Use of Nickel Slag as An Aggregate Replacement Material In Weared Asphalt Concrete Mixtures

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The increase in development growth throughout the world every year is directly proportional to the increase in demand for construction materials. To overcome the very limited sources of natural materials, alternative materials are needed as substitutes for construction materials. Utilizing nickel slag waste as an alternative material to replace natural aggregate to reduce the extraction of excess natural aggregate and preserve limited natural resources. The purpose of this study was to determine the Marshall characteristics and ideal composition for using nickel slag as a substitute for aggregate in worn-coated asphalt concrete (AC-WC) mixtures. The test specimens used were a mixture of worn coated asphalt concrete (AC-WC) with variations in nickel slag content, namely 0%, 10%, 40% and 70% and optimum asphalt content (KAO) respectively of 5.5%; 6%; 5.5%; and 5%. Based on the results of study that has been carried out, the optimum stability value was obtained at 1087.38 kg at a nickel slag content of 70% with an optimum asphalt content (KAO) of 5%. This value is greater than the stability value obtained at a nickel slag content of 0% with an asphalt content. optimum 5.5%, namely 1034.39 kg. From these results it can be concluded that nickel slag can improve the performance of worn coated asphalt concrete (AC-WC) mixtures and the ideal composition of nickel slag is at a nickel slag content of 70% with an optimum asphalt content (KAO) of 5%.

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1. INTRODUCTION

Infrastructure development in a country will continue [1]. With worldwide development growing at 6-9% annually, the demand for construction materials will also increase. However, sources of natural building materials are limited. Therefore, a solution is needed to preserve natural resources and continue to carry out infrastructure development [2], [3]. One solution is to find alternative materials to replace construction materials.

On the other side, nickel production around the world has also increased. This is due to the large demand for nickel slag in the electronics industry sector, battery industry and metal industry. With the increase in material production, it is also directly proportional to the increase in processing waste that can pollute the environment. Indonesia is the largest nickel producing country in the world. Every year there are 1 million tons of nickel slag produced from nickel processing, and it is estimated that the total waste from nickel processing in 2019-2024 will reach 14,173,000 tons [4]. In addition, with a stainless-steel consumption target of 1.5 kg per capita in 2025, nickel production in Indonesia will continue to increase [5]. Nickel slag has a physical form that resembles natural rock, this allows nickel slag to be used as a road pavement material for surface layers and foundation layers [6]. Due to the influence of physical properties and chemical properties, it is necessary to conduct laboratory testing first before widespread use.

Quoted from the website of the Ministry of PUPR, it is said that based on PP No.101 of 2014, the utilization of materials with the category of B3 waste must be tested to determine the content of hazardous substances [7]. One way is to conduct a Toxicity Characteristic Leaching Procedure (TCLP) test [8]. The results of the TCLP test carried out the content of toxic materials contained in nickel slag waste is entirely smaller than the TCLP-A and TCLP-B value requirements. This shows that nickel slag waste can be used as a substitute for natural aggregate as a pavement material and can be categorized as an environmentally friendly material because the TCLP test results are all smaller than the permissible requirement value [9].

The asphalt concrete mixture consists of coarse aggregate, fine aggregate, filler, and asphalt as a binder. The set of materials will be mixed and compacted at a certain temperature. In the implementation of asphalt concrete mixtures, the characteristics of the aggregate will greatly affect the result of the asphalt concrete mixture. One of the difficulties often encountered in the manufacture of asphalt concrete is to obtain aggregates that meet the requirements. Therefore, alternative materials are needed as fillers that can meet the necessary requirements. Alternative materials that are often used include nickel slag, steel slag, plastic waste, and so on [10], [11].

The filler serves to increase the specific gravity of the mixture and reduce the amount of asphalt needed to fill voids [12]. Asphalt is defined as a black or dark brown material that can be solid to slightly solid at room temperature, but if heated to a certain temperature it can become liquid. This makes asphalt able to wrap aggregate particles when making asphalt concrete mixtures [13]. Nickel slag is industrial waste from nickel processing in the form of chunks and is produced due to the combustion and smelting of nickel[14]. The slag must be properly utilized because it has the potential to cause environmental problems and social phenomena in the community[15]. Thus, the results of this study can solve the problem and can reduce the effects of pollution and can provide economic value for the slag.

The utilization of nickel slag has been carried out on wear layer asphalt concrete (AC-WC) mixtures; nickel slag is used as a fine aggregate additive by showing that nickel slag levels that meet Marshall properties are at 10% nickel slag levels [16]. The use of nickel slag has been carried out to substitute natural aggregates with variations in nickel slag mixes of 0%, 25%, 50%, 75%, and 100%. The use of nickel slag in concrete mixtures can affect the compressive strength value of concrete, the more slag composition used, the higher the compressive strength value of concrete [17]. In another study, it was shown that FeNi4 fine nickel slag with variations in nickel slag content of 0%, 50%, and 100% has the potential to be used as fine aggregate in HRS-WC asphalt mixtures. The more use of FeNi4 nickel slag, can reduce the range of Optimum asphalt content obtained, but its use is limited to a maximum of 50% [18]. While in Marshall testing for HRS-WC mixtures it can be concluded that the use of FeNi III nickel slag filler can improve the quality of the mixture [19].

2. METHODOLOGY

This study was done at the Civil Engineering Laboratory of Sultan Ageng Tirtayasa University, Cilegon City, Banten Province. The aggregates used in this study are natural aggregates from PT Bukit Sunur Wijaya, and nickel slag aggregates from PT Growth Java Industry. The asphalt used is Pertamina Pen 60/70 asphalt.

Figure 1. Natural Aggregates and Nickel Slag Aggregates

The guidelines used in this study are the General Specification Standard Division 6 Bina Marga 2018 and the Indonesian National Standard (SNI). The method used as a mixture tester is the Marshall method. Aggregate, nickel slag and asphalt were tested with SNI and General Specifications Division 6 Bina Marga 2018. Variations in nickel slag levels used in this study were 0%, 10%, 40% and 70%.

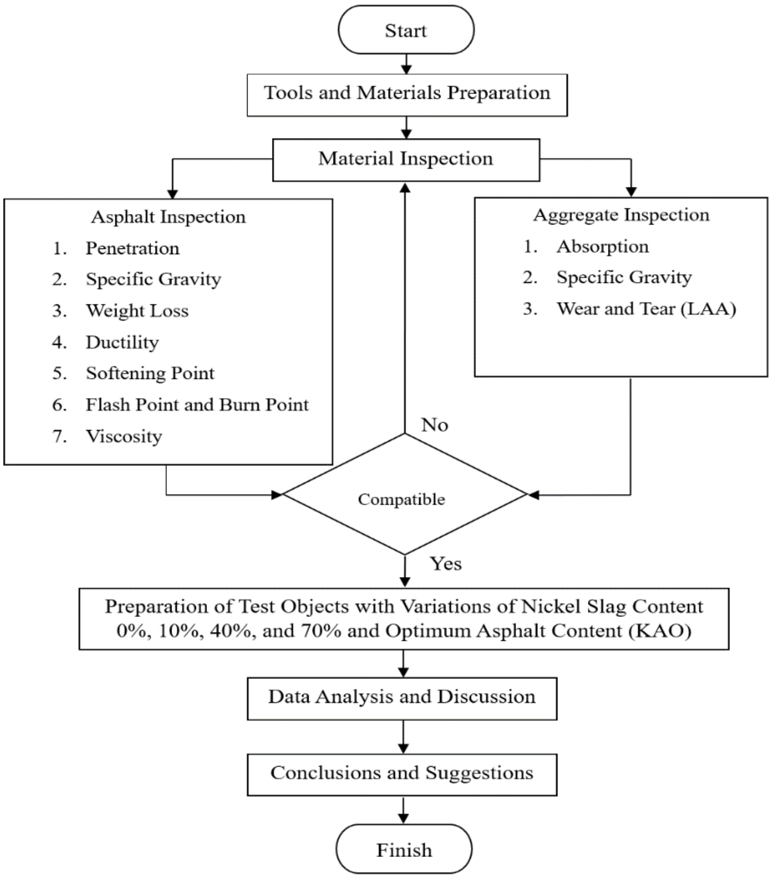

Figure 2. Study Flow Diagram

3. RESULTS AND DISCUSSION

Before marshall testing, the following tests were carried out to investigate the characteristics of natural aggregates, nickel slag and asphalt. This test is used to check the proper use of the materials needed before making the test samples that will be tested for Marshall. The test uses the standard of SNI and Bina Marga Specification 2018. The contents of these tests are the results obtained from testing the characteristics of the material.

3.1 Testing the Physical Properties of Materials

The physical properties of the materials in this study include testing the specific gravity and absorption of course aggregates and testing the wear of coarse aggregates with a los angeles abration machine. The tests were conducted on two types of aggregates, namely natural stone aggregate and nickel slag aggregate.

Table 1. Natural Stone Aggregate Testing Results

No	Test	Result	Spesification		Standard
		Nature Aggregate	Min	Max	
1	Abration (%)	19,337		40	SNI 2417-2008
2	Specific Gravity of Coarse Aggregate (g/cm^3)				
	Bulk	2,681			
	SSD	2,712	2,5		
	Apparent	2,769			
3	Absorption of Coarse Aggregate (%)	1,185		3	SNI 1969-2008
4	Specific Gravity of Fine Aggregate				
	Bulk	2,544			
	SSD	2,604	2,5		
	Apparent	2,775			
6	Absorption of Fine Aggregate (%)	2,354		3	

In the natural stone coarse aggregate test, the average bulk specific gravity obtained was 2.910 g/cm^3. The average water absorption was 0.249%. While the average specific gravity obtained for natural stone fine aggregate is 2.786 g/cm^3. As for water absorption, the average is 1.112%. The wear test for natural stone aggregate is 19.337%.

Table 2. Nickel Slag Aggregate Testing Results

No	Test	Result	Spesification		Standard
		Slag Nickel	Min	Max	
1	Abration (%)	23,615		40	SNI 2417-2008
2	Specific Gravity of Coarse Aggregate (g/cm^3)				
	Bulk	2,910			
	SSD	2,917	2,5		
	Apparent	2,931			
3	Absorption of Coarse Aggregate (%)	0,249		3	SNI 1969-2008
4	Specific Gravity of Fine Aggregate				
	Bulk	2,875			
	SSD	2,899	2,5		
	Apparent	2,944			
6	Absorption of Fine Aggregate (%)	0,806		3	

In the nickel slag coarse aggregate test, the average bulk specific gravity obtained was 2.910 g/cm^3. The average water absorption was 0.249%. While the average specific gravity obtained for nickel slag fine aggregate is 2.910 g/cm^3. As for water absorption, the average is 0.249%. Wear testing for nickel slag aggregates was found to be 23.615%.

During the calculation of the mix composition of the test samples, the value of specific gravity will affect it. Based on the results from the aggregate test, the specific gravity of nickel slag is more than the specific gravity of natural aggregates. This can cause the mixture weight with the addition of nickel slag to be heavier than that without nickel slag. Meanwhile, the absorption rate of nickel slag aggregate is smaller than the natural stone aggregate which can affect the porosity of the aggregate.

The wear value indicates the resistance of an aggregate to withstand the friction that occurs during testing. The smaller the wear value obtained indicates the material has greater wear resistance. The tests conducted on natural aggregates and nickel slag showed that natural aggregates have greater wear resistance than nickel slag.

Table 3. Testing Asphalt Characteristics

No	Test	Result	Specification		Standard
			Min	Max	
1	Penetration 25°C (mm)	65,2	60	70	SNI 06-2456-2011
2	Soft Point 25°C (°C)	50	48		SNI 2434-2011
3	Specific Gravity (g/cm^3)	1,013	1		SNI 06-2441-2011
4	Ductility (cm)	109	100		SNI 2432-2011
5	Flash Point (°C)	325	232		SNI 2433-2011
6	Burning Point (°C)	340			
7	Losing Weight (%)	0,21		0,8	SNI 06-2441-1991
8	Viscosity 135°C (Cst)	400	300		ASTM D2170-10

An asphalt is generally defined as a cement-based material, which has a dark brown or black color, with tar as its main element. The asphalt used in this study is Pertamina Penetration 60/70 asphalt. Asphalt penetration 60/70 has characteristics that make it suitable for various environmental conditions and road surfaces. The specific gravity of asphalt in this study was found to be 1.013 g/cm3 which can indicate that the asphalt used has a small oil content and particles so that this asphalt has good quality. The softening point of the asphalt was found to be 50 °C so that this asphalt is good for use in asphalt mixtures. The weight loss of asphalt oil was found to be 0.21%, which can be concluded that the asphalt used has good durability because it can maintain its original properties. From the study results, the flash point is 325 ˚C and the burn point is 340˚C, it can be concluded that the asphalt has good resistance to the risk of fire and other hot materials because it meets the requirements of at least 232˚C. Thus, in the field when the temperature reaches 325 ˚C, the asphalt starts to burn and when the temperature reaches 340 ˚C, the asphalt starts to burn. The higher the temperature of the asphalt burning point, the better because it is not flammable.

3.2 Marshall Testing

The test was used Marshall instrument in following the procedure of SNI 06-2489-1991 or AASHTO T245-90, which is by placing the test sample into the lower segment of the Marshall instrument, the time needed since the test sample was taken out of the maximum water bath should not be more than 30 seconds. Then the test sample is weighted at a speed of about 50 mm per minute until the maximum weight is reached and then the stability and flow loads are noted. The Marshall test results are obtained in the form of mixture and material characteristics, namely, stability, flow, VIM, VFA, VMA and Marshall Quotient which can be calculated.

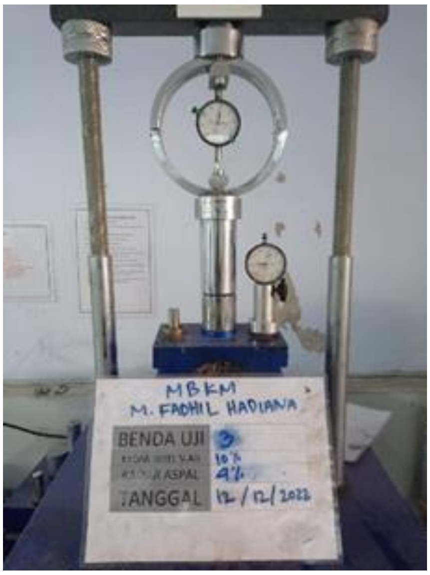

Figure 3. Marshall Testing

a. Analysis of VMA (Void in Mineral Aggregate)

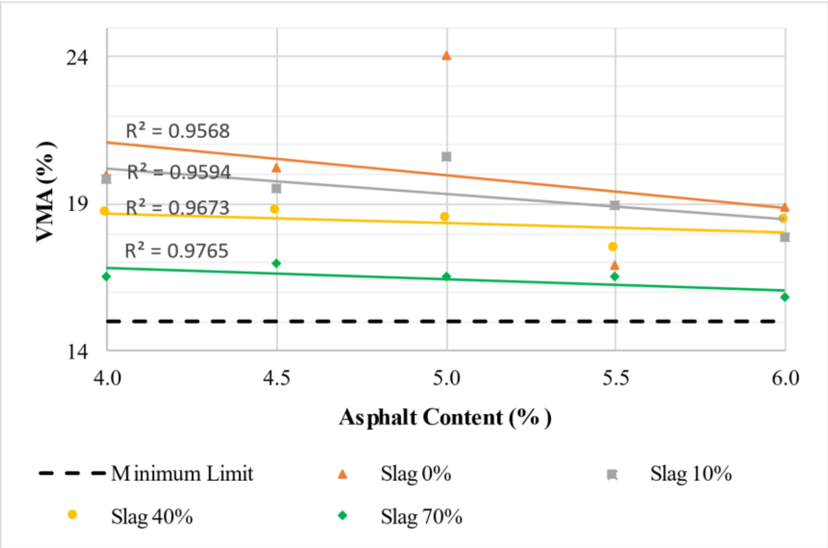

Figure 4. VMA vs Asphalt Content

VMA is the cavity in the pores of asphalt mixtures including air voids and effective asphalt volume. The VMA value is influenced by several factors such as aggregate gradation, compaction energy, asphalt content, and grain shape [20]. From the graph in Figure 4, the highest VMA value is found in the specimen with 0% nickel slag content. Precisely at 5% asphalt content with a value of 24.01%. VMA value affects the cavity filled by asphalt. The greater the value, the greater the cavity filled by asphalt. When viewed in terms of the addition of nickel slag, the addition results in a reduced VMA value. This is because the weight content of the mixture is small which is caused by high absorption in the mixture. Judging from the weight of the large SSD condition test specimens. Based on the coefficient of determination on the VMA value of 0.9568 - 0.9756, it shows that the relationship to the VMA value has a strong correlation.

b. Analysis of VIM (Void in Mixture)

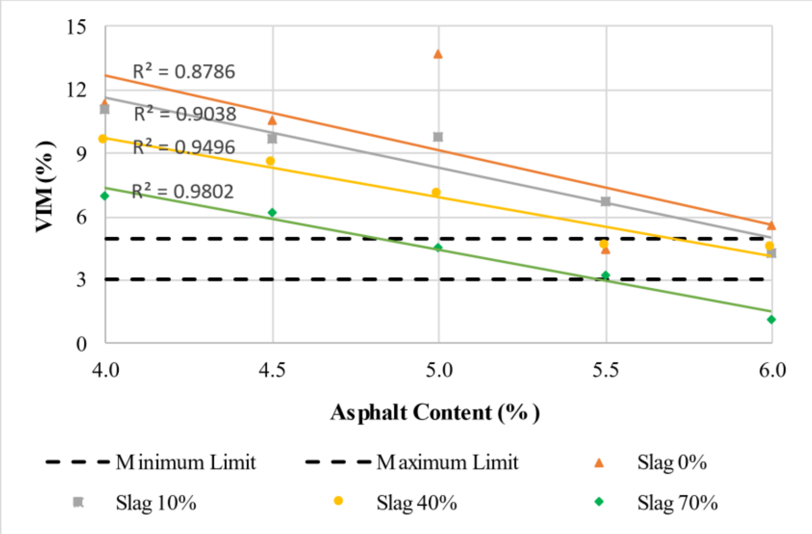

Figure 5. VIM vs Asphalt Content

VIM is the voids that are not filled by asphalt. VIM is part of the VMA but not filled with asphalt. From the graph in Figure 5, in terms of asphalt variation, the VIM value tends to decrease. This is because the more asphalt is used, the less empty voids are filled with asphalt. So, it can be concluded that the greater the asphalt content used, the smaller the VIM produced. The VIM value can also be influenced by the porosity or absorption of the aggregate [21]. When viewed from the variation of nickel slag used, the use of nickel slag can be said to be effective because there are 5 levels of nickel slag that meet Bina Marga requirements. Precisely at 70% nickel slag content there are 2 qualified asphalt levels, namely 4.5% and 5%, at 40% nickel slag content there are 2 qualified asphalt levels, namely 5.5% and 6%. While only 1 level with 0% and 10% nickel slag meets Bina Marga requirements. Precisely at 5.5% and 6% asphalt content. Based on the coefficient of determination on the VIM value of 0.8786 - 0.9802 which shows that there is a strong correlation relationship.

c. Analysis of VFA (Void Filled with Asphalt)

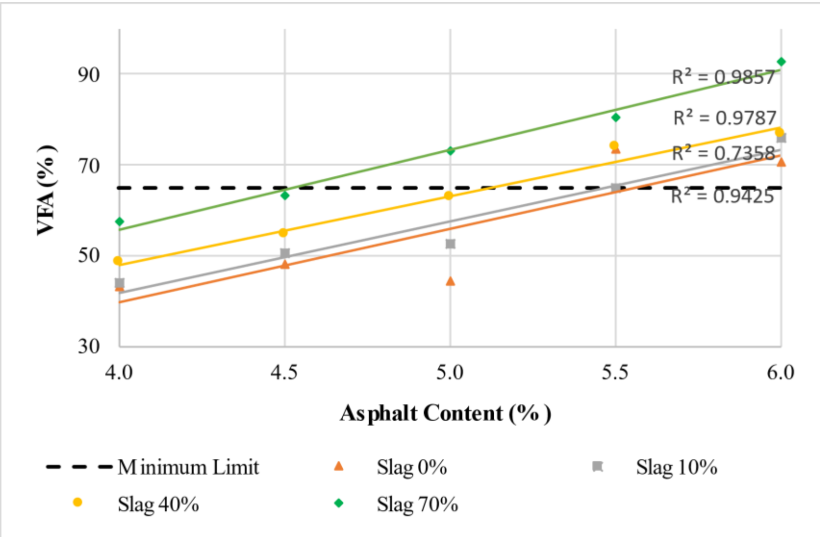

Figure 6. VFA vs Asphalt Content

VFA is the percentage of voids filled by asphalt. This value is influenced by the VIM and VMA values. From the graph in Figure 6, in terms of asphalt variation, the VFA value tends to increase. This is because the more asphalt used, the more voids are filled by asphalt, besides that the number of collisions and temperature when the asphalt is compacted can also affect the VFA value [22]. So, it can be concluded that the greater the asphalt content used, the greater the VFA produced. When viewed from the variation of nickel slag used, the use of nickel slag can be said to be effective because it gets a higher VFA value compared to the mixture without nickel slag. This is because the relatively hollow shape of nickel slag makes it easy for asphalt to fill the voids in the mixture.

The VFA value is also related to the VIM and VMA values. The relationship between VIM and VFA is inversely proportional, which means that the greater the VIM value, the smaller the VFA value. While the relationship between VFA and VMA is directly proportional, which means that the greater the VMA value, the greater the VFA value. However, too large a VMA value can result in bleeding at high temperatures which will cause the asphalt to rise to the surface. Based on the coefficient of determination of the VFA value of 0.7358 - 0.9857, it shows that the relationship to the VFA value has a strong correlation.

d. Analysis of Stability

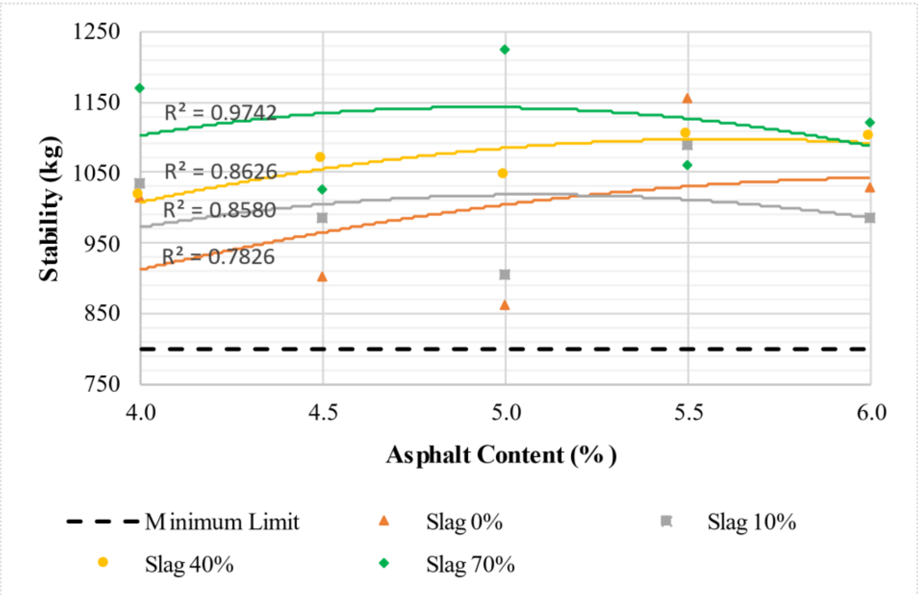

Figure 7. Stability vs Asphalt Content

Stability is the maximum load that a paved mixture can withstand until it collapses. The stability value can be influenced by several factors, namely specific gravity, gradation of mixed aggregates, and asphalt content in the mixture [23]. From the graph contained in Figure 7, the stability value is relatively close between all objects varying levels. However, the highest stability value of 1222.53 kg was obtained when the nickel slag content was 70% and the asphalt content was 5%. From the results of this test, it can be concluded that the substitution of nickel slag can increase the stability value that exceeds the Bina Marga requirements. Judging from Figure 5, the stability value tends to increase with the addition of nickel slag. When viewed at 5% asphalt content, when 0% nickel slag content is obtained, the stability value of 860.75 kg increases when 10%, 40%, and 70% nickel slag is added, the stability value becomes 904.41 kg; 1046.70 kg; and 1222.53 kg. Based on the coefficient of determination of the stability value of 0.7826 - 0.9742 shows that the relationship to the stability value has a strong correlation.

e. Analysis of Yield (Flow)

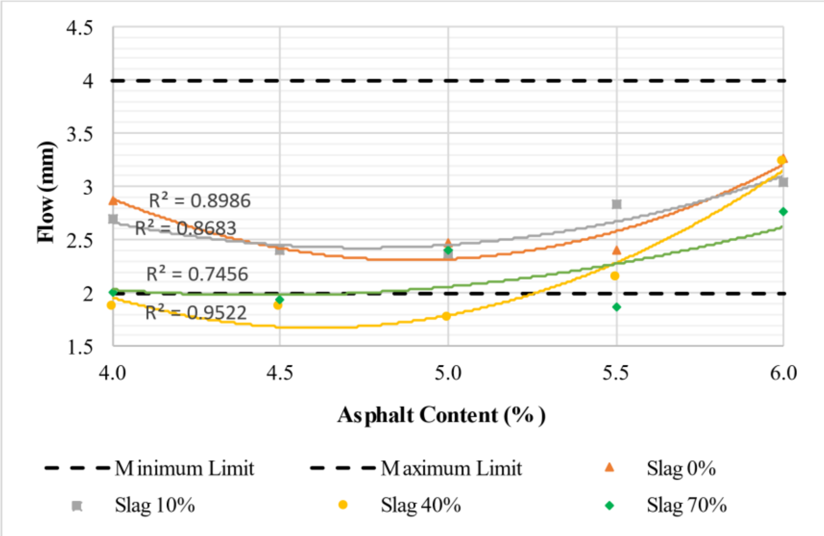

Figure 8. Flow vs Asphalt Content

The flow value is the decrease value obtained after the Marshall test is carried out. This value is obtained from the flow dial on the Marshall tool used. From the graph in Figure 8, most of the decrease (flow) values meet the provisions of Bina Marga. However, there are 5 flow values that do not comply with the provisions, namely at 40% nickel slag content at 4.5%; 5%; and 6% asphalt content and at 70% nickel slag content at 4.5% and 5.5% asphalt content. With the addition of nickel slag, the flow value tends to decrease. As in the 5.5% asphalt content, there is a decrease with the addition of nickel slag. At 0% nickel slag, the flow value is 2.40 mm, at 10% nickel slag, the flow value is 2.83 mm, at 40% nickel slag, the flow value is 2.13 mm and at 70% nickel slag, the flow value is 1.87 mm. This is because the wear value of nickel slag tends to be lower than the wear of natural aggregates which results in the mixture more easily decreasing or deforming. Based on the coefficient of determination of the flow value of 0.7456 - 0.9552 shows that the relationship to the flow value has a strong correlation.

f. Analysis of Marshall Qoutient (MQ)

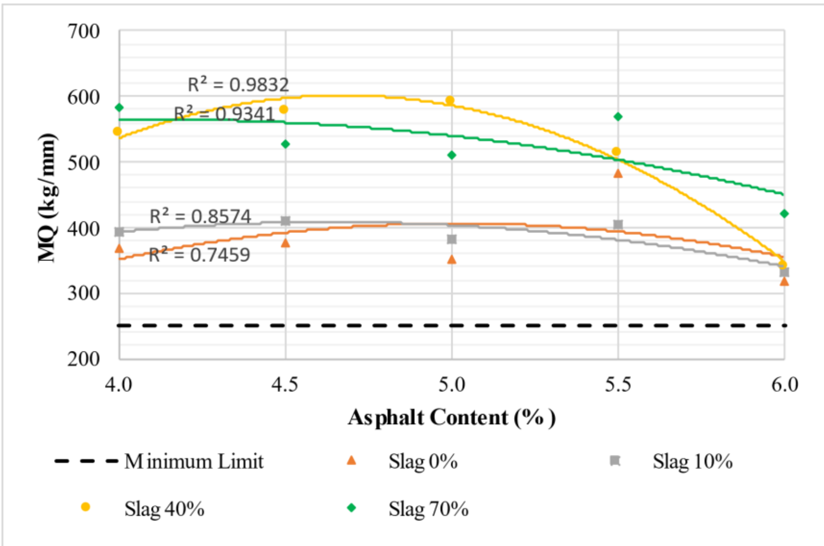

Figure 9. MQ vs Asphalt Content

MQ is the ratio of stability value and flow value. The MQ value is an approach to the level of stiffness and flexibility of the mixture, if the MQ value is greater, the mixture is stiffer, and vice versa if the MQ value is smaller, the pavement is more flexible [24]. From the graph in Figure 9, the MQ value tends to increase when adding nickel slag. This is directly proportional to the increase in stability value and decrease in flow value as the nickel slag content increases. Based on the coefficient of determination on the Marshall Qoutient value of 0.7459 - 0.9832, it shows that the relationship to the Marshall Qoutient value has a strong correlation.

g. Analysis of Optimum Asphalt Content Value

The determination of the KAO value aims to determine the effective asphalt content that meets the Marshall parameters. Determination of this value is to get the optimum asphalt content for the mixture, which later the mixture with the optimum asphalt content and with the percentage of nickel slag each can be compared. From the test, the optimum asphalt content value in this study was 5.5% for 0% and 40% nickel slag content, 6% for 10% nickel slag content and 5% for 70% nickel slag content. Judging from the results obtained, the optimum asphalt content (KAO) value decreases with the addition of nickel slag. This is because the shape of nickel slag is hollow and makes nickel slag easily adhere to asphalt, so the more nickel added, the less asphalt is needed for the mixture.

Table 4. Marshall Test Results with Optimum Asphalt Content

Marshall Characteristics	Optimum Asphalt Content (%)	Nickel Slag Content (%)	Result	Specifications
VMA (%)	5,5	0	16,90	Minimum 15%
	6	10	17,87	
	5,5	40	17,44	
	5	70	16,51	
VIM (%)	5,5	0	4,50	3% - 5%
	6	10	4,30	
	5,5	40	4,67	
	5	70	4,52	
VFA (%)	5,5	0	73,39	Minimum 65%
	6	10	75,96	
	5,5	40	73,59	
	5	70	72,72	
Stability (kg)	5,5	0	1034,39	Minimum 800 kg
	6	10	984,63	
	5,5	40	904,41	
	5	70	1087,84	
Flow (mm)	5,5	0	2,70	2mm - 4mm
	6	10	2,40	
	5,5	40	2,37	
	5	70	2,83	
MQ (kg/mm)	5,5	0	395,28	Minimum 250 kg/mm
	6	10	411,03	
	5,5	40	384,08	
	5	70	403,34	

Based on Table 4, the VMA value decreases with the addition of nickel slag in the mixture. Likewise, the VIM value, as the addition of nickel slag content decreases, so does the VIM obtained. The VFA value is strongly influenced by the VIM and VMA values because VFA is the percentage difference between the VIM and VMA values. As in the results obtained at 5.5% asphalt content with 0% nickel slag content, the VMA value is 16.90% and the VIM value is 4.5%. From the two results the same value produces a small value, it will produce a small VFA value as well, which is 73.39%.

In terms of the stability values obtained from the table above, there is an increase and decrease. The decrease occurred when adding 10% and 40% nickel slag content. Based on Table 4, the stability values obtained when adding 10% and 40% nickel slag are 984.63 kg and 904.41 kg, while without the addition of nickel slag the stability value obtained is 1034.39 kg. When compared to the mixture with 0% nickel slag content, there was a decrease of 49.76 kg at 10% nickel slag content and a decrease of 129.98 kg at 40% nickel slag content or equivalent to a decrease of 4.8105% at 10% nickel slag content and a decrease of 12.5658% in stability value. However, there was an increase when adding 70% nickel slag, obtaining a stability value of 1087.84 kg. When compared to 0% nickel slag content, there was an increase of 53.45 kg or equivalent to 4.9134% stability value. Based on the results of this study, the optimal nickel slag to be used as a substitute is 70% because this level meets the Bina Marga requirements and increases the stability value of the mixture. This is due to the hollow shape of nickel slag, resulting in stronger bonding between nickel slag and asphalt.

In terms of the decrease in flow value that occurred in the results of the table above, there was an increase in flow value at 70% nickel slag content. The result obtained from the slag was 2.83 mm, while the mixture without nickel slag had a flow value of 2.70 mm. This occurs because the wear value of nickel slag is slightly greater than the wear on natural aggregates. However, of all the mixtures with variations in nickel slag content and asphalt content, all met the provisions required by Bina Marga Division 6 of 2018 which requires a decrease value of 2-4 mm [25].

4. CONCLUSIONS

The ideal proportion obtained from this study is the addition of 70% nickel slag. This is because with 70% nickel slag content, the optimum stability value is obtained and meets all the requirements of the Marshall characteristics regulated by Bina Marga Division 6 of 2018. The stability value is the strength of the asphalt mixture to resist deformation due to repeated loads.

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