MARSHALL PROPERTIES OF POROUS ASPHALT WITH GONDORUKEM RUBBER ADDITION

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MARSHALL PROPERTIES OF POROUS ASPHALT WITH GONDORUKEM RUBBER ADDITION

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Abstract

This study aims to investigate the Marshall properties of porous asphalt pavement containing Gondorukem rubber. Gondorukem rubber was used in 0%, 3%, 5%, 7% and 10% as replacement to the asphalt binder. In this study, modified Gondorukem/Asphalt (G/A) was examined for its compatibility with porous asphalt pavement mixture by testing the Marshall properties particularly the void in mixture (VIM), stability and flow. It was found that 7% of G/A produced the maximum stability at 902.309 kg with flow value of 4.55 mm and void in mixture (VIM) of 21.74%. Hence, the 7% G/A was selected as the optimum percentage of Gondorukem for the local design of porous asphalt.

Keywords: Porous Asphalt, Gondorukem, Marshall Properties, Maximum Stability

1. Introduction

Porous asphalt is a flexible pavement prepared with an open-graded porous mixture and average air voids content of 20% [1]. Due to this characteristic, porous asphalt with a thickness of 2-4 inches allows water to drain through the mixture. As the porous asphalt is known to have low stability, its usage has been recommended for parking areas as well as for low-volume roadways [2].

Nomenclatures

FHWA	Federal Highway Administration
AAPA	Australian Asphalt Pavement Association
P	Asphalt binder content before aggregate gradation determination
K	Surface Roughness Index
S	the ratio of SG from material standard with material used (2. 65/ (SG for the Aggregates Used)
T	the amount of asphalt based on total surface area method

Abbreviations

VIM	Void in Mixture
VMA	Void in Mineral Aggregate
VFA	Void Filled with Asphalt
MQ	Marshall Quotient

Since the demand for porous asphalt application is increasing, mixtures with strong aggregate binders and high durability are needed so that water passing through the air cavity on the pavement does not accelerate its oxidation. In addition, the porous asphalt must have high stability. Stability is commonly increased with addition of elastomeric polymer materials. The asphalt mixture performance can be improved through modification of asphalt properties such addition of materials. Previous study by Putri (2016) indicated that locally available material named Gondorukem rubber showed potential on asphalt properties improvement [3]. Gondorukem rubber or Colophony is a solid distillate derived from the resin of Sappine trees such as longleaf pine (*Pinus palustris*) [4].

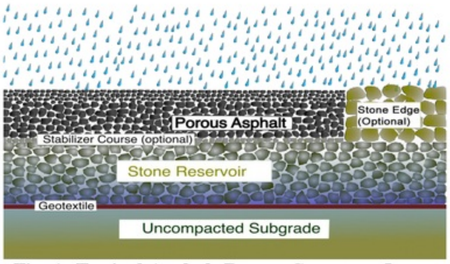

Fig. 1: Typical Asphalt Porous Structure Layer
(Source: FHWA-HIF-15-009) **[5]**

The objective of this research is to determine the suitability of Gondorukem rubber as additive for porous asphalt and to compare the characteristics of 85/100 penetration asphalt with Gondorukem modified asphalt. Samples were tested using the Marshall Test following the Indonesian local standards which is General Specifications 2010, Revision 3, Directorate General of Highways Indonesia [6].

2. Literature Review

2.1. Gondorukem Rubber (Colophony)

Gondorukem is a common name used for products prepared from the sap of pine trees. Fig. 2 shows samples of bulk and powdered Gondorukem obtained from the Gondorukem & Turpentine Factory near Kampung Pematang, Central Java, Indonesia. This material has rubber-like properties which known to absorb and transfer heat efficiently. The addition of Gondorukem rubber is therefore expected to increase the asphalt pavement layer resistance to damage caused by water and weather indicated by its high stability value. Gondorukem rubber is resistant to weather changes and has high melting point so that no defects will occur due to heavy traffic loading [3].

(a) (b)

Fig. 2. (a) Bulk Gondorukem (b) Powdered Gondorukem

As seen on Fig. 2, Gondorukem is usually yellowish in colour and consists of 85% - 95% monocarboxylic acid and 5%-15% neutral fractions (> 50 components identified). In Indonesia, including West Sumatra [4], there are approximately 5,521,985 hectares of pine forests that produce Gondorukem. It is exported to Asian countries such as India, Singapore and Taiwan (56%), United States (3%) and to Europe including France, Netherlands, Italy and the UK, (40%) [7]. Gondorukem is widely used in paper, soap, varnish, batik, shoe polish, electrical insulation and the printing ink industry [8]. It is also used as an adhesive that serves as tackifiers, hyper adhesion (adhesion promoter) or viscosity promoter.

2.2. Porous Asphalt

Asphalt is a thermoplastic material that will become harden if the temperature is reduced and will become softer or liquid if the temperature increases [9]. While, porous asphalt is an asphalt mixture that contains certain grades of aggregate and after it is compacted the air voids are around 20%. Porous asphalt mixture composition is an innovation in flexible pavement because its' allows water to seep from the top layer or wearing course both vertically and horizontally. This layer uses open aggregate gradation spread over a waterproof asphalt layer. As the air void gets smaller, the water flowing into the asphalt mix gets slower as well [10].

As shown in Fig. 2, the porous asphalt samples appear to have higher air voids compared to the densely graded asphalt samples. Porous asphalt generally has a lower Marshall Stability value than concrete asphalt that has dense gradation. Marshall Stability can be enhanced if the open gradations contain more subtle fractions [11], or when high quality aggregate binder is being used during construction.

(a) (b)

Fig. 2. (a) Porous Asphalt Sample (b) Asphalt Concrete Sample

Porous asphalt is a type of pavement that designed to improve the coefficient of friction on the surface of the pavement. This pavement should have a good binder quality as the ability to bind between aggregate items is crucial, so that high air voids do not reduce the stability and durability of the pavement. Table 1 shows the porous asphalt specification that adopted in this study.

Table 1. Porous Asphalt Specification

No.	Planning Criteria	Value
1	Marshall Stability (kg)	Min. 500
2	Flow (mm)	2 – 6
3	Void in Mixture (%)	10 – 25
4	Marshall Quotient (kg/mm)	Max 400

Source: AAPA (1997) [12]

There are some disadvantages associated with porous asphalt pavement which are: low stability, costly maintenance and low service life (7 to 10 years only). However, the use of Gondorukem as an additive able to increase the binding strength of the asphalt, thus the disadvantages are expected to be minimized.

Although there are some disadvantages in the use of porous asphalt, it is still a good choice in area that experience heavy annual rainfall. Porous asphalt is reported to have high shear resistance and quicker drying. During rainy season, the surface water drained faster from the surface of the porous pavement thus reducing splashes and flushes as well as the wet time. In addition, the reflection of light during day and night can be reduced. With the addition of Gondorukem rubber, it is expected to create a stronger bond of aggregates and produce higher stability so that it can withstand high traffic loads even with high air voids.

2.3. Marshall Characteristics

In order to determine the suitability of Gondorukem rubber for porous asphalt pavement mixture, its characteristics were tested and analyzed using the Marshall instrument. The main results of that obtained from the test are Stability and Flow values. While, other parameters such as Void in the Mixture (VIM), Voids in Mineral Aggregates (VMA), Void Filled with Asphalt (VFA) and Marshall Quotient (MQ) were obtained from calculations using the Marshall table [13].

The Gondorukem rubber is added into asphalt binder to create a pavement mixture and it is tested for its stability value to determine its ability to withstand traffic loads without undergoing permanent deformation. Flow value is the indicator of sample deformation as the result of the applied loading [9],[13],[14].

The VMA affects the performance of a mixture. If the VMA is too small, then the mixture may experience durability problems due to thinner films of asphalt binder on the aggregate particles. Moreover, when VMA is too large, the stability will be very low. The value of VMA is influenced by the compaction factor, i.e amount and compaction temperature, aggregate gradation and bitumen content, which affect the permeability of the water and air and its elastic properties.

In general, a higher VFA resulted in higher water and air resistance. However, excessive VFA will cause bleeding and low VFA will cause the mixture to be less impermeable to water and air due to the thin film asphalt layer. This will produce pavement that easily cracks under loading and exposed to the oxidation processes that will eventually cause the layer to be aged and non-durable.

MQ is the ratio of stability and flow, which illustrates the flexibility of the mixture. A higher MQ value indicates a stiffer mixture and a smaller MQ value indicates a more flexible mixture. In practice, a MQ value that is too flexible causes the pavement to change easily under loading.

The optimum asphalt content is determined by averaging the asphalt content which gives the maximum stability value, maximum density and asphalt content to the required VIM. These results are then checked whether at this average value the requirements of other asphalt mixtures such as VMA, VFB and Flow mix have met the specifications. The optimum asphalt binder content determined from the Marshall tests could then be used to produce asphalt pavement mixture.

3. Material and Methodology

3.1. Gondorukem Rubber (Colophony)

In this study, asphalt 85/100 penetration was used as an asphalt binder for the porous asphalt pavement mixture with the properties obtained from this investigation shown in Table 2.

Porous Asphalt with various ratios of Gondorukem/Asphalt were tested in the laboratory using the Marshall test. The variations of Gondorukem/Asphalt (G/A) ratio were 0%, 3%, 5%, 7% and 10%. Detail calculation on how obtain the appropriate weight of Gondorukem is tabulated in Table 4.

Table 2. Specification of Asphalt Pen 85/100

No	Experiments	Value
1	Penetration (mm)	100.53
2	Flash Point (°C)	337.33
3	Fire Point (°C)	369.66
4	Softening Point (°C)	61
5	Specific Gravity	1.03
6	Ductility (cm)	>100

Prior to the preparation of the specimens, the mix design for the pavement mixture was prepared. This includes aggregate sieve analysis, asphalt binder content determination and composition measurement of each fraction of aggregate, asphalt and filler. Materials were including coarse aggregate, fine aggregate, Gondorukem rubber and 85/100 penetration asphalt were prepared as per the Marshall Standard [12]. Porous asphalt gradation and specifications were in accordance with AAPA Standard 1997 [14], as shown in Table 1. Mixtures of modified asphalt were prepared with variation of 0%, 3%, 5%, 7% and 10% G/A and the proportion is determined based on the middle limit of the porous asphalt specification. There are 75 samples containing Gondorukem rubber fabricated in this study.

The equation to determine asphalt binder content theories (P) consists of:

$$P = S \times K \times T \qquad (1)$$

Where:
P = Asphalt binder content before aggregate gradation determination
S = the ratio of SG from material standard with material used as seen on Eq.(2) determined by (2. 65/ (SG for the Aggregates Used)
K = Surface Roughness Index
T = the amount of asphalt based on total surface area method

$$\text{SG for the aggregates used} = \frac{100}{\frac{Course\ Agg}{SG.Course\ Agg} + \frac{Fine\ Agg}{SG.Fine\ Agg} + \frac{Filler}{SG.Filler}} \qquad (2)$$

With a total surface area determined from aggregate gradation testing at 3119. 5 cm^2 shown in Table 3, a value of T equal to the amount of asphalt = 7.21% can be obtained from the total surface area method.

Table 3. Aggregate Surface Area

Sieve size (Inch)	% Cumulative Passing	% Retained	% fraction	Surface Area, cm^2
3/4"	100	0	0	0
1/2"	92.5	7.5	7.5	10.5
3/8"	57.5	42.5	35	112
2/7"	35	65	22.5	72
#4	17.5	82.5	17.5	56
#8	11	89	6.5	41.5
#16	9	91	2	33
#30	7.5	92.5	1.5	54.5
#50	6	94	1.5	122.5
#100	5	95	1	182
#200	3.5	96.5	1.5	273
Filler	0	100	3.5	2162.5
Total				3119.5

The value of S = 1.027 and K = 0.95 are chosen because the surface type is considered to be sheathed slightly irregularly. Hence the value of P calculated based on Eq. (1) is equal to 7.035%. It is required for the surface layer to have an air void of 0.3% - 0.5% to prevent flow of the pavement or loss of stability. Therefore, the optimum bitumen content theoretically is P = 7.035% - 0.3 % = 6.7%.

Based on the calculated theoretical value of asphalt binder content, the composition of the mixture was prepared and then tested for Marshall properties. Table 4 shows the variations of pavement mixture as well as Gondorukem rubber mixture for each variation of asphalt binder content in gram.

Table 4. Composition of Asphalt and Gondorukem Rubber

kadar aspal	5.7%		6.2%		6.7%		7.2%		7.7%	
berat aspal (gram)	68.4		74.4		80.4		86.4		92.4	
	aspal	karet gondorukem	aspal	karet gondorukem	aspal	karet gondorukem	aspal	karet gondorukem	aspal	karet gondorukem
0%	68.4	0	74.4	0	80.4	0	86.4	0	92.4	0
3%	66.35	2.05	72.17	2.23	77.99	2.41	83.81	2.59	89.63	2.77
5%	64.98	3.42	70.68	3.72	76.38	4.02	82.08	4.32	87.78	4.62
7%	63.61	4.79	69.19	5.21	74.77	5.63	80.35	6.05	85.93	6.47
10%	61.56	6.84	66.96	7.44	72.36	8.04	77.76	8.64	83.16	9.24

3.2. Marshall Parameter Analysis

Marshall Parameters such as Stability and Flow, Void in the Mixture (VIM), Voids in Mineral Aggregates (VMA), Void Filled with Asphalt (VFA) and

Marshall Quotient (MQ) were used to determine the performance of the porous asphalt mixture with added Gondorukem rubber.

The stability is defined as the maximum compressive load carried at a temperature of 60°C, reported in kilograms (kg). This test evaluated the variation in stability with the variation in asphalt binder content incorporated with Gondorukem.

The flow is defined as the vertical deformation during the stability test and is reported in millimeter (mm). The higher the flow the more the permanent deformations such as rutting or shoving that tends to occur during its service life. However, too low value of flow may indicate that a stiffer asphalt binder was used in the mixture, and it tends to produce cracks when high loads are imposed on the pavement. A certain amount of voids in the mixture (VIM) are needed to allow for some additional pavement compaction under traffic and to provide spaces into which small amounts of asphalt can flow during this subsequent compaction.

The void filled with asphalt (VFA) is the percentage of the void in mineral aggregate (VMA) that is filled with asphalt binder. VFA implies the asphalt film thickness. Thin asphalt film thickness may result in a less durable pavement. VFA is an important design property, that is required the specifications to be between 70%-80% during the design phase. This requirement is intended for the mix during the design phase only and is typically not a production requirement.

4. Results and Discussions

The main objective of this research was to evaluate the effect of Gondorukem rubber added to the asphalt binder on the properties of the Porous Asphalt. In this section all the performance based testing conducted on the Porous Asphalt pavement mixture are presented and discussed.

4.1. Stability

The results of the Stability test in this study can be seen in Fig.3. Figure 3 shows the relationship between asphalt binder content and the Stability for all variations of G/A on porous asphalt pavement. It shows that the stability value increases as the percentage of G/A in the mix increase from 0% until 7%. After this, further addition to 10% G/A decreases the stability. The maximum stability value for each percentage of the mixture was 545 kg, 741 kg, 710 kg, 890 kg and 780 kg for 0%, 3%, 5%, 7% and 10% of G/A respectively. It can be concluded that the optimum is 7%.

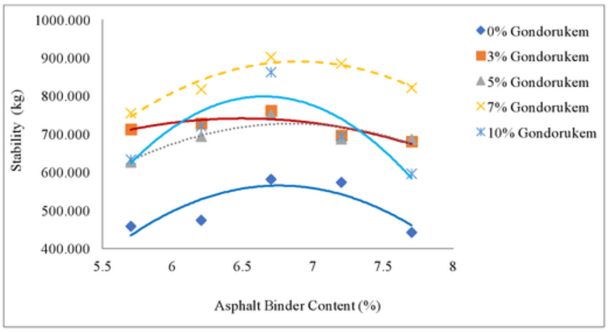

Fig. 3. Stability (kg) vs. Asphalt Binder Content (%)

4.2. Flow

Flow is a state of deformation of an asphalt mixture occurring as a result of a load imposed on the surface of the pavement and it is expressed in mm (SNI 06-2489-1991). Fig. 4 shows the relationship between Flow and asphalt binder content for all variations of G/A on porous asphalt pavement mixtures. The results indicate that as the asphalt binder content increases, the flow will increase as well. All the G/A percentages yield values within the standard specification of between 2mm to 6 mm [14].

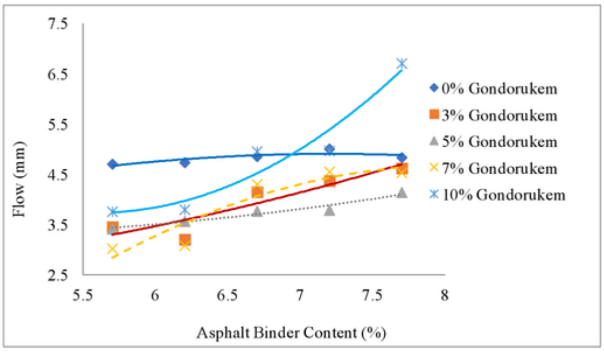

Fig. 4. Flow (mm) vs. Asphalt Binder Content (%)

4.3. Void in Mixture (VIM)

Air voids or VIM is one of the essential parameters of porous asphalt as indicated in Table 1. Fig. 5 shows the relationship between asphalt binder content to the VIM. It shows that the higher the asphalt binder content the lower the air voids in the mixture . On the other hand, higher percentages of G/A produce higher air voids in the mixture values. It is also noted that all variations of G/A tested produce VIM within the specification range of 10% to 25%.

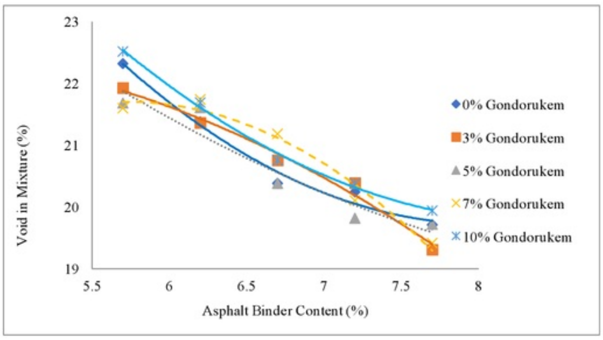

Fig. 5. Void in Mixture (%) vs Asphalt Binder Content (%)

4.4. Void in the Mineral Aggregate (VMA)

Void in the Mineral Aggregate (VMA) values include air voids and effective asphalt binder content expressed as a percent of the total volume. Fig. 6 shows the average VMA value of each variation and its relationship to the asphalt binder content.

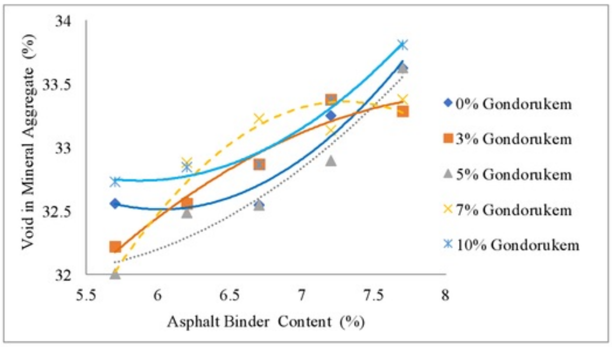

Fig. 6. Void in the Mineral vs Asphalt Binder Content (%)

Figure 6 indicates that the higher the content of asphalt in the sample, the higher the percentage of VMA. It can be observed that the value of VMA for 7% G/A is 33.35%.

4.5. Void Filled with Asphalt (VFA)

Void Filled with Asphalt (VFA) is the amount of the void in the mineral aggregate (VMA) that is filled with asphalt and is expressed as a percentage. Figure 7 shows the relationship between asphalt binder content to the void filled with asphalt (VFA) value.

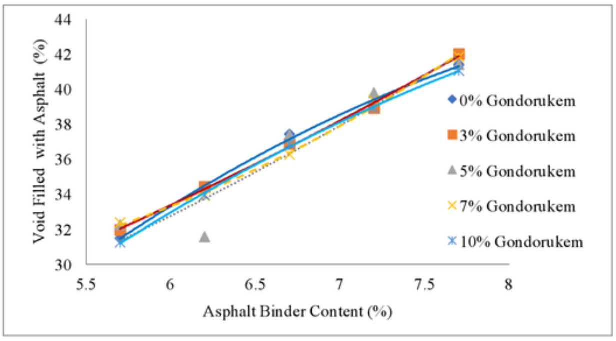

Fig. 7. Void Filled with Asphalt (%) vs Asphalt Binder Content (%)

The relation obtained is directly proportional to the exponential level of VFA. The change in asphalt binder resulted in the change in VFA. It is also noted that while VFA is increasing with asphalt binder content, it is decreasing with addition of Gondorukem rubber.

4.6. Marshall Quotient (MQ)

Figure 8 shows the relationship between Marshall Quotient and asphalt binder content. Marshall Quotient is the ratio between load (Stability, kg) and deformation (Flow, mm). The higher the ratio the stiffer the mixture is. As shown in Fig. 8, 7% G/A reached the highest MQ, followed by 5%, 3% and 10% G/A. Overall, the MQ value dropped when asphalt binder content was increased for all G/A mixtures. The MQ value increases when the level of G/A in the mixture rises, until it reaches the optimum point at 7%. Beyond this point, the MQ value drops again. The test results show that all of the variations tested met the standard of MQ<400 kg/mm.

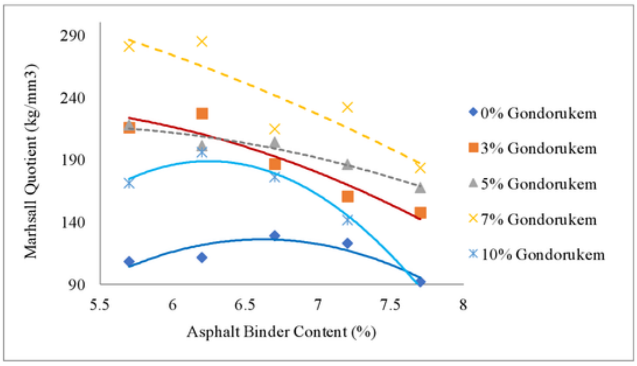

Fig. 8. Marshall Quotient vs Asphalt Binder Content (%)

4.7. Statistical Analysis of VIM and MQ

Air voids and Marshall Quotient are the two important parameters in porous asphalt. Higher air voids are required to allow permeability of water especially during rainy season. Table 5 shows the analysis of variance (ANOVA) of VIM and MQ. The asphalt content used in the mixture is significant to the VIM as compared to the Gondorukem content. In terms of MQ, asphalt content and Gondorukem content are statistically significant. This indicate when designing the mixture for porous asphalt that incorporating Gondorukem, appropriate amount of asphalt and Gondorukem need to be investigated.

Table 5. The ANOVA of VIM and MQ

Test	Variable	DF	Adj SS	Adj MS	F	P	Significant
VIM	Asphalt content (%)	4	22.71	5.68	19.43	0.000	Yes
	Gondorukem (%)	4	0.42	0.11	0.36	0.833	No
	Error	16	4.68	0.30			
	Total	24					
	R-Sq(adj) = 74.78%						
MQ	Asphalt content (%)	4	14909.50	3727.40	9.22	0.000	Yes
	Gondorukem (%)	4	44479.00	11119.70	27.49	0.000	Yes
	Error	16	6471.80	404.50			
	Total	24					
	R-Sq(adj) = 85.26%						

5. Conclusion

The addition of Gondorukem rubber as asphalt binder (G/A) at of 0%, 3%, 5%, 7% and 10 % affected the stability based on Marshall instrument. The maximum Stability obtained for these percentages were; 545 kg, 740 kg, 710 kg, 890 kg and 780 kg respectively. This indicated that the addition of Gondorukem rubber increased the stability. It was also observed that the Flow values for all G/A content were within the standard range of 2-6 mm.

The VIM value, an indicator of durability, was within the range of 10-25% for all G/A additions. A higher VIM in porous asphalt leads to oxidation and accelerates the aging and thus decreases its durability. But a large value of VMA and VFA helps negate this negative impact because this indicates that a thick asphalt film will coat the aggregates and hence helps increase the durability and stability of the pavement.

Based on the Marshall test results, addition of 7% G/A is recommended because it provides the maximum Stability and sufficient VIM and VFA values. These results support the Putri and Perdana (2016) findings on the optimum Gondorukem addition for asphalt stiffness. In addition, the optimum asphalt binder content of 6.6% is considered to be able to withstand the traffic load and deformation damage such as rutting, shoving and cracks.

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