Analysis of Stiffness Modulus of Asphalt Concrete Mixture by Using Artificial Aggregates

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***Abstract*—The type of damage to the pavement layer is cracking and permanent deformation. The mechanism of cracking in the pavement layer occurs because of the tensile force at the bottom of the pavement layer due to the wheel load of the vehicle. One parameter of a mixture to achieve strength and durability as needed is the relationship of stress and strain which shows the stiffness of a mixture. Indirect Tensile Strength is a method used to show the stiffness of a mixture. As infrastructure development in Indonesia continues to increase, the availability of natural aggregate materials is decreasing. One of the uses of geopolymer can be used as artificial aggregates to replace the depleted natural aggregates. The purpose of this study was to review the stiffness modulus of concrete asphalt mixture with the use of artificial aggregates made from geopolymer by using open gradations of BBA (Beton Bitumineux pour chausees Aeronautques). From the test results using the Dynapave UTM30 tool at 20° Celsius and 60° Celsius, stiffness modulus values of the asphalt mixture are 3542 MPa and 147 MPa. The increase in temperature causes a decrease in the stiffness modulus value of 96%, so that the increase in temperature will be accompanied by a decrease in the stiffness modulus.**

***Keywords*—Indirect Tensile Modulus Test, Runway Pavement, Marshall Test, Artificial Aggregates.**

I. INTRODUCTION

The asphalt concrete mixture consists of coarse aggregates, fine aggregates, fillers and uses asphalt as a bonding material. As the development of infrastructure in Indonesia continues to improve, the use of natural aggregates is increasing, so that this will cause the availability of natural aggregates to dwindle. One of the uses of geopolymers can be used as artificial aggregates in concrete asphalt mixtures. As has been done in previous studies where coarse aggregates, geopolymer aggregates, and asphalt are mixed in one proportion, then compacted into concrete asphalt pavement. The results of this study show that the asphalt mixture with artificial aggregates made from the geopolymer fly ash mentioned above has met the specification requirements and has good Marshall stability values such as natural aggregate use[1].

Each type of concrete asphalt mixture for the pavement layer has a certain aggregate gradation. The aggregate gradation can be said to greatly affect the performance of the asphalt mixture because the aggregate gradation serves to provide deformation strength and durability which ultimately affects the stability, density and porosity in the mixture, with interlocking conditions of each coarse aggregate particle[2].

BBA Gradation (Bitumineux pour chausées Aéronautiques) is an open gradation which is the airfield runway standard that is mostly used in France, including in the two runways of the Paris Charles de Gaulle airport, and Toulouse airport (where A380 aircraft are built and tested). The use of BBA gradation on the pavement layer can improve the performance of a pavement. From the results of pavement design analysis shows that it can reduce the thickness of the asphalt layer by about 15% compared to the thickness of the pavement layer in general. And also has a positive impact on the environment such as noise levels and low greenhouse gas emission[3].

In planning the asphalt mixture uses several parameters to achieve strength and durability. One of the asphalt mixture parameters so that the strength and durability achieved according to needs is the stress and strain that shows the stiffness of a mixture. Stiffness value of ordinary materials is assessed from the modulus of the material, namely modulus of elasticity, but asphalt mixture is a material that is not perfectly elastic so the use of the term modulus of elasticity (E) is not suitable for use and instead the term stiffness modulus is used instead[4].

Therefore, the purpose of this study was to conduct an indirect tensile strength test of concrete asphalt mixture with the use of artificial aggregates made from geopolymers in the laboratory to review the mixture stiffness modulus values.

II. LITERATURE REVIEW

Stiffness modulus is a measure of the stiffness of a material, so that the higher the modulus of elasticity of a material, the fewer changes in shape that occur when given a force. So, the greater the stiffness modulus, the smaller the elastic strain that occurs or becomes stiffer[5].

Modulus of asphalt mixture is influenced by many factors, including temperature, asphalt type, variations in asphalt levels, gradations and variations in compaction. Temperature is one of the most important factors affecting the planning and performance of asphalt pavement[6].

Tensile strength is influenced by temperature and loading time. An increase in temperature will cause asphalt viscosity to decrease. This is caused by increasing thermal energy (thermal energy) and dissolving asphalt into oil. If it is associated with traffic, the old load will occur in traffic at low speed. The longer the loading on the pavement, the asphalt that was originally elastic will become more viscous[7].

In compaction of the asphalt mixture, the spatial distribution and effectiveness of the contact area between aggregate particles depends on the shape, angularity and texture of the aggregate surface, especially for coarse aggregates. High temperatures result in modulus reduction in the asphalt mixture bond, so strong interlocking is needed on coarse aggregates, interlocking is influenced by aggregate morphological properties[8].

The bond between asphalt and aggregates or the resistance of the asphalt mixture and aggregate can be influenced by the aggregates shape and aggregates roundness, thus affecting the lifetime and performance of the asphalt pavement there is a linear relationship between shape or roundness and asphalt coverage ratio. better adhesion properties for the asphalt mixture are shown by the higher the stiffness, the rougher the aggregate texture, and the smaller the roundness, the greater the asphalt coverage ratio[9].

In existing research generally focuses on the properties of asphalt[10], [11], the use of various gradations [12] and the use of various types of asphalt [4] to optimize the asphalt mixture. But researches on the material used or aggregate characteristics are being left far behind.

III. METHOD

Preparation of research work plans is carried out first, this is intended to facilitate the implementation of research. Steps are taken to identify problems, objectives, literature studies, as well as preparation of tools and materials. Next, prepare the materials used in the form of coarse aggregates, fine aggregates, fillers and asphalt. On coarse aggregates using artificial aggregates made from geopolymers as much as 25% and natural aggregates as much as 75%[1].

The gradation used in this study use open gradations (BBA). Following this the percentage specifications of the weight values held on the BBA gradation are shown in Table 1. To make it easier to see the percentage of the weight value held on the specification requirements will be illustrated in the graph shown in Figure 1.

A. *Sample Fabrication*

The optimum binder content according to the examination of the mixture is carried out by the Marshall Test which aims to determine the stability and flow result of the asphalt and aggregate mixture and determine the optimum bitumen content for testing afterwards. The method used for the manufacture of geopolymer concrete asphalt will follow the stages of implementing the Marshall method (AASTHO T 245-90, or ASTM D 1559-76. The specimens were prepared at optimum bitumen content (OBC) using Marshall method. Making test specimens using bitumen content where each specimen is made 5 pieces, the test object is compressed with an automatic pounder 75 times on one side, then reversed and another pounding is done on the other side 75 times. So that compaction for one specimen is carried out twice, each 75 blows, then Marshall test is performed to determine the asphalt content that meets the Marshall parameter specifications to determine Optimum Bitumen Content (OBC). Marshall testing method in accordance with SNI 06-2489. Furthermore, making test specimens using the optimum bitumen content value.

Table 1.
Aggregate Gradation Specifications

Sieve number	Sieve size	% weight pass the sieve
¾’’	19,1 mm	100
½’	12,7 mm	80 – 100
3/8’	9,25 mm	60 – 70
No. 4	4,76 mm	36 – 44
No. 10	2,38 mm	33 – 40
No. 80	0,59 mm	Oct-25
No. 200	0,074 mm	6 – 9

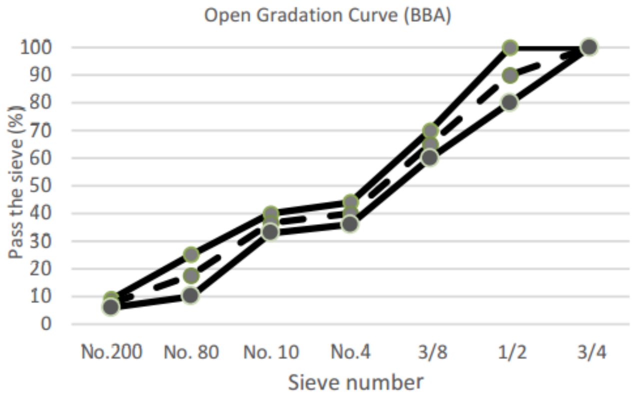

Figure 1. Gradation of BBA

B. *Stiffness Test*

The stiffness reffered to here is Indirect Tensile Stifnness Modulus (ITSM) test. Indirect tensile modulus strenght test was carried out to measure the stiffness modulus of asphalt mixtures as an indicator for cracking susceptibility. The test was conducted at a temperature of 20 °Celcius, where the sample is given a dynamic load at a certain strain range (linear elastic condition) with a test configuration as shown in Figure 2. This test is carried out under repeated loading at low stresses so that the response of the specimen tested remains elastic[13]. The test is regarded as non - destructive test conducted using Dynapave UTM 30 machine. ITSM testing is calculated by formulas and set up parameters according to the provisions in the British Standard (BS EN 12607–26: 2012).

The measurement is conducted by applying a load on a generating line of a cylindrical specimen, and by recording the resulting strain in the plane perpendicular to the loading plane (with the test configuration as shown in Figure 2). Horizontal deformation of the specimen was measured by two LVDTs (linear variable displacement transducers) and used to calculate the strain due the tensile stress. The deformations of specimen and the load of Dynapave UTM 30 were monitored and recorded by a computerized data-logging system.

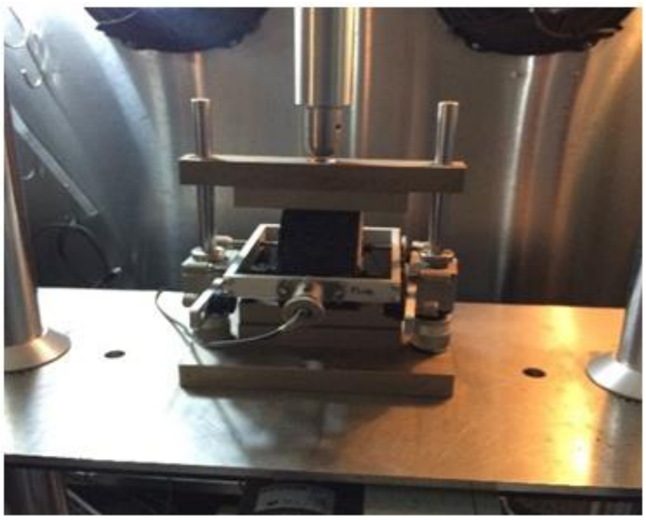

Figure 2. The testing machine (Dynapave UTM 30)

If we know Poisson’s ratio value, specimen size and the load applied, the asphalt mix modulus is calculated with the following formula:

$$E=(F(v+0.27))/((z\times h)) \quad (1)$$

Where E is the Stiffness Modulus (MPa), F is the peak value of the applied vertical load (N), z is the amplitude of the horizontal deformation obtained during the load cycle (mm), v is the poisson's ratio (0,35) and h is the mean thickness of the specimen (mm).

IV. RESULT AND DISCUSSION

A. Material Testing Result

Examination of aggregate and asphalt material was carried out at the Laboratory of Transportation and Road Construction Materials, Civil Engineering, Faculty of Civil Engineering, Environment and Geo, Sepuluh Nopember Institute of Technology. Examination carried out is testing of coarse aggregate specific gravity, fine aggregate, absorption and abrasion testing. The inspection of asphalt is penetration testing, ductility testing, softening test, flash point and specific gravity. The results of coarse aggregate and fine aggregate quality test results are shown in Table 2 and Table 3. The results of asphalt inspection are shown in Table 4.

Testing the characteristics of the mixture was carried out to determine the stability, flow, Marshall Quotient, and volumetric asphalt mixture. Stability and flow values are quantities measured directly from the test when the specimen is loaded with Marshall test equipment. While the mixed volumetric values carried out include the Void In Mixture (VIM), Void in the Mineral Aggregate (VMA), and Volume of Voids filled Bitument (VFB) which is a parameter that greatly affects the nature of the asphalt mixture. In this study the characteristics of the mixture were reviewed based on concrete asphalt mixture with the use of geopolymer artificial aggregates using open gradations (BBA).

Table 2.
Properties of Coarse Aggregate.

Test	Natural Aggregate	Artificial Aggregate	Unit
Bulk specific gravity	2.54	1.85	gr/cm3
Apparent specific gravity	2.7	2.09	gr/cm3
Absorption	2.34	6.08	%
Abrasion	30.8	22.78	%

Table 3.
Properties of Fine Aggregate.

Test	Natural aggregate	Unit
Bulk specific gravity	2.557	gr/cm3
Apparent specific gravity	2.767	gr/cm3
Absorption	2.965	%
Specific gravity (filler)	2,614	gr/cm3
Apparent specific gravity	2.726	gr/cm3

Table 4.
Properties of Asphalt.

Test	Result	Unit
Penetration	64	0,1 mm
Softening point	51	Celsius
Ductility	150	cm
Flash point	256	Celsius
Specific gravity	1,033	

B. Bitument Content

Making test specimens for the geopolymer concrete asphalt mixture starts from the plan bitumen content. In testing with a Marshall tool, the first thing to do is calculate the early estimate of OBC (Pb) using Equation 2.

$$Pb = 0{,}035(\%CA) + 0{,}045(\%FA) + 0{,}18(\%Filler) + K \quad (2)$$

Example calculation of optimum bitumen content.

Pb = 0,035 (% CA) + 0,045 (% FA) + 0,18 (% filler) + K
= 0,035 (60%) + 0,045 (32,5%) + 0,18 (7,5) + 0,75
= 5,66 % ≈ 6%

The specimens made to determine the Optimum asphalt content are specimens at asphalt levels of 5%, 5.5%, 6%, 6.5%, 7%, and 7.5%. Each bitumen content is made of 3 specimens.

C. Marshall Test

The Marshall test was carried out with 30 minutes immersion time at 60ºC. Marshall test results can be listed in Table 5.

Based on the data from Table 5, a graph of the relationship between Marshall parameters and asphalt content is graphed. Each of the Marshall parameters is described as asphalt content limits that meet the mixed specification limits. The optimum bitumen content is the middle asphalt content of the range that meets the marshall parameters spesifications, shown in Figure 3.

Table 5.
Marshall Test

Bitumen content (%)	Stability (Kg)	Flow (mm)	VMA (%)	VIM (%)	VFB (%)
	1687.15	4.4	18.387	7.858	57.261
5	1991.95	3.3	17.326	6.661	61.557
	1805.49	3.3	17.1	6.406	62.54
	1797.3	3.1	18.092	6.408	64.582
5.5	2059.84	3.9	17.661	5.915	66.508
	2012.63	4.1	17.099	5.273	69.162
	1967.29	4	17.022	4.04	76.265
6	2014.32	4	16.932	3.936	76.756
	1714.12	3.9	16.475	3.408	79.316
	1737.67	4.1	15.414	1.001	93.507
6.5	1699.83	4	16.552	2.333	85.906
	1605.36	3.9	16.315	2.055	87.402
	1635.62	4	15.609	0.04	99.742
7	1715.69	4.3	16.116	0.64	96.029
	1454.25	3.9	15.683	0.127	99.191

From Figure 3 shows a graph that shows each characteristic drawn by the polynomial line for the addition of asphalt content. From the results of the polynomial line drawings, it is obtained that: the more asphalt content in the mixture will change the trend of the value of stability, flow, VIM, VMA, VFB, and MQ. This is due to the increase in asphalt content in the mixture resulting in many aggregate surfaces in the mixture being covered by asphalt and also reducing the cavity in the mixture, so that the binding between aggregates and asphalt becomes optimal. Based on the graph of Marshall parameters of BBA gradation, it can be determined the optimum bitumen content of BBA gradations using the bar-chart method. The optimum bitumen content is the middle asphalt content from the range that meets the Marshall parameter specifications as shown in Figure 4.

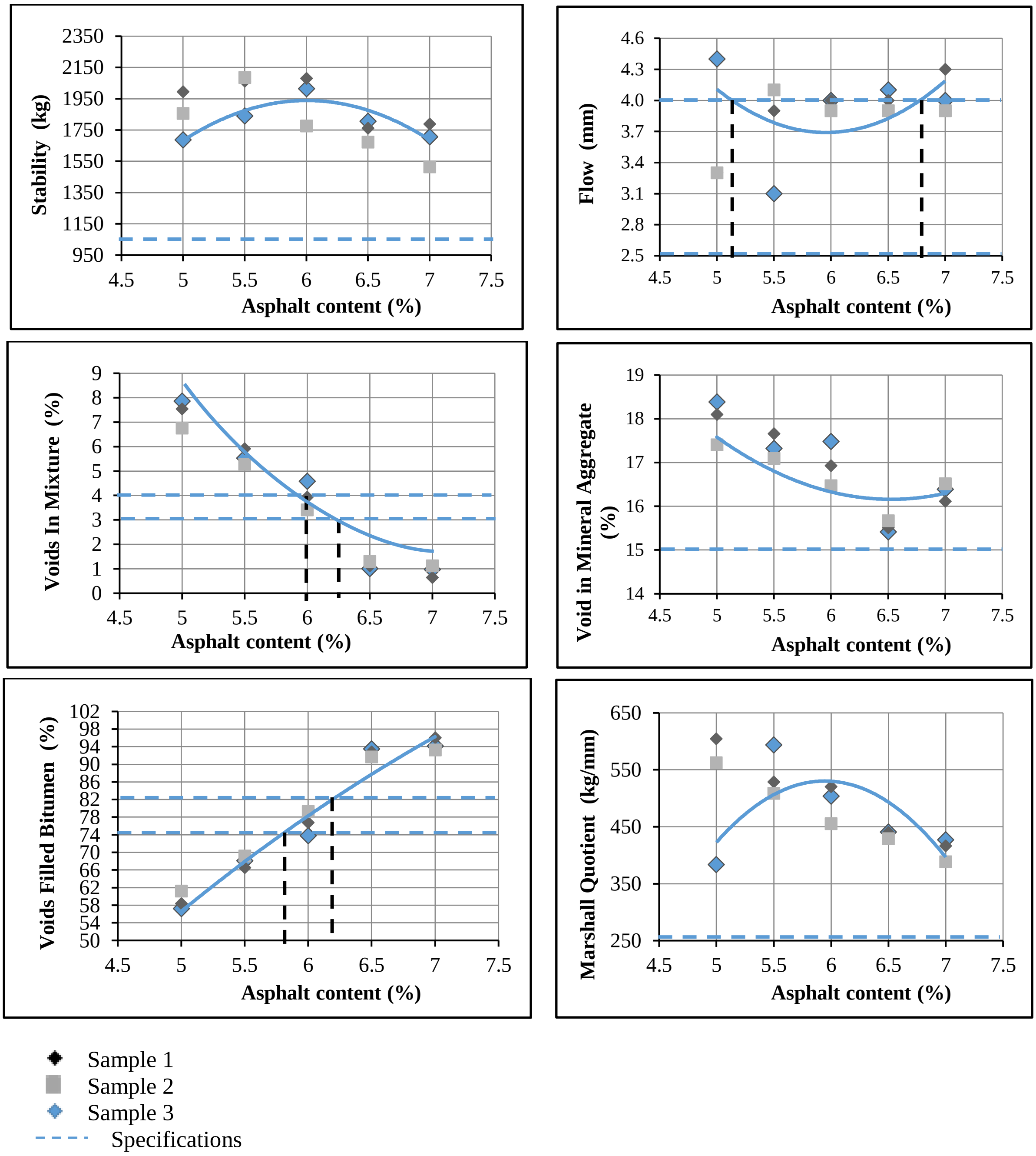

Figure 3. Relationship of Marshall parameters and asphalt content.

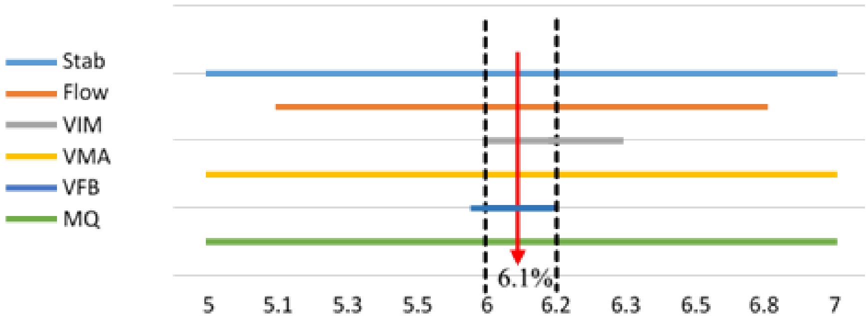

Figure 4. Optimum Bitumen Content.

Based on Figure 4, it can be seen that 6.0% asphalt and 6.2% produce mixed characteristics that meet specifications. So that the optimum bitumen content is the average of the two asphalt levels. The average of the two asphalt levels is 6.1%. Therefore 6.1% bitumen content meets the mixture properties and will be used in mixed designs for BBA gradations.

D. Indirect Tensile Stiffness Modulus Test

The Indirect Tensile Stiffness Modulus test was carried out at the Transportation and Construction Materials Road Laboratory at Udayana University, Denpasar, Bali. The stiffness modulus properties of asphalt mixtures are of interest to pavement engineers because of the problems associated with cracking. The resistance of asphalt mixture to fatigue cracking is dependent upon its tensile properties, notably its tensile strength and stiffness[13]. The ITSM (Indirect Tensile Stiffness Modulus) test is intended to determine the maximum stress that can be held by a mixture when stretched or pulled, before the mixture is destroyed. Stiffness modulus is obtained by performing a tensile test and recording strain and stress changes. Table 6 shows the results stiffness modulus of the mixture are influenced by temperature.

Table 6.
Properties of Asphalt.

Temperature (°C)	Stiffness modulus (MPa)	
20ºC	3296	3476
	3255	3477
	3118	3542
60ºC	110	128
	147	101
	130	154

From the results of the study in Table 6, it is found that the higher the pavement temperature will result in the lower modulus of stiffness of the asphalt mixture. It can be seen that the difference in pavement temperature is very influential on the mixture stiffness modulus, this occurs because of the high asphalt content. The asphalt response to load is viscous elastic, so this property also affects paved pavement, especially if the asphalt content is high.

V. CONCLUSION

This paper evaluates the effects of using artificial aggregates and BBA gradations on the behaviour of asphalt pavement. Indirect Tensile Stiffness Modulus test is used to measure the pavement stiffness. Optimum Bitumen Content and mechanical properties of the mixture were studied, including Marshall stability, and stiffness modulus. From the results of research and data analysis that has been done, conclusions can be taken as follows:

- The test results using the Dynapave UTM30 tool indicate that the stiffness modulus value of the mixture at a temperature of 20 degrees Celsius is 3542 MPa, while the mixture stiffness modulus at a temperature of 60 degrees Celsius is 147 MPa.
- At a temperature of 20 °C it was found that the stiffness modulus value using artificial aggregates met the standards set by the FAA (2009), which is a minimum of 1380 MPa. However, the addition of temperatures from 20°C to 60°C reduces the mixture's stiffness modulus by 96%. This shows that the addition of temperature will be accompanied by a decrease in stiffness modulus.
- The stiffness modulus of a mixture does not depend on the size of the mixture, but rather because of the mixture type. Factors that can influence such as asphalt content in the mixture, mixture gradation, temperature, mixed humidity, aggregate form, and preparation of asphalt mixture.
- Absorption in artificial aggregates is different compared to natural aggregates. High absorption makes the artificial aggregate more in need of high asphalt content to be able to cover all aggregate layers to provide stronger interlocking power, so that when high temperatures cause the asphalt to emerge from the artificial aggregate and make the pavement mixture softer.

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