Mechanistic Rheological Evaluation of Asbuton Modified Asphalt on Stiffness Modulus of Asphalt

Fitra Ramdhani¹, Harmein Rahman², Bambang Sugeng Subagio³

¹Department of Civil Engineering, University Abdurrab, 73 Riau Ujung Street, Pekanbaru, Riau, 28292, Indonesia
²Department of Civil Engineering, Institut Teknologi Bandung, Jl. Ganesa No.10, Bandung, Jawa Barat, 40132, Indonesia

fitra.ramdhani@univrab.ac.id

Abstract. Asphalt rheology greatly affects the performance of asphalt mixtures. One of the properties and behavior of asbuton is visco-elastic which is a rheological parameter. Asbuton's visco-elastic properties will affect the durability of the pavement layer. Therefore, knowing the rheological properties of pure asbuton, especially the proportion of visco-elastic asbuton, is expected to improve the rheological properties of oil asphalt. This study aims to evaluate the mechanistic rheology of asphalt modified Asbuton on the stiffness modulus of asphalt. The methodology used in this study is an experimental method, with asphalt mechanistic rheology testing. The results showed that the asphalt stiffness modulus (E*) increased with the addition of Asbuton content. In addition, a review of the effect of temperature with the asphalt stiffness modulus (E*) shows that the higher the test temperature, the lower the asphalt stiffness modulus (E*). Based on the minimum criterion limit of asphalt stiffness modulus, the optimum level of asbuton addition is obtained, which is 30% asbuton content into asphalt pen 80/100.

1. Introduction
The performance of the asphalt mixture is strongly influenced by the rheological properties of the asphalt, namely the chemical composition and physical properties of the asphalt. This is because asphalt serves as a binder. Asphalt rheology is the flow properties of asphalt materials. Asphalt has the property of changing from flowing pseudoplastic to Newtonian, which is ideal viscous, due to temperature and loading time [1]. The performance of asphalt pen 60/70 modified pure asbuton based on its rheological properties and performance in the mixture obtained an optimum content of 10% pure asbuton increasing permanent deformation resistance [2,3], performance of asphalt mixture pen 60/70 modified filler asbuton obtained optimum content of 2.01% [4], the performance of asphalt pen 60/70 modified pure asbuton and filler asbuton obtained better results with 10% asbuton and 2.01% filler asbuton [5,6].

The modulus of asphalt cement is a measure of the rheological condition of the bitumen, on which the fracture properties depend. The effective temperature and loading time on the fracture properties of road bitumens of various grades and origin is thus condensed in the stiffness as a single parameter. Parameters for the fracture properties of mixes can be separated into the stiffness of the asphalt cement and a mix factor which is independent of variables, but dependent
on the proportion of asphalt cement, grading of the minerals and compaction of the mix. A further study of these variables can be simplified by determining the value of the mix factor only, so that much laboratory effort can be saved [7]. The stiffness modulus and the loss angle are determined with the aid of two nomographs or a computer program [8]. The purpose of this study was to determine the mechanistic rheology of asphalt modified Asbuton on the stiffness modulus of asphalt.

2. Methodology
This research was conducted using asphalt pen 80/100, asbuton used was pure asbuton from the extraction. The quality of modified asphalt that meets the specifications is that it can increase the bond between asphalt and aggregate so that the road surface is not easily peeled off and has high stiffness at high temperatures so as to minimize deformation, low stiffness at low temperatures can minimize the occurrence of cracks on the road surface. The quality of modified asphalt is very influential on the raw materials, the better the quality of the raw materials, the better the quality of the modified asphalt [9].

This research method uses experimental methods in the laboratory with three stages, the first stage is to make a mixture of asphalt Pen 80/100 and pure asbuton at variations in pure asbuton levels, namely 0%, 2%, 6%, 10%, and 30% [10]. Furthermore, the second stage of testing mechanistic rheological properties is carried out using a Dynamic Shear Rheometer (DSR) based on the AASHTO T315-10 test standard on a mixture of 80/100 pen asphalt and pure asbuton [11]. Then the third step is to analyze the stiffness modulus on pure asphalt modified asphalt. After that determine the optimum level of addition of asbuton into asphalt pen 80/100 which meets the specifications for the two damage criteria.

3. Results and Discussion

3.1 Effect of Asbuton on Mechanistic Rheological Parameters
This research uses a temperature sweep starting from 46°C, 52°C, 58°C, 64°C, 70°C, 76°C, and 82°C. Mechanistic rheology testing with the performance of the Dynamic Shear Rheometer (DSR) tool starts from the lower temperature, which is 46°C with an increase of 6°C for every increase in temperature as regulated in AASHTO T 315-10. Figure 1 shows that for the same temperature the value of Complex Shear Modulus (G*) will increase with the addition of pure Asbuton content.

![Complex Shear Modulus vs. Pure Asbuton Level](image)

**Figure 1.** Relationship between pure asbuton level and complex shear modulus (G*)

The relationship between Complex Shear Modulus (G*), temperature and pure Asbuton content can be obtained with the help of SPSS program from data on Complex Shear Modulus (G*) values.
The output produced in the SPSS program to explain the relationship between Complex Shear Modulus ($G^*$), temperature and pure Asbuton content is summed up in one equation as follows:

$$G^* = 30095.804 - 427.126T + 131.742(\text{Ab})$$

$$R^2 = 0.646$$

With, $G^* = \text{Complex Shear Modulus (Pa)}$, $T=\text{temperature (°C)}$, $\text{Ab} = \text{pure Asbuton content}$

![Figure 2. Relationship between pure asbuton level and phase angle ($\delta$)](image)

From the review in Figure 2, for the relationship between pure Asbuton content and Phase Angle ($\delta$) it is explained that the decrease in the Phase Angle value is in line with the addition of pure Asbuton content, so that the bitumen is more elastic. This condition is related to fatigue cracking resistance because the more elastic the bitumen, the lower the bitumen in resisting fatigue cracking. In accordance with the theory that has been conveyed by Francken, 1998, it shows that along with the addition of temperature to the bitumen, the value of Phase Angle ($\delta$) also increases. With the help of SPSS obtained an equation of the relationship between Phase Angle ($\delta$), temperature and pure Asbuton content as follows:

$$\delta = 79.799 + 0.130T - 0.035(\text{Ab})$$

$$R^2 = 0.868$$

With, $\delta = \text{Phase Angle}$, $T=\text{temperature (°C)}$, $\text{Ab}=\text{pure Asbuton content}$

3.2 Bitumen Stiffness Modulus ($E^*$)

3.2.1 Bitumen Stiffness Modulus ($E^*$) based on Mechanistic Rheology

Bitumen stiffness modulus ($E^*$) based on Complex Shear Modulus data is calculated using the formula: $E^* = 2 \times G^* \times (1 + \nu)$

With, $E^* = \text{Stiffness Modulus of Bitumen (Pa)}$, $G^* = \text{Complex Shear Modulus (Pa)}$, $\nu = \text{Poisson Ratio (assuming = 0.5)}$. The calculation results are shown in Table 1 and Figure 4.
Table 1. Bitumen Stiffness Modulus (E*)

| No | Kadar Asbuton (%) | E* = 2 G* (1 + γ) (Pa) | T = 46°C | T = 52°C | T = 58°C | T = 64°C | T = 70°C | T = 76°C | T = 82°C |
|----|-------------------|------------------------|----------|----------|----------|----------|----------|----------|----------|
| 1  | 0%                | 39630                  | 15624    | 6633     | 3030     | 1466     | -        |          |          |
| 2  | 2%                | 42420                  | 16602    | 6999     | 3171     | 1542     | 806      | 446      |          |
| 3  | 6%                | 46890                  | 18174    | 7560     | 3417     | 1658     | 860      | 479      |          |
| 4  | 10%               | 52260                  | 20472    | 8583     | 3849     | 1917     | 933      | 506      |          |
| 5  | 30%               | 83130                  | 31920    | 13059    | 5676     | 2665     | 1352     | 719      |          |

In Figure 3, the value of the Bitumen Stiffness Modulus (E*) increases with the addition of Asbuton content. The relationship between pure Asbuton content and Bitumen Stiffness Modulus (E*) shows that the higher the pure Asbuton content, the higher the Bitumen Stiffness Modulus (E*).

Figure 3. Relationship between Pure Asbuton Content and Bitumen Stiffness Modulus (E*)

The Bitumen Stiffness Modulus (E*) is also assessed based on the test temperature of each Asbuton content which is shown in Figure 4. From the review in Figure 4, shows that the higher the test

Figure 4. Relationship of Temperature and Bitumen Stiffness Modulus (E*) for Pure Asbuton Level 0% - 30%
At levels of pure Asbuton 0% to 30%, the Bitumen Stiffness Modulus (E*) at a test temperature of 46°C ranges from 0.040 MPa to 0.083 Mpa, at a test temperature of 52°C Bitumen Stiffness Modulus (E*) ranges from 0.016 MPa to 0.032 Mpa, at a test temperature of 58°C the Bitumen Stiffness Modulus (E*) ranges from 0.007 MPa to 0.013 Mpa, at a test temperature of 64°C the Bitumen Stiffness Modulus (E*) ranges from 0.003 MPa to 0.006 MPa and 0.001 MPa to 0.003 MPa for the test temperature of 70°C.

3.2. 2 Bitumen Stiffness Modulus (E*) based on Ullidtz Model

Analysis of the Bitumen Stiffness Modulus (E*), was carried out by comparing the calculation results from the Ullidtz equation derived from the Van Der Poel nomograph based on asphalt properties [12,13]. The calculation of the Bitumen Stiffness Modulus (E*) is presented in Table 2, calculated using the following equation:

\[ E^* = 1.157 \times 10^{-7} t^{-0.368} 2.718^{\text{PI}_r} (\text{SP}_r - T)^5 \]

With, PIr=Recovered Penetration Index of asphalt, SP= 98.4 – 26.35 log Pr, T= Temperature of asphalt, Pr= Recovered Penetration at 25°C 0.65Pi, Pi= Initial penetration of asphalt, PI= Penetration index of asphalt , T= Length of loading, seconds

| No | Kadar Asbuton (%) | t (detik) | Pi (dmm) | Pr (dmm) | SP (°C) | Pir | SP - T (°C) | E* (Mpa) |
|----|------------------|----------|---------|----------|---------|-----|------------|---------|
| 1  | 0                | 0.016    | 88.4    | 57.4     | 52.05   | -0.367 | 27.047    | 11.069  |
| 2  | 4                | 0.016    | 72.2    | 46.9     | 54.36   | -0.314 | 29.357    | 15.814  |
| 3  | 6                | 0.016    | 69.4    | 45.1     | 54.81   | -0.304 | 29.810    | 16.910  |
| 4  | 10               | 0.016    | 65.9    | 42.8     | 55.40   | -0.292 | 30.402    | 18.435  |
| 5  | 30               | 0.016    | 43.3    | 28.1     | 60.21   | -0.209 | 35.208    | 35.330  |

Stiffness Modulus (E*) value from the DSR test, because it was carried out at different test temperatures. The value of the Bitumen Stiffness Modulus (E*) from the Ullidtz Equation uses the Penetration Value data obtained from the Penetration test at a temperature of 25°C, while the DSR test is carried out at a temperature of 46°C, 52°C, 58°C, 64°C, 70°C, 76°C, and 82°C.

Therefore, in order to be able to compare the two values of the Stiffness Modulus, that is by making a regression equation model so that the Stiffness Modulus value can be drawn at the desired temperature, namely at a temperature of 25°C. The calculation of the value of the Bitumen Stiffness Modulus (E*) for the test temperature of 25°C is presented in Table 3.

From the results of the calculation of the Bitumen Stiffness Modulus (E*) at 25°C as presented in Table 3, it can be seen the comparison of the Bitumen Stiffness Modulus (E*) value with the Bitumen Stiffness Modulus (Sbit) value derived from the Ullidtz equation. The comparison of the Bitumen Stiffness Modulus (E*) values from the DSR test and the Ullidtz equation (Sbit) is presented in Table 3.
Comparison of Bitumen Stiffness Modulus (E*) at 25°C

| No | Kadar Asbuton (%) | E* (Mpa) Reologi Mekanistik | E* (Mpa) Persamaan Ullidtz |
|----|-------------------|-----------------------------|-----------------------------|
| 1  | 0%                | 5.21                        | 11.06                       |
| 2  | 4%                | 5.43                        | 15.81                       |
| 3  | 6%                | 5.59                        | 16.91                       |
| 4  | 10%               | 5.72                        | 18.44                       |
| 8  | 30%               | 14.19                       | 35.33                       |

Comparison of the Bitumen Stiffness Modulus (E*) at 25°C From Figure 5 above, it can be explained that the Bitumen Stiffness Modulus (E*) resulting from the Dynamic Shear Rheometer test has a smaller value than the Bitumen Stiffness Modulus value from the Ullidtz Equation (Sbit). for all variations of pure Asbuton levels. Along with the increase in pure Asbuton content, the greater the value of Bitumen Stiffness Modulus (E*).

The limiting criteria taken for the Bitumen Stiffness Modulus is the minimum value of the Bitumen Stiffness Modulus, which is equal to or greater than 5 MPa at a temperature of 25 °C. This limitation is a limit where the influence of bitumen on the determination of the stiffness modulus of the asphalt mixture is small [14]. Based on these limits, the bitumen stiffness modulus (E*) through mechanistic rheology testing with a dynamic shear rheometer (DSR) has a value greater than 5 MPa at the addition of 30% asbuton content with a bitumen stiffness modulus (E*) value of 14.19 MPa while the bitumen stiffness modulus (E*) with the Ullidtz model was obtained by adding 30% asbuton rubber content with a bitumen stiffness modulus (E*) of 35.33 MPa. Based on the results of the analysis of the two methods used to determine the value of the bitumen stiffness modulus (E*), it can be concluded that the optimum level of asbuton addition is the addition of 30% asbuton content into 80/100 asphalt pen.

4. Conclusion
The results showed that the value of the Bitumen Stiffness Modulus (E*) increased in line with the addition of asbutone content. This can be seen from the results of the two methods used to determine the bitumen stiffness modulus, namely the mechanistic rheology test method using the complex shear modulus parameter and the Ullidtz model calculation. Based on the results obtained, it can be concluded that the optimum level of asbuton addition is the addition of 30% asbuton content into 80/100 asphalt pen.
References

[1] Rahman H 2010 Evaluasi Model Modulus Bitumen Asbuton dan Model Modulus Campuran yang Mengandung Bitumen Asbuton.” Disertasi (tidak dipublikasikan). Program Doktor Teknik Sipil. Institut Teknologi Bandung. Bandung

[2] Indriyati E W, Subagio B S, Rahman H and Wibowo S S 2012 Kajian Perbaikan Sifat Reologi Visco-Elastic Aspal dengan Penambahan Asbuton Murni Menggunakan Parameter Complex Shear Modulus Inst. Teknol. Bandung

[3] Sitompul B 2017 Penentuan Kadar Aspal Optimum Pen 60/70 dan Asbuton T5/20 Terhadap Kinerja Pada Campuran Aspal Concrete-Wearing Course (ACWC). ugas Akhir Program Studi Teknik Sipil Universitas Abdurrah. PekanbaruT

[4] Ramdhani F, Suhanggi S and Rhoma B H 2018 Kadar Optimum Filler Asbuton Butir T. 5/20 Dalam Campuran Perkerasan Asphalt Concrete-Wearing Course (Ac-Wc) J. Kaji. Tek. SIPIL 3(1) 32–38

[5] Ramdhani F, Tisnawan R and Saputra H 2018 Evaluasi Kinerja Campuran Aspal Modifikasi Ekstraksi Asbuton dan Filler Asbuton sebagai Penentuan Kadar Modifikasi Optimum,” Jurnal Ipteks Terapan Research Of Applied Science And Education 13(I3) 210-216

[6] Ramdhani F, Saputra H and Tisnawan R 2018 Pengaruh Campuran Aspal Pen 60/70 Dan Bahan Modifikasi Ekstraksi Asbuton T5/20 Dengan Filler Asbuton T5/20 Terhadap Kinerja Campuran Prosiding Seminar Nasional Aplikasi Sains dan Teknologi (SeNASTeK) Universitas Abdurrah

[7] Heukelom W 1966 Observations on the rheology and fracture of bitumens and asphalt mixes Assoc Asphalt Paving Technol Proc

[8] Bonnaure F, Gest G, Gravois A and Uge P 1977 A new method of predicting the stiffness of asphalt paving mixtures

[9] Al-Mansob R A, Ismail A, Yusoff N I M, Albrka S I, Azhari C H and Karim M R 2016 Rheological characteristics of unaged and aged epoxidised natural rubber modified asphalt,” Constr. Build. Mater 102 190–199

[10] Ramdhani F 2013 Evaluasi reologi campuran aspal pen 80/100 dan bahan modifikasi asbuton ekstraksi penuh sebagai dasar penentuan kadar bahan modifikasi optimum.” Tesis (tidak dipublikasikan). Program Pasca Sarjana Teknik Sipil. InstitutTeknologi Bandung. Bandung

[11] AASHTO 2012 Standard method of test for determining the rheological properties of asphalt binder using a dynamic shear rheometer (DSR) Am. Assoc. state Highw. Transp. Off

[12] Yoder E J and Witczak M W 1975 Principles of pavement design John Wiley & Sons

[13] Poel C D V 1954 A general system describing the visco-elastic properties of bitumens and its relation to routine test data J. Appl. Chem 4(5) 221–236

[14] Read J and Whiteoak D 2003 The shell bitumen handbook. Thomas Telford