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# Performance of Resilient Modulus (SMix) and Dynamic Modulus ((|E*|) on Asphalt Concrete – Wearing Course (AC-WC) Using Pen 60/70 Asphalt and Styrene-Butadiene-Styrene (SBS) Polymer

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***Abstract*— Premature damage to pavements in Indonesia before its service life ends is partly due to climate variations and traffic loads. This study's main objective is to compare Dynamic Modulus (| E*|) and the Resilient Modulus of the Pen 60/70 AC-WC mixture using the SBS polymer modified asphalt. The performance from Marshall test shows that the highest Marshall Stability value (1007 kg) for AC-WC, and the Marshall immersion test gives the highest value of 98.13% for the same AC-WC mixture with 3% SBS. At low temperature (4°C), AC-WC with 0% SBS mixture has the highest Dynamic Modulus value (1792.7 MPa). While at high temperature (45°C), AC-WC with 3%, SBS has the highest Dynamic Modulus value (61.8 MPa). The test results show that the SBS modified asphalt mixture gives better performance at high temperatures. Overall, the AC-WC with 3% SBS mixture is better than the other mixtures. Thus, the use of SBS polymer asphalt can be a solution to improve the performance of the mixture. The dynamic modulus with AMPT test and Witczak equation showed a high correlation (0.9844). Additionally, the correlation for resilient and dynamic modulus also has higher correlation with $R^2$ = 0.9818.**

***Keywords*— AC-WC; SBS polymer; Marshall test; dynamic modulus; resilient modulus.**

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## I. Introduction

In Indonesia, pavement layers that use oil asphalt as a binder material have experienced various damage problems during their service life, especially caused by high temperatures and heavy traffic, which enlarge with Indonesia's climatic condition. It can cause the acceleration of rutting, cracks, and others. A development to modify the existing conventional oil asphalt by adding an additive such as a polymer is a solution for improving its performance. Several additives can be mixed with asphalt, such as crumb rubber [1]–[3], Sasobit additive and Rheofalt [4], bio asphalt RAP [5], [6], and SBS (styrene-butadiene-styrene) [7]–[9]. Additives are considered to have better resistance for rutting and have balance performance properties [10].

SBS polymer is commonly used in several regions. The SBS is applied mainly for thermal elastic polymer in pavement mixture. The addition of SBS can raise the asphalt binder's elastic characteristic and reduce the fluidity [11]. It can also maintain a good damping property with a wide temperature range of pavement mixture and a high loss factor in normal working temperature [12]. It allows significant changes in the physical properties of asphalt, such as viscosity and resistance to temperature. The combination of decreased asphalt stiffness and shifting of the aggregate position on the pavement due to the stress will cause deformation, which exceeds a specific strain limit so that it cannot return to its original shape. The SBS can extend the age of bitumen [13]. Deformation resistance improvement in road pavement structures should be made to improve the asphalt mixture's performance by increasing the asphalt's stiffness. Although various pavement mechanisms failed to occur at different strain or stress values, asphalt as a binder can experience loading out of linear regime during service life. Therefore, the nonlinear rheological properties of asphalt should be considered [14].

Several studies investigated the SBS characterization. Ding *et al.* [15] conducted research to find the viscous flow of SBS and the result showed that after the mix of SBS, the temperature sensitivity and fluid properties are inconsistent. Kaya *et al.* [8] presented that the bitumen modification with SBS could enhance the bitumen thermal stability and alter the degradation of the aged sample. Dong *et al.* [16] studied to utilize CTR and SBS to make the bio-asphalt composite modified asphalt with superior high-temperature performance.

The indirect tensile test measured Resilient Modulus using the "Universal Material Testing Apparatus (UMATTA)" tool. Meanwhile, the Dynamic Modulus was measured using the Asphalt Mixture Performance Tester (AMPT), previously known as Simple Performance Test (SPT). This tool is a test method that can measure the response characteristics of mixtures or parameters accurately and reliably to road pavement damage (cracking and rutting) due to traffic loads and climatic conditions [17]

The objective of this study was to conduct a comparative analysis of the Dynamic Modulus (| E*|) and the Resilient Modulus (Smix) of the Pen 60/70 Asphalt Concrete Wearing Course (AC-W C) [17] mixture using the SBS polymer modified asphalt. This study will also develop the Master Curve as a parameter for performance parameter.

## II. Material and Methods

The flowchart of this research can be illustrated in Fig.1. Indonesian standard test can measure the basic properties of asphalt and aggregates. While the mixture's performance can be measured by Standard Marshall Test and Marshall Immersion Test, AMPT Dynamic Modulus Test, and UMATTA Resilient Modulus Test.

### *A. Aggregate and Asphalt Test Results*

The aggregate and asphalt characteristics were tested based on Indonesia's standard reference to the Ministry of Public Works (Revision 3) 2018 [18]. It was tested to compare the characteristics of asphalt and aggregate used in this study to the minimum requirement based on Indonesia Standard. The minimum requirement includes fine and coarse aggregate, Laston gradation, asphalt specification, and asphalt with polymer modification with elastomer specification (SBS).

The asphalt test was conducted on Pen 60/70 Asphalt characteristics and 3% and 4.5% SBS Polymer Modified Asphalt. The asphalt test result shows the penetration value gets smaller with increasing SBS content. Furthermore, the addition of SBS polymer showed an increase in asphalt mixing and compaction temperature. The laboratory test results generally produced values that match the Indonesia standard requirements [18]. Regarding the laboratory results, the value of penetration becomes smaller with increasing SBS polymer content. The addition of SBS polymer affected an increase in asphalt mixing and compaction temperatures from the viscosity test.

### *B. Marshall Test Results*

Parameters in Marshall analysis are Density, Void in Mixture (VIM), Voids in Mineral Aggregates (VMA), Voids Filled with Asphalt (VFA), Stability, Flow, Marshall Quotient (MQ), and density. The laboratory test was conducted for 0% SBS, 3% SBS, and 4.5% SBS. The Density of asphalt mixture with 3% is higher than 0%SBS and 4.5% SBS which means it can fill the void faster than other proportions of SBS. In general, the addition of asphalt content can cause VIM to decrease. It showed that if asphalt content increased, the amount of asphalt that covers the aggregate became higher and reduced the void in the mixture. Thus, the mixture density is higher. The asphalt mixture with 3% SBS has the lowest VIM. Furthermore, the asphalt mixture with 3% SBS has the lowest VMA and highest VFA compared to the other mixture.

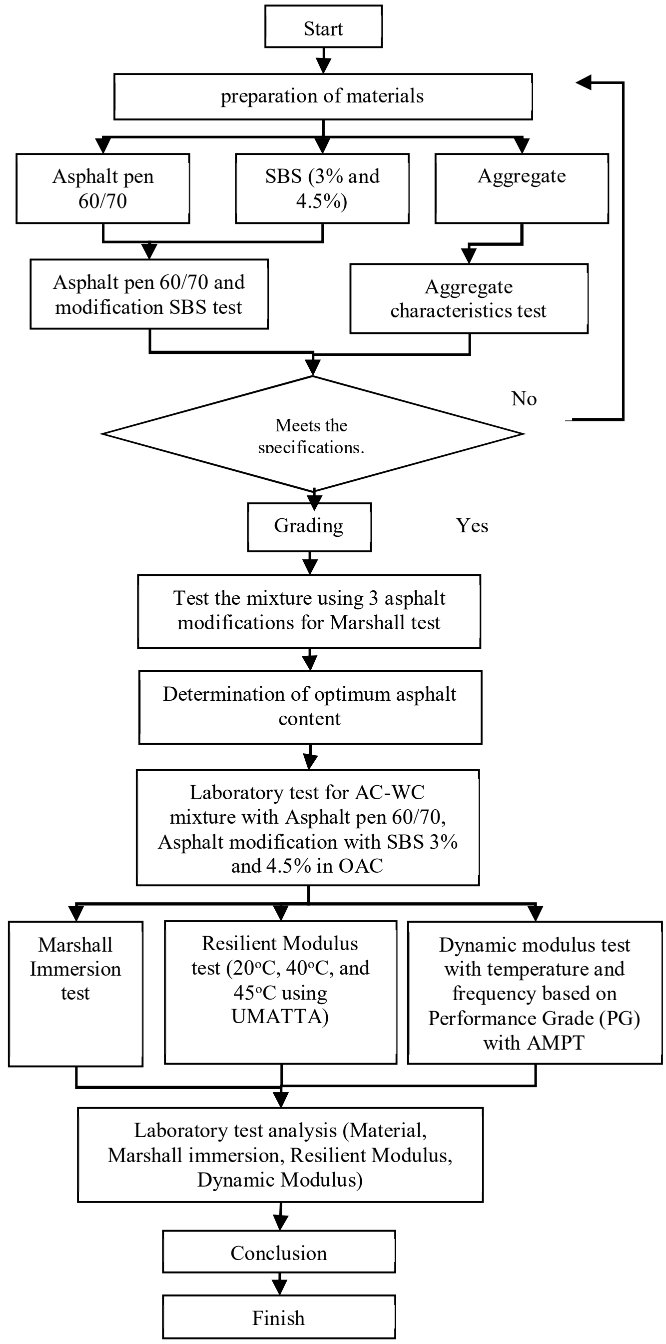


Fig. 1 Research Methodology

The result of the Marshall test shows that the stability value and asphalt content have a nonlinear relationship. The Stability value of the asphalt mixture with 3% SBS is higher than the asphalt mixture with 0% SBS and 4.5% SBS. The high value of stability is because the AC-WC density with 3% SBS mixture is higher than other mixtures, with a small VIM value and high MC value. Hence, the AC-WC with a 3% SBS mixture is better at accepting the maximum load (stability). Besides, SBS polymer gave a higher (stiffer) stability value than the mixture without SBS polymer. It is consistent with the decreasing penetration value of SBS, which indicates a stiffer asphalt property.

The relationship for flow and asphalt content from laboratory test tend to have a positive linear relationship. The asphalt mixture with 4.5% SBS and 0% SBS tends to have almost the same gradient. The flow of a mixture is affected by the density of the mixture. Based on the Marshall test values results, the mixture with 4.5% SBS has the lowest density value, and the void in mineral aggregates is greater than 3%. Thus, based on the Marshall flow test results, the level of resistance of the mixture to plastic deformation is more significant due to a higher amount of asphalt in filling the void that covers the aggregate.

### *C. Dynamic Modulus Test Results*

The Dynamic Modulus Test was conducted using the Asphalt Mixture Performance Tester (AMPT). This test is based on AASHTO PP 61-10, Developing Dynamic Modulus Master Curve for Hot Mix Asphalt (HMA) using the Asphalt Mixture Performance Tester (AMPT). Dynamic Modulus was tested for each variation of temperature and loading frequency based on performance grade (PG). the AC-WC with 0%SBS has several temperatures as 4ºC, 20ºC, and 40ºC with the frequency of 10 Hz, 1 Hz, 0.1 Hz, and 0.01 Hz. The variation for 3% SBS and 4.5% SBS are 4ºC, 20 ºC, and 45ºC with the frequency of 10 Hz, 1 Hz, 0.1 Hz. Each of the temperatures tested with a different frequency. The laboratory test results can be seen in Table 1.

TABLE I
DYNAMIC MODULUS TEST RESULTS

| Condition | | AC-WC 3% SBS | | AC-WC 4,5% SBS | |
|---|---|---|---|---|---|
| T | Freq | Modulus | Phase Angle | Modulus | Phase Angle |
| °C | Hz | Ksi | Deg | Ksi | Deg |
| 4 | 10 | 2259.6 | 9.28 | 2291.1 | 11.26 |
| 4 | 1 | 1714.5 | 14.64 | 1638.7 | 17.86 |
| 4 | 0,1 | 1089.1 | 23.1 | 953.6 | 27.72 |
| 4 | 0,01 | 480 | 35.66 | 444 | 36.43 |
| 20 | 10 | 913 | 26.7 | 1000.2 | 26.89 |
| 20 | 1 | 421.5 | 38.7 | 451.7 | 37.68 |
| 20 | 0,1 | 150.4 | 42.57 | 161.6 | 39.63 |
| 20 | 0,01 | 60.2 | 31.02 | 68.9 | 29.83 |
| 45 | 10 | 173.3 | 43.75 | 103.1 | 37.78 |
| 45 | 1 | 61.8 | 33.77 | 48.6 | 23.12 |
| 45 | 0.1 | 34.9 | 22.16 | 36.8 | 17.15 |
| 45 | 0.01 | 24.7 | 19.49 | 33.8 | 11.24 |

The dynamic modulus test is highest at the lowest temperature (4ºC) for all SBS polymer mixture proportions. Meanwhile, the higher frequency will result in a higher dynamic modulus for all SBS mixture percentages. Therefore, the relationship between dynamic modulus and temperature is negative correlation, nevertheless, it is a positive correlation for dynamic modulus and frequency.

Dynamic Modulus test data analysis is used to create Master Curves. The master modulus curve, as a function of frequency, was created to describe the frequency dependence of a material. The sigmoidal equation of the Dynamic Modulus master curve is presented as follows Pellinen & Witczak [19] :

$$Log\ |E^*| = \delta + \frac{(Max-\delta)}{1+e^{\beta+\gamma(\log fr)}} \quad (1)$$

where:

|E*| : Dynamic Modulus (psi)
fr : Reduced load frequency (Hz)
Max : Maximum modulus limit (psi)
Δ, β,γ : Parameters that describe the form of the function

The Dynamic Modulus Master Curve analysis based on the equation above is shown in Fig 2 Dynamic Modulus Values Comparison for all mixture. The figure describes the relationship between dynamic modulus (MPa) and frequency (Hz) reduction. Dynamic modulus will be higher along with the increase of reduced frequency. The value of reduced frequency is proportional to the dynamic modulus and shift factor, and the opposite is proportional to temperature. The addition of SBS content will increase the mixture resistance to high temperatures.

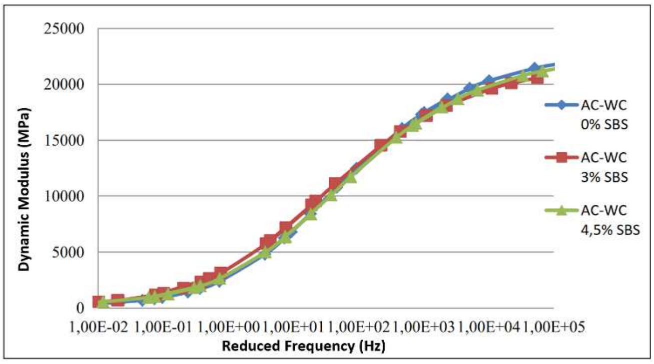


Fig. 2 Relationship between Dynamic Modulus and Reduced Frequency

### *D. Resilient Modulus Test Results*

The Resilient Modulus in laboratory test was conducted using the Universal Material Testing Apparatus (UMATTA). It uses a diametral test specimen similar to the Marshall test, and prepared at the Optimal Asphalt Content. The test referred to ASTM D 4123-82 (1987). The laboratory test temperatures used were 20°C, and 40°C for 0% SBS polymer mixture, and 20°C and 45°C for 3% and 4,5% SBS polymer mixture.

The maximum value for the coefficient of variance (VoC) is 5% based on the standard. The UMATTA Test results show the CoV less than 5% for all of the tests and mixture. Thus the test result can be used. The Resilient Modulus test results are represented in Table 2. The test describes the material's condition in some temperatures and frequencies for several SBS polymer mixture proportions. At 20°C test temperature, the AC-WC with 3% SBS mixture has the highest Resilient Modulus. Meanwhile, at higher temperatures (45°C), the AC-WC with 4.5% SBS polymer mixture has the highest Resilient Modulus.

The asphalt mixture with 3% SBS has a greater Resilient Modulus than the asphalt mixture with 0% SBS and 4.5% SBS. It is due to several factors, such as high stability, density, and Marshall Quotient (MQ), and low optimum asphalt content (OAC). This smaller OAC indicates that the mixture is stiffer than the other mixtures.

It can be caused by several factors, such as high stability, density, and Marshall Quotient. It has consistency with the Resilient Modulus value, where the high value indicates that at 20°C, the asphalt mixture with 3% SBS is stiffer than the mixture with 4.5% SBS and 0% SBS. However, at 45°C, the mixture's Resilient Modulus value with 3% SBS is smaller than 4.5% SBS. It can be caused by the OAC of 3% SBS is smaller than 4.5%. Therefore, the asphalt weight for 3% SBS is less than that of 4.5% SBS.

TABLE II
RESILIENT MODULUS TEST RESULTS

| Mixture Type | OAC (%) | Temp (°C) | UMATTA values: Total Horizontal Deformation (μm) | Peak Load (N) | Resilient Modulus (Mpa) | CoV |
|---|---|---|---|---|---|---|
| 0% SBS | 6,10 | 20 | 4.26 | 1998 | 4863 | 4.20 |
| | | 40 | 20.47 | 1005 | 517 | 3.38 |
| 3 % SBS | 5,93 | 20 | 3.69 | 2052 | 5812 | 3.39 |
| | | 45 | 21.12 | 707 | 352 | 4.47 |
| 4,5 % SBS | 6,14 | 20 | 4.11 | 2017 | 5152 | 3.67 |
| | | 45 | 18.15 | 704 | 408 | 4.51 |

The properties of the SBS polymer influence the ability of the mixture to accept loads at a different temperature. The proportion of SBS and the mixture resistance to the temperature is a positive correlation. The higher the SBS content, the mixture has higher the resistance to the temperature's escalation. Besides, the Resilient Modulus is also influenced by the OAC value. The higher OAC, the adhesiveness of asphalt to the aggregate is better than the percentage of 3% SBS with a smaller OAC. Thus, it indicates that the amount of asphalt content in the mixture affects the mixture's adhesiveness and strength in receiving loads.

## III. RESULT AND DISCUSSION

### A. *Comparison Analysis of Laboratory Dynamic Modulus with the Witczak Equation*

The Witczak equation was first introduced in 1995 and modified in 2000 with the following equation, quoted from the report of FHWA-ICT-07-005, Garcia et al., [20].

$$\text{Log}\,|E*| = 3{,}750063 + 0{,}02932P200 - 0{,}0017676\,(P200)^2 - 0{,}002841P4 - 0{,}05809(VIM) - 0{,}802208\left(\frac{\text{Vbeff}}{Vbeff+Va}\right) + \frac{[3{,}871977-0{,}0021P4+0{,}003958P38-0{,}000017(P38)^2+0{,}00547P34]}{1+e^{(-0{,}603313-0{,}313351\log f-0{,}393532\log\eta)}} \qquad (2)$$

where:
|E*| = Asphalt Mixture Dynamic Modulus, psi
η = Asphalt viscosity, 106 poise
f = Load frequency, Hz
Va = Percent of void, %
Vbeff = Percent of effective asphalt, %
ρ34 = Percent of aggregate retained in ¾ in a sieve (total aggregate weight)
ρ 38 = Percent of aggregate retained in 3/8 in a sieve (total aggregate weight)
ρ 4 = Percent of aggregate retained in sieve no. 4 (total aggregate weight)
ρ 200 = Percent of aggregate passing sieve no. 200 (total aggregate weight)

The correlation between Dynamic Modulus from the AMPT test and Dynamic Modulus from the Witczak theoretical calculation is shown in Fig 3. It is shown that the two methods to obtain the Dynamic Modulus value have a reasonable correlation. It is proven by the $R^2$ value, which is 0.98 (very high, the correlation is nearly 1). The equation y = 1,7254x + 808,23 was obtained where the y-axis is the Dynamic Modulus of the Witczak method, and the x-axis is the Dynamic Modulus of AMPT. The $R^2$ value shows that the analysis using theoretical calculation has a good correlation value. The laboratory test has almost the same accuracy and pattern as the analysis using the Witczak Equation.

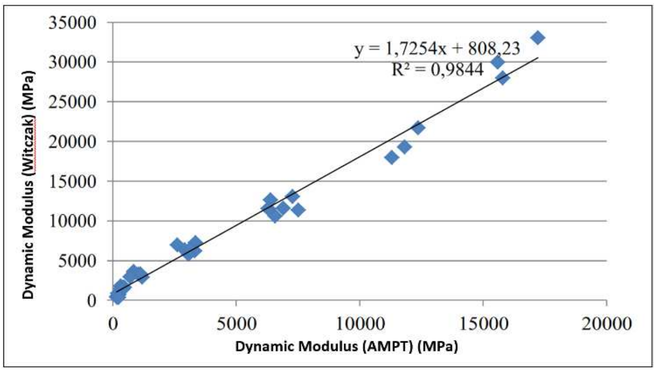


Fig. 3 Dynamic Modulus of Each Mixture Comparison

### B. *Comparison Analysis of Laboratory Resilient Modulus with the Nottingham Equation*

The asphalt stiffness modulus (Sbit) was calculated using the Van Der Poel nomograph, and the mixture stiffness modulus (Smix) was calculated based on the Nottingham equation. The mixture types consist into 0% SBS mixture, 3% SBS mixture, and 4.5% SBS mixture. The temperature condition are 20°C and 40°C for 0% SBS mixture; and 20°C and 45°C for 3% SBS polymer mixture and 4.5% SBS polymer mixture. Table 3 shows the comparison of resilient modulus value using UMATTA and Nottingham method and its ratio. Comparison of Resilient Modulus value in Table 3 consists of the Resilient Modulus's theoretical results using the Nottingham equation for the 3 (three) types of mixtures, showing different values with the Resilient Modulus from the UMATTA laboratory test results. The types are 0% SBS polymer mixture, 3% SBS polymer mixture, and 4.5% SBS polymer mixture.

The UMATTA and Nottingham ratio range varies between 1.14 to 1.48, with the average ratio of UMATTA and Nottingham is 1.36. The highest ratio was found in 4.5% SBS polymer mixture in 45°C, while the lowest ratio point was also found in 4.5% SBS polymer mixture while the temperature was 20°C. The Resilient Modulus from UMATTA is higher compared to Resilient Modulus from Nottingham. The relationship between temperature and Resilient Modulus for both UMATTA and Nottingham is negative, which means the higher the mixture temperature, the lower Resilient Modulus for both UMATTA and Nottingham.

Table 3. show that at temperature of 20°C and AC-WC mixture with 3% SBS had a higher Resilience Modulus than the AC-WC with 0% SBS and 4.5% SBS. This is due to several factors such as high stability, density, and MQ, and low OAC. This smaller OAC value indicates that the mixture is stiffer than any other mixture. SBS is smaller than 4.5% SBS. This phenomenon is because the OAC 3% SBS value is smaller than 4.5% so that the asphalt weight for 3% SBS is

less than 4.5% SBS. The properties of the SBS polymer influence the ability of the mixture to accept the load on temperature. The more SBS levels, the mixture has resistance to high temperatures.

TABLE III
COMPARISON OF THE RESILIENT MODULUS VALUE

| Mixture Type | Temp °C | Resilient Modulus (Smix) UMATTA | Resilient Modulus (Smix) Nottingham | Ratio UMATTA/ Nottingham |
|---|---|---|---|---|
| 0% SBS | 20 | 4863 | 3706 | 1.31 |
| | 40 | 517 | 386 | 1.34 |
| 3% SBS | 20 | 5812 | 4034 | 1.44 |
| | 45 | 352 | 239 | 1.47 |
| 4,5% SBS | 20 | 5152 | 4505 | 1.14 |
| | 45 | 408 | 276 | 1.48 |
| | | Average Ratio | | 1.36 |

Besides, the Resilient Modulus value is also influenced by the asphalt content, where the higher OAC adhesion power bitumen to aggregate is better than the percentage of 3% SBS with smaller OAC. This indicates that the mixture's amount of asphalt content affects the mixture's stickiness and strength in accepting the load. To acquire the theoretical results that are close to laboratory values, a calibration process was conducted using the following equation:

$$k = \frac{\sum_{i=1}^{n} [f(Xi) x\ MFVi]}{\sum_{i=1}^{n} f(Xi)^2} \quad (3)$$

Table 4 shows present the Resilient Modulus ratio from the laboratory and the Resilient Modulus calculated using the calibrated Nottingham equation. The result will be compared in ratio for laboratory tests and theory to see its ratio.

TABLE IV
RATIO OF RESILIENT MODULUS FROM LABORATORY AND THE NOTTINGHAM EQUATION

| Temp °C | Resilient Modulus MPa F(x) | Resilient Modulus MPa MFV1 | Lab/ Theoretical Ratio | Modulus after Calibration | Ratio After Calibration |
|---|---|---|---|---|---|
| 0%SBS | | 4.863 | 1.312 | 4768 | 1.02 |
| 20 | 2,706 | 517 | 1.339 | 497 | 1.04 |
| 40 | 386 | Average | 1.326 | Average | 1.03 |
| 3%SBS | | 5.812 | 1.441 | 5189 | 1.12 |
| 20 | 4,034 | 352 | 1.473 | 307 | 1.14 |
| 45 | 239 | Average | 1.457 | Average | 1.13 |
| 4.5%SBS | | 5.152 | 1.144 | 5795 | 0.89 |
| 20 | 4,505 | 408 | 1.478 | 355 | 1.15 |
| 45 | 276 | Average | 1.311 | Average | 1.02 |
| | | | Total | Average Total | 1.06 |

The proportion of SBS mixture considered are 0%, 3%, and 4.5% for the temperature of 20°C, 40°C and 45°C. Before calibration, the ratio between laboratory test and theory varies from 1.144 to 1.478. The calibration was calculated using (3) equation. After calibration, the ratio between laboratory test and theory reduces and approximately 1 compared to before calibration. It shows that the laboratory test results closer to the theory.

After calibration was conducted, the Modulus value tends to reduce, especially for 0% SBS polymer mixture and 3% SBS polymer mixture. Before calibration, the Modulus range varies from 352 to 5812, while after calibration, the Modulus range is between 307 to 5795. The calibration process was conducted to obtain the theoretical results closer to the actual (laboratory test) values. The UMATTA calibration generated a value of 1.29, while the Resilient Modulus (UMATTA) value ratio was 1.06. The ratio after calibration for a laboratory test and the theory range between 0.89 to 1.5 (approximately equal to 1), which means the theory's laboratory test approach.

### *C. Comparison Analysis of Dynamic Modulus and Resilient Modulus*

The Dynamic Modulus tends to have a lower value compared to the Resilient Modulus from Fig.4. The highest difference values of Resilient Modulus and Dynamic Modulus is when the temperature is low (20°C), and AC-WC contains 3% SBS polymer mixture. The difference value between Dynamic Modulus and Resilient Modulus is quite high at the lower temperature (20°C). Besides, at the higher temperature (40°C), the Resilient Modulus and Dynamic Modulus value is almost the same and only slightly different.

The lowest point of Dynamic Modulus is when the AC-WC 0% SBS polymer mixture is at a temperature of 40°C. In comparison, the lowest point of Resilient Modulus is different at AC-WC 3% SBS polymer mixture with a temperature of 45°C. The relationship for both Resilient Modulus and Dynamic Modulus to temperature is a negative correlation. It means which means if the temperature rises, the Dynamic and Resilient Modulus will reduce.

In general, Resilient Modulus has a higher value compared to Dynamic Modulus. The difference in the value of Dynamic Modulus and Resilient Modulus was because, in the Dynamic Modulus, there is a proportion of the elastic and viscous parts or in other words, the Dynamic Modulus value considers the viscoelasticity properties meanwhile, the Resilient Modulus only considers the elastic part. It does not consider the viscous part.

Sbit influences the Modulus value for the Resilient Modulus, where the Sbit value in the AC-WC with 3% SBS polymer mixture is smaller than the AC-WC with 4.5% SBS polymer mixture. A small Sbit value indicates that the mixture is less stiff or more elastic. Therefore, the Resilient Modulus value in the AC-WC mixture is 3% smaller. Meanwhile, the Modulus value is influenced by viscosity and elasticity in Dynamic Modulus. It can be related to the Marshall Quotient value, where the Marshall Quotient value of the AC-WC with 3% SBS mixture is greater than the AC-WC with 4.5% SBS polymer mixture.

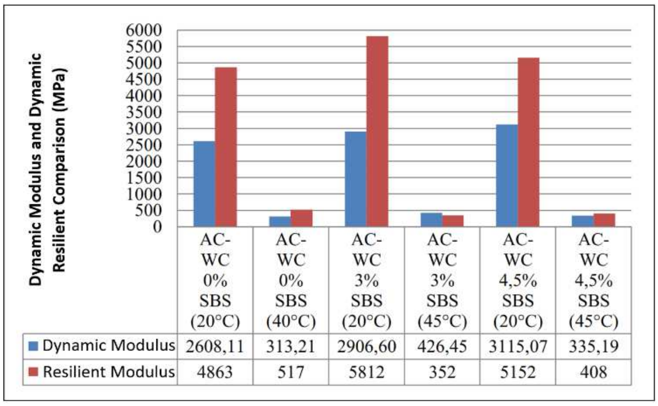


Fig. 4 Dynamic Modulus and Resilient Modulus Comparison

The correlation between Dynamic Modulus and Resilient Modulus is shown in Fig.5 Dynamic Modulus and Resilient Modulus Correlation. The correlation for Dynamic and resilient Modulus using linear regression is positive linear. It means that the reduction of Dynamic Modulus will affect the reduction of the Resilient Modulus.

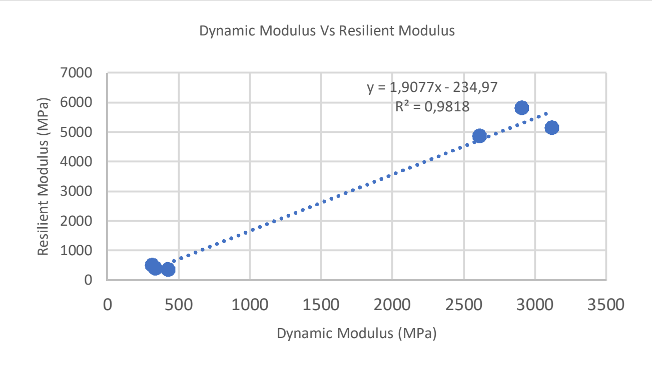


Fig. 5 Dynamic Modulus and Resilient Modulus Correlation

R2 can interpret the goodness of fit for the relationship of Resilient Modulus and Dynamic Modulus. The value of goodness of fit is $R^2 = 0.98$ (approximately equal to 1). This indicates that Resilient Modulus and Dynamic Modulus have a strong correlation (very high). The linear equation calculated from the laboratory test for the relationship between Resilient Modulus and Dynamic Modulus using linear regression is $y = 1.9077x - 234.97$, where the x-axis is Dynamic Modulus (MPa), and the y-axis is Resilient Modulus (MPa). For every 1 point, increasing the point of Dynamic Modulus will result in Resilient Modulus to increase around 1.9077. The laboratory test for the result proves that it approaches the theory with a strong correlation with the goodness of fit 0.98, and the formulation is $y = 1.9077x - 234.97$.

## IV. Conclusions

SBS polymer's addition gives the better resistance on the Dynamic Modulus value at a high temperature (45°C) and low frequency (0,01 Hz and 0,1 Hz). The calculation of Dynamic Modulus using the Witczak equation has a good correlation to the laboratory test results. The correlation equation obtained was $y = 1.7254x + 808.23$, where y is the Dynamic Modulus from Witczak equation and x is Dynamic Modulus from laboratory test results with value of $R^2 = 0.98$. The Dynamic Modulus test results were smaller than the Resilient Modulus in almost all of the test temperature variations, except for the AC-WC with 3% SBS mixture. Moreover, the ratio of Resilient Modulus values between laboratory test (UMATTA) and the Nottingham method gave an average value of 1.30 at 20°C and 1.47 at 45°C. While the average ratio for all temperature variations was 1.36. The relationship between Dynamic Modulus and Resilient Modulus is linear (positive) with the formulation $y = 1.9077x - 234.97$ where y is Resilient Modulus, and x is Dynamic Modulus.

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