Utilization of Nickel Slag as an Aggregate Substitute in Asphalt Pavement Mixtures (AC-BC)

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ABSTRACT

Developments in road construction and repair are currently increasing in number. The length of roads in Indonesia in 2020 according to the level of authority is 548,366 km (Ministry of Public Works and Public Housing; Prov / City Government Public Works Office). To support the smooth running of daily community activities, roads can connect one region to another. This study aims to determine how the effect of using nickel slag as a substitute for aggregate with nickel slag levels of 0%, 10%, 40% and 70% on the characteristics of the intermediate layer (AC-BC) by testing material and Marshall characteristics. The results obtained from this study indicate that the use of nickel slag as an aggregate substitute meets the specifications of LFA class A. Through the Marshall test referring to the 2018 Bina Marga general specifications, the ideal proportion of nickel slag addition to asphalt concrete mixtures is obtained based on the highest stability value in each mixture proportion that meets all the characteristics of the Marshall mixture according to the 2018 Bina Marga general specifications Division 6 for the type of mixture of Asphalt Concrete Layer (Laston) Layer Between (AC-BC), namely at 70% slag content with 5.5% asphalt content with a stability value of 1098.30 kg. Where from the results of this study it can be concluded that the use of nickel slag as a substitute for aggregate can be utilized as a road pavement material because it meets the Bina Marga Standard Specifications.

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1. INTRODUCTION

The number of road construction and repair companies is on the rise right now. According to the level of authority, Indonesia's roads will be 548,366 kilometers long in 2020 (Ministry of Public Works and Public Housing; Prov/Regional Government Public Works Office) [1]. However, the demand for natural materials grows alongside the demand for roads. One solution to the growing demand for natural materials is to make use of locally sourced materials [2]. Asphalt is a black or dark brown hydrocarbon compound made from oils, asplathenes, and resins. In the pavement layer, asphalt serves as a material that binds aggregates together to form a compact mixture, giving each aggregate its strength. Asphalt not only acts as a binding material, but it also fills in the spaces between aggregate grains and the aggregate's own pores [9]. There are three kinds of asphalt concrete layer (AC), also known as lastons: AC Wear Layer (AC-WC), AC Moderate Layer (AC-BC), and AC Establishment Layer (AC-Base), with the greatest total size of every combination being 19 mm, 25.4 mm, and 37.5 mm. Each kind of AC combination utilizing changed bitumen is alluded to individually as Adjusted AC-WC, Altered AC-BC, and Changed AC-Base [3]. This research will focus on nickel slag as a substitute for aggregate [4]. Asphalt Concrete Layer (Laston) is a type of pavement that is frequently used in Indonesian road pavements due to its numerous benefits. Indonesia is the nickel lord of the world by controlling 20% of the world's nickel mineral products. Nickel slag is a substitute for depleting natural resources because it is produced domestically, producing approximately 1 million tons annually [5]. Numerous studies have attempted to use alternative materials as components of asphalt concrete mixtures due to the advancement of current materials technology [6]. In this way the total is the really material that assists with enduring the heap got by the asphalt area where the black-top fastener is utilized, which is emphatically affected by the nature of the total [3]. Smelting nickel ore produces nickel slag as a byproduct. Nickel slag is the product of nickel ore smelting and is produced by PT Growth Java Industry, which is located in Cilegon city. At first, this slag is liquid; however, as a result of the cooling process, it has solidified into solid slag or porous slag [10]. The primary method for obtaining nickel slag waste from nickel ore smelting is the direct release of liquid slag to the granulation pond through the slag runner at a temperature of 1550 C. The flowing liquid slag will then undergo cooling. Nickel slag has even been used by the community in some places to make bricks and paving blocks. Nonetheless, the assimilation of nickel slag squander volume is exceptionally low, specifically 1% of the volume of nickel slag squander in the country. According to BINEKA, Vol. 1, October 2020 Edition, the only potential application that would absorb more nickel slag waste is as a pavement coating material. The utilization of nickel slag as a class an establishment layer material shows a Splashed CBR worth of 115% with the goal that it meets as a class an establishment layer material since it is higher than 90% [7]. By using nickel slag in view of research facility testing where from the consequences of this review it tends to be presumed that the utilization of nickel slag as a substitute for coarse total can be used as a street asphalt material since it fulfills the Bina Marga Guideline Determinations [8]. By and large, the organization of slag comprises of silicon dioxide, iron, and aluminum oxide [5]. In light of this reality, the creator needs to lead research fully intent on knowing the use of nickel slag as a total substitution material in the middle of the road layer black-top blend (AC-BC).

2. METHODS

The most vital phase in this exploration starts with setting up the devices and materials to be utilized. After every one of the instruments and materials were gathered, an investigation was completed first to decide the qualities of the materials to be utilized. The investigation incorporates examination of black-top, regular total and nickel slag total. In the assessment of black-top, the tests did are entrance trying, explicit gravity, pliability, consume and streak point, delicate point, and oil misfortune. The normal total and nickel slag total were tried for explicit gravity, ingestion, wear, and mud content. The consequences of the assessment did on the off chance that the outcomes meet the 2018 Bina Marga determinations can then continue to the phase of making test objects. In the production of test examples, the expansion of nickel slag varieties to the blending of test examples with varieties in slag content of 0%, 20%, and 60%. Subsequent to wrapping up making the test examples, Marshall testing was done to decide the quality and attributes of the test example blend. After all the testing processes are completed, trailed by dissecting the experimental outcomes and conversation is made, then, at that point, ends and ideas are produced using the consequences of the examination that has been finished.

3. RESULTS AND DISCUSSION

The tests carried out before Marshall testing are testing the characteristics of natural aggregates, nickel slag and asphalt. This test aims to check the feasibility of the materials used before making test objects that will be tested Marshall. These tests use SNI testing standards and 2018 Bina Marga Specifications. The following are the results obtained from testing the characteristics of the material.

3.1 Aggregate Characteristics Test Results

Table 1. Aggregate characteristics test results

No	Test	Results	Spesifikasi Umum 2018	
		Nature	Maks	Min
1	Abration %	19,3367	40%	-
2	Specific Gravity Of Coarse Aggregate			
	Bulk	2,681	-	-
	SSD	2,712	-	2,5
	Apparent	2,769	-	-
3	Absorption	1,185	3%	-
4	Specific Gravity of Fine Aggregate			
	Bulk	2,547	-	-
	SSD	2,611	-	2,5
	Apparent	2,722	-	-
5	Absorption	2,529	3%	-

For coarse aggregates, the average bulk specific gravity obtained is 2.681 while the water absorption is 1.185%. While the average specific gravity obtained for fine aggregates is 2.541. The average water absorption was 2.529%. The specific gravity value will affect the weight of the aggregate. The greater the specific gravity of the aggregate, the greater the weight of the aggregate. However, the greater the specific gravity, the smaller the volume of the aggregate. Judging from the specific gravity formula, volume is inversely proportional to specific gravity. The specific gravity value is also used to determine the weight of each fraction to be used later. The wear test for natural aggregates was found to be 19.3367%. This wear value affects the strength of the aggregate to resist friction and impact. The greater the wear value, the weaker the aggregate is to resist friction and impact [11].

For the nickel slag coarse aggregate, the average bulk specific gravity obtained was 2.91. Meanwhile, the water absorption was found to be 0.249% on average. For nickel slag fine aggregate, the average bulk specific gravity obtained was 2.788. The average water absorption was 1.113%. The specific gravity value will affect the weight required when calculating the mix composition. When compared, the specific gravity of nickel slag is greater than the specific gravity of natural aggregate. This causes the weight of the nickel slag to be heavier than the natural aggregate. The wear test for nickel slag aggregate was found to be 23.6%. The wear value of nickel slag is greater than the natural aggregate. The wear of the nickel slag was 23.615% while the natural aggregate was 19.337%. There was a 4.278% difference in the two types of aggregates. This is influenced by the slightly hollow shape of the nickel slag which results in the nickel slag being slightly easier to crush when exposed to impact or friction [12].

Table 2. Nickel Slag Aggregate Characterization Results

No	Test	Results	Spesifikasi LFA A Class	
		Nickel Slag	Maks	Min
1	Abration %	23,6%	40%	-
2	Specific Gravity of Coarse Aggregate			
	Bulk	2,91	-	-
	SSD	2,917	-	-

	Apparent	2,931	-	-
3	Absorption	0,249	-	-
4	Specific Gravity of Fine Agg.			
	Bulk	2,788	-	-
	SSD	2,819	-	-
	Apparent	2,876	-	-
5	Absorption	1,113	-	-

Figure 1. Nickel Slag & Natural Aggregate

Testing the specific gravity and ingestion of coarse totals in view of SNI 1969-2016 was completed multiple times on every normal total and nickel slag. From the typical aftereffects of the particular gravity tests classified in Tables 2 and 3, it is found that the particular gravity of nickel slag is more prominent than the particular gravity of normal totals, which influences the heaviness of the combination to be heavier than regular totals. The coarse total assimilation test was led multiple times each. In Tables 2 and 3, the aftereffects of the coarse total retention test in view of the SNI 1969-2016 test technique for nickel slag totals are more modest than those of normal totals. It very well may be reasoned that nickel slag totals are better at holding among black-top and other black-top combinations on the grounds that the more prominent the retention esteem, the more prominent the potential for stripping or debilitating of the total bond with black-top [11]. From the consequences of the typical total wear test, it was found that nickel slag total is more prominent than normal total, this can influence the strength or nature of the black-top combination so that assuming the utilization of nickel slag total is excessively huge, it can possibly decrease the toughness of the black-top blend against high traffic loads.

3.2 Asphalt Characteristics

Asphalt is defined as a cementitious material, black or dark brown in color, with bitumen as the main constituent. Asphalt can be obtained in nature or is a residue from petroleum refining. Asphalt is a material commonly used for aggregate binders, asphalt is a material that at room temperature is solid to slightly solid, and is thermoplastic. So, asphalt will liquefy if heated to a certain temperature, and refreeze if the temperature drops. Together with aggregate, asphalt is the material that forms the pavement mixture. The asphalt used in this research is asphalt with a penetration of 60/70 [13].

Table 3. Nickel Slag Aggregate Characterization Results

No	Type of Inspection	Result	Bina Marga Specifications 2018	
			Minimum	Maximum
	Asphalt Penetration 60/70			
1	Penetration, 25ºC; 100 gr;5	65,1	60	70

2	Softening point (°C)	50	≥48	-
3	Specific Gravity	1,013	1	-
4	Ductility at 25° (cm)	109	≥100	-
5	Flash Point (°C)	325	≥232	-
6	Loss on Heating (%)	0,21	≤0,8	-

The asphalt test results are stated to meet the specifications set out in the 2018 General Specifications of Division 6 of the Department of Public Works. From the research results obtained asphalt specific gravity 1.013 with a minimum limit ≥ 1, it can be concluded that the asphalt to be used is still of good quality because it meets the 2018 Bina Marga specifications. For the research results of asphalt weight loss obtained 0.21 from the minimum limit ≤ 0.8, it can be concluded that the asphalt to be used has good durability because it can maintain its original properties due to weather influences or temperature changes during the road service period. In the softening point test, a temperature of 50 ° C is obtained from the minimum limit ≥ 48 ° C, the softening point test is carried out to obtain information at what temperature the asphalt changes phase from solid to liquid form and this temperature is needed during the implementation of work in the field. For ductility testing, a value of 109cm is obtained from the minimum limit ≥ 100cm, it can be concluded that the asphalt to be used has good plasticity because if the ductility of the asphalt is too low, it will experience cracks in its use in the field.

For flash point testing, the value is obtained at a temperature of 325 ° C from the minimum limit, namely ≥ 232°C, this test is carried out to obtain information on the temperature at which the asphalt starts to ignite and burn. This is very necessary when implementing in the field for the sake of safety at work. In the penetration test, the penetration value is 65.1 with a limit of 60-70, it can be concluded that the test results show the level of asphalt hardness in accordance with the asphalt to be used, namely asphalt pentrasi 60/70.

3.3 Testing Of Asphalt Concrete Mixtures

This test is carried out with a Marshall tool in accordance with SNI 06-2489-1991 or AASHTO T245-90 procedures, namely by placing the test specimen into the lower segment of the Marshall tool, the time required from the time it is lifted from the maximum water bath should not exceed 30 seconds. Then the test specimen is loaded at a speed of about 50 mm per minute until the maximum loading is reached and then record the stability and flow loads. The following are the results obtained from the Marshall test.

3.3.1 Characteristics of Asphalt Concrete Mixtures

• VMA (void in mineral agregates)

In the figure above, the effect of adding nickel slag content on VMA value in the variation of nickel slag content above that with the addition of asphalt content into the mixture tends to decrease the VMA value but the decrease in VMA value is still within the required limits.

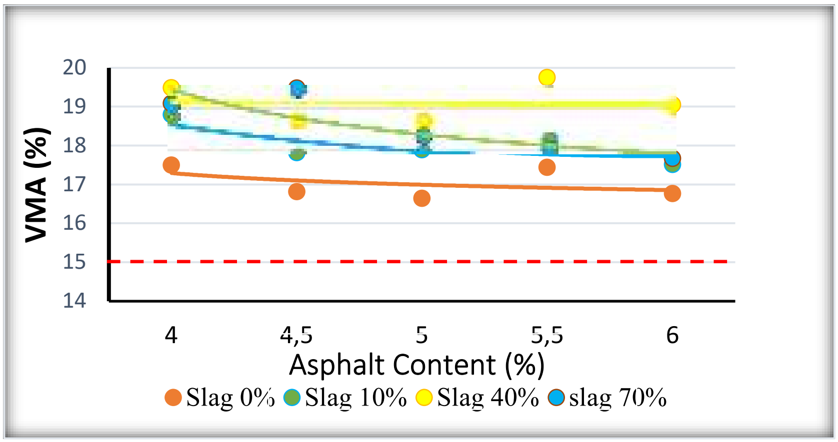

Figure 2. Relationship Graph of VMA Value and Asphalt Content

• VIM (void in mixture)

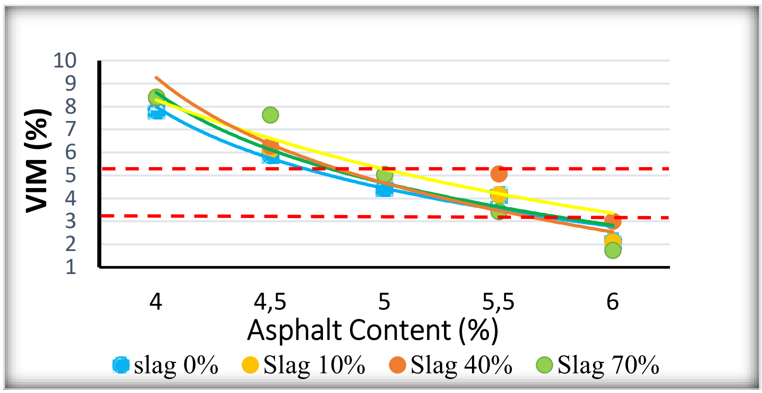

Figure 3. Relationship Graph of VIM Value and Asphalt Content

The graph shows that the effect of adding nickel slag content to the VIM value at each asphalt content shows that the addition of asphalt content to the mixture tends to reduce the VIM value. This is because the voids between the grains of the aggregate are still large enough so that with each addition of asphalt content, the asphalt is easy to enter the cavities of the mixture which can make the mixture tighter and the VIM value smaller. Pavement layers that have too low VIM values will cause bleeding [13].

• VFA (void filled with asphalt)

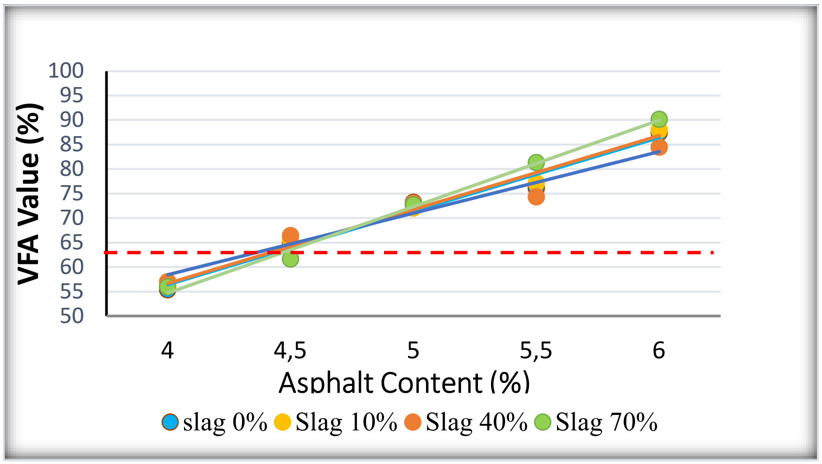

Figure 4. Relationship Graph of VFA Value and Asphalt Content

The effect of adding asphalt content to the VFA value shows that with each addition of asphalt content to the mixture will increase the VFA value, this is because the use of nickel slag makes the cavity between grains quite large than without nickel slag because nickel slag has an uneven and rough surface so that asphalt easily enters the mixture cavity, so that the mixture becomes tighter and the VFA value is getting bigger [8].

• Stability

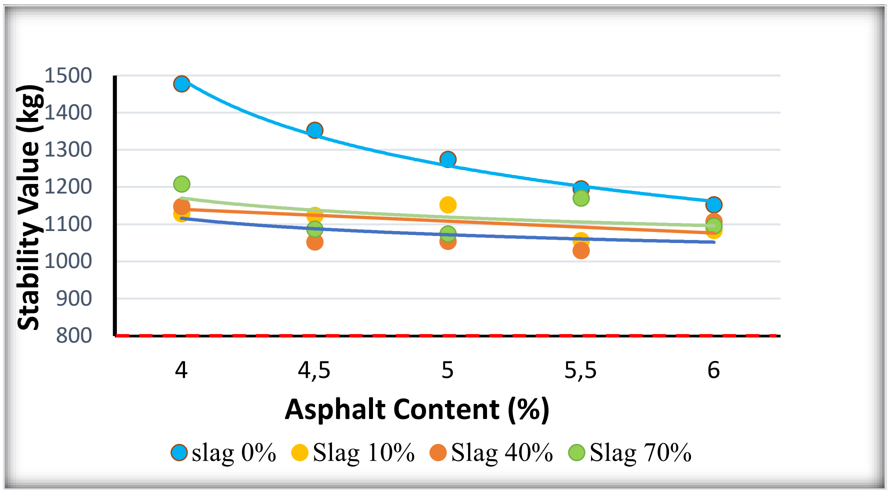

Figure 5. Relationship Graph of Stability Value and Asphalt Content

The graph show, the addition of nickel slag to the stability value tends to increase with each addition of nickel slag content, this occurs because the more nickel slag content is added, the higher the interlocking effect between the nickel slag aggregate grains [12].

• Flow

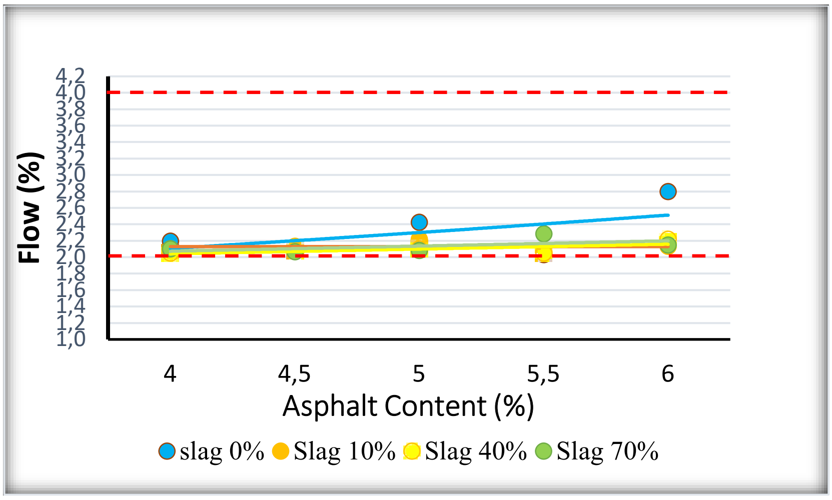

Figure 6. Relationship Graph of flow Value and Asphalt Content

The effect of the addition of asphalt content on the flow value shows that the flow value increases and decreases with each addition of asphalt content, the smallest decrease is at 5.5% asphalt content with 0% slag content and the largest increase is at 6% with 0% slag content.

• MQ (Marshall Quotient)

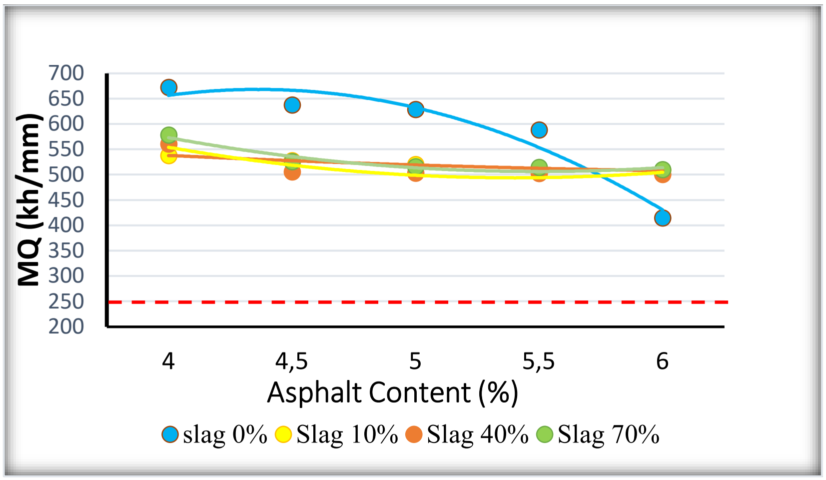

Figure 7. Relationship Graph of MQ Value and Asphalt Content

In the figure it can be seen that the MQ (Marshall Quotient) values all tend to decrease. The decrease in the MQ (Marshall Quotient) value in asphalt concrete mixtures is due to the mixture becoming plastic and flexible with the addition of asphalt content.

3.3.2 Phase Two Marshall Testing Results

The next test was the Marshall test using the optimum asphalt content of each nickel slag content used. The optimum asphalt content obtained was 5.25% for the mixture without nickel slag, 5.5% for the mixture with 10% nickel slag, 6% for the mixture with 40% nickel slag and 5,5% for the mixture with 70% nickel slag. The KAO value is obtained from the results of the previous Marshall characteristics test. The following are the Marshall test results for the KAO obtained.

Table 4. Test Result Data

Marshall Characteristics	Nickel Slag (%)	Results	Asphalt Optimum (%)	Specification
VMA (%)	0	17,38	5,25	Minimum 15%
	10	17,69	5,5	
	40	19,35	6	
	70	19,48	5,5	
VIM (%)	0	4,54	5,25	3% - 5%
	10	3,57	5,5	
	40	4,61	6	
	70	5,17	5,5	
VFA (%)	0	73,88	5,25	Minimum 65%
	10	79,89	5,5	
	40	76,21	6	
	70	73,48	5,5	
Stablilitas (kg)	0	1088,89	5,25	Minimum 800kg
	10	1049,91	5,5	
	40	1077,38	6	
	70	1098,30	5,5	
Flow (mm)	0	2,47	5,25	2mm - 4mm
	10	2,22	5,5	
	40	2,43	6	
	70	2,47	5,5	
MQ (kg/mm)	0	441,97	5,25	

10	474,98	5,5	Minimum 250kg
40	442,77	6	
70	444,91	5,5	

Based on the recapitulation of Marshall test results in Table 12. above, the highest VMA value is 19.48% at 70% slag content with an optimum asphalt content of 5.5% and tends to increase from each addition of nickel slag content, this occurs because the surface of nickel slag is rougher and uneven than natural aggregates [12]. The highest VIM value is 5.17% at 70% slag content with an optimum asphalt content of 5.5% and shows that the addition of slag content tends to increase the VIM value, this occurs because nickel slag has an uneven surface than natural aggregates so that spaces are formed at each addition of nickel slag and result in the formation of cavities in the asphalt mixture. The highest VFA value is 79.89% at 10% slag content with an optimum asphalt content of 5.5% and tends to increase with each addition of slag content, this occurs because the slag has an uneven surface than natural aggregates so that it leaves a lot of space in the asphalt mixture that can be filled by asphalt. The optimum stability value is 1098.30 kg at 70% slag content with an optimum asphalt content of 5.5%, this is because the addition of nickel slag can increase the interlocking effect on the asphalt concrete mixture. The optimum flow value is 2.47 mm at 70% slag content with an optimum asphalt content of 5.5%, the addition of nickel slag increases the flow value because nickel slag has a higher wear value than natural aggregate. the more nickel slag used, the greater the flow value, this causes the mixture to easily deform due to load. The MQ values obtained all meet the general specifications of Bina Marga 2018 [15].

3.3.3 Residual Marshall Stability Testing Results

Tabel 5. Result Tables

Residual Marshall Characteristic	Nickel Slag (%)	Result	Asphalt Optimum (%)	Minimum
Stablilitas (kg)	0	1055,48	5,25	≥ 980 kg
	10	1030,01	5,5	≥ 980 kg
	40	1079,11	6	≥ 957,34 kg
	70	1091,33	5,5	≥ 979,06 kg

Based on the results of the recapitulation of residual Marshall stability can be seen in Table 13 Residual Marshall stability at 0%, 10%, 40% and 70% slag content meets the general specifications of division 6 bina marga 2018. So it can be concluded that the asphalt mixture can withstand the effects of weather, water, temperature or wear due to vehicle friction [14].

4. CONCLUSION

The results of the study can be concluded that the use of nickel slag in the intermediate asphalt mixture (AC-BC) is highly recommended, because from the results of testing the characteristics meet the LFA Class A specifications. Based on the results of the analysis of the effect of adding nickel slag content on the test results show that each addition of slag content and asphalt content shows varied results on the Marshall characteristics of a mixture and the results show that the ideal proportion of adding nickel slag content to the asphalt mixture based on the optimum stability value in each proportion of the mixture that meets the value of the Marshall characteristics of the mixture according to the General Specifications of Bina Marga 2018 Division 6 for the type of mixture of Asphalt Concrete Layer (Laston) Layer Between (AC-BC), namely at 60% slag content with 5.5% asphalt content with a stability value of 1087.84 kg.

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