The study of stiffness modulus values for AC-WC pavement

AS Lubis1,2,*, Z A Muis and T D Iskandar

1Civil Engineering Department, Faculty of Engineering, Universitas Sumatera Utara, Padang Bulan, Medan 20155, Indonesia
2Sustainable Energy and Biomaterial Center of Excellence, Universitas Sumatera Utara, Padang Bulan, Medan 20155, Indonesia.

*Email: adinasarilubis@gmail.com

Abstract. One of the parameters of the asphalt mixture in order for the strength and durability to be achieved as required is the stress-and-strain showing the stiffness of a material. Stiffness modulus is a very necessary factor that will affect the performance of asphalt pavements. If the stiffness modulus value decreases there will be a cause of aging asphalt pavement crack easily when receiving a heavy load. The high stiffness modulus asphalt concrete causes more stiff and resistant to bending. The stiffness modulus value of an asphalt mixture material can be obtained from the theoretical (indirect methods) and laboratory test results (direct methods). For the indirect methods used Brown & Brunton method, and Shell Bitumen method; while for the direct methods used the UMATA tool. This study aims to determine stiffness modulus values for AC-WC pavement. The tests were conducted in laboratory that used 3 methods, i.e. Brown & Brunton Method, Shell Bitumen Method and Marshall Test as a substitute tool for the UMATA tool. Hotmix asphalt made from type AC-WC with pen 60/70 using a mixture of optimum bitumen content was 5.84% with a standard temperature variation was 60°C and several variations of temperature that were 30, 40, 50, 70 and 80°C. The stiffness modulus value results obtained from Brown & Brunton Method, Shell Bitumen Method and Marshall Test which were 1374,93 Mpa, 235,45 Mpa dan 254,96 Mpa. The stiffness modulus value decreases with increasing temperature of the concrete asphalt. The stiffness modulus value from the Bitumen Shell method and the Marshall Test has a relatively similar value. The stiffness modulus value from the Brown & Brunton method is greater than the Bitumen Shell method and the Marshall Test, but can not measure the stiffness modulus value at temperature above 80°C.

1. Introduction
The asphalt mixture is a combination of aggregate mixed evenly and coated with hard asphalt. In a planning of the asphalt mixture use several parameters to achieve strength and durability. One of the parameters of the asphalt mixture in order for the strength and durability to be achieved as required is the stress-and-strain showing the stiffness of a material [1]. The stiffness value of ordinary material is assessed from the elastic modulus of the material. The elastic modulus is a measure of the stiffness of a material; so that the higher of the elastic modulus of the material is the less form changes that occur when given the force. Thus, the greater of the stiffness modulus is the smaller of the elastic strain that occurs or the more rigid [2].
The stiffness modulus value of an asphalt mixture material can be obtained from the theoretical (indirect methods) and laboratory test results (direct methods). The empirical approach of the stiffness modulus is, among others, the Van der Poel method which later developed into the Shell Bitumen method [3], and the other one is Brown & Brunton method [4]. While one of the laboratory tool to test the stiffness is the UMATTA tool, but in this study used the Marshall tool [5].

Al-Jassar et al. [6] and Widodo [5] tested the elastic modulus of concrete asphalt with Marshall tool. The test result states that the elastic modulus of asphalt concrete is strongly influenced by the temperature factor. Wardoyo J. [7] tested the effect of gilsonite as an additive material on the stiffness modulus value of the concrete asphalt at low temperature using Brown and Brunton method. The test results show that the addition of gilsonite can decrease the penetration value and increase the softening point of asphalt. Sjahdanulirwan [8, 9] conducted a literature study on the effect of the time loading on the stiffness of concrete asphalt according to several methods. This research is a study about the stiffness modulus value of concrete asphalt using indirect methods and direct methods. For the indirect methods used Brown & Brunton method, and Shell Bitumen method; while for the direct methods used Marshall tool.

2. Literature Review
The elastic modulus is the number that used to measure the object or resistance of the material to undergo elastic deformation when force is applied to the object. One type in the elastic modulus is the stiffness modulus. The stiffness modulus is the elastic modulus used in the elastic theory. As it is known that almost all of the pavement materials are not elastic but have permanent deformation after receiving load repetition. But if the load is relatively small against the strength of the material, then the permanent deformation occurring at each high load repetition can almost be perfectly and proportional to the load. In this condition the material can be considered as an elastic material [10].

Stiffness is the resistance of a material to elastic deformation, because the rheological nature of the asphalt stiffness is the relation between stress and strain as a function of the duration of loading and temperature. Van der Poel [3] termed stiffness of bitumen (Sb) as a comparison between stress-strain on asphalt, which is a function of the duration of loading (frequency) applied, temperature difference with T800 and Penetration Index. T800 is the temperature at the time of penetration reached 800. Based on Bina Marga 2013 [11] the modulus characteristics of materials for Indonesia’s climate and loading conditions on the AC-WC type is 1100 Mpa. AASHTO [12] says the need for attention to asphalt concrete surface coarse has a stiffness modulus value above 450,000 psi. The high stiffness modulus value causes the asphalt concrete to be more rigid and resistant to deflection, but susceptible to temperature and fatigue cracking.

There are two approaches to measure the stiffness modulus value of an asphalt mixture material, i.e. by indirect methods and direct methods. In the indirect approach the stiffness modulus is estimated through the asphalt routine data using formulas and nomograms that have been developed by Brown & Brunton, and Shell Bitumen.

According to Brown & Brunton [4] method, the stiffness modulus of the concrete asphalt mixture (Sme) is influenced by the asphalt stiffness modulus (Sb) and the VMA (Voids in Mineral Aggregate). The asphalt stiffness modulus (Sb) is influenced by temperature, recovered penetration, recovered softening point, penetration index and duration of loading. The equations of Brown & Brunton methods are:

\[
S_{me} = S_b \left[1 + \frac{257.5 - 2.5VMA}{n \times (VMA - 3)}\right]^n \quad (1)
\]

\[
n = 0.83 \times \log (4.10^{10}/S_b)
\]

with: Sme = Stiffness modulus of concrete asphalt mixture/Mix Stiffness (MPa) and Sb = asphalt stiffness modulus/Bitumen Stiffness (MPa).
According to Shell Bitumen method [3] the stiffness modulus of concrete asphalt mix (Sm) is influenced by asphalt stiffness modulus (Sb) and air pore content (Cv). The asphalt stiffness modulus (Sb) is affected by T800, penetration index, pavement temperature and duration of loading. The equation of Shell Bitumen method is:

\[ Sm = Sb \left[ 1 + \frac{2.5 \times Cv}{N \times (1-Cv)^n} \right] \]  

(2)

where: \( Sm = \) stiffness mixture of asphalt concrete (N/m²); \( Sb = \) stiffness of bitumen/asphalt (N/m²); \( N = 0.83 \times \log (4.1010/Sb) \) and \( Cv = 0.70-0.90 \)

The stiffness modulus sought through a direct approach is obtained from the results of laboratory testing. The direct approach is the best method of determining the value of the Rigid Modulus. Laboratory tests for the stiffness modulus has several provisions such as AASHTO T294-92, 1992 and SNI 03-6836-2002 using the UMATTA (Universal Materials Testing Apparatus) triaxial repeater.

To be able to determine the value of modulus by laboratory testing can be determined by testing the dynamic modulus and resilient modulus [13]. Dynamic modulus is the ratio between the working voltage compared to the measured vertical strain. The dynamic modulus is determined by the loading of the sinusoidal to the cylindrical test object having a high ratio and a 2:1 diameter. The resilient modulus is the unity of the required volume strain energy so that the material gets a voltage from the unloading state to the point of yield. resilient modulus is determined by Indirect Tensile/RLIT Repeated Load testing [13]. In this RLIT test, the specimen is not burdened to collapse, but it is only burdened about 2-20% of its indirect tensile strength.

To test the stiffness modulus in the laboratory, the following tools can be used:
1. Universal Testing Machine (UTM); is a testing machine to test the tensile stress and compressive strength of material. The usage of UTM is by giving force or tensile force to the material tested.
2. Universal Material Testing Apparatus (UMATTA); this test is performed under repetitive load at low voltage so that the response of the specimen tested remains elastic. This test is considered a nondestructive test carried out using a machine of UMATTA according to ASTM D4123, Computer-controlled equipment and use a pneumatic actuators to apply the loads.
3. Indirect Tensile Stiffness Modulus; the test is performed in accordance with BS DD 213:1993. The test method using either cylindrical specimen is made from field or laboratory cores formed, with a diameter of 100-150mm and thickness between 30-80mm.
4. Bending Point Test, bending test carried out by giving the load on the specimen either with the principle of 3-point bending or 4-point bending. At 3-point bending the maximum moment is only formed at one point, i.e. at the point of giving the test load. However, at 4-point bending, the maximum moment is formed along the distance of one loading point with another point of loading.

If the four types of tools above are not available, the stiffness modulus test of concrete asphalt can be carried out by Marshall Test tool, by using the Voltage and Strain value approach [5].

From Marshall Test results obtained stability and flow value. The amount of stress is known from the stability value divided by the area of the press field, while the amount of strain is known from the flow value divided by the diameter of the specimen. The voltage and tension equations are:

\[ \sigma = \frac{p}{d \cdot t} \]  

(3)

\[ \varepsilon = \frac{f}{d} \]  

(4)
where: \( \sigma \) = the voltage occurring on the specimen; \( p \) = work load; \( d \) = the diameter of the specimen; \( t \) = thick/height of specimen; \( \varepsilon \) = strain occurring on the specimen and \( f \) = melting of specimens.

Based on equation (3) and equation (4), a curve of the relationship between stress and strain can be made, where the stiffness modulus value is the slope of the straight line curve.

3. Research Methods

The research was conducted in Asphalt Mixing Plan Laboratory (AMP) Rapi Arjasa Binjai City and Laboratory of Pavement Highway, Department of Civil Engineering, Faculty of Engineering, Universitas Sumatera Utara. The material used consists of asphalt, aggregate and filler for mixed AC-WC type. The aggregate material sourced from the Wampu river Binjai, the asphalt was from Iran and the filler was Portland Cement.

For aggregate materials, the tests were consists of specific gravity, fine grain analysis, and absorption of coarse and fine aggregates. While, for asphalt conducted penetration test of asphalt, softening point and Thin Film Oven Test (TFOT).

To get the value of Optimum Asphalt Content (OAC) made by specimen with variation of asphalt content 4,5%, 5%, 5,5%, 6% and 6,5%, each 3 pieces. For the PRD (Percentage Refusal Density) test the specimens were made using only 5%, 5.5% and 6% asphalt, one each. The total samples were 18 pieces.

After the OAC value obtained, then made 30 samples to be tested at 60°C. For the tests at several temperature variations i.e. 30°C, 40°C, 50°C, 70°C and 80°C, each 5 samples. All of the 55 samples were tested with Marshall Test. The method of observation was done by the addition of melting mechanism of the sample on 0.5mm.

The stability and flow values obtained from the test then used to calculate the values of stress and strain. Then we got the modulus of stiffness value from the correlation curve between stress and strain that happened at the beginning of loading.

Next, calculated of stiffness modulus value with Brown & Brunton method and Bitumen Shell method. The values of these two methods then compared with the stiffness modulus from Marshall Test, including the influence of temperature as well as the correlation of Marshall values against the modulus values and comparing the value of the analysis results with Bina Marga 2013.

4. Results and Analysis

4.1. Before OAC

The test results before OAC presented in Table 1. From the Barchat for Presentation of Mix Design Data and Selection of Design Bitumen AC-WC, the value of OAC obtained 5.84%.

| No. | Type of Test | Asphalt Content (%) | Spec. |
|-----|-------------|---------------------|-------|
| 1   | Stability (Kg/cm2) | 4.5 | 5.0 | 5.5 | 6.0 | 6.5 | ≥ 800 |
| 2   | Flow (mm) | 3.03 | 3.20 | 3.17 | 3.60 | 3.80 | 2 - 4 |
| 3   | Density (%) | 2.27 | 2.30 | 2.31 | 2.27 | 2.29 | - |
| 4   | VIM (%) | 5.77 | 5.68 | 4.59 | 3.64 | 4.03 | 3 - 5 |
| 5   | VIM PRD (%) | - | 3.89 | 3.02 | 2.14 | - | 2 |
| 6   | VMA (%) | 15.72 | 16.92 | 17.02 | 16.93 | 18.55 | ≥ 15 |
| 7   | VFB (%) | 63.34 | 66.46 | 73.01 | 78.52 | 78.27 | ≥ 65 |
| 8   | Marshall Quotient (Kg/mm) | 399 | 373 | 370 | 452 | 312 | ≥ 250 |

Source: Laboratory of AMP PT.Rapi Arjasa, 2016
4.2. After OAC

| Temperature (°C) | Marshall Test (MPa) | Brown & Brunton Sme (MPa) | Shell Bitumen Smix (MPa) |
|------------------|----------------------|---------------------------|--------------------------|
| 30               | 425,54               | 4,076,82                  | 419,05                   |
| 40               | 382,68               | 3,099,46                  | 377,28                   |
| 50               | 309,73               | 2,264,58                  | 301,34                   |
| 60               | 254,96               | 1,374,93                  | 235,45                   |
| 70               | 178,37               | 403,36                    | 170,76                   |
| 80               | 136,99               | -                         | 126,34                   |

The results obtained were analyzed to see the effect of temperature, the correlation of marshall stability with modulus of stiffness and comparison of Modulus Stiffness value.

![Figure 1](image1.png)

**Figure 1.** Correlation between Temperature and Stiffness Modulus according to Marshall Test

From Figure 1 it can be seen that the temperature and modulus stiffness have a inverse correlation. The higher the temperature the stiffness modulus value is lower. So at high temperature conditions the material is not elastic. The matter of temperature has also been proven by Widodo [5].

![Figure 2](image2.png)

**Figure 2.** Correlation between Marshall Stability with Stiffness Modulus
From Figure 2 it can be seen that the marshall stability value and the stiffness modulus have a proportional relationship. The higher the marshall stability value the higher the modulus of stiffness. The value of R2 obtained is also good enough that is 0.9097.

![Figure 2](image-url)

**Figure 2.** Comparison of Marshall Stability Value and Stiffness Modulus

From Figure 3 it can be seen that Brown & Brunton and Shell Bitumen methods are not much different, but in Brown & Brunton method there are additional parameters: recovered penetration, recovered softening point, pentration index and VMA. As a result, there are additional parameters of Sbit value to rise and higher power factor to produce high Smix value.

![Figure 3](image-url)

**Figure 3.** Comparison of Stiffness Modulus Value Brown & Brunton Methods, Bitumen Shell and Marshall Test

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| No. | Methods                  | Results (MPa) | Bina Marga 2013 (MPa) |
|-----|--------------------------|---------------|-----------------------|
| 1   | Brown & Brunton          | 1374,93       | 1100                  |
| 2   | Metode Shell Bitumen     | 235,45        | 1100                  |
| 3   | Marshall                 | 254,96        |                       |

From Table 3 stiffness modulus value resulting from Brown & Brunton method has fulfilled the requirement determined by Bina Marga 2013. While the value produced by Shell and Marshall has not reached the required value. The results of the analysis should still be validated again with a special tool that tests the Universal Material Testing Apparatus Modulus (UMATTA).

5. Conclusion

The stiffness modulus value decreases with increasing temperature of the concrete asphalt. The stiffness modulus value from the Bitumen Shell method and the Marshall Test has a relatively similar value. The stiffness modulus value from the Brown & Brunton method is greater than the Bitumen
Shell method and the Marshall Test, but can not measure the stiffness modulus value at temperature above 80°C.

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