PACE-2023

International Congress on the Phenomenological Aspects of Civil Engineering

PACE-2023

International Congress on Phenomenological Aspects in Civil Engineering

Research Article 20-23 June 2023

The Use of Natural Resin and Natural Asphalt as A Substitution of Oil Asphalt in Pavement Flexible

La One*,[1], Edward Ngii[2], Rini Sriyani [3], Laode Muh Adhrian Syahputra Atodding[4]
[1,2,3]Civil Engineering, Engineering Faculty, Haluoleo University, Kendari-Indonesia
[4]student of Civil Engineering, Engineering Faculty, Haluoleo University, Kendari-Indonesia
Corresponding Author E-mail: laone@uho.ac.id

Keywords

Pine Resin,
Buton Natural Asphalt,
Marshall Stability,
Hot Mix Asphalt,
AC-WC.

Abstract

The objective of this study was to analyze the effect of using natural resin and natural asphalt on the performance of flexible road pavements. Natural resin and natural asphalt are local materials that are widely available in Indonesia as binders for flexible road pavements. This material has binding properties and can substitute some of the oil asphalt. This research is a laboratory experiment using Marshall cylinder Specimens. The material used in this study consisted of asphalt penetration 60/70, Buton Natural Asphalt B 50/30, pine resin, and standard aggregate. The Specimens were made using aggregate gradation for hot mix asphalt of Asphalt Concrete Wearing Course, bituminous content of 6.5%, natural asphalt as a substitute for asphalt pen 60/70 and fine aggregate as much as 10% of the total weight of Specimens, and pine resin as a substitute for oil asphalt with variations 0%, 2.5%, 5.0%, 7.5%, 10%, and 12.5%. The results showed that the use of 12.5% pine resin content and natural asphalt as much as 10% still met the requirements specified by Indonesia Standard with Marshall Stability is 2515 kg, flow is 2.0 mm, Marshall Quotient is 1,237 kg/mm, and Void in Mixture is 3.6%. Here shows that the use of 12.5% pine resin and 10% Buton Asphalt can substitute as much as 42.28% of oil asphalt. This research is expected to be applied to reduce dependence on the use of oil asphalt for flexible road pavement materials.

1. Introduction

Roads are basic infrastructure in supporting the economic growth and social welfare of a country. Road construction consists of rigid pavement, flexible pavement, and composite pavement (a combination of rigid pavement and flexible pavement). The quality of rigid pavements and composite pavements is higher than that of flexible pavements. However, the initial investment for rigid and composite pavements is more expensive than flexible pavements. Due to the limited funding for road construction and the high demand for road infrastructure in Indonesia, the selection of flexible pavement is a solution in the context of fulfilling road infrastructure. The main materials for flexible pavement construction are bitumen as a binder and aggregate.

Currently, the commonly used flexible pavement binders in Indonesia include oil asphalt and natural asphalt. Oil asphalt is obtained from the remaining processing of crude oil refining. Meanwhile, natural asphalt is found in the southern part of Buton Island from Sampolawa Bay to Lawele Bay, 75 km long. Asphalt sludge is located in the valleys under the slopes of the hills. Asphalt sludge deposits average 4 meters, with variations from 1–17 meters, below the soil surface. Asphalt content also varies from 10-50 percent. Natural asphalt is from the petroleum family, with long carbon chains. The color is dark black, and in it mixed various kinds of mineral grains [1].

The deposit of Buton natural asphalt is around 662 million tons. Here is equal to 340 million tons of bitumen. The asphalt deposit was discovered in the early 1920s. Until 1994, it was used very little as a binder material for flexible pavement. It does not reach 5 million tons. After that, the natural asphalt mining and processing industry was quiet and Indonesia was flooded with imported asphalt. This condition is very ironic with the incessant development of road infrastructure in Indonesia where the national asphalt demand reaches 4 to 5 million tons per year [1]. Here was triggered the results of processing natural asphalt did not provide a homogeneous asphalt content. So the performance of the road pavement does not meet the requirements both in terms of stability and durability.

Currently, in increasing the use of Buton natural asphalt, the Indonesian government has issued some policies for using Buton natural asphalt in roads construction, namely: the regulation of public work minister Number 18-2018 concerning technical references for using Buton asphalt, Regulation of Home affair minister Number 27-2021 concerning optimizing and increasing the use of Buton asphalt, and Regulation of Public work minister number 5-2021, which requires the use of Buton asphalt for the construction and preservation of provincial/ regency/ city roads, which is financed by the Special Allocation Fund. The existence of this policy is supported by an increase in the quality of processed Buton asphalt products. PT. Wika Bitumen, a subsidiary of the State Enterprise-PT Wijaya Karya, continues to improve the quality of Buton asphalt processing. Some of the natural asphalt products include are Lawele Granular Asphalt (LGA), Asbuton Granular Filler (AGF) for high traffic, Asbuton Active Filler (AAF), and Asbuton Instant Concrete (AIC)[1].

Flexible road construction in Indonesia, apart from using oil asphalt as a binder, also uses natural asphalt. Natural asphalt which is often found in the Indonesian market is in the form of granules. This natural asphalt is commonly used as a partial substitution for oil asphalt.

There were many studies on the use of Buton natural asphalt showing that the natural asphalt product can be applied to high traffic. The use of Buton asphalt can protect the road distress due to bleeding problems and rutting, increase the Marshall stability and dynamic stability, increase tensile strength and unconfined compressive strength, and have sufficient flexibility. Meanwhile, the disadvantage of using Buton natural Asphalt, especially in formed granular, is the release of granules higher. The use of Buton granular asphalt in more contents could the mixture more brittle [2,3,4,5].

In encouraging the construction of green road pavements, one alternative is the use of renewable natural resources such as natural resins. One of which is pine resin. Pine Tree is one of the plants developed by PT. Perhutani, one of the state companies. PT. Perhutani processes pine resin into gondoruken and turpentine. Perhutani has 8 pine resin processing factories with a production capacity of 92,550 tons. Pine resin processing production in 2021 is 81,788 tons [6].

Several studies showed that the use of pine resin can improve the characteristics of asphalt mixtures. The addition of pine resin reduced the asphalt ductility and was resistant to water immersion (Yuniarti et al., 2021). The use of pine resin affects the increase in the value of stability, Cantabro Loss, Asphalt Flow Down, and Void in the Mixture [7,8,9].

2. Research Methodology

The research method used is a laboratory experiment. It was be conducted at the Civil Engineering Laboratory, Engineering Faculty of Halu Oleo University. The research began with the material preparation and testing of its physical characteristics. Then, prepare Marshall cylindrical specimens with a target specimen height of 63.5 mm. All the materials were mixed at a mixing temperature of 160oC and compacted with 3x75 blows at a temperature of 150oC. After that, the specimens were soaked for 24 hours to obtain a volumetric mixture. Then, the specimens were immersed in a water bath at 60oC for 30 minutes. Lastly, the Marshall Stability test was carried out using Marshall Stability Testing Machine. It is used to determine the maximum load and flow of the mixture. The apparatus used has a capacity of 50 KN with a load plate speed of 50.8 mm/minute.

3. Materials

Materials used to make the specimens of hot mix asphalt AC-WC consist of aggregate, asphalt pen 60/70, Buton natural asphalt grade B 50/30, and pine resin.



a. Aggregate b. Filler c. Asphalt Grade 60/70


b. Granular Asphalt e.Pine Resin

Figure 1. Materials used to make specimens of hot mix asphalt AC-WC

3.1. Aggregate and Filler

The aggregate and filler used in this study were taken from the Moramo Stone Crusher in Kendari. The physical characteristic of coarse aggregate, fine aggregate and filler meet The Indonesian National Standard. The physical characteristics of aggregate and filler are shown in Table 1.

Table 1. Physical Properties of Aggregate and Filler

Description	Unit	Testing Method	Specification	Testing Result
Course Aggregate	-	SNI 03-1969-2008	>2.5	2.65
Bulk Specific Gravity	-	SNI 03-1969-2008	>2.5	2.65
SSD Specific Gravity	-	SNI 03-1969-2008	>2.5	2.72
Apparent Specific Gravity	-	SNI 03-1969-2008	>2.5	2.78
Water Absorption	%	SNI 03-1969-2008	<3	1.27
Abrasion	%	SNI 03-2417-2008	<40	31.1
Material passed sieve No. 200	%	SNI 03-4142-1996	<1	0.73
Bulk Specific Gravity	-	SNI 03-1969-2008	>2.5	2.65
SSD Specific Gravity	-	SNI 03-1969-2008	>2.5	2.68
Apparent Specific Gravity	-	SNI 03-1969-2008	>2.5	2.74
Water Absorption	%	SNI 03-1969-2008	<3	1.24
Material passed sieve No. 200	%	SNI 03-4142-1996	<1	0.43
Filler				
Specific gravity	-	SNI 03-1969-2008	>2.5	2.56

Aggregate and filler were combined to meet well gradation for the Asphalt Concrete Wearing Course (AC-WC). It is presented in Figure 1 as follows.

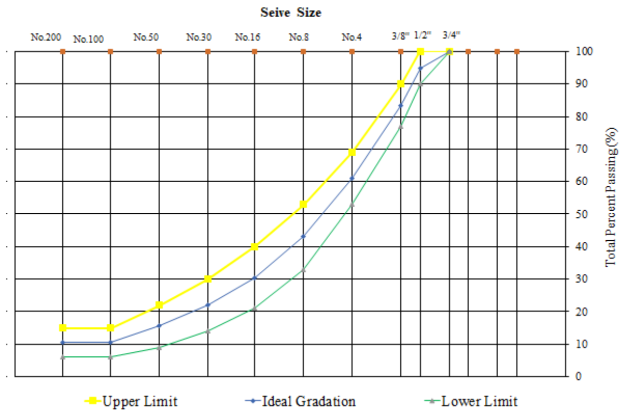

Figure 2. Combined Aggregate gradation for AC-WC

3.2. Oil Asphalt

The oil asphalt used in the study is asphalt grade 60/70. The physical properties of oil asphalt are 68.2 (0.1 mm) penetration, 1.02 specific gravity, and 146 cm ductility.

3.3. Natural Asphalt product

The tests carried out on the physical properties of LGA grade 50/30 were bitumen content, water content, and mineral gradation. The bitumen content of LGA was extracted with a reflux method. The bitumen content of LGA 50/30 is 22.12% and its water content is 0.64%. The mineral gradation of LGA grade 50/30 showed in Table 2.

Table 2. The Mineral Gradation of LGA grade 50/30

Sieve Size	3/8"	No.4	No.8	No.16	No.30	No.50	No.100	No. 200
% passed cumulative	100	95.5	79.3	68.2	58.4	52.6	28.91	18.29

3.4. Pine Resin

The tests carried out on the physical properties of pine resin were specific gravity and water content. The specific gravity of pine resin is 1.05 and the water content is 1.39%.

3.5. Asphalt grade 60/70 modified Pine Resin

Pine resin used as the partial substitution of oil asphalt was 2.5-12.5% interval 2.5%. The use of pine resin affected to physical characteristics of the modified asphalt. The More pine resin content used, the lower penetration on the modified asphalt. Here is shown in Table 3 as follows.

Table 3. The Physical characteristic of oil asphalt modified pine resin

Pine resin content	Ductility (cm)	Penetration (0,1 mm)
2.5%	>140	67.0
5.0%	>140	65.1
7.5%	>140	64.4
10.0%	>140	64.1
12.5%	>140	63.8

3.6. Material Composition of specimen

All specimens were made with 6.5% bitumen content, 10% LGA content, aggregate gradation for hot mix AC-WC, and pine resin variations of 0-12.5% of oil asphalt. Pine resin is used as a partial substitute for oil asphalt. The composition of materials used to make a Marshall cylindrical specimen is shown in Table 4 as follows.

Table 4. The material composition of AC-WC hot mix specimen

Specimen Code	Pine resin Content (%)	Oil Asphalt Content(%)	10% Natural Asphalt Content		Aggregate Content (%)	Total (%)
			Bitumen LGA (%)	Mineral LGA (%)		
P0	-	4.29	2.21	7.79	85.71	100
P2.5	0.11	4.18	2.21	7.79	85.71	100
P5.0	0.21	4.08	2.21	7.79	85.71	100
P7.5	0.32	3.97	2.21	7.79	85.71	100
P10.0	0.43	3.86	2.21	7.79	85.71	100
P12.5	0.54	3.75	2.21	7.79	85.71	100

4. Data Analysis

Data obtained from a volumetric test and Marshall Stability test was analyzed to find the Marshall characteristic consisting of density, void Mineral Aggregate (VMA), Void Filled Bitumen (VFB), Void in Mixture (VIM), Marshall Stability (MS), Flow, and Marshall Quotient (MQ). To analyze the Marshall characteristic used equations (1) -(6) as follows [10].

$$\gamma_d = \frac{w_d}{V} \tag{1}$$

$$\text{VMA}= \frac{100(G_{sb} - G_{mb}) + G_{mb} \cdot p_b}{G_{sb}} \tag{2}$$

$$\text{VIM}= \frac{G_{mm} - G_{mb}}{G_{mm}} \times 100 \tag{3}$$

$$\text{VFB}= \frac{(\text{VMA} - \text{VIM})}{\text{VMA}} \times 100 \tag{4}$$

4.1. Marshall Stability

The Marshall stability indicates the strength of the asphalt mixture to withstand the maximum static load before deformation failure. It is calculated using equation (1).

$$\text{MS} = 100 S_d c_a c_v \tag{5}$$

4.2. Flow

Flow is the deformation ability of the asphalt mixture due to loading. The flow of the asphalt mixture identifies the ductility of the mixture. The higher the mixture flow, the more flexibility the mixture. Conversely, the lower the flow, the higher the stiffness of the mixture.

4.3. Marshall Quotient

The Marshall Quotient indicates the stiffness of the asphalt mixture. The higher the Marshall Quotient of the asphalt mixture, the stiffer the mixture is. Marshall Quotient is a comparison between the marshall stability with the flow.

$$MQ = \frac{MS}{F} \quad (6)$$

5. Discussion

5.1. Volumetric of Asphalt Mixture

5.1.1. Density

Density is usually used to determine the quality and quantity of pavement work. A density relates to the tonnage of the asphalt mixture. If the pavement thickness is known, referring to the density of the mixture, the tonnage of the work will be obtained. Density also is related to void in asphalt mixture.

The higher using of resin as the partial substitution of oil asphalt is effected to increase of the mixture density. The use of 1% pine resin as a substitution for oil asphalt increases 0.0023 gr/ml of the mixture density. The correlation between pine resin content and the density of asphalt mixture using natural asphalt is shown in Figure 3.

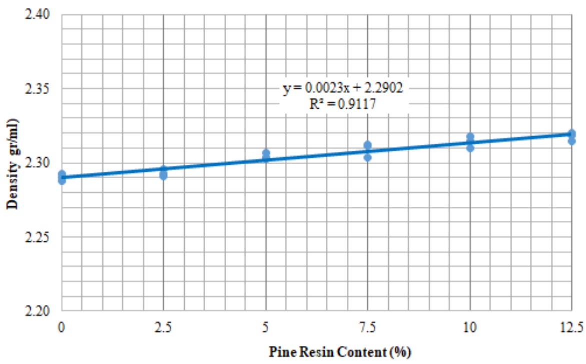

Figure 3. The correlation between pine resin content and the density of asphalt mixture

5.1.2. Void Mineral Aggregate

The use of 2.5-12.5% pine resin as a partial substitution for oil asphalt can reduce Void mineral aggregate. The VMA of a mixture of asphalt without pine resin was 18.1% and the use of 12.5% pine resin reduced the VMA to 16.9%. Here still meets the specifications required by Indonesia Standard, Bina Marga-2010, a minimum of 15% VMA [11]. The viscosity of pine resin at mixing temperature (160oC) and compaction temperature (150oC) is lower than oil bitumen. Pine resin as a partial substitute for oil asphalt can be more easily absorbed into void mineral aggregate. So that the void in mineral aggregate decreases. The correlation between pine resin content and VMA of asphalt mixture using natural asphalt grade B 50/30 is shown in Figure 4.

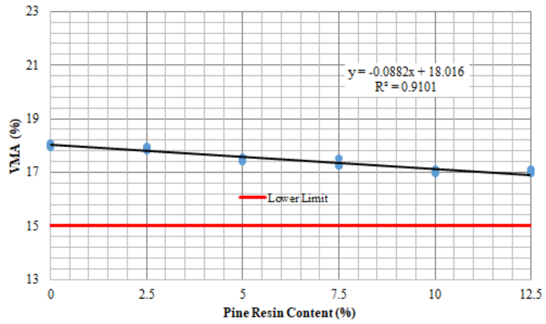

Figure 4. The correlation between pine resin content and VMA of asphalt mixture

At figure 4 above, it is shown that the higher using of pine resin as a partial substitution for oil asphalt influences to decrease of the void in mineral aggregate. The use of 1% pine resin as a substitution for oil asphalt can decrease 0.0882% VMA.

5.1.3. Void in Mixture

The VIM test result showed that the VIM of asphalt mixture without pine resin is 4.8% and the use of 12.5% pine resin produces a VIM of 3.5%. Based on Indonesia Standard, Highways specifications-2018, the VIM of asphalt mixture used 2.5-12.5% pine resin still meets the requirements, 3-4%. The decreasing of VIM was affected by the viscosity of pine resin which was lower than the viscosity of asphalt at mixing temperature and compaction temperature. This condition allows asphalt modified with pine resin to have the ability to fill more voids in asphalt mixing. The correlation between pine resin content and the VIM of asphalt mixture is shown in Figure 5.

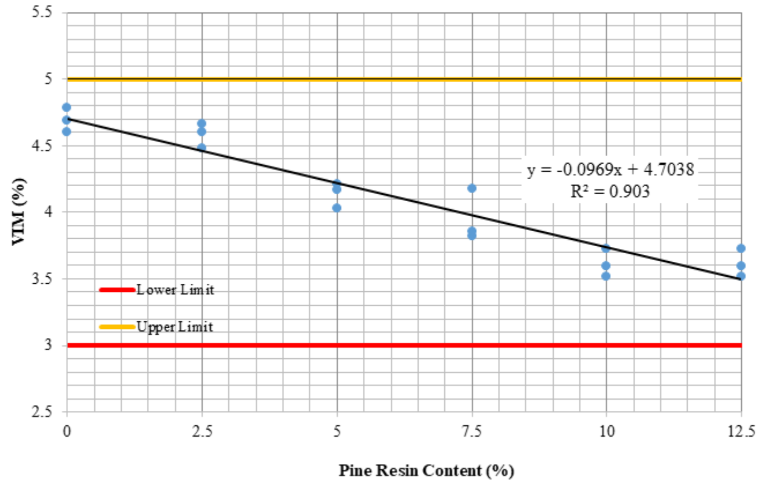

Figure 5. The correlation between pine resin content and VIM of asphalt mixture using natural asphalt

At figure 5 above, it is shown that the higher using of pine resin as a partial substitution for oil asphalt influences to decrease of the VIM of asphalt mixture. The use of 1% pine resin as a substitution for oil asphalt can decrease 0.0969 VIM.

5.1.4. Void Filled Bitumen

The VFB of Asphalt filled bitumen has a strong correlation to Void in Mixture. Increasing voids filled bitumen results in reduced voids in the mixture. The VFB test result showed that the VFB of asphalt mixture without pine resin is 73.6% and the use of 12.5% pine resin produces a VFB of 79.2%. Based on Indonesia Standard, Highways specifications-2018, the VFB of asphalt mixture used 2.5-12.5% pine resin still meets the requirements, more than 65% [11]. Increasing VFB was influenced by the viscosity of oil asphalt modified with pine resin at mixing temperature and compaction temperature lower than oil asphalt viscosity. Therefore, the more the use of pine resin the more voids filled bitumen. The correlation between pine resin content and the Void filled bitumen of asphalt mixture using natural asphalt grade 50/30 is shown in Figure 6.

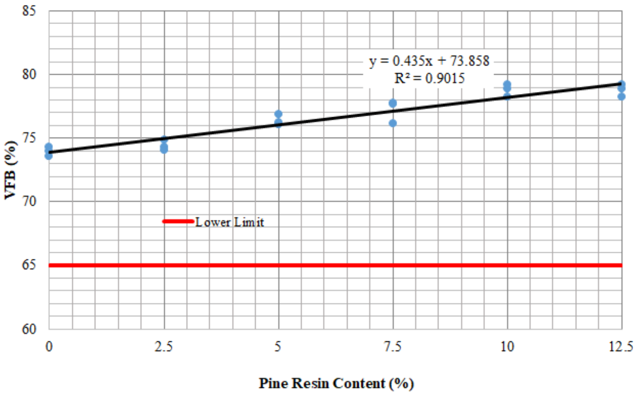

Figure 6. The correlation between pine resin content and VFB of asphalt mixture

At figure 6 above, it is shown that the higher using of pine resin as a partial substitution for oil asphalt is effected to increase of the voids filled bitumen. The use of 1% pine resin as a substitution for oil asphalt can increase VFB by 0.435 %.

5.2. Stability, Flow, and Marshall Quotient

5.2.1. Marshall Stability

The use of pine resin for hot mix AC-WC containing natural asphalt influences the Marshall criteria. Increasing the use of pine resin due to the decreasing of Marshall Stability. The stability of hot mix asphalt without pine resin is 3055 kg and the stability of hot mix asphalt with 12.5% pine resin is 2397 Kg. The use of pine resin up to 12.5% in asphalt mixtures containing natural asphalt produces Marshall Stability 2.4 times more than that designated in the Indonesian Standard, Highway Specifications-2018, which is more than 1000 kg [11]. The correlation between pine resin content and Marshall Stability is shown in Figure 7.

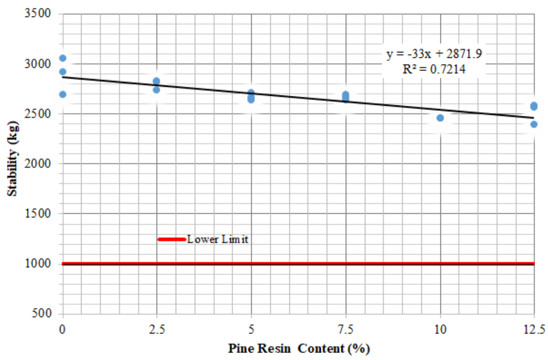

Figure 7. The correlation between pine resin content and stability of asphalt mixture

At figure 7 above, it is shown that the higher using of pine resin as a partial substitution for oil asphalt decreases the Marshall Stability. The use of 1% pine resin as a substitution for oil asphalt can decrease MS by 33 kg.

5.2.2. Flow

The addition of the use of pine resin as much as 2.5 -12.5% decreases the flow of the asphalt mixture. The flow of asphalt mixture without pine resin is 3.2 mm and the flow of asphalt mixture with 12.5% pine resin is 2.0 mm. These results indicate that the flow of asphalt mixture containing up to 12.5% pine resin still meets Indonesian standards, highway specifications-2018, namely 2-4 mm [11]. The reduced flow of asphalt mixture is caused by the penetration of asphalt modified with pine resin at room temperature which is lower than the penetration of oil asphalt. The correlation between the flow of asphalt mixture and the use of pine resin in hot mix A-WC containing natural asphalt is shown in Figure 8.

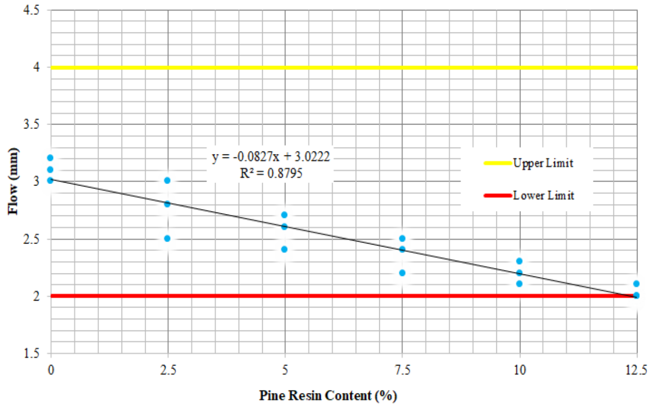

Figure 8. The correlation between pine resin content and flow of hot mix AC-WC using natural asphalt

At figure 8, it is shown that the higher use of pine resin as a partial substitution for oil asphalt can decrease Flow. The use of 1 % pine resin as a substitution for oil asphalt can decrease 0.0827 mm of Flow.

5.2.3. Marshall Quotient

The addition of pine resin with a variation of 2.5-12.5% has the effect of reducing the Marshall stability and the flow of the asphalt mixture. The Marshall question is the ratio between the stability of the marshall to the flow of the asphalt mixture. The greater the MQ of the asphalt mixture, it indicates that the mixture is stiffer. The MQ of asphalt mixture without pine resin is 840 kg/mm and The MQ of asphalt mixture containing 12.5% pine resin is 1,293 kg/mm. These MQ meet the Indonesian standard, Highway specification-2018, namely more than 250 kg/mm [11]. The correlation between the MQ of asphalt mixture and the use of pine resin in hot mix asphalt AC_WC containing natural asphalt is shown in Figure 9.

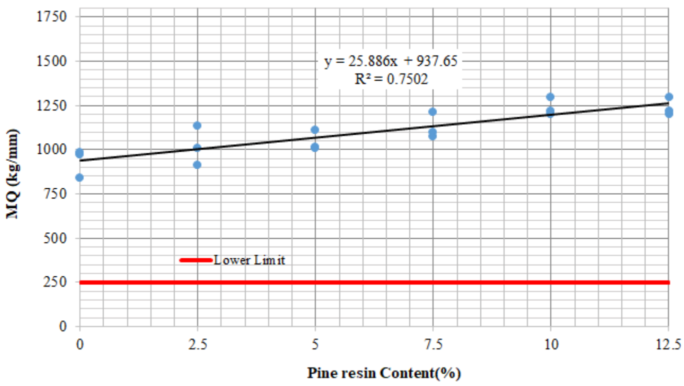

Figure 9. The correlation between pine resin content and MQ of asphalt mixture using natural asphalt

At figure 9 above is shown that the higher using of pine resin as partially substitution of oil asphalt is effected to increase of the Marshall Quotient. Using 1% of pine resin as substitution of oil asphalt can increase 25.89 kg/mm of MQ. At figure 9, it is shown that the higher use of pine resin as a partial substitution for oil asphalt can increase the Marshall Quotient. The use of 1% pine resin as a partial substitution for oil asphalt can increase MQ by 25.89 kg/mm.

In brief, the effect of using pine resin in the hot asphalt AC-WC containing natural asphalt on the Marshall criterion is shown in Table 5 below.

Table 5. The Marshall criterion of asphalt mixture containing natural asphalt and pine resin

Pine Resin Content (%)	**Density** (gr/ml)	**VMA** (%)	**VIM** (%)	**VFA** (%)	**Marshall Stability** (Kg)	**Flow** (mm)	**Marshall Quotient** (kg/mm)
0	2.290	18.0	4.7	73.9	2,889	3.1	908
2.5	2.293	17.9	4.6	74.4	2,796	2.8	1,017
5	2.304	17.5	4.1	76.4	2,672	2.6	1,043
7.5	2.309	17.3	4.0	77.0	2,664	2.4	1,128
10	2.314	17.2	3.8	78.1	2,570	2.2	1,099
12.5	2.318	17.0	3.6	78.8	2,515	2.0	1,237
Spesification	-	14	3-5	>65	1000	2-4	>250

6. Conclusion

Based on the discussion above, the use of pine resin as a partial substitute for oil asphalt in hot mix asphalt AC-WC containing natural asphalt greatly influences the Marshall criterion. The conclusions of this research are:

- ✓ The higher use of resin as a partial substitution of oil asphalt has an impact on increasing the density of the mixture, decreasing voids in the mixture, decreasing voids in the mixture, increasing voids filled with asphalt, decreasing Marshall Stability, decreasing Flow, and increasing Marshall Quotient.
- ✓ The use of 1% pine resin as a partial substitution for oil asphalt can increase 0.0023 gr/ml of the mixture density, decrease 0.0969 % of VIM, decrease 0.0969 % of VIM, increase 0.435 % of VFB, decreases 33 kg of MS, decreases 0.0827 mm of Flow, and increase 25.89 kg/mm of MQ.
- ✓ The use of up to 12.5% pine resin and 10% natural asphalt in the AC-WC asphalt mixture meets the requirements of the Indonesian Standard, Highway Specifications - 2018.
- ✓ The use of 12.5% pine resin and 10% natural asphalt can substitute as much as 42.28% of oil asphalt.

Future Work

Following up on the research that has been done, some research that needs to be continued in the future is as follow:

- The durability of the hot mix asphalt containing natural asphalt and pine resin.
- The characteristics of hot mix asphalt containing natural asphalt and pine resin due to cyclic loading.
- The contribution of using other natural resins as a substitute for oil asphalt in asphalt mixtures containing natural asphalt and pine resin.

Nomenclatures

c_a : apparatus calibration (KN)
c_v : correction on specimen volume.γ_d : dry density of specimen (gr/ml)
F : flow (mm)
G_{mb} : the bulk specific gravity of specimen(gr/ml)
G_{mm} : the maximum specific gravity of specimen (gr/ml)
G_{sb} : the bulk specific gravity of combined aggregate (gr/ml)
MS : Marshall stability (kg)
MQ : Marshall quotient (kg/mm),
V : the volume of specimen(ml)
VFB : void filled bitumen (%)
VIM : void in the mixture (%)
VMA: Void Mineral Aggregate (%)
w_d : the dry weight of specimen(gr)
S_d : stability dial needle display
p_b : proportion aggregate to the total weight of the specimen (%)
γ_d : density (gr/ml)

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1.] Trihusodo, P. Beralih ke Aspal Buton. Portal Informasi Indonesia.Indonesia.go.id. Oktober 2022.

[2.] Affandi, F. Pengaruh Asbuton Semi Ekstrasi Pada Campuran Stone Mastic Asphalt, Puslitbang Jalan Dan Jembatan, Bandung. 2010.

[3.] One L, Tjaronge M.W, Irmawaty R, Hustim M. Effect of Buton Granular Asphalt Gradation and Cement as Filler on Performance of Cold Mix Asphalt Using Limestone Aggregate. Journal of Engoneering Science and Technology. Vol.16(1). Taylor's University. Malaysia. 2020.

[4.] One L, Tjaronge M.W, Irmawaty R, Hustim M. Effect of buton's granular asphalt gradation on marshall stability of cold emulsified asphalt mixtures under wet condition. IOP Conference Series: Earth and Environmental Science. Volume 419. The 3rd International Conference on Civil and Environmental Engineering (ICCEE 2019) Bali, Indonesia. 29–30 August 2019.

[5.] Ngii E, One L, Nasrul N, and Udo M.I. Effects of Dammar as the partial substitution of bitumen in HMA AC-WC containing Buton Asphalt. IOP Conference Series: Earth and Environmental Science. Volume 1065. The Fourth International Conference on Sustainable Infrastructure and Built Environment. Bogor. Indonesia. 2022.

[6.] PT. Perhutani. Rise and Growth (Bangkit dan Tumbuh). Laporan Tahunan/ annual report 2021. Jakarta – Inodenisia. 2022. https://drive.google.com/file/d/1XECYi4lh0DeamLAsTGo19X__IzLCl9e8/view.

[7.] Kencanawati C., Sugita I.K.G, Suardana N, and Suyasa, I.W.B. Karakteristik Dan Analisis Awal Getah Pinus Merkusii (Pine Resin) dengan Variasi Suhu Pemanasan sebagai Alternatif Resin Pada Komposit. Proceeding Seminar Nasional Tahunan Teknik Mesin (SNTTM). Surabaya-Indonesia.2017.

[8.] Maula A, Saleh S.M, and Mita F. Pemanfaatan Gondorukem Sebagai Bahan Substitusi ke Dalam Aspal Pen 60/70 pada Campuran Aspal Porus. 1(2), 93–99. 2019.

[9.] Perceka D.P, and Ing T.L. Pengaruh Getah Pinus Pada Stabilitas, Pelelehan, dan Durabilitas Lapis Pengikat Beton Aspal. 64–83. (2016).

[10.] Asphalt Institute. Manual Series No. 4 (MS 4). 1989.

[11.] Direktorat Jendral Bina Marga. Spesifikasi Umum 2018 Untuk Pekerjaan Jalan Dan Jembatan. Jakarta: Direktorat Jendral Bina Marga. 2018.