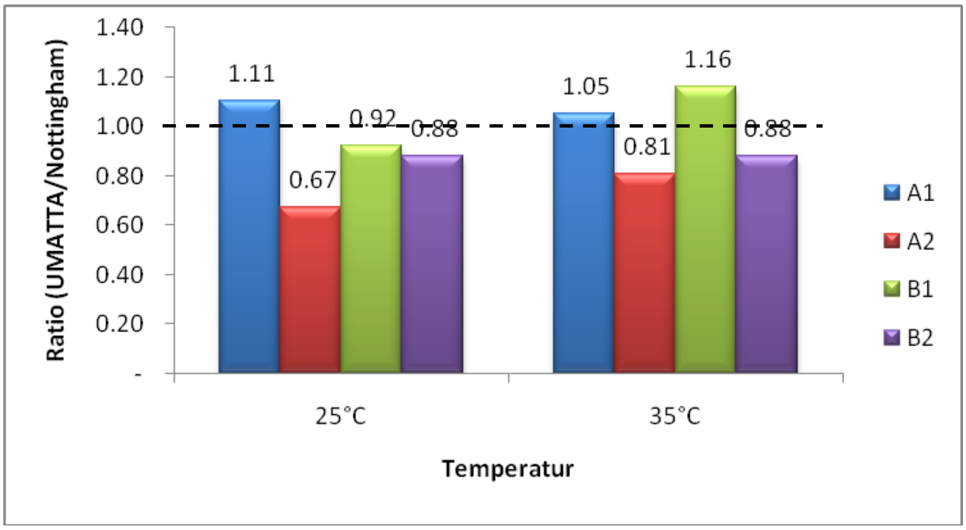

Figure 11. Ratio of Stiffness Modulus UMATTA vs Nottingham

4.6. Plastic Deformation

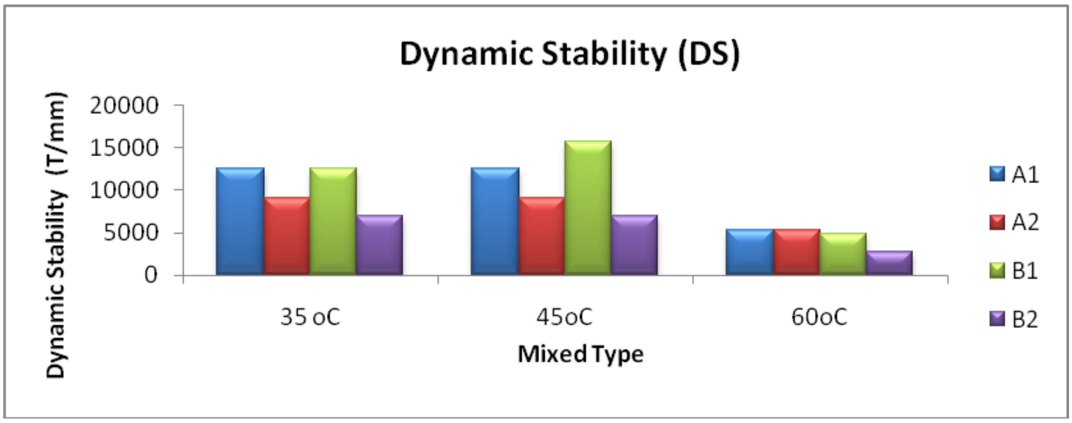

Figure 12. Results of Dynamic Stability

The resistance of plastic deformation in this study, was represented by 3(three) parameters i.e. Dynamic Stability (DS), Total Deformation (D_o) and Rate of Deformation (RD). The results for all specimens, examined at temperature of 35°C,45°C and 60°C, were presented in Figure 2, 3 and 4.

It is shown that the Dynamic Stability (DS) at temperature of 35°C and 45°C, were higher for A1-mix and B1-mix than the others, while the highest value of DS was achieved by B1-mix at temperature of 45°C. It is shown also that the value of Dynamic Stability for all specimens at 3(three) temperatures, was higher than the Minimum value (see Figure 12) as specified by the Indonesian standard, that is 2500 tracks/mm. (Dept. PW, 2010).

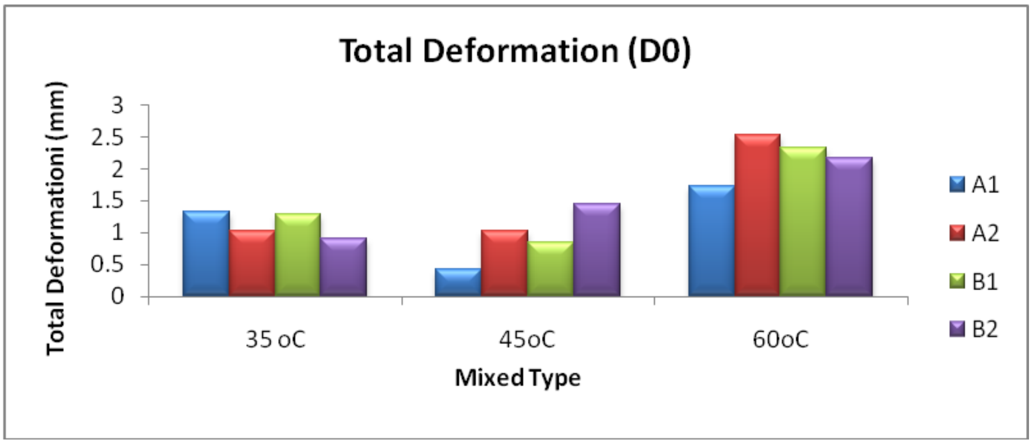

Figure 13. Results of Total Deformation

Regarding Figure 3 and Figure 4, it is shown that A1-mix achieved the lowest value of Total Deformation (Do), at a temperature 45°C and 60°C. Hence, considering the value of Dynamic Stability and Total Deformation, it was confirmed the A1-mix gave the highest Resistance to Plastic Deformation.

The second position of Resistance to Plastic Deformation was achieved by the B1-mix, as seen in Figure 2, Figure 3, Figure 4 and Figure 13. In can be concluded then that the Modified Binder (Elvaloy bitumen blend) has an important role in obtaining those results.

5. CONCLUSIONS

The conclusion could be drawn from the research result, are as follows:

1. Due to low Penetration value of bitumen blending between Pen 60/70, RAP's bitumen and Elvalov® Polymer, it was decided then the percentage of RAP materials used in HMRA mixes was 7.50% and 10%.
2. Due to very low Penetration value of RAP's bitumen, it was considered that RAP's bitumen did not give any contribution in the bitumen content of HMRA mixes. In the grading curve, RAP's bitumen was assumed to become the fine aggregates.
3. The high OBC value was achieved by the specimen A1 and B1 with Elvaloy Bitumen blend and 7.50% and 10% RAP's content, respectively. It was concluded that the Elvaloy bitumen blend required more bitumen than the mix without modified asphalt.
4. The high Marshall Stability was obtained by the specimen A1 and A2 which had RAP's content of 7.50%, while the high resistance to water immersion (IRS) was achieved by the specimen B1 and B2 which had 10% RAP's content. It could not be concluded then the optimum percentage of RAP's content, regarding only the Marshall's test results.
5. Regarding the results of UMATTA test, it is shown that the highest Resilient Modulus at

25^{o}C and 35^{O}C was obtained by the specimen A1 which contains 7.50% RAP materials and Elvaloy bitumen blend, for both temperatures (25^{o}C and 35^{o}C). This result could probably confirm the results of Marshall Stability test, as mentioned in point 4 above, that the optimum RAP's content in this research was 7.5%.

6. The average ratio of Resilient Modulus between experiments and calculation using Shell and Nottingham formula was relatively small (1.23 and 0.94) for 2(two) temperatures. It means that the Shell and Nottingham formula could give a "better" approximation formula to predict the Resilient Modulus of Asphalt Mix.
7. Regarding the results of Wheel Tracking test, it is shown that highest Resistance to Plastic Deformation was achieved by the specimen A1 which contains 7.50% RAP materials and Elvaloy bitumen blend, for high temperature (45^{o}C and 60^{o}C). It could be concluded then that the use of Elvaloy bitumen blend could increase the Resistance to Plastic Deformation.

6. RECOMMENDATION

It is recommended to use another type of modified binder, such as : SBS Premix, Buton Natural Asphalt (BNA) or others, in order to increase the percentage of RAP materials in the HMRA mixture.

7. REFERENCES

Bonnaure, F., Gest G., Gravois A., Uge P., (1977), *A New Method of Predicting the Stiffness of Asphalt Paving Mixtures*, Proc. Assn. of Asphalt Paving Technologists, vol.46.

Brown, S.F., (1980), *An Introduction to the Analytical Design of Bituminous Pavements*, Dept. of Civil Engineering, University of Nottingham, Nottingham, UK.

Department of Public Works, (2010), *Section 6.3: Specification for Hot mix Asphalt Mixture,* Jakarta, Indonesia..

McElvaney, J. (1988), *Layered Elastic Analysis and the Structural Design of Flexible Pavements,* Seminar on Road Pavement Design & Evaluation, University of Hongkong.

SHELL Bitumen (2003), *SHELL Bitumen Handbook, fifth edition,* United Kingdom.

Subagio, B.S., Rahman H., Hendarto S., Philips F.J., (2009), *Stiffness Modulus of Asphaltic Concrete Wearing Course (AC-WC) mix containing Retona Blend 55 : Theoretical and Experimental Analysis*, Proceedings of the 8th International Conference of EASTS, Surabaya, Indonesia.

Subagio, B.S., Yofianto D., Rahman H., (2011), *The Laboratory Performance of Cold Mix Recycling Base with Foam Bitumen (CMRFB-Base) Using Cement Filler*, Proceedings of the 9th International Conference of EASTS, Jeju, South Korea.

Ullidtz P. (1979), *A Fundamental Method for the Prediction of Roughness, Rutting and Cracking in Asphalt Pavements*, Proc. Assn. of Asphalt Paving Technologists, Vol .48.

Uzarowski, L. Manolis, S. Lu, P. Greco, M. (2008). *Initial Evaluation of Foamed Asphalt Stabilization Using Modified Asphalt Cement*. Proceeding of Soils and Material : Warm Asphalt as Sustainable Strategy for Pavement Conference. Ontario.

Zurni Rahmi .,(2013). *Laboratory Performance of AC-BC mixture using RAP materials and Elvaloy Bitumen blend* , Thesis, Master's Program in Highway Engineering and Development, Institute of Technology Bandung (ITB), Bandung, Indonesia.