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DEVELOPMENT OF RESILIENT MODULUS MODEL PROPOSED FOR BIO-ASPHALT AS MODIFIER IN ASPHALT CONCRETE CONTAINING RECLAIMED ASPHALT PAVEMENT

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ABSTRACT: The aim of this study was to determine the effect of bio-asphalt in AC-WC mixture containing reclaimed asphalt pavement (RAP), based on resilient modulus (Smix) of asphalt mixture with variations of RAP content were 10, 20, and 30% to the weight of the mixture. Bio-asphalt was produced by pyrolysis process from biomass of coconut shell (BioCS) used in asphalt mixture as a modifier with 23% content to the weight of RAP bitumen. Mixture was compared to AC-WC with fresh material by resilient modulus under OBC conditions using UMATTA. The conditions of testing were carried out by loading pulse width 250 ms, pulse repetition period 3000 ms and at test temperatures 20, 25, 35, and 40 °C. The test results showed that by increasing number of RA, the Smix was getting bigger. Although the Smix value was greater than the control mixture, the performance of BioCS was shown by the Smix production. The number of RAP increases indicating the activation of the RAP bitumen so that there was a bond between the bitumen and the aggregate. Based on these data, a Smix model for a mixture of ACWC + RAP with 23% BioCS was obtained. the use of coconut shell biomass as bioaspal has potential as a renewable and sustainable pavement material, this can be seen from the results of testing the effect on AC-WC hot asphalt mixture.

Keywords: Bio-asphalt, RAP, AC-WC, Resilient Modulus, Modelling

1. INTRODUCTION

Resilient modulus is an important property of material, and is also an analogy of elastic modulus that can be used to estimate the response of material due to moving loads such as those that occur on the road surface due to tire wheels. In asphalt mixtures with bitumen stiffness modulus less than 5 MPa the resilient modulus depends on many things such as aggregate gradation, aggregate size, asphalt viscosity, temperature and frequency of loading. The resilient modulus of mix are depends only on the bitumen stiffness modulus and volumetric of the mixture [1–3].

Reclaimed asphalt pavement (RAP), is a waste of asphalt pavement that is taken directly from the pavement have been damaged or have already passed the age of the plan consisting of aggregates and bitumen. The asphalt component of the RAP has been aging so it is very hard and brittle, as well as the aggregate that has been damaged. The reuse of RAP in asphalt mixtures requires a rejuvenating agent that can improve its performance, at least equal to the quality of new asphalt mixtures [4–7].

Bio-asphalt is a fraction of bio-oil derived from biomass containing lignin [8–11]. Bio-asphalt has the potential as a bitumen, extender and modifier/rejuvenator Peralta et.al, 2012. In Indonesia, at this time indeed, while developing non-fossil fuel technology that can be renewed. The existence of bio-asphalt is one alternative of bitumen which is produced from non-fossil materials, currently bio-asphalt which is trying to be developed in Indonesia is bio-asphalt from the pyrolysis biomass of coconut shell [12–14], but research on its potential has not been done much. In previous research on the potential of coconut shell bio-asphalt as a modifier/rejuvenator for aged bitumen (RAP bitumen), it is known that the addition of 23% bio-asphalt coconut shell (BioCS) can improve the performance of RAP bitumen in terms of its chemical structure, morphology and rheology [15,16].

The use of bioCS in the mixture was further carried out in the research, the research was conducted on the effect of the use of BioCS in AC-WC mixtures containing 30% RAP, it was known that the use of BioCS can improve the performance of asphalt mixtures as seen from the OBC values, with Comparison of 30% ACWC mix RAP without BioCS which did not get OBC value [17].

This study will examine the effect of the use of BioCS in ACWC mixtures containing RAP based on mechanistic properties of asphalt mixture, the resilient modulus (Smix). The Smix data are then used to develop the resilient modulus model.

2. OBJECTIVES AND SCOPE

The purpose of this study was to determine the

potential of BioCS as a modifier/rejuvenator in AC-WC asphalt mixtures containing RAP based on the resilient modulus value which was then used as the basis for developing the AC-WC mixed modulus resilient modulus model containing RAP and bio-asphalt as a modifier.

3. MATERIALS

3.1 Bio-asphalt

Bio-asphalt used was coconut shell bio-asphalt (BioCS) from PT Nucifera Indonesia. With basic specifications as described in Table 1.

Table 1 Basic properties of bio-asphalt

Property	Unit	BioCS
Viscosity (60 °C)	Cps	< 100
Flash Point	F	95
Density	Kg/L	1.008
Moisture content	%	10-20
Appearance	-	Clear, Dark Brown Colored Flowable liquid

3.2 Aggregate

The aggregate used in this study was obtained from asphalt plant PT KADI West Java Indonesia. The nominal maximum aggregate size was 19 mm. Table 2 showed the aggregate properties and aggregate gradation, respectively.

Table 2 Aggregate properties

Test	Test Method	Result
Specific gravity	ASTM C 127-84	2.63
Los Angeles abrasion (%)	ASTM C 131-76	16.25
Water absorption (Course aggregate) (%)	ASTM C 127-84	1.59
Water absorption (Fine aggregate) (%)	ASTM C 128-84	1.37
Percent fracture (%)	ASTM D581	98.17/97.149
Flakiness and Elongation	ASTM D-4791	6

3.3 Fresh Bitumen

The fresh bitumen used in this research was pen 60/70 from PT Pertamina Persero, with basic properties as described in Table 3.

Table 3 Basic properties of bitumen pen 60/70

Property	Unit	Test Result	Specification
Penetration (25 °C, 100g, 5 s)	0.1 mm	65	60-70
Ductility (10 °C, 5cm/min)	Cm	>100	$\geq$ 100
Softening point	°C	51	$\geq$ 48
Viscosity (135 C)	Pa.s	409,6	$\geq$ 300
Mass Loss After TFOT	% Weight	0,149	$\leq$ 0,8
Softening Point After TFOT	^{0}C	56	$\geq$ 48
Ductility after TFOT	cm	110	$\geq$ 100

3.4 Reclaimed Asphalt Pavement

The reclaimed asphalt pavement (RAP) used was recycled material obtained from the scratching of the old road in Karawang, West Java, Indonesia.

Table 4 RAP aggregate properties

Test	Unit	Test Method	Test Result
Asphalt Bitumen Content	%	ASTM D2172	5.15
Water absorption (Coarse aggregate)	%	ASTM C127	1.49
Water absorption (Fine aggregate)	%	ASTM C128	1.77
Specific gravity (Coarse aggregate)	%	ASTM C127	2.49
Specific gravity (Fine aggregate)	%	ASTM C128	2.25

Table 5 RAP bitumen properties

Property	Unit	Test Result
Penetration (25 °C, 100g, 5 s)	0.1 mm	10
Ductility (10 °C, 5cm/min)	cm	38
Softening point	^{0}C	80

3.5 Bio-asphalt Modified Aged Asphalt

RAP bitumen was mixed with 23% BioCS, then was tested using FTIR, SEM and DSR. The results of the FTIR (Fig. 1) were analyzed to get carboxylic index (Ic) and sulfoxide index (Is) [18] showing the potential for rejuvenation. The SEM results (Fig. 2), showed that the addition of bio-asphalt could change the morphology of the RAP bitumen by decreasing the size of "catana phase". Morphologically, the aged asphalt was dominated by the large diameter catana phase, the larger the catana phase diameter was, the older bitumen was getting [19], the decrease in the size of the "catana phase" indicated the rejuvenation process. The DSR test results showed that the Performance Grade of the RAP bitumen PG 112 decreased after being added BioCS to PG 76.

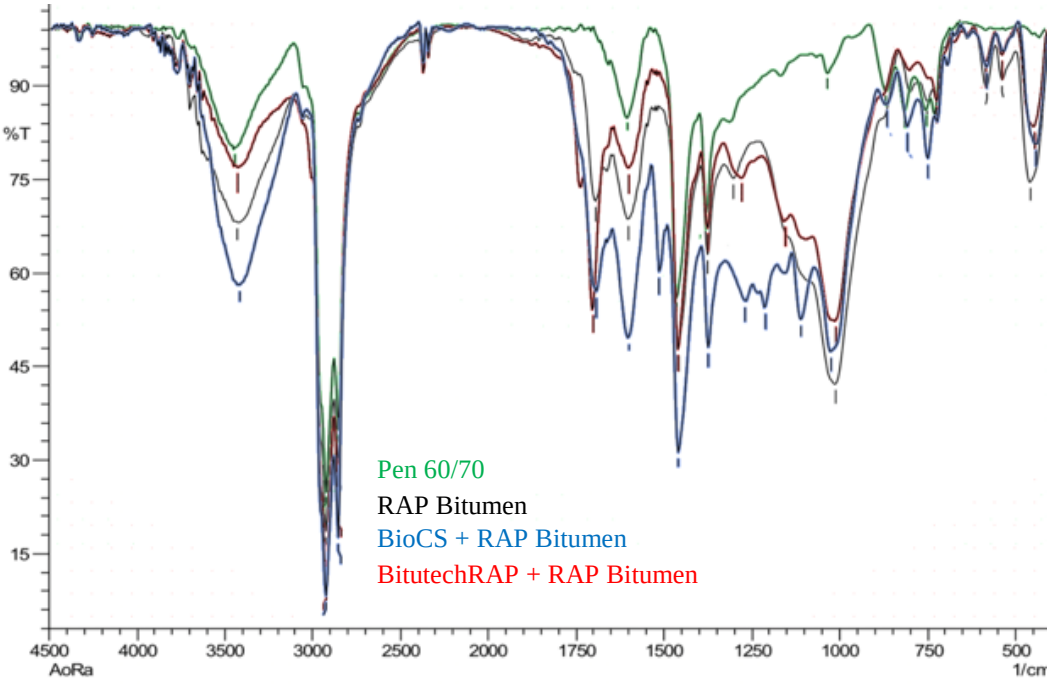
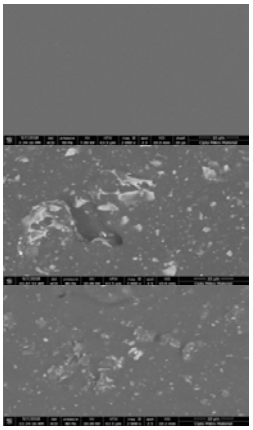


Fig.1 FTIR result of Bitumen



a. Pen 60/70

b. RAP Bitumen

c. BioCS+RAP Bitumen

Fig.2 SEM result of Bitumen

4. METHODS

4.1 Mixing Methods

Mixing and compaction temperature could be obtained from the relationship of asphalt viscosity and temperature, they were, 153 °C and 143 °C. Binder content was taken by calculation of Pb, which was equal to 5.8%, so the test was carried out on variations in bitumen levels of 5%, 5.5%, 6%, 6.5% and 7%. In the AC-WC control mixture was made with fresh aggregates and virgin bitumen heated at 153 °C according to the mixing temperature of the plan. Bitumen was mixed and stirred with aggregate at mixing temperature. The average stirring time is 30 to 60 seconds. After the mixture temperature reached 143 °C, the compaction was carried out.

The asphalt mixture containing RAP was made using fresh aggregates, virgin bitumen, RAP (10%, 20% and 30%), and 23% BioCS (by weight of RAP bitumen). RAP was preheated to 150 ºC (RAP heating temperature based on the test results). Then, the RAP was combined with the fresh aggregate (preheated ±181°C), binder (preheated 153 °C), and bioCS at mixing temperature with an average stirring time is 30 to 60 seconds. Compaction was carried out after the compaction temperature had been reached. Compaction method was carried out by Marshall Compactor. The number of collisions used was 75 each side [20].The design of ACWC hot mixed grade was showed in Fig. 3.

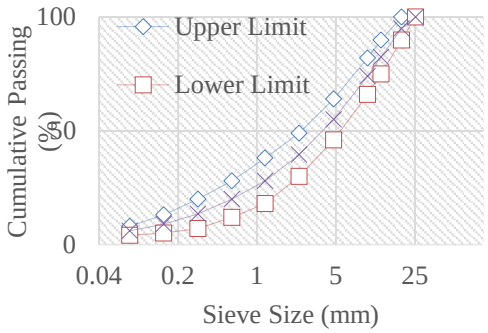


Fig.3 Sieve analysis ACWC aggregates

4.2 Bitumen Stiffness (Sbit)

Stiffness modulus of bitumen (Sbit) with a theoretical approach used ullidtz equation approach [21]. In ullidtz equation, to the value of Pr and SPr using test results directly to calculate the value of pears with limit values between -1 to +1, where the temperature value was adjusted to the temperature at which the mixture resilient modulus testing conducted in the laboratory, the results obtained by theoretical calculations that prediction stiffness modulus of bitumen using equation ullidtz could not be performed on the entire mixture (ACWC virgin and ACWC + BioCS + RAP) because the maximum time of loading was 100 ms, while used in this calculation was 250 ms which was adapted to the loading conditions of UMATTA testing, so the Van der Poel Nomogram approach was used to determine the Sbit value.

4.3 UMATTA Test

Stiffness modulus of asphalt mixtures, were measured by using "Universal Material Testing Apparatus (UMATTA)". The test was done by measuring the indirect tensile strength using a repetitive load (Indirect Tensile Repeated Load) referring to [22], as shown in Fig. 4. In this study, the UMATTA device is set at a loading pulse width of 250 ms, pulse repetition period 3000 ms and at test temperatures 20 ° C, 25 ° C, 35 ° C and 40 ° C. Mixed resilient modulus testing was carried out on specimens under OBC conditions.

4.4 Modelling of Resilient Modulus

The prediction model was built in multilinier regression model with the form of Eq.(1). As for finding the best approach form, it was compiled from several models by varying the independent variables and the dependent variables in the form of first equation, quadratic, log function, and combination. SPSS Multiple Linear Regression Program and classic assumption test (statistics) [23] against the regression model were used in the selection of the model being built.



Fig.4 Universal Material Testing Apparatus (UMATTA)

$$S_{mix} = a + bx_1 + cx_2 + dx_3 + ex_4 + fx_5 + gx_6 \quad (1)$$

where:

Smix	=	Resilient Modulus
a,b,c,d,e,f,g	=	Regression coefficient
x1, x2, x3, x4, x5, x6	=	Bitumen Stiffness Modulus (Sbit), VMA, VIM, VFB, and RAP

Several assumptions and conditions were used in the preparation of the resilient modulus model in this study:

a. BioCS content used was 23% by weight of RAP bitumen.
b. There was blended between fresh bitumen and RAP bitumen.
c. The minimum value of Sbit is 5 MPa, with that value Smix was assumed to be influenced only by bitumen stiffness and volumetric including bioasphalt and RAP that used in this study.
d. Resilient modulus was obtained from UMATTA test with 250 ms pulse width and 3000 ms pulse repetition.

5. TEST RESULT AND DISCUSSION

5.1 Stiffness Bitumen Modulus (Sbit)

Comparison between Sbit DSR frequency sweep (FS) and Sbit from Van der Poel nomogram was done to calibrate the accuracy of DSR test results, where in the calibration an adjustment factor (af) was required resulting from the comparison of Sbit values at the same temperature conditions and loading times. Sbit DSR frequency sweep test results in RTFOT conditions taken for loading time (t) of 0.02 seconds proportional to the loading frequency of 8 Hz was also considered to represent vehicle speeds ranging between 30 mph - 40 mph [24]. The results of the comparative analysis of Sbit DSR and Van der poel test results

got an adjustment factor of 1.27 with an average ratio of 1.03, a decrease compared to the average ratio before being multiplied by an adjustment factor of 1.29, it was caused by the Sbit value after adjustment was smaller than the Sbit of the DSR test results . Thus, the Sbit value used as the basis for the formation of the model was used as described in Table 6.

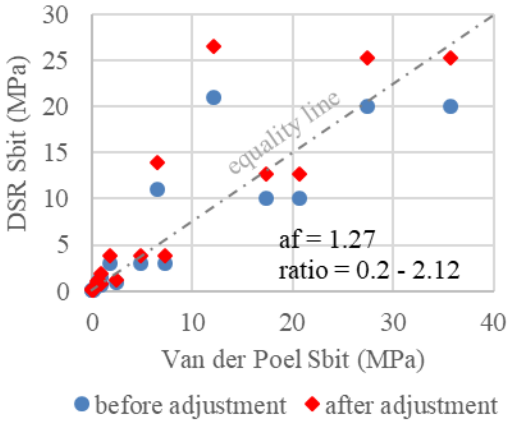


Fig.5 Adjustment Factor Sbit DSR vs Sbit Van der Poel

Table 6 Bitumen stiffness modulus (Sbit)

Temperature °C	Sbit (MPa)	
	Pen 60/70	BioCS + RAP Bitumen
20	25.31	25.31
25	12.65	12.65
35	3.80	3.80
40	1.27	1.14
45	0.63	0.76

5.2 Optimum Bitumen Content (OBC)

Based on the results of volumetric and marshall asphalt mixtures, the OBC values for each mixture type can be seen as follows:

Table 7 Optimum bitumen content of mixtures

Mixed Asphalt	OBC values (%)
AC-WC Virgin	6.10
AC-WC 10%RAP with BioCS	5.90
AC-WC 20%RAP with BioCS	5.80
AC-WC 30%RAP with BioCS	5.75
AC-WC 30%RAP without Bio-asphalt	-

By looking at the volumetric and marshall results tested, adding bioasphalt to the asphalt mixture containing RAP could identify the value of OBC.

This is because without bioasphalt, the value of OBC was not identified. With increasing RAP content in mixtures with bioasphalt as modifiers, OBC values could still be defined even though their values were reduced. This condition indicated the activation of RAP bitumen which has undergone aging. The OBC value was then used as a basis for making asphalt mix samples for testing by UMATTA.

5.3 Resilient Modulus of Mixture

Resilient modulus (Smix) value of asphalt mixture is largely influenced by bitumen stiffness modulus (Sbit) used in the mixture. To see this connection, it is necessary to do a review using a comparison graph between changes in the value of Sbit and Smix to changes in temperature, so it can be seen the temperature with Sbit most affects Smix in a mixture (Fig. 6).

From Fig 6, it is known that Sbit more influences the Smix value at temperatures less then 35 °C, overall when compared to the Sbit value used in each mixture, the change in Smix value is in line with the change in Sbit at each additional test temperature. In mixtures containing RAP, the role of RAP aggregates is quite high and at low temperatures (20 ° C and 25 ° C) with Sbit > 5MPa, where resilient modulus is affected by asphalt stiffness, indicating that the asphalt is stiff enough to produce increasing the Smix value. Smix test results show that as the number of RAP increases, the resilient modulus increases. The asphalt mixture is also sensitive to temperature changes, it can be seen from the higher the test temperature, the smaller the Smix value. Overall, the performance of BioCS is demonstrated by producing Smix even though the number of RAP is increasing, which indicates the activation of RAP bitumen which results in bonding between bitumen and mixed aggregate.

5.4 Resilient Modulus Model

5.4.1 Establish of Dataset

The final data for modelling resilient modulus was set based on the result of experimental resilient modulus test in temperature 20 ºC and 25 ºC. Input variables (or predictors) were considered as, sbit of two kind bitumen (pen 60/70 and BioCS + RAP bitumen) as showed on Table 8, volumetric data, BioCS content 23%, and percentage of RAP (0, 10, 20, and 30%). Output (or dependent variable) was assumed as resilient modulus of asphalt concrete mixtures in MPa. Statistical properties of different fields of experimental dataset are given in Table 8.

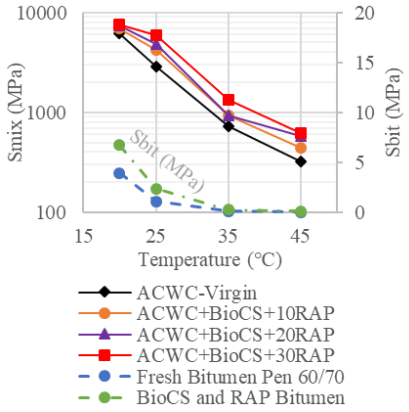


Fig.6 Effect of Temperature Change (T) on Smix dan Sbit

Table 8 Statistical properties of different field of data

Statistical Parameter	Min	Max	Mean	Dev Std
Sbit (MPa)	12.65	25.31	18.98	6.53
VIM (%)	3.58	4.72	4.20	0.35
VMA (%)	15.00	17.13	16.03	0.69
VFA (%)	72.37	76.12	73.83	1.32
RAP (%)	0	30	15.00	11.55
Smix (MPa)	2796	7693	5716	1629

5.4.2 Variables Relationships

Pearson correlation analysis results using SPSS for each independent variable to the dependent variable (Smix) from the test results data can be seen in Table 9.

Table 9 Pearson correlation predictor to result (Smix)

Variable	Smix
Tuji	-0.811 (strong)
S_{bit}	0.609 (strong)
VIM	-0.416 (medium)
VMA	-0.510 (medium)
VFA	0.259 (low)
RAP	0.504 (medium)

5.4.3 Statistical Analysis

Analysis of variance (ANOVA) statistic test was used to determine the significance of data to develop the model.

5.4.4 Determination of the Resilient Modulus Model

The results of the statistical test selection of several possible models built from the results of the operation of the SPSS Multiple Linear Regression program, the model for each mixture is as follows:

$$\text{Log Smix} = 0.026\text{Sbit} - 0.044\text{VIM} + 0.008\text{RAP} + 3.482 \quad (2)$$

($adjR^2 = 0.792$)

$$\text{Log Smix} = 0.026\text{Sbit} - 0.109\text{VMA} + 0.003\text{RAP} + 5.124 \quad (3)$$

($adjR^2 = 0.823$)

Where:

Smix = resilient modulus of mixture (MPa)
Sbit = bitumen stiffness modulus (MPa)
VMA = void in mineral aggregate (%)
VIM = void in mix (%)
VFB = void filled with bitumen (%)
RAP = RAP content on mixture (%)

Note: model are for ACWC + RAP with BioCS = 23% by weight of RAP bitumen

Table 10 Pearson Correlation Predictor to Result (Smix)

Model	Sum of Square	Df	Mean Square	F	Sig.
Model 1 (Y = Smix, X1= Sbit, X2=VIM, X3=RAP)					
Reg	0.265	3	0.088	25.38	0.000[b]
Res	0.042	12	0.003		
Total	0.307	15			
Model 2 (Y = Smix, X1= Sbit, X2=VMA, X3=RAP)					
Reg	0.268	3	0.089	27.02	0.000[b]
Res	0.040	12	0.003		
Total	0.307	15			

5.4.5 Selection of Resilient Modulus Model

Model selection was carried out to get the most appropriate model. Besides using suitability ratio and adjR2, the parameters used to choose the best model also used the parameters of the AIC and SIC method [25], both methods were based on the maximum likelihood estimation (MLE) method. According to the AIC and SIC methods, when model fits were ranked according to their AIC and SIC values, the model with the lowest AIC and SIC values was considered as the 'best'. Conformity between Smix model results and UMATTA can be seen in Fig. 7.

6. CONCLUSIONS

The conclusions that can be drawn from this study are:

a. Bioasphalt coconut shell (BioCS) can be used as modifier on AC-WC mixture containing RAP (10%, 20%, and 30%).
b. The UMATTA Smix test results showed that as the number of RAP increases, the resilient modulus is greater. BioCS performance is shown by producing Smix even though the amount of RAP increases indicating the activation of RAP bitumen resulting in bonding between bitumen and mixed aggregate.
c. The model chosen for the mix ACWC+BioCS+RAP is model 2 Eq (3) with note BioCS = 23% by weight of RAP Bitumen

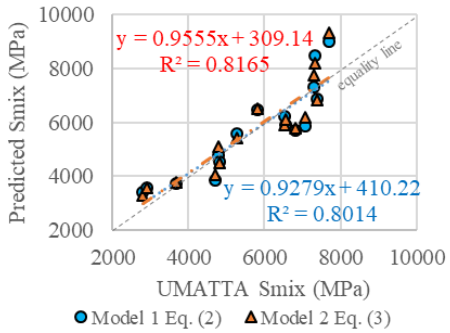


Fig.7 The suitability of Mixture Resilient Modulus values based on the model and UMATTA

In Table 11 we can find a summary of the model selection parameters, the model chosen is model 2 Eq.(3).

Tabel 11 Results of Selection of the Best Regression model

Smix Model	Model characteristics			
	Average Ratio	Adj R^2	AIC	SIC
Model 1 Eq. (2)	1.00	0.792	0.00525	-5.0553
Model 2 Eq. (3)	0.99	0.823	0.00443	-5.2259

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