International Journal of GEOMATE, Nov., 2020, Vol.19, Issue 75, pp.107-114
Geotec., Const. Mat. & Env., DOI: https://doi.org/10.21660/2020.75.00140
ISSN: 2186-2982 (Print), 2186-2990 (Online), Japan

STIFFNESS MODULUS OF WARM MIX ASPHALT (WMA) USING ASBUTON AND SYNTHETIC ZEOLITE ADDITIVES

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ABSTRACT: The use of asphalt modification with Asbuton semi extraction in asphalt mixtures requires a higher temperature and compaction mixture than petroleum asphalt. Synthetic Zeolite is one type of additive used to reduce the temperature of mixing and compaction of Asphalt mixture until it reaches a warm mixture condition so that it can reduce emissions from the Asphalt mixture production process and is more environmentally friendly. Warm Mix Asphalt (WMA) is a technology for making asphalt mixtures with mixing temperatures 20-40 ^{0}C below Hot Mix Asphalt (HMA) but at temperatures higher than boiling water. This study aimed to determine the stiffness modulus of WMA using asphalt modified Asbuton Semi Extraction and Aspha-min synthetic Zeolite. Asphalt mixture stiffness modulus testing uses Indirect Tensile Strength (ITS) with cyclic loading, the testing procedure refers to ASTM D4123-82. The results showed that WMA using Asphalt modified Asbuton and synthetic zeolite can be realized with mixing temperature and compaction of 30 ^{0}C lower than WMA. Stiffness modulus of WMA with asphalt pen grade using synthetic zeolite is lower than HMA, whereas WMA with Asbuton modified Asphalt produces modulus of stiffness value that is greater than HMA.

Keywords: WMA, Asbuton modified asphalt, Synthetic zeolite, Stiffness modulus.

1. INTRODUCTION

Buton Rock Asphalt is natural rock asphalt from Buton Island, Northwest Sulawesi, Indonesia and it is named locally as Asphalt Buton or Asbuton. The total potential of natural asphalt is estimated at 677,247,000 tons which are scattered in several places on the island. The largest deposits are found in the Lawele Region [1]. In nature, Asbuton is found in the form of light brown porous black-brown porous rocks that contain aggregates, bitumen, and water [2]. To support the construction and maintenance of roads in Indonesia, and to reduce dependence on petroleum asphalt, research on Asbuton is important. The results of these studies can encourage increased use of Asbuton for road construction [3].

Before use, Asbuton needs to be processed first. One of the results of Asbuton processing is Asbuton semi extraction by separating Asbuton bitumen from minerals and removing some mineral content to produce Asbuton with lower mineral content than the original. With the breaking of the mineral bonds with the bitumen through extraction, Asbuton Semi extraction can be easily mixed with petroleum asphalt [4].

In its use, semi-extraction Asbuton functions as a modification material for petroleum asphalt. Modification of petroleum asphalt with Asbuton Semi Extraction can increase the stiffness modulus of asphalt mixture, increase asphalt mixture resistance to high temperatures [3], increase the resistance of asphalt mixture to water [5]. increase the fatigue resistance of asphalt mixture [6] and can increase the service life of asphalt pavement with high load [2].

As is the case with the use of modified asphalt in general, the disadvantage of using Asbuton semi extraction as a modification material for petroleum asphalt is that it requires a higher mixing and compaction temperature than petroleum asphalt [4]. The ideal temperature for mixing in the asphalt mixture production process using Asbuton semi-modified asphalt modification is 170 ^{0}C and for compacting 156 ^{0}C, while for petroleum asphalt, the mixing temperature ranges from 140-160 ^{0}C compaction temperature 130 ^{0}C - 150 ^{0}C [7]. Increasing the temperature in the process of making asphalt mixture will also increase the need for fuel and production costs and increase emissions.

According to the Asphalt Institute, Warm Mix Asphalt (WMA) is a modification of a mixture of Hot Mix Asphalt (HMA) produced with temperatures 20-40 °C lower than HMA, both for mixing and for compaction, but at temperatures higher than boiling water. WMA is sometimes also referred to as "Low-Temperature Asphalt" [8]. The process used in making warm mix asphalt is a double layer, asphalt foam, and the use of some additives such as zeolites, or organic additives such as paraffin or other wax types. The aim is to reduce the viscosity of asphalt to be produced, transported, and spread and compacted at lower temperatures without reducing the quality and workability of the mixture. This warm asphalt mixture will be able to significantly reduce gas emissions, smoke, and odors, both at AMP and at work sites. Besides, lower temperature production also means slowing the aging of asphalt and better working ability of the mixture [9]. WMA manufacturing can use synthetic zeolites and natural zeolites as additives to reduce the temperature of mixing and compaction of asphalt mixtures [10,11].

This study focuses on testing the stiffness modulus of WMA asphalt mixture using Asbuton modified semi-extraction Asphalt and synthetic zeolite additives and then the results are compared with HMA.

2. THE MATERIAL AND METHOD

2.1 Material

Base Asphalt is a petroleum asphalt penetration grade 60/70 Pertamina production. Asbuton semi extraction Retona® briquette type production of PT Olah Bumi Mandiri as bitumen modification material which is packed in sacks weighing 40 kg. For asphalt modification, Asbuton briquettes are heated to be poured and then mixed into an asphalt pen grade 60/70 with a certain percentage, stirring at +150 ^{0}C for 30 minutes. In this study, the percentage of the use of Asbuton semi extraction was 15% and 20% of the total weight of asphalt.

To determine the properties of the base asphalt and Asphalt modification Asbuton, conventional test methods such as penetration test (ASTM D5-06), softening point test (ASTM D36-95), specific gravity (ASTM D92), flash point (ASTM D92-02B), viscosity at 135 ^{0}C (AASHTO T 72-90), ductility (ASTM D113), and thin-film oven test (TFOT) (ASTM D1754-97) done. Based on the results of previous research [12], these tests are carried out according to the relevant test methods presented in Table 1.

Previous research [12] reported that from the results of extraction with the soklet method it is known that similar Asbuton contains 39.95% bitumen and 60.05% minerals. Asbuton mineral grain size distribution from the sieve analysis results are 100% pass the 1.18 mm sieve, 99.29% pass the 0.60 mm sieve, 97.37% pass the 0.30 mm sieve, 92.97% pass the 0.15 mm sieve, and 82.10% pass the 0.075 mm sieve. Asbuton minerals are considered as part of the aggregate composing the asphalt mixture. The aggregate gradation is corrected according to the Asbuton mineral size distribution and the percentage of the use of Asbuton so that the asphalt mixture produced contains the same aggregate percentage as the asphalt mixture without Asbuton. Aggregates used are crushed stone aggregates produced by PT KADI International (Quarry located in Kawarang – West Java Province). The graded aggregate of asphalt mixture used is for concrete binder course (AC-BC) asphalt mixture according to Indonesia specification, (Bina Marga 2010 3 rd revision) by taking the mean value of the existing gradation boundary in the specification as see in Fig.1. The reference specifications are also used to determine the limits of aggregate properties, asphalt properties, and Marshall Properties of asphalt mixtures.

A kind of the synthetic zeolites that are used as additives for WMA is Aspha-min®, a product of Eurovia Services based in Germany. Synthetic zeolite in Aspha-Min® technology comprises about 21% by weight of water, which is released in the temperature range 85-182°C. The use of Aspha-min synthetic zeolite in the manufacture of asphalt mixtures can reduce the mixing and compaction temperature to 30 ^{0}C below HMA with the recommended use dose is 0.3% of the total weight of the mixture [10].

Table 1 Properties of the petroleum asphalt Pertamina 60/70 penetration grade and modified asphalt with semi-extraction Asbuton [12]

Asphalt Type	Penetration (25 ^{0}C; 0.1 mm)	Softening point (^{0}C)	Specific gravity	Flash point (Cleveland Open Cup) (^{0}C)	Viscosity at 135 ^{0}C (cSt)	Ductility at 25 ^{0}C, 5 cm/minute (cm)	Loss on heating (TFOT) (163 ^{0}C; 5 h) (%)
Asphalt Pen Grade 60/70	66.70	49.50	1.037	349	529.74	>100	0.417
Asmod Asbuton 15%	57.10	54.25	1.091	336	614.76	>100	0.044
Asmod Asbuton 20%	54.00	55.00	1.123	330	636.56	>100	0.073

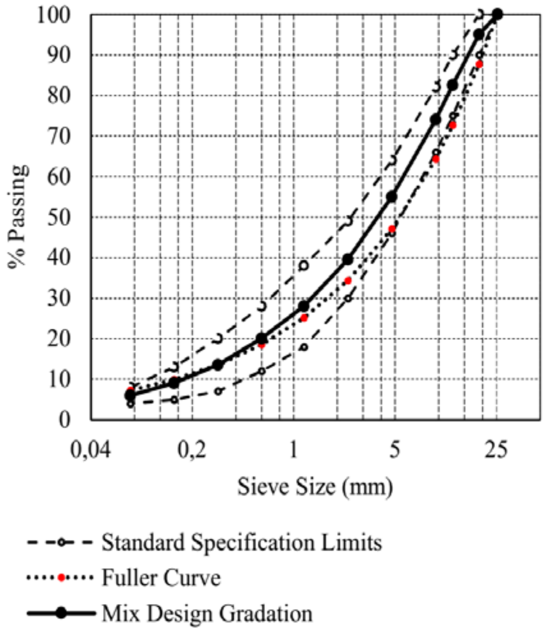

Fig.1 The aggregate gradation of AC-BC asphalt mixed refers to the Indonesian Specification (Bina Marga 2010 Revised 3) [12]

2.2 Experiment Plan

Rheological characteristics of the binder, i.e. complex shear modulus (G*) and phase angle (δ) were determined by using Dynamic Shear Rheometer (DSR). Three groups of the asphalt with different binder compositions were prepared. The binder of each group was: (i) asphalt pen grade 60/70; (ii) blend of asphalt pen grade with 15% Asbuton semi extraction; and (iii) blend of asphalt pen grade with 20% Asbuton semi extraction.

The effect of viscosity on asphalt bitumen's workability is very important in selecting proper mixing and compacting temperatures. For HMA, Brookfield Viscometer (ASTM D4402-12) and Sybolt Furol viscosity (ASTM D88-07 and ASTM E102-93) were employed to determine the mixing and compaction temperatures. For WMA the mixing and compaction temperature is 30 ^{0}C below HMA. In the process of making a WMA, the addition of zeolite to the mixture is done after adding asphalt to the aggregate before mixing asphalt with the aggregate. The addition dose of zeolite is 0.3% of the total weight of the mixture for all asphalt type. Mixing and compacting temperature as shown in Table 2.

Asphalt mixture stiffness modulus value measured by the method of indirect tensile strength test with cyclic loading referring to ASTM D4123-82 using the Pavetest DTS-30 universal test equipment. The Modulus Stiffness test equipment used and sample settings are shown in Fig.2.

The test conditions set on the loading pulse width of 250 ms and 3000 ms pulse repetition period assuming a value of Poisson's ratio of 0.35. Temperature testing was conducted at a temperature variation of 20 °C, 25 °C, 37.5 °C, 41 °C, 50 °C and 60 °C. The samples are 4 inches in diameter made by compaction using a Gyratory Compactor on the optimum asphalt content condition. Control the compaction process is done with the density obtained from the previous Marshall test on the Optimum Asphalt Content (OAC) condition. The Optimum asphalt content and control density as shown in Table 3.

Table 2 Mixing and compacting temperature for HMA and WMA of each asphalt type [12]

Asphalt Type	HMA Temp. (°C)		WMA Temp. (°C)	
	Mix.	Com.	Mix.	Com.
Asphalt Pen Grade 60/70	157	147	127	117
Asmod Asbuton 15%	163	153	133	123
Asmod Asbuton 20%	167	156	137	127

Fig.2 Pavetest DTS-30 universal test equipment and sample position when testing

Table 3 Asphalt optimum content (OAC) and density for HMA and WMA [12]

Asphalt Type	HMA		WMA	
	OAC (%)	Density (gr/cm^3)	OAC (%)	Density (gr/cm^3)
Asphalt Pen Grade 60/70	5.27	2.391	5.38	2.388
Asmod Asbuton 15%	5.65	2.376	5.83	2.374
Asmod Asbuton 20%	5.69	2.390	5.93	2.372

3. RESULT AND DISCUSION

3.1 Effect of Asbuton as material modification to Asphalt Rheology

Effect of Asbuton as a material modification to asphalt rheology seen from the test results Dynamic Shear Rheometer (DSR). The commonly obtained rheological indices from the DSR test were the dynamic shear modulus (G*) and phase angle (δ). The temperature and frequency sweep tests were conducted to evaluate the linear rheological characteristics of modified asphalt. Master curves are developed from the measured linear viscoelastic data using the time-temperature superposition principle at a reference temperature. Master curve can then be used to determined particular values of moduli for any combination of temperatures or frequencies located in the experimental range. Master curve is a depiction of the sensitivity of the complex shear modulus od asphalt to changes in temperature and loading frequency [13]. The master curve in the original condition from the DSR test results is shown in Fig.3.

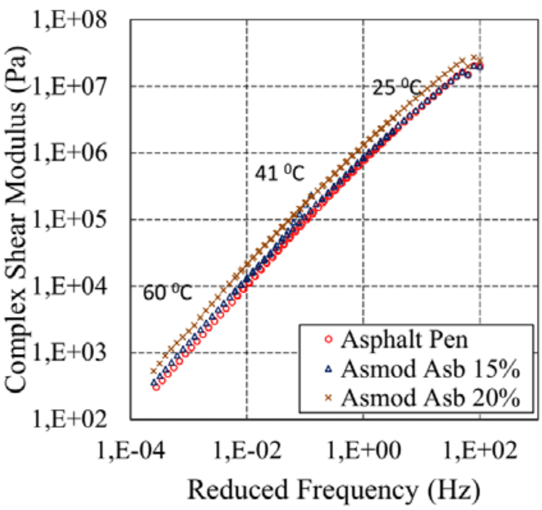

Fig.3 Master curve diagram of asphalt original condition (reference temperature 25 ^{0}C)

In this study, the Williams-Landel-Ferry (WLF) equation for shift factors fitting was used to develop complex shear modulus and reduced frequency master curves. Frequency sweep testing is performed with a frequency range of 0.2-100 Hz, at temperatures of 25 ^{0}C, 41 ^{0}C, and 60 ^{0}C. The reference temperature for the depiction of the master curve is 25 ^{0}C. Hafeez [14] stated that the slope diagrams on the master curve illustrate the sensitivity of asphalt to changes in temperature and frequency of loading. The sloping master curve shows that asphalt is less sensitive to changes in temperature and frequency of loading, on the contrary, if the steeper shows that asphalt is more sensitive to temperature and frequency of loading.

The master curve diagram shows that the use of Asbuton as an asphalt modification material can increase the value of complex shear modulus asphalt at the same test temperature and loading frequency. At a test temperature of 25 ^{0}C, the loading frequency of 10 rad/s the value of the pen grade modulus asphalt complex shear is 1153000 Pa, with the addition of 15% Asbuton is 1262000 Pa, with 20% Asbuton is 1933000 Pa. At a test temperature of 41 ^{0}C, the reduced loading frequency of 1 rad/s the value of the pen grade modulus asphalt complex shear is 153800 Pa, with the addition of 15% Asbuton is 170700 Pa, with the addition of 20% Asbuton is 271400 Pa. At a test temperature of 60 ^{0}C, the reduced loading frequency of 0.5 rad / s the value of the pen grade asphalt complex shear modulus is 87330 Pa, with the addition of 15% Asbuton is 121900 Pa, with the addition of 20% Asbuton is 156500 Pa. From these results, it can be seen that with the same loading frequency at the test temperature of 25 ^{0}C the use of Asbuton 15% has increased asphalt modulus complex shear by 9.45%, the use of Asbuton 20% increased by 67.68%. At a test temperature of 41 ^{0}C, the increase in the value of complex shear modulus was 10.99% in the use of Asbuton 15%, and 76.46% in the use of Asbuton 20%. At the test temperature of 60 ^{0}C the use of Asbuton 15% increased the value of complex shear modulus by 39.59% and with Asbuton 20% increased by 79.21%. From these results, it can be seen that the percentage increase in the value of asphalt modulus shear at the same reduced testing frequency increases with increasing test temperature, and results in a slope of a slower curve than pen grade asphalt. This shows that the use of Asbuton can increase asphalt resistance to temperature and loading temperature [14].

Black diagram illustrates the relationship between asphalt complex shear modulus with phase angle (δ). Black diagram of the effect of adding Asbuton to the original binder condition, as shown in Fig.4.

The value of phase angle (δ) illustrates the durability of asphalt, the smaller the Phase Angle (δ) value indicates that the asphalt is more durable. If extrapolation is done backward until the phase angle value = 0^o, then the asphalt complex shear modulus can be obtained in purely elastic conditions [13].

From the black diagram, it can be seen that the value of asphalt phase angel modified with Asbuton is below the asphalt pen. The same results were also seen from the DSR test with temperature sweep, at a test temperature of 41 ^{0}C, the value of phase angle with asphalt pen grade was 84.44^0, asphalt modification of Asbuton 15%, the phase angle value was 83.27^0 and with Asbuton 20% was

82.13^0. Lower phase angle values indicate that the addition of Asbuton can improve the elasticity of asphalt [15] and asphalt durability [13].

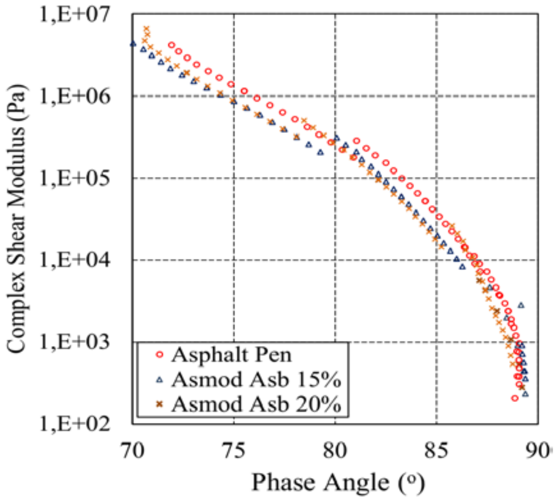

Fig.4 Black diagram of asphalt original condition

3.2 Stiffness Modulus of Asphalt Binder

Asphalt stiffness modulus (Sbit) can be obtained from the DSR test results using the following Eq. (1) [13].

$$\text{Sbit} = 2\,(1 + \mu)\,G^* \tag{1}$$

Where Sbit is Asphalt stiffness modulus in MPa, G* is Complex Shear Modulus from DSR test result in MPa, and m is Poisson's Ratio. The μ value depends on the compressibility of the material and can be assumed to be 0.5 for almost all pure asphalt [15]. Asphalt modulus stiffness value calculated based on the results of the DSR test on the angular frequency test of 10 rad/s, the strain value of 12% with the temperature variation of the test temperature is shown in Fig.5.

The use of Asbuton 20% can increase the value of asphalt modulus Stiffness significantly. The same results have also been reported by [2], where the use of 20% of Asbuton semi extraction RETONA® produces is stiffer than asphalt pen grade. While the use of 15% Asbuton only slightly affects the value of asphalt modulus stiffness. At the test temperature of 25 ^{0}C, the value of pen grade asphalt modulus stiffness is 3,459 MPa, with the addition of 15% Asbuton is 3,786 MPa while the addition of 20% Asbuton is 5,799 MPa.

3.3 Stiffness Modulus of Hot Mix Asphalt (HMA)

Stiffness modulus asphalt mixture is influenced by temperature. The relationship between the stiffness modulus of asphalt mixtures by testing temperature is presented in Fig.6.

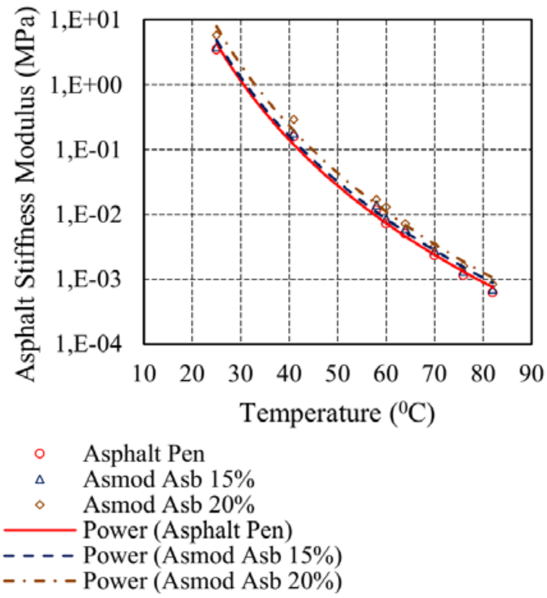

Fig.5 Asphalt stiffness modulus for each asphalt type and variation of temperature

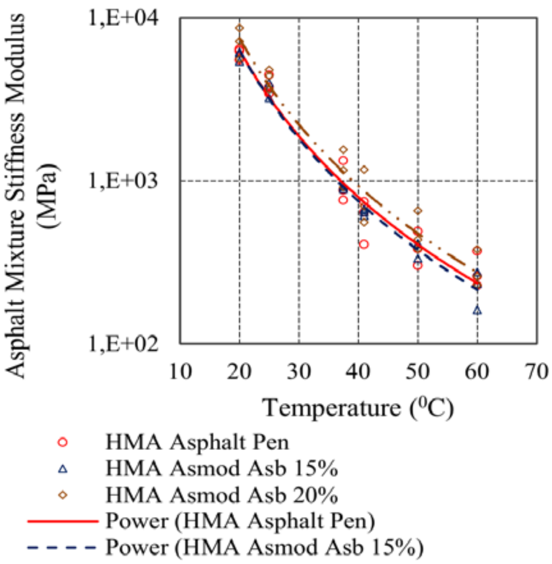

Fig.6 Asphalt mixture stiffness modulus of HMA

Asphalt mixture stiffness modulus by using Asbuton 20% shows a tendency in line with asphalt stiffness modulus, which is the modulus of stiffness value that is greater than asphalt pen grade at all test temperatures. The use of Asbuton 15% shows the opposite results, the value of Asphalt mixture stiffness modulus is lower than using asphalt pen grade. At a test temperature of 25 ^{0}C, the average value of stiffness modulus asphalt mixture HMA using asphalt pen grade was 6058.35 MPa, using 15% Asbuton was 5861.76 MPa, and using 20% Asbuton was 7130.13 MPa. At a test temperature of 60 ^{0}C, the average value of stiffness modulus asphalt mixture HMA using asphalt pen grade was

285.76 MPa, using 15% Asbuton was 223.10 MPa, and using 20% Asbuton was 288.58 MPa.

3.4 Stiffness Modulus of Warm Mix Asphalt (WMA)

The results of the WMA asphalt mixture modulus stiffness test for each type of asphalt and its comparison to HMA are shown in Figs.7-9.

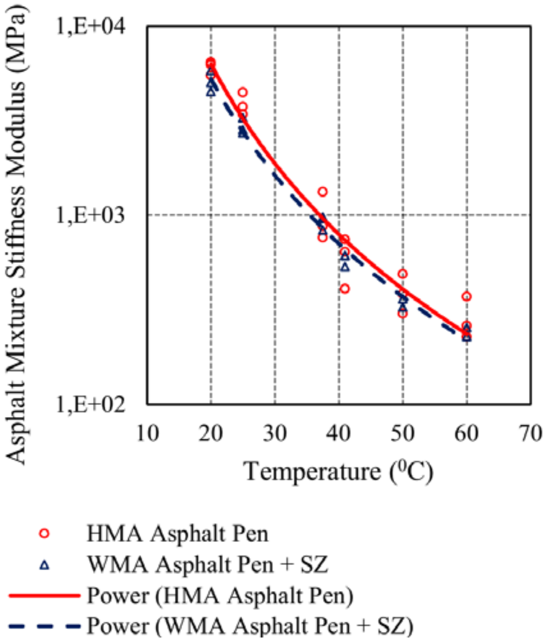

Fig.7 Comparison of the asphalt mixture stiffness modulus of HMA and WMA using asphalt pen grade

Asphalt modulus Stiffness test results on WMA with synthetic zeolite using asphalt pen grade showed an average value lower than HMA, as shown in Fig. 7. At a test temperature of 25 0C, the modulus of the stiffness asphalt mixture value of the HMA is 3979.85 MPa, while WMA is 2942.66. On average the stiffness value of the modulus of the WMA asphalt mixture at all test temperatures is 12.65% lower than HMA.

WMA using Asbuton modified Asphalt give Asphalt Mixture stiffness modulus higher than the HMA, either by Asbuton 15% and 20%, as shown in Figs.8,9.

The difference in the Stiffness modulus value of Asphalt mixture HMA with WMA using asphalt modification of Asbuton, the higher the test temperature, the greater the difference. At a temperature of 25 ^{0}C testing the stiffness modulus of asphalt mixture difference between WMA with HMA using Asbuton 15% is 0.73%, using Asbuton 20% is 9.45%, and at a temperature of 60 ^{0}C difference testing 14.60% using Asbuton 15% and 11.77% using Asbuton 20 %. The increase in modulus stiffness value is caused by minerals in Asbuton containing $CaCO_3$, SiO_2, and Al_2O_3. The addition of zeolite synthetic with its main components are SiO_2, and Al_2O_3 will further increase the mineral content in the asphalt mixture. Zang [19] states that These minerals might contain good binding sites for adsorption of asphalts. Such factors make it present good adsorption, good adhesive properties, and stable dispersions, and thus good workability.

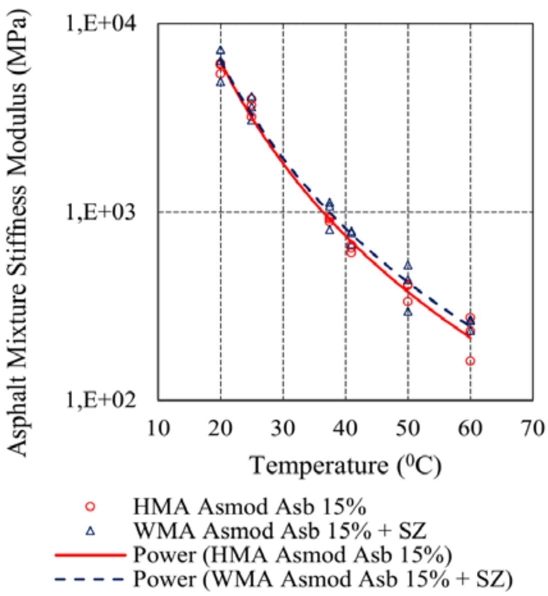

Fig.8 Comparison of the asphalt mixture stiffness modulus of HMA and WMA using asphalt modification Asbuton 15%

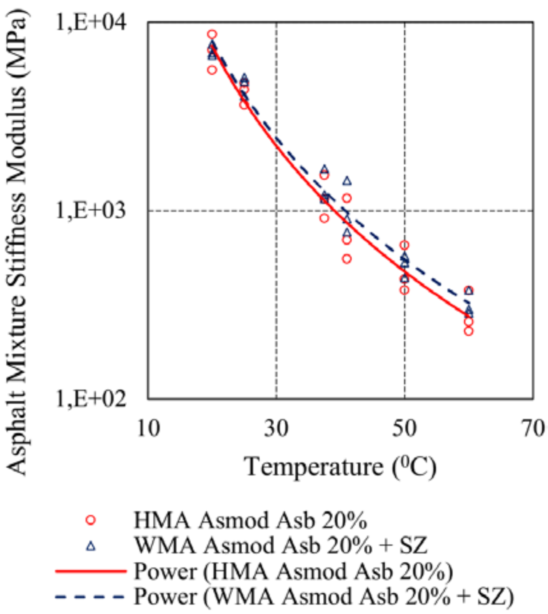

Fig.9 Comparison of the asphalt mixture stiffness modulus of HMA and WMA using asphalt modification Asbuton 20%

Increasing the stiffness modulus at high temperatures can improved temperature susceptibility and the potential to increase the resistance of asphalt mixtures to permanent deformation [17-18]

4. CONCLUSION

A significant increase in the value of asphalt stiffness modulus was seen in the use of Asbuton 20% of the total weight of asphalt. Stiffness modulus of WMA with asphalt pen grade using synthetic zeolite is lower than HMA, whereas WMA with Asbuton modified Asphalt produces modulus of stiffness value that is greater than HMA. Stiffness modulus test results of asphalt mixture WMA with asphalt modified Asbuton and synthetic zeolite indicate more resistant to permanent deformation when compared to HMA.

The future potential research areas and problems that could be addressed are the followings: (1) Further performance tests (e.g. assess the performance against rutting and fatigue life) are required to be carried out in order to get a thorough understanding of zeolite synthetic influence on WMA asphalt mixtures. (2) The same study uses different types of zeolites, such as natural zeolites.

5. ACKNOWLEDGMENT

We would like to thank PT. Olah Bumi Mandiri, PT. KADI International, and MHI Naturstein & Baustoff service GmbH for providing the material for this research.

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