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Properties of Bitumen Containing Powdered Gondorukem Rubber Additives

ELSA EKA PUTRI AND PUJA PERDANA
Civil Engineering Department, Andalas University, Padang, Indonesia
***Email:** elsaeka@gmail.com; elsaeka@ft.unand.ac.id*

Abstract: The objective of the research is to determine the stiffness of bitumen with Gondorukem additives that form a new binder for pavement construction. The binders were subjected to conventional tests including penetration, softening point to determine the penetration Index. The stiffness of binder is determined by means of Van der Poel Nomograph. A new modified binder with Gondorukem additives improved the conventional properties of the base bitumen such as; penetration, softening point, temperature susceptibility. Moreover, all the four percentages of G/B (3%, 5%, 7% and 10%) might be applicable for road construction and the optimum percentage of modified binder Gondorukem in Bitumen (G/B) is achieved at 7% G/B.

Keywords: *Gondorukem, Penetration, Softening Point, Penetration Index, Viscosity, Stiffness*

1. Introduction

Currently, the research of adding additives to improve the material performance is widely investigated. The additives may be added to cement, for concrete material. While to produce the stiffer, to improve the performance and durability of the pavement any additives are typically added to the bitumen. For very heavily trafficked pavements, the use of stiffer binders offers significant savings as a result of the reduced thickness possible due to the increasing stiffness.

In this investigation the additives is chosen from local material. Gondorukem (Colophony) is solid distillates sappine trees (Pinus sp.). It is derived from the resin of the longleaf pine (*Pinus palustris*). In Indonesia, pine forest extensively planted around 5,521,985 ha, and some of them are in West Sumatra [1]. Gondorukem is exported to Asian countries (such as India, Singapore, Taiwan) about 56%, United States for 3%, Europe (France, Netherlands, Italy, UK) approximately 40%[2].

Gondorukem has been widely used for the paper industry, soap, varnish, batik, shoe polish, insulating electrical appliance and printing inks [3]. Gondorukem is also used as an adhesive material that serves as tackifiers, hyper adhesion (adhesion promoter) or booster thickness (viscosity promoters). It is weathering resist and the shape is changeable when reaching its melting point.

Thus, in this research the addition of Gondorukem in Bitumen is expected to improve the stiffness of the pavement to support heavy traffic loading.

As can be seen in Figure 1, Gondorukem is yellowish in colour. All types of Gondorukem have the same basic chemistry. It consists of diterpenic monocarboxylic acids, 85% – 95% and neutral fraction of 5% to 15% “neutrals” (> 50 components identified). It is unlikely that any of these constituents are present at concentration > 10 %.

Figure 1: *Gondorukem as a powdered and bulk*

The study focuses on the determination of the softening point, penetration and penetration index of bitumen adding Gondorukem in order to ascertain their grades. Then, the stiffness of a new bonding bitumen that more rigid and might improve the elastic performance was determined using a nomograph Van Der Poel (Figure.2)[4]. The Nomograph enables the average behaviour of a given grade to be calculated with accuracy sufficient for engineering purposes [4] [5].

2. Material and Experimental

2.1. Materials

The 80-100 penetration bitumen was used in this study and its physical properties are listed in Table 1. The Gondorukem (Figure.1) obtained by filtering the residue from the distillation process pine sap.

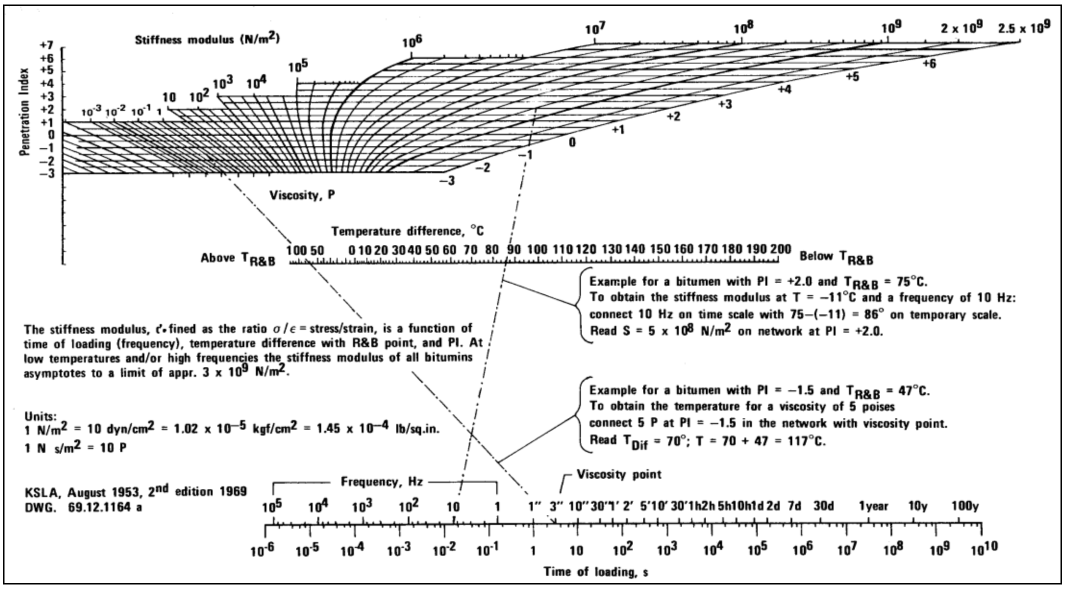

Figure 2; *Van der Poel Nomograph used to determine Bitumen Stiffness [5] and [7]*

Table 1: *Bitumen Properties*

Performance Indexes	Test Results
Penetration(25°C, 100 g, 5 s) (0.1 mm)	80 mm
Penetration After Loss On Heating	75 mm
Flash Point (Cleveland Open Cup)	223°C
Burning Point	298 °C
Loss On Heating (163 °C, 5 hours)	0,1963 %
Ductility (25 °C)	>1000 Mm
Unit Weight (25 °C)	1,0315 gr/cm^3
Softening Point (Ring and Ball Test)	48 °C

2.2. Sample Preparation

Gondorukem is mixed with bitumen conventionally where the bitumen is heated to a temperature of 90°C as well as Gondorukem which has been refined through sieve no. 200 (<0.075 mm), and stir for 5 minutes until completely mixed. The mixed temperature of 90°C is hot enough to make a solid mixture, and does not exceed the weight loss tests temperature of 163°C (ASTM D 2872 - EN 12607), so the content of the asphalt does not change due to heating.

The sample were prepared at five different percentages of Gondorukem in bitumen i.e. 0%, 3%, 5%, 7% and 10% for Softening Point and Penetration tests respectively. There are three samples at each percentage. The results are presented in average value.

3. Tests Performed

3.1. Conventional Tests

Penetration test at 25°C and softening point test were conducted to characterize the conventional physical properties of bitumen according to ASTM D5, ASTM D36, respectively. Penetration value and Softening Point were utilized in order to estimate the stiffness property of Gondorukem modified bitumen based on Van der Poel Nomograph (Figure.2).

The addition of additives in bitumen might improve its stiffness. However, too high stiffness might create brittle and cracked bitumen. The ductility test according to ASTM D113 was utilized to assess the ductile properties of binder. All tests performed in the Civil Engineering Department Laboratory in the University of Andalas.

Penetration test is to determine the consistency of bituminous material as well as to assess the suitability of bitumen for use under different climatic conditions and various types of construction. The stiffness of the material is strongly related to the penetration of the bitumen.

3.2. Penetration Index Determination

The penetration index, used to define the binder type, is based on two empirical indirect measures of viscosity: the ring and ball and the penetration tests. The penetration index represents a quantitative measure of the temperature susceptibility response of bitumen. Knowing the penetration index of particular bitumen, it is possible to predict its behaviour in an application [6] [7].

One of the best known to predict the behaviour of bitumen is that developed by Pfeiffer and Van Doormaal in 1936 [8]. First is to determine the temperature susceptibility and the second is the Penetration Index. The value of A varies from 0.015 to 0.06 showing that there may be considerable difference in temperature response [9]. Pfeiffer and Van Doormaal developed an equation for the temperature response that assumes a value of about zero for road bitumen. For this reason they defined the penetration index (PI) as:

$$PI = \frac{20\,(1-25A)}{1+50\,A} \tag{1}$$

The value of PI ranges from around -3 for high temperature susceptible bitumen to around +7 for highly blown low temperature susceptible (high PI) bitumen [7] [10]. The PI is an unequivocal function of A and hence it may be used for the same purpose. The values of A and PI can be derived from penetration measurements at two temperatures, T_1 and T_2 using the equation:

$$A = \frac{\log pen\ at\ T_1 - \log pen\ at\ T_2}{T_1 - T_2} \tag{2}$$

And, assuming a penetration test temperature of 25°C gives:

$$PI = \frac{1952 - 500 \log pen - 20 \text{ softening point}}{50 \log pen - \text{softening point} - 120} \tag{3}$$

Equations (2) and (3) were applied in this study to calculate first for A (temperature susceptibility of bitumen) and PI (penetration index). These were calculated from the measured softening point temperatures and penetrations value [6] [7] and [8].

C. The Viscosity of Bitumen

Two tests for bitumen that can indirectly measure the viscosity are the penetration test and the softening point test [11]. The viscosity of various G/B binder is calculated from penetration value using Eq. (4) for penetrations less than or equal to 54 and Eq.(5) for penetrations greater than 54, based on TxDOT Designation: Tex-535-C.

$$\mu = \frac{1.559719 \times 10^{9} .\ \ln\left(\frac{0.0275}{3.94 \times 10^{-6} .\ P + 0.000075}\right)}{P^2} \tag{4}$$

$$\mu = \frac{1.559719 \times 10^{9} .\ \ln\left(\frac{0.0275}{0.0005 - \frac{0.0114488}{P}}\right)}{P^2} \tag{5}$$

Where:

μ = viscosity in poise
P = penetration in penetration units.

The viscosity of a fluid slows down its ability to flow, and particular significance at high temperatures when the ability of the bitumen to be sprayed onto or mixed with aggregate material is of great significance. The penetration test is in no way indicative of the quality of the bitumen but it does allow the material to be classified.

D. Stiffness of Bitumen

In the current study, a Nomograph developed by Van der Poel was used to predict the stiffness property of modified binder G/B based on penetration value and softening point of the various G/B percentages.

A Nomograph is used to predict the stiffness of bitumen. It requires three parameters [9];

- a penetration index value that obtained from penetration value and softening point of the bitumen,
- a shape parameter that indicates the time dependency of the asphalt, and
- a temperature dependency parameter that indicates the temperature dependency of the bitumen.

The stiffness of bitumen is time dependent—they flow with time--and consequently asphalt binders are classified as rheological materials [8].

4. Results and Discussion

4.1. Softening Point (SP) and Penetration

The Penetration and Softening Point (SP) results for the bitumen samples are presented in Figure 2 and 3 respectively.

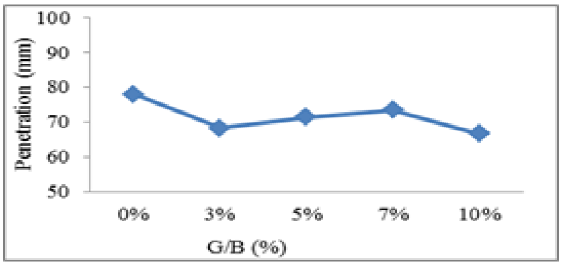

Figure 2: *Penetration value of Gondorukem/Bitumen*

Figure 2 shows the average value of penetration at each percentage of G/B. The Penetration value of 0% Gondorukem in Bitumen is 80 mm, while the penetration value for 3% to 10% G/B results ranged from 70 to 60 mm. This is the typical grades of bitumen penetration that may be used for warm climates.

As the percentage of G/B increases the penetration value is decreases. The lower the penetration the harder the sample, therefore bitumen with high penetration value (called "soft") are used for cold climates while bitumen with low penetration value (called "hard") are used for warm climates. Moreover, high penetration grade is better used in spray application works [6].

The softening point test results are shown in Figure 3. Bitumen should never reach its softening point while under traffic loading, T.

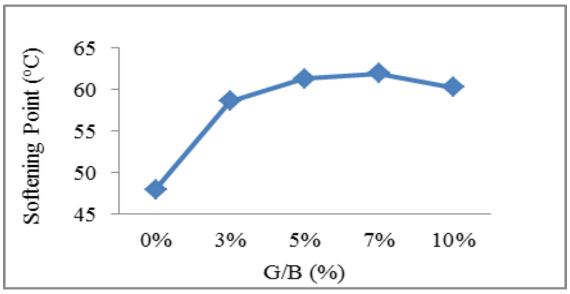

Figure 3: *Softening Point of various Gondorukem in Bitumen*

The softening point for 0% G/B is low that is 48^{o}C, while for G/B ranged from 3% to 10% lied on ranged from 58 to 62°C where the highest softening point value is at 7% Gondorukem in Bitumen.

Gondorukem added to bitumen increases its softening point thus improves the bitumen durability. As shown in Figure 3, the 7% Gondorukem addition is the highest softening point thus, it is more resist to higher temperature under traffic loading due to the higher the softening point temperature.

4.2. Penetration Index (PI)

Figure 4 shows the penetration index of various percentages G/B. It ranges from -0.5 to 1.8 for 0% G/B to 10% G/B. The maximum PI achieved at 7% G/B of 2.5. According to Shell Bitumen Handbook in 2003, it stated that the value of PI ranges from around -3 for highly temperature susceptible bitumens to around +7 for highly blown low-temperature susceptible (high PI) bitumens [7].

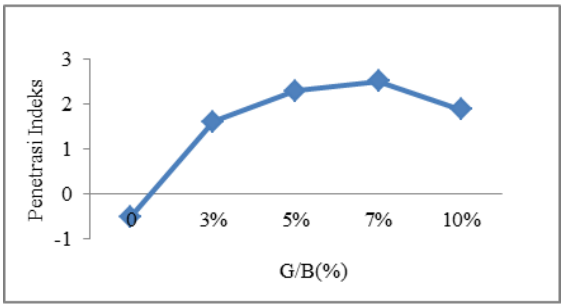

Figure 4: *Penetration Index of various Gondorukem in Bitumen*

Thus, for all the percentages of G/B in this research meet the requirement, where the binder is not categorized of temperature susceptible and also not too hard that may create binder brittle and easily crack.

Penetration grading's basic assumption is that the less viscous the asphalt, the deeper the needle will penetrate. The viscosity of various G/B calculated from penetration test at 25^{o}C are presented in Table 2. The calculation procedure is based on The ASTM Penetration Method Measures Viscosity (Tex-535-C). The calculated viscosity is the viscosity of the sample at that temperature [11].

Table 2: *Viscosity of Gondorukem/Bitumen*

Gondorukem/ Bitumen (%)	Penetration (mm)	Viscosity (poise)
0%	78	1.20×10^6
3%	68.2	1.45×10^6
5%	71.4	1.33×10^6
7%	73.33	1.27×10^6
10%	66.66	1.56×10^6

As can be seen in Table 2, the results showed the viscosity of the binder increasing with an increase in the additive. It is expected to improve the viscosity properties of the modified binder and enhance its resistance to deformation when used in pavement mixtures.

The ductility values for all percentages of G/B meet its minimum requirement that is more than 100 cm, as specified by the ASTM D113. The ductility of a bituminous material is measured by the distance to which it will elongate before breaking when two ends of a briquet specimen of the material, are pulled apart at a specified speed and at a specified temperature.

It is known that as penetration and ductility decrease the viscosity of asphalt increases. As viscosity of asphalt increases, stiffness at for all G/B percentages combination of temperature and loading time also increase.

Table 3 shows the stiffness of various percentages of G/B with 0.0151 sec time of loading, T_w (which equates to a vehicle speed around 60 km/h) for 20^{o}C, 40 ^{o}C, and 60^{o}C of pavement temperature, T.

For the same pavement temperature, the stiffness is increases with the increasing of G/B up to 7% of G/B. As the percentage of G/B is increasing until 10%, the stiffness is decreases with the increasing of G/B.

Table 3 *Stiffness of G/B with time of loading of 0.00151 sec*

Temperature	***Stiffness of G/B* (MPa)**			
(^{o}C)	3%	5%	7%	10%
20	6	5	4	5
40	0.55	0.6	0.56	0.5
60	0.06	0.07	0.07	0.06

Table 4 shows the stiffness of various percentages of G/B at maximum pavement temperature for various time of loading. The trend is similar as presented in Table 3, as the G/B increases the stiffness is also increases until 7% G/B. Then it decreases for 10% G/B.

Table 4 *Stiffness of G/B with time of loading variation at 60^{o}C*

Time of Loading	***Stiffness of G/B* (MPa)**			
Sec	3%	5%	7%	10%
0.0151	0.06	0.079	0.079	0.06
1	0.003	0.0049	0.0049	0.004
60	0.000051	0.00001	0.00001	0.00001
3600	1.9×10^7	2×10^7	2×10^7	2×10^7

For the same time of loading, the stiffness is increases with the increasing of G/B up to 7% of G/B. As the percentage of G/B is increasing until 10%, the stiffness is decreases with the increasing of G/B.

It can be concluded from Table 3 and 4, the objective of addition the Gondorukem in Bitumen is to create a new binder that generate the higher stiffness modulus. At the higher temperature or longer loading times (stationary traffic) the stiffness modulus is substantially reduced and under these conditions, permanent deformation of the road surface is much more likely to occur.

Thus, these new binders which having higher stiffness minimizes the permanent deformation. The higher binder stiffness is suitable for tropical climate where the temperature is high.

5. Conclusion

The addition of Gondorukem in bitumen to produce a new modified binder would have definitely affected the stiffness modulus, Softening Point and Penetration value of the binder.

A higher stiffness is required for rutting prevention especially along the wheel path. However, the higher stiffness at low temperature might lead to thermal cracking. The improved values of Penetration Index (PI) of Gondorukem modified Binder indicate reduced chances of low temperature cracking. Moreover, the effect of PI as shown on Figure 4 is clearly illustrated by comparing Tables 3 and 4. The bitumen with the higher PI (7% G/B) is considerably stiffer at higher temperatures and longer loading times, i.e. it is less temperature susceptible that will be more resistant to deformation.

Thus, it can be concluded that all the four percentages of G/B (3%, 5%, 7% and 10%) might be applicable for road construction however the optimum percentage of modified binder G/B is achieved at 7% G/B.

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