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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 a 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 a 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: Gondorukem, Marshall properties, Maximum stability, Porous asphalt.

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 seen on Fig. 1. 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].

Since the demand for porous asphalt application is increasing, mixtures with strong aggregate binders and high durability are needed. Therefore, water passing through the air cavity on the pavement does not accelerate its oxidation. According to Australian Asphalt Pavement Association (AAPA) [3], in addition, the porous asphalt must have high stability, which is the value of maximum load can be afforded by the specimen.

Walsh et al. [4] explained that stability can be increased by elastomeric polymer material addition due to it having the elasticity and plasticity behaviour altogether of asphalt binder. In addition, the mixture can strongly be bond together to afford the load imposed to the pavement. The asphalt mixture performance can be improved through modification of asphalt properties such as an addition of materials like waste rubber that may improve the elasticity of asphalt [4]. Forrest [5] commented it has been investigated the used of crumb rubber and waste rubber in the product of asphalt, roofing, and sound or reducing the vibration, etc. Then, it can be concluded that the waste rubber can improve the durability of asphalt, increase the impact performance as well as insulation production and so on [4]. As well as the other rubber products, such as Gondorukem, which is the sap of pine trees.

The previous study by Putri and Perdana [6] indicated that locally available material named Gondorukem rubber showed potential on asphalt properties improvement. Gondorukem rubber or Colophony is a solid distillate derived from the resin of Sappine trees such as longleaf pine (Pinus palustris).

The objective of this research is to determine the suitability of Gondorukem rubber as an 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 of Highways Indonesia [7].

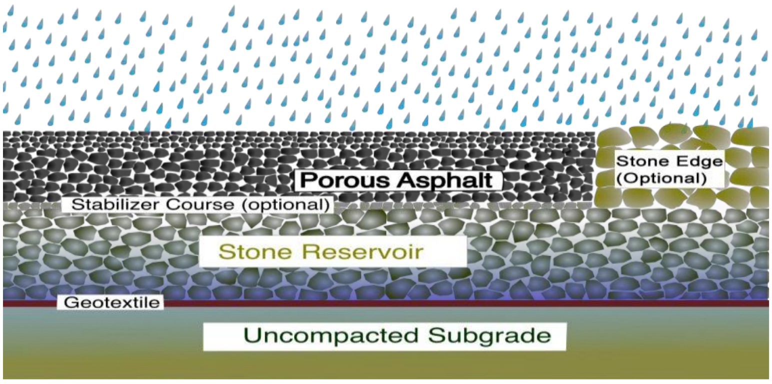

Fig. 1. Typical asphalt porous structure layer [8].

2. Literature Review

2.1. Gondorukem rubber (colophony)

Gondorukem is a common name used for products prepared from the sap of pine trees. Figure 2 shows samples of bulk obtained from the Gondorukem and Turpentine Factory near Kampung Permatang, Central Java, Indonesia and powdered Gondorukem that has been mashed in the lab. 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 a high melting point, therefore, no defects will occur due to heavy traffic loading [4]. Gondorukem properties are shown in Table 1 [9, 10].

As seen in Fig. 2, Gondorukem used in this investigation is usually yellowish in colour and consists of 85% - 95% monocarboxylic acid and 5%-15% neutral fractions (> 50 components identified). In Indonesia, including West Sumatera [11], 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%) [11]. Based on studies by Fachrodji et al. [11] and Satriawan [12], Gondorukem is widely used in paper, soap, varnish, batik, shoe polish, electrical insulation and the printing ink industry and the price in Indonesia US$800 per ton. It is also used as an adhesive that serves as tackifiers, hyper adhesion (adhesion promoter) or viscosity promoter.

Table 1. Properties of Gondorukem (colophony) [9, 10].

No.	Characteristics	Colophony
1	Form	Liquid
2	Colour	White/ pale yellow
3	Solubility	Hidrophobic
4	Softening point	65 - 75 ºC
5	Density (gr/cm^3)	1.11 - 1.12
6	Other specification	Adhering
7	Tensile strength (MPa)	0.077 ± 0.06
8	Tensile modulus (GPa)	0.009 ± 0.001
9	Max strain (%)	1.71 ± 0.03
10	Moisture (%)	2.42 - 3.93
11	Ash (%)	0.01 - 0.03
12	Fixed carbon (%)	0.01 - 0.05

Fig. 2. (a) Bulk Gondorukem (b) Powdered Gondorukem [6].

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 [7, 13]. 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 it 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. Tanan [14] commented that, as the air void gets smaller, the water flowing into the asphalt mix gets slower as well.

As shown in Fig. 3, 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 a dense gradation. Marshall stability can be enhanced if the open gradations contain more subtle fractions [13], or when the high-quality aggregate binder is being used during construction.

Porous asphalt is a type of pavement 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, therefore, high air voids do not reduce the stability and durability of the pavement. Table 2 shows the porous asphalt specification that adopted in this study [3].

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 to the use of porous asphalt, it is still a good choice in an area that experiences heavy annual rainfall. Porous asphalt is reported to have high shear resistance and quicker drying. During a 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 additions, the reflection of light during day and night can be reduced. Moreover, it can reduce vehicle noise, the glare effects caused on roads that are wet surfaces, spray and spray effects when the vehicle crosses the surface of the wet pavement, aquaplaning effects when the surface of the pavement is wet, then it can also reduce drainage costs because porous pavement would emit water to the soil surface without the need for drainage channels [15].

Thus, with the addition of Gondorukem rubber, it is expected to create a stronger bond of aggregates and produce higher stability, therefore, it can withstand high traffic loads even with high air voids.

Table 2. Porous asphalt specification [3].

No.	Properties 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

Fig. 3. (a) Porous asphalt (b) Asphalt concrete.

2.3. Marshall characteristics

In order to determine the suitability of Gondorukem rubber for porous asphalt pavement mixture, its characteristics were tested and analysed 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 [16].

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 [13, 16].

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, an 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

Aggregate and asphalt were prepared as per General Specifications 2010, Revision 3, Directorate of Highways Indonesia.

3.1. Preparation of amples

In this study, asphalt 85/100 penetration was used as an asphalt binder for the porous asphalt pavement mixture with the specifications derived from the investigation as shown in Table 3.

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

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 Marshall Standard [7]. Porous asphalt gradation and specifications were followed the AAPA Standard 1997 [3], as shown in Table 2. Mixtures of modified asphalt were prepared with a 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.

Table 3. Specification of asphalt pen 85/100.

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

Source: Investigation results (2018)

Table 4. Composition of asphalt and Gondorukem in mixture.

Asphalt content	5.7%		6.2%		6.7%		7.2%		7.7%	
Asphalt weight	68.4 gram		74.4 gram		80.4 gram		86.4 gram		92.4 gram	
Gondorukem content	**Asphalt weight (g)**	**Gondorukem weight (g)**	**Asphalt weight (g)**	**Gondorukem weight (g)**	**Asphalt weight (g)**	**Gondorukem weight (g)**	**Asphalt weight (g)**	**Gondorukem weight (g)**	**Asphalt weight (g)**	**Gondorukem weight (g)**
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. Asphalt content determination

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

$$P = S \times K \times T \tag{1}$$

where:

P = Asphalt binder content before aggregate gradation determination

S = the ratio of SG from material standard with material used (2. 65/ (SG for the aggregates used)

K = Surface roughness index

T = the amount of asphalt based on total surface area method

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

With a total surface area of 3119. 5 cm^2 shown in Table 5, a value of T equal to the amount of asphalt = 7.21% can be obtained from the total surface area method. 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 a 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 Colophony mixture for each variation of asphalt binder content in gram.

Table 5. 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**

3.3. 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 ºC [17], reported in kilograms (kg) [7]. 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 millimetre (mm). The higher the flow the more the permanent deformations such as rutting or shoving that tends to occur during its service life.

However, a 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. The thin asphalt film thickness may result in a less durable pavement. VFA is an important design property, that is required for 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 for the stability test, as can be seen in Fig. 4 shows the relationship between asphalt binder content against the stability for all variations of G/A for porous asphalt pavement. It shows that the stability value initially increases to 7% as the percentage of G/A in the mix increase.

However, for further addition of G/A may decrease the stability. The maximum stability value for each percentage G/A 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. The maximum stability achieved at 7% G/A that can increase the stability by 63.3% compared to a mixture without Gondorukem addition.

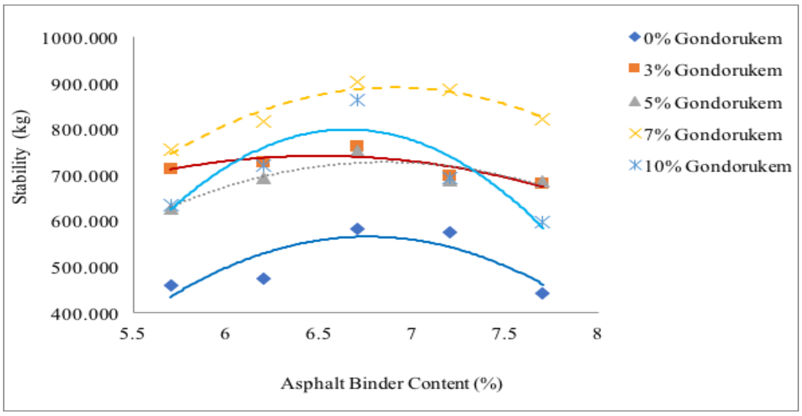

Fig. 4. Stability (kg) vs. asphalt binder content (%).

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). Figure 5 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 2 mm to 6 mm [16]. The minimum value of Flow is needed to ensure the mixture has sufficient asphalt binder content and produced a stiffer mixture. The upper limit of flow 6 mm, was to ensure the mixture is not too soft to withstand the traffic load [18].

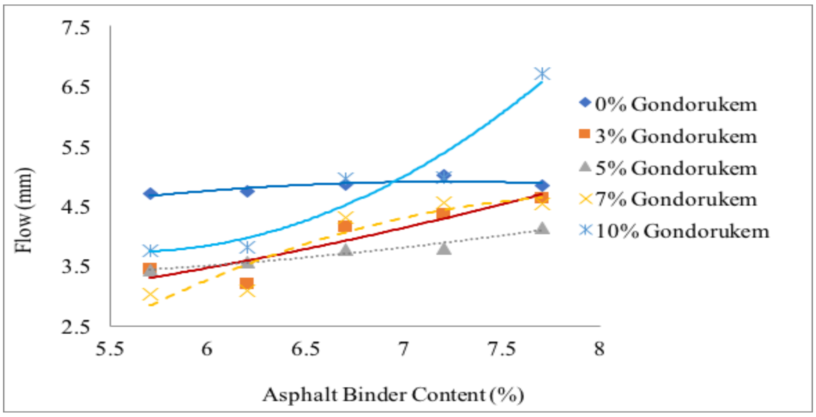

Fig. 5. Flow (mm) vs. asphalt binder content (%).

4.3. Void in mixture (VIM)

Air voids or VIM is one of the essential parameters of porous asphalt as indicated in Table 2. Figure 6 shows the relationship between asphalt binder content to the VIM.

As can be seen in Fig. 6, 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, which is the important parameter for porous asphalt to allow water passage through the pavement. It is also noted that all variations of G/A tested produce VIM within the specification range of 18% to 25% [7].

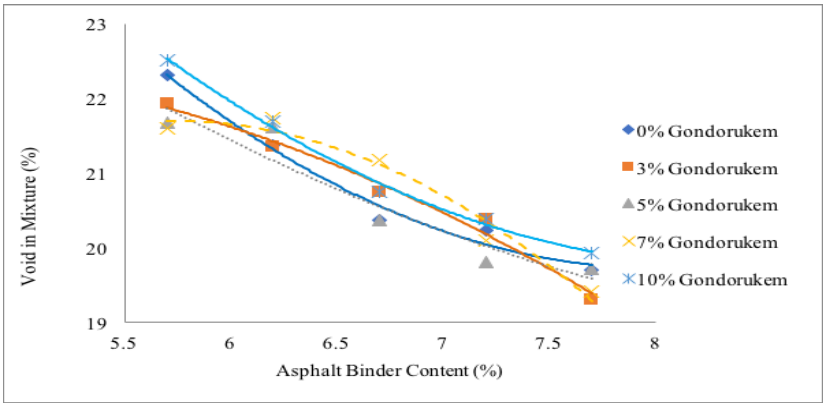

Fig. 6. Void in mixture (%) vs. asphalt binder content (%).

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. Figure 6 shows the average VMA value for G/A variation and its relationship to the asphalt binder content.

As shown in Fig. 7, the addition of asphalt binder content increases the Void in Mineral Aggregate (VMA). The higher VMA indicates the more space available for asphalt film. It can be observed that the value of VMA for 7% G/A is 33.35%, that is adequate for asphalt film thickness to produce a durable pavement mixture.

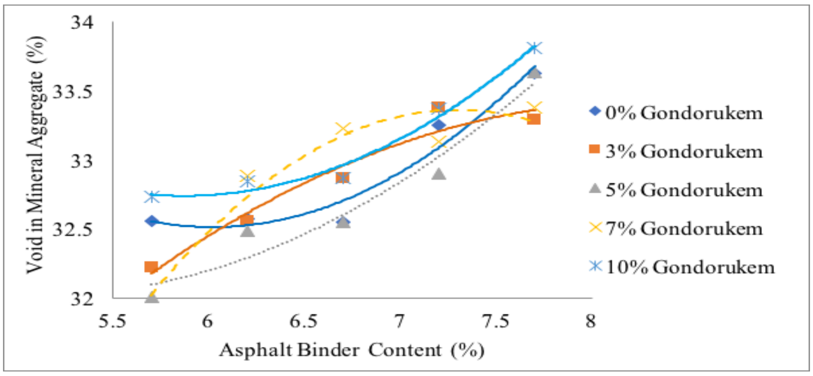

Fig. 7. Void in the mineral vs. asphalt binder content (%).

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 8 shows the relationship between asphalt binder content to the Void Filled with Asphalt (VFA) value.

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. Thus, it indicates that too much Gondorukem it can decrease the effective asphalt film thickness, which results in lower durability of the asphalt mixture.

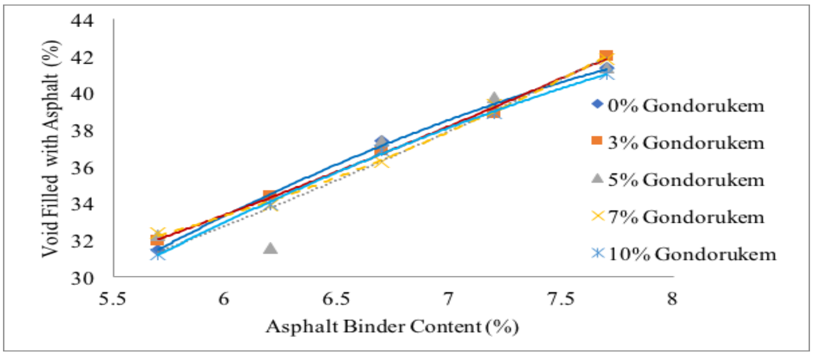

Fig. 8. Void filled with asphalt (%) vs. asphalt binder content (%).

4.6. Marshall quotient (MQ)

Figure 9 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. 9, 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 of 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.

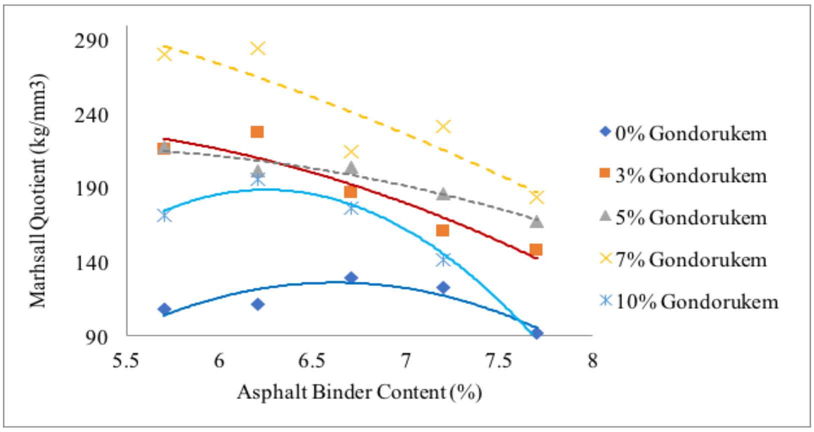

Fig. 9. Marshall quotient vs. asphalt binder content (%).

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 the permeability of water, especially during the rainy season.

Table 6 shows the Analysis of Variance (ANOVA) of VIM and MQ. Statistical analysis shows that the R^2 for both tests are 74.78% and 82.26 % respectively. The R^2 indicates the fitness of the proposed model. A higher R^2 represents a model with higher accuracy. However, the acceptable value of R^2 s also dependent on how the dependent variables are defined. Due to the higher variability of asphalt mixtures, 70% is considered acceptable in this study. According to Vallabhu [19], the R^2 n 70 - 89 % is considered as good. Hence, this analysis can be used to describe the effects of the selected variables to the VIM and MQ. Based on the statistical analysis, that 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 statically significant. This indicates that when designing the mixture for porous asphalt that incorporating Gondorukem appropriate amount of asphalt and Gondorukem need to be investigated.

Table 6. 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. Conclusions

The addition of Gondorukem rubber as an additive for 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. The addition of Gondorukem rubber increased the stability and 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 ageing and thus decreases its durability. However, a large value of VMA and VFB 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, the addition of 7% G/A is recommended because it provides the maximum stability and sufficient VIM and VFB 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 [14].

Thus, it can be concluded that the addition of 7% Gondorukem is expected to improve the quality of porous asphalt. Even though the additional cost of about 7% of the total asphalt binder used, however, the stability can significantly increase by 63.3%.

Acknowledgement

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Nomenclatures

K	Surface roughness index
P	Asphalt binder content before aggregate gradation determination
S	Ratio of SG from material standard with material used (2. 65/ (SG for the aggregates used)
T	Amount of asphalt based on total surface area method

Abbreviations

AAPA	Australian Asphalt Pavement Association
FHWA	Federal Highway Administration
MQ	Marshall Quotient
SG	Specific Gravity
VFA	Void Filled with Asphalt
VIM	Void in Mixture
VMA	Void in Mineral Aggregate

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