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Effects of Gondorukem addition on AC-WC pavement containing reclaimed asphalt pavement

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Abstract. Increasing the level of the road due to overlay, by adding additional layers continuously, will thicken the pavement layer and utilize the virgin materials. The dredged asphalt pavement materials can be reused, for example for new pavements, commonly called Reclaimed Asphalt Pavement (RAP). However, adding RAP on the new pavement result in a decrease in the physical properties of the pavement. Gondorukem is a sap that was chosen as an asphalt concrete additive ingredient that can absorb heat. The use of Gondorukem as additive expected to increase the stability of the asphalt pavement. In this study, the Marshall characteristics of the mixture of asphalt concrete - wearing course (AC-WC) containing RAP and Gondorukem additives were tested. Asphalt concrete containing 35% of RAP and Gondorukem which content varied of 0%, 3%, 5%, 7%, and 10% was tested. The obtained stability value increased by 28.48%. The optimum Gondorukem addition into the asphalt was 3.2%; the optimum bitumen content was 6.45%.

1. Introduction

The use of recycled asphalt pavement nowadays become a popular issue. The usage of RAP may prevent the exploitation of the virgin aggregate. RAP is a stripped pavement or a pavement repacking material containing asphalt and aggregate. This material arises when asphalt pavement is peeled for reconstruction, resurfaced, or dug to access the embedded utility network underneath. When shelled, and filtered properly, RAP can contain high-grade and well-aggregated aggregates [1].

There are many benefits obtained from recycling asphalt pavement. Based on estimation, the asphalt pavements recycle saves the US taxpayer more than 2.5 billion USD annually, saves more than 60 million yd³ of landfill space annually. In addition, it reduces the needs for natural resources and material transportation process [2].

RAP contains the aggregate material that has been used in the old pavement service life. Hence, it is recommended that the RAP be mixed with the new material to produce the new pavement structure. RAP can be used for 20% - 60% of the total pavement material. By mixing the RAP and the new material, the new pavement material still has the appropriate quality to serve in the next service life.

The use of RAP for AC-WC, AC-BC, and HRS-WC has been investigated by Putri et al. [3]. RAP was varied by 35%, 50%, and 60% for the three types of pavement. The use of 35% RAP on AC-WC pavements results in high stability values compared to the stability of the asphalt concrete containing 55% RAP and 60% RAP. Unfortunately, the performance of asphalt pavement containing RAP and virgin material is not as strong as the pavement containing the virgin material only [3].



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Moreover, it is important to investigate the improvement of the performance of the pavement mixture containing RAP. Gondorukem is chosen as an additive material because its physical properties like rubber: soften when the temperature increases and harden when the temperature decreases. The use of Gondorukem for porous asphalt pavement containing all new virgin aggregates has been investigated by Putri et al. [4]. Based on the investigation, the Marshall stability increased by 63.3% [4].

Hence, this study aims to improve the AC-WC pavement mixture containing 35% RAP by adding Gondorukem. This study also aims to determine optimum Gondorukem content.

2. Methodology

2.1. Aggregate properties

The properties of aggregate used have been investigated in the Civil Engineering Department, Andalas University, which is presented in table 1.

Table 1 Aggregate parameter.

No	Parameter	Method	Value	Requirement as per SNI
1	Coarse aggregate density			
	a. Bulk density	SNI 1969-2008	2.53	
	b. Apparent density	SNI 1969-2009	2.59	2.5 – 3.0
	c. SSD density	SNI 1969-2010	2.56	
	d. Water absorption	SNI 1969-2011	0.83	max. 2
2	Fine aggregate density			
	a. Bulk density	SNI 1969-2008	2.47	
	b. Apparent density	SNI 1969-2009	2.81	2.5 – 3.0
	c. SSD density	SNI 1969-2010	2.59	
	d. Water absorption	SNI 1969-2011	4.98	
3	Mass volume			
	a. Lose mass volume	PB-0204-76	1.41	
	b. Shaking	PB-0204-77	1.55	
	c. Stabbing	PB-0204-78	1.60	
4	Aggregate adherence to asphalt, %	SNI 06-2439-1991	96	min. 95
5	Los Angeles test abrasion			
	a. New aggregate, %	SNI 247 : 2008	29.09%	max. 35
	b. RAP aggregate, %	SNI 247 : 2009	44.30%	max. 40
6	Aggregate impact value (AIV)			
	a. New aggregate, %	BS : 182 Part 111: 1990	7.18%	max. 35
	b. RAP aggregate, %	BS : 182 Part 111: 1990	31.72%	max. 40
7	Aggregate crushing value (ACV)			
	a. New aggregate, %	BS : 182 Part 111: 1990	26.02%	max. 35
	b. RAP aggregate, %	BS : 182 Part 111: 1990	35.70%	max. 40

Based on table 1, the properties of aggregate meet the requirements. Meanwhile, the first parameter property until the fourth one is to characterize their physical properties. The properties were suitable for pavement mixture. Meanwhile, based on the fifth until the seventh properties, it was observed that RAP aggregate has lower quality in terms of strength, such as abrasion test, impact test and crushing test. As a consequence, the usage of RAP to substitute the aggregate in the pavement can reduce the pavement quality.

Thus, the addition of Gondorukem in the asphalt was investigated. It is expected to increase the adhesion between aggregate and asphalt in order to protect the aggregate from oxidation, impact load,

etc. during its service life. As a result, adding Gondorukem is expected to increase the Marshall properties, especially the Stability value.

2.2. Gondorukem

Gondorukem (resina colophonium), as shown in figure 1, is a product of sap from the lead in the tusam (pine) stem. Gondorukem is the result of the cleaning process of the residue obtained from the steam distillation of tusam sap. The result of the distillation is turpentine [1-2].



Figure 1. Gondorukem.

The result of the distillation of the sap becomes turpentine with the chemical element of $C_{10}H_{16}$. Gondorukem is obtained from the processing of pine sap from the tapping process. Table 1 shows the properties of Gondorukem.

Table 2. Properties of Gondorukem (colophony) [1-2].

No.	Characteristics	Colophony
1	Form	Liquid
2	Colour	White/ pale yellow
3	Solubility	Hydrophobic
4	Softening point	65 - 75 °C
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

Gondorukem is a product of the pinewood processing industry. Pine trees at a certain age can be tapped into the sap. When the pine sap is distilled, it will produce Gondorukem and turpentine. Generally, Gondorukem is used in the batik industry, while the turpentine oil is used as paint solvents. However, by the development of pine resin processing technology, it provides an opportunity to utilize products produced from pine sap as adhesives raw material, one of the ingredients in papermaking, printing ink, chewing gum, and others [5].

Gondorukem can be added to asphalt to produce the modified binder [6]. It has been investigated that Gondorukem can improve the conventional properties of the base bitumen such as penetration, softening point, and temperature susceptibility. Moreover, Gondorukem is applicable to road construction. The optimum percentage of modified binder Gondorukem in bitumen was achieved at 7%.

2.3. Asphalt content theories

To calculate the theoretical asphalt content needed, firstly the area of the aggregate particle of AC-WC pavement is determined in order to calculate the area of the surface aggregate to be coated by asphalt for sample testing. Then, the area of the aggregate surface obtained is used to calculate the theoretical asphalt content.

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2.4. Optimum asphalt content

The optimum asphalt content is the asphalt content that yields maximum stability based on Marshall test, on condition that the other Marshall parameters, such as flow, VMA, VIM, and Marshall stability are within the standard. The optimum asphalt content for AC-WC pavement containing 35% RAP was used to produce the samples with various percentages of Gondorukem addition, between 0% until 10%.

2.5. Optimum Gondorukem content

Optimum Gondorukem content in the mixture is the content of Gondorukem to obtain the maximum stability and to fulfill the requirement of the other Marshall test parameters, such as flow, VIM, and VMA.

In general, the research is recapitulated as the following steps:

- Conducted the sieve analysis investigation for aggregate that contains 35% RAP;
- Calculated the theoretical optimum asphalt content using Surface Area Methods for aggregate containing 35% RAP;
- Investigated the optimum asphalt content by conducting Marshall testing for AC-WC pavement mixture containing 35% RAP;
- The samples were produced using the optimum asphalt content by adding various percentages of Gondorukem in asphalt in order to determine the optimum Gondorukem to the 35% RAP AC-WC mixture.

3. Results and discussion

3.1. Theoretical asphalt content

The surface area of the aggregate was determined in order to obtain the asphalt needed to coat the aggregate. In this study, 35% of the coarse aggregate was substituted with the RAP. The total surface area of the aggregate that was used can be seen in table 3.

Table 3. Surface area calculations.

Sieve No	Specification	Passing cumulative (%)	Retain of sieve (%)	% of each sieve	Surface Area (mm ²)
¾"	100	100	0	0	0
1/2"	90 – 100	95	5	5	7
3/8"	77 – 90	83.5	16.5	11.5	36.5
#4	53 – 69	61	39	22.5	72
#8	33 – 53	43	57	18	113
#16	21 – 40	30.5	69.5	12.5	205
#30	14 – 30	22	78	8.5	309.5
#50	9 – 22	15.5	84.5	6.5	530
#100	6 – 15	10.5	89.5	5	910
#200	4 – 9	6.5	93.5	4	728
pan	0	0	100	6.5	3997.5
Total					6908.5

The asphalt binder content can be calculated by using the empirical formula as follows:

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

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

Where:

P = Asphalt binder content before aggregate gradation determination;

S = The ratio of SG from the material standard, with the material used as seen on equation (2), determined by $(2.65 / (SG \text{ for the aggregates used}))$;

K = Surface roughness index; and

T = The amount of asphalt based on total surface area method.

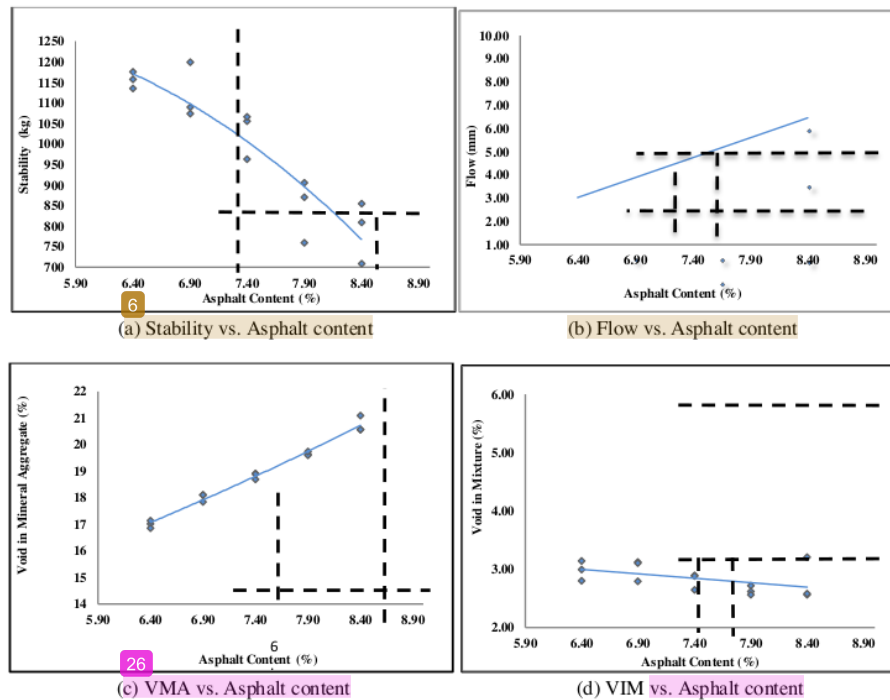
With a total surface area determined from aggregate gradation testing at 6908.5 cm² shown in table 3, a value of T equal to the amount of asphalt of 7.832% can be obtained from the total surface area method. The value of S of 1.049 and K of 0.95 are chosen because the surface type is considered to be sheathed slightly irregularly. Hence, the value of P calculated based on equation (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 the flow of the pavement or the loss of stability. Therefore, the optimum bitumen content theoretically is 7.4%.

After obtaining the theoretical optimum asphalt content of 7.4%, the asphalt content used was varied by 6.4%, 6.9%, 7.4%, 7.5%, and 8.4%, namely 1% below and 1% above the theoretical optimum asphalt content. ¹⁹ At this stage, the Marshall sample is made for 15 pieces, where 3 pieces for each asphalt content to obtain optimum bitumen content by Marshall test.

The optimum bitumen content is then used for making samples to determine the optimum levels of Gondorukem for AC-WC pavements, which results in maximum Marshall stability. So, the AC-WC pavements containing the RAP have enough strength and durability during service life.

3.2. Optimum asphalt content obtained by Marshall parameter

To determine the optimum asphalt content for AC-WC pavements containing 35% RAP, Marshall tests were carried out for 15 samples. The results obtained can be seen in figure 2(a) until figure 2(f).



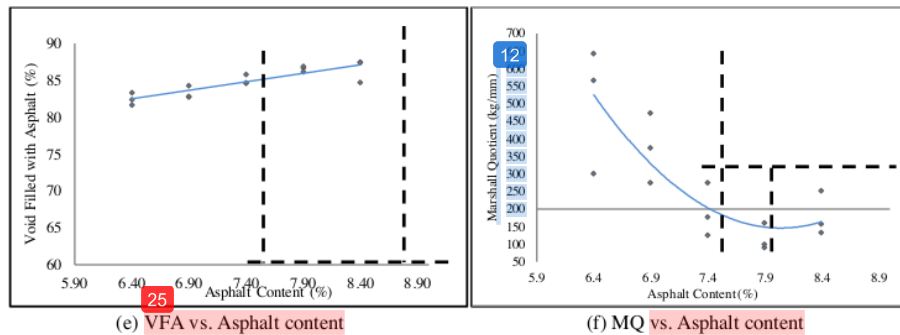


Figure 2. The Marshall test results of 35% RAP AC-WC for asphalt content optimum determination.

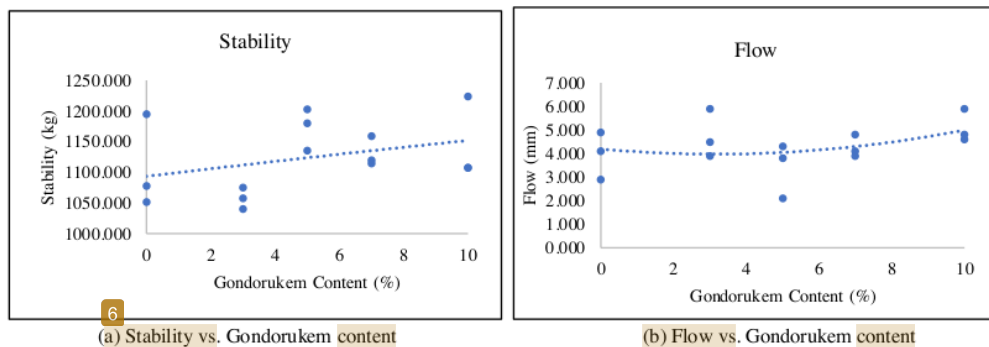
The stability test results were shown in figure 2(a). The results show that the stability increases with increasing asphalt content up to the optimum asphalt content and after that, it decreases. The stability for all samples was above the minimum standards, except for samples with overwhelming asphalt content. The asphalt content having maximum stability was 6.4%. Moreover, the flow values of asphalt mixtures against asphalt content are shown in figure 2(b). The asphalt content that resulted in Flow value within the standard was 6.4% to 6.92%.

Figure 2(c), 2(d) and 2(e) show the average VMA value, void in the mixture, void filled with asphalt and the above-mentioned parameters' relationship to the asphalt binder content. Figure 2(f) shows Marshall quotient of the sample which is the ratio of stability and flow.

Based on the Marshall test results from Fig 2(a) until Fig 2(f), the optimum asphalt content was found to be 6.4% for AC-WC pavement mixture containing 35% RAP. It is recommended because it provides maximum stability and sufficient VIM and VFB values. Hence, this optimum asphalt content will be used to prepare the sample to determine the optimum Gondorukem content for the 35% RAP of the AC-WC pavement.

3. Optimum Gondorukem content

To determine the optimum content of Gondorukem addition to the asphalt, the Marshall test was conducted. The Marshall parameter test results for 35% RAP AC-WC pavement for various Gondorukem addition were presented from figure 3(a) to 3(f).



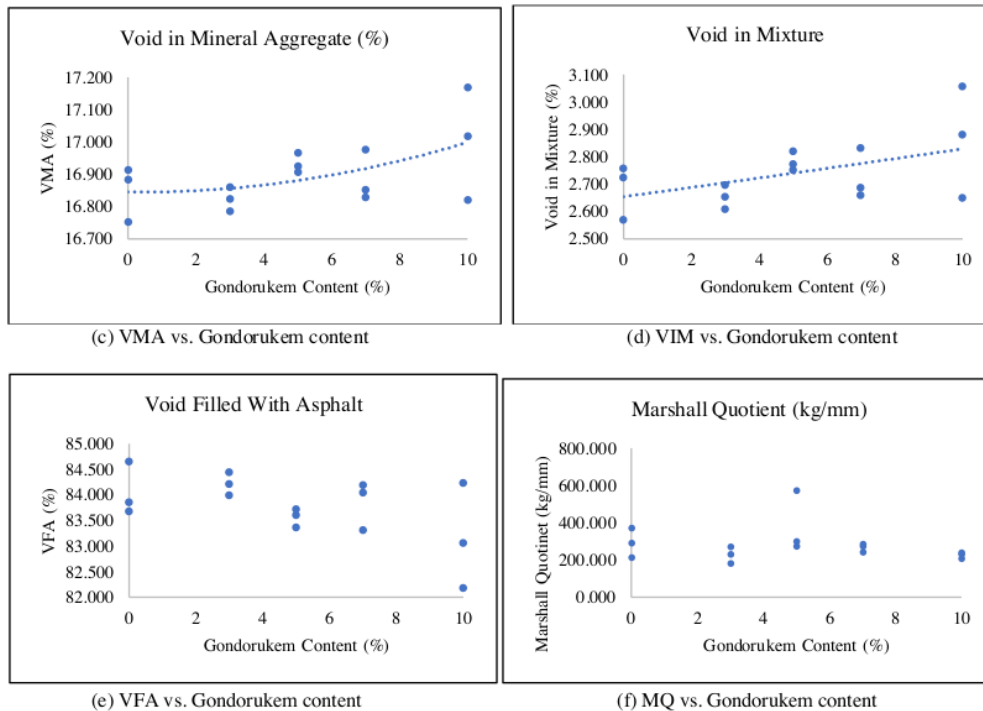


Figure 3. The Marshall test result vs Gondorukem content.

Figure 3(a) until figure 3(f) shows the results of various Gondorukem content in the Asphalt versus the Marshall Parameters, such as stability, flow, VIM, VMA, VFA, and MQ. The stability test results, as seen in Fig. 3(a), increases with the increasing of the Gondorukem content until the optimum content; and thereafter the value decreases. Moreover, it can be seen that the stability values for all the asphalt concrete containing the Gondorukem with various contents met the general specification from the Department of Public Works Indonesia, which is equal to or higher than 800 kg [7].

Meanwhile, in figure 3(b), it can be seen from the results that flow values are in the range of 3 to 5mm. Some data falls under the standard flow requirement values of about 2 to 4 mm.

As can be seen from figure 3(c), some of the voids in the mixture of the various Gondorukem value was not within the standard of the 2010 General Specification, which is 3 - 5%. Furthermore, the value of void in mineral aggregate falls under the standard requirement (figure 3 (d)).

Figure 3(e) shows the various Gondorukem content in the asphalt versus void filled with asphalt. The results show that all the VFA values were within the standard requirement, which is less than 65%. It should be noted that an increase in VFA means that there are more spaces to be filled with asphalt. This condition results in less strength of the asphalt concrete.

The 2010 General Specification requires that the Marshall quotient must be more than 250 kg/mm. As a result, the Gondorukem content must be between 0 – 9,1%, as shown in figure 5(f). From the overall results of the Marshall parameter investigation, the Gondorukem content in the asphalt was assessed. The Gondorukem content is chosen to fulfill the 2010 specification standard. The optimum value of Gondorukem contained in the AC-WC pavement mixture is 3.2% with the asphalt content of 6.45%. Thus, from all the Marshall parameter results, it can be concluded that the Gondorukem addition is strongly recommended for asphalt modification.

4. Conclusion

Based on the results of the laboratory investigation, it can be concluded as follows:

- The optimum asphalt content for 35% RAP for AC-WC pavement is 6.45%;
- The addition of Gondorukem tends to increase the strength and quality of the asphalt mixture. Using the asphalt mixed with the addition of the Gondorukem which percentage of total asphalt concrete weight is 2% to 10%, improve the Marshall Stability, flow, bulk density, void in the mix, and the Marshall quotient of the asphalt concrete. Results showed that Gondorukem rubber may increase stability by 28.48%;
- The optimum content of Gondorukem is 3.2% with 6.45% of asphalt content for AC-WC pavement mixture.

With the result obtained it can be concluded that the use of Gondorukem rubber as an additive in the asphalt for 35% RAP AC-WC pavement mixture is recommended as the Marshall properties results show good properties in their asphalt binder.

8. Acknowledgments

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