Value Of Indirect Tensile Strength And Deformation On Ac-Bc Asphalt Mixture Using Nickel Slag As A Fine Aggregate

Jusmidah, Antariksa, Wisnumurti, Lambang Basri Said

Abstract: Slag is the largest aggregate source as a substitute for natural aggregates due the consideration of the availability of natural resources, sustainable development, environmental protection, and very good nature of slag engineering (1). Some countries lack of natural aggregate, namely the United States, Japan, and other countries, and it is solved by the use of slag as a substitute for natural aggregates that have good nature of engineering (2). Based on the results of the analysis, it is shown in detail that asphalt pavement structure using slag as a pavement layer provides a very satisfying response to static and dynamic effects (3). To avoid the degradation of aggregate and unbounded-added material, it is important to have the strength of flexible pavement mixture layer that is able to withstand the pressure of repeated loads. Aggregate is pavement layer strength, including inherent strength between particles, density, and gradation that must be strong enough to withstand the load while being used. The use of slag as an aggregate gives a high strength and hardness value (4). In this research, nickel slag is used as fine aggregate on AC-BC pavement mixture. The purpose of this study is to find out the effects of adding nickel slag as a fine aggregate on the tensile strength and resistance strength of AC-BC pavement mixture on permanent deformation. Based on the results of indirect tensile strength (ITS) testing of the mixture using nickel slag as a fine aggregate, it shows improvement and performance of the mixture to the mechanical nature of nickel slag. The stiffness of nickel slag gives effect on the increase of ITS value, where the higher positional ratio value is an indicator of degree of flexibility of the mixture based on the ratio of vertical deformation to horizontal deformation. The higher the value of the position ratio, the more flexible the mixture is.

Keywords: asphalt concrete, nickel slag, indirect tensile strength

1. Introduction

Flexible pavement is the most popular pavement layer for road construction. It mostly uses non-renewable materials and industrial products such as aggregates, bitumen, cement, lime, and other added materials used during road construction and maintenance (5). Road construction plays a major role in the movement of industries for world economic growth. It is estimated that 95% of roads in the world are made of flexible pavement layers (6). Flexible pavement layer consists of four parts, namely the subgrade structure, the bottom foundation, the upper foundation layer, and the surface layer (7). The subgrade is modified using added materials such as certain additives. This modified foundation layer is called a sub-base layer, which is a layer consisting of high quality aggregates of different sizes as a load bearing layer called the upper foundation layer. The surface layer is an aggregate mixture, fillers, other added ingredients, and binders. This layer is in direct contact with the vehicle wheel load, so this layer must use quality materials (8), the mixed surface layer is the main component in a flexible pavement layer cycle associated with political, economic, technical, social and environmental problems. In Europe, there have been various studies on the nature of the surface layer, using both the material and the mixed design method (9).

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Asphalt concrete is a hot asphalt mixture design that is sensitive to pavement characteristics so that its performance is strong and waterproof, and it can reduce crack surface (10). Hot mixed asphalt concrete (HMA) is a type of flexible pavement construction in which the aggregate acts as a flexible pavement structure framework, the mixture is evenly distributed between the aggregate and asphalt as binding material at a certain temperature (11), hot mixed asphalt concrete (HMA) is often referred to as hot mix in the last few years. It has been using waste such as cellulose waste (12), wood lignin, slag (13), fly ash (14), used rubber (15), and glass waste (16) as added materials in hot concrete asphalt mixture. Technical requirements for the use of waste, like slag waste, need to be reviewed based on the source of the waste. Additionally, the test method must comply with the standard specifications as transportation material (17) (18) (19) (20) (21). Slag is the largest aggregate source as a substitute for natural aggregates due to the consideration of the availability of natural resources, sustainable development, environmental protection, and the very good nature of slag engineering (22). Some countries lack of natural aggregate, namely the United States, Japan, and other countries, and it is solved by the use of slag as a substitute for natural aggregates that have good nature of engineering (23), based on the results of the analysis, it is shown in detail that asphalt pavement structure using slag as a pavement layer provides a very satisfying response to static and dynamic effects (24). To avoid the degradation of aggregate and unbounded-added material, it is important to have the strength of flexible pavement mixture layer that is able to withstand the pressure of repeated loads. Aggregate is pavement layer strength, including inherent strength between particles, density, and gradation that must be strong enough to withstand the load while being used. The use of slag as an aggregate gives a high strength and hardness value (4) In this research, nickel slag is used as fine aggregate on AC-BC pavement mixture. The purpose of this study is to find out the effects of adding nickel slag as a fine aggregate on the tensile strength and resistance strength of AC-BC pavement mixture on permanent deformation.

2. Experimental

2.1. Experimental

Material is mined around 4759 billion tons every year (25), Since the material is the main material of concrete, where concrete is most widely used in construction in the world, the need for sand and gravel represents about 80% of the mass in concrete. One of the European Aggregate Association reports that the demand for annual aggregate needs in the European Union is equivalent to 2.70 billion tons of 20% intended for infrastructure (26). In the study on the use of nickel slag as a fine aggregate, in which the research samples are brought directly from Camp Engineering of PT Vale Sorowako, which is the largest nickel mine in Indonesia, Indonesia produces nickel around 190 thousand tons per year and thousands of tons per year (27). The main chemical composition of nickel slag is ferric oxide (Fe2O3), calcium oxide (CaO), Nickel (Ni), manganese oxide (MnO), diphosphorus pentoxide (P2O5), disodium oxide (Na2O), dipotsium oxide (K2O), and aluminum oxid (Al2O3) (28) Meanwhile, other supporting aggregates are taken at the Asphal Mixing Plant (AMP) Base Camp. The results of the filter analysis test can be seen in Table 1. Figure 1 below shows the final disposal of waste from nickel mine at Sorowako.

Figure 1.*Final disposal site for Nickel (Slag Nickel) waste in Sorowako*

2.2. Asphalt

There are two types of asphalt used, namely 60/70 penetration hard asphalt and Buton asphalt. Buton Stone Asphalt or commonly called Asbuton Lawele Granular Asphalt (LGA) found on Buton Island has characteristics based on the place where it is obtained. There are two areas to mine buton asphalt, namely Kambungka and Lawele areas. Bitumen of the buton asphalt contents differs. The content of asphalt/bitumen in Lawele is 25% – 35% and contains silicate lot. Meanwhile, asphalt/bitumen in Kambungka is only 12% - 20% and contains a lot of carbonate. Asphalt Concrete is a mixture of coarse aggregate, fine aggregate, and filler and binder in temperature conditions 145-155^{o}C with the composition examined and regulated by technical specifications. Figure 1 shows Lawele asphalt (Lawele Granular Asphalt) retained sieve no. 8 and sieve No. 16 (29)

2.3 Sample Preparation

Hot asphalt mixture consists of a combination of aggregate, filler and asphalt that are mixed under the heat at a certain temperature. The composition of ingredients in the hot asphalt mixture must be planned beforehand, which can be seen in Table 1. The percentage of nickel slag content in the fine aggregate mixture are 100% broken stone, 100% slag, and a mixture of broken stone with slag (0%, 25%, 50 %, 75%, and 100%). The results of aggregate granulation based on filter number can be seen in Figure 2 below

Table 1.*Composition of Mixture Variation of Nickel Slag 50% Substitution of Stone Ash 48.75%*

Sieve Size	Composition of Mixture KAO 5.70 % and Variation of nikel slag 50 %					Asphalt weight
	Aggregate 1-2	Aggregate 0.5 -1	Stone ash	Nikel slag	Lawele	Gram
12.5(1/2")	38.36	10.83	0.39	0.39	-	68.4
9.5(3/8")	8.66	221.41	40.20	40.20	5.01	68.4
No.4	3.56	91.80	49.34	49.34	2.72	68.4
No.8	0.17	1.97	49.51	49.51	2.57	68.4
No.16	-	0.14	44.84	44.84	2.74	68.4
No. 30	-	0.20	39.18	39.18	11.70	68.4
No.50	0.34	0.88	20.07	20.07	17.90	68.4
No. 100	0.34	1.53	9.25	9.25	11.27	68.4
No. 200	2.21	9.10	23.33	23.33	16.80	68.4

Figure 2.*Particle distribution based on filter analysis*

3. Testing Program

3.1 Marshall Stability, Flow, and Marshall Quotient Test The purpose of Marshall test is to get the value of stability, air cavity, flow as other parameters such as cavity volume in solid asphalt concrete (VIM) and volume of asphalt concrete filled with asphalt (VFA). Cavity volume between aggregate grains (VMA) of the indicator obtains optimum asphalt content (KAO) (30). Testing the stability value and stability of the Marshall flow is tested on a sample of various asphalt concrete contents based on ASTM D 1559. The asphalt concrete contents are in accordance with the gravity specification of maximum stability of the air cavity in 4% (31).

Figure 3.*Marshall Test Equipment with test specimens (briquettes) for mixture testing*

3.2. Absolute Density

The hot asphalt mixture planning using absolute density approach is to complete the conventional Marshall method in order to guarantee the asphalt mixture used for heavy and dense traffic with high temperature that can be achieved by the mixture. Thus, the mixture cannot become solid again (32). This research is closely related to plastic deformation with high asphalt levels and reduction of air cavity in the mixture (VIM) during the service life of the road. Different compaction procedures are developed by various researchers around the world, including Humbbard method, Marshall method, Hveen method, French Roller Method, and the latest development, which is Superpave with absolute density (33).

3.3. Indirect tensile strength (ITS) test

Indirect tensile strength testing is carried out by using a cylindrical sample with a load rate of 51 mm/min and experiences pressure loading which works in parallel and contains a vertical diameter plane. Tensile strength testing is carried out to determine the mechanical nature of asphalt concrete mixture using nickel slag as a fine aggregate including strains, stress, and elastic modulus.

Indirect tensile strength can be calculated using the equation:

$$\mathrm{ITS} = \frac{2.\mathrm{P}}{\pi.\mathrm{td}} \qquad (1)$$

Where P = burden until collapse occurs, d = specimen diameter, and t = specimen thickness, fatigue, cracking, and permanent deformation (34). Figure 4 shows LTS test equipment and briquette test sample for tensile strength test.

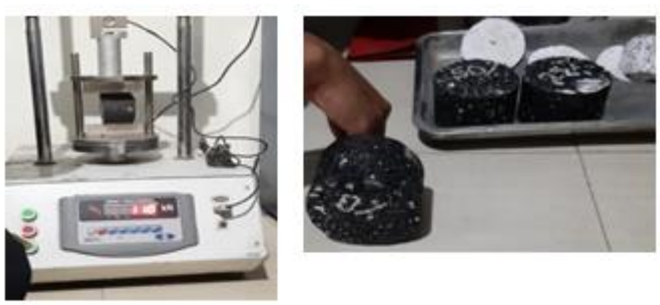

Figure 4.*Marshall Test Equipment with test specimens (briquettes) for mixed testing*

4. Data Analysis

Data obtained in this study will be analyzed qualitatively and quantitatively. Data analysis is done manually using Microsoft Office Excel program computers and SPSS 24 program. All data described in the matrix of relationship between data sources and data analysis methods are used to answer the objectives of the study

5. Result and Discussion

5.1 Marshall stability, flow, and Marshall Quotient test

Test samples for AC-BC mixture uses asphalt content variation of 4.5%, 5.0%, 5.5%, 6.0% and 6.5%, the proportion of nickel slag of 0%, 25%, 50%, 75% and 100% to fine aggregate. The test results of asphalt content verification are presented in table 2, while nickel slag variations can be seen in table 3.

Table 2. *Recapitulation of Marshall AC-BC Mixture Pen 60/70 for Optimum Asphalt Content*

Characteristics of Mixture	Test results of asphal variation					Specification
Asphalt Content%	4,5	5	5,5	6	6,5	
VIM; %	5.004	4.408	4.093	3.82	3.86	3-5%
VMA; %	17,617	17,749	17,00	17,222	17.310	≥ 15%
VFA; %	63.505	65.046	67.702	69.816	76.117	≥ 63%
Stabilitas; kg	1012.36	1025.64	1047.5	1038.88	1034.12	800-1800 kg
Flow; mm	3.18	3.14	3.21	3.34	3.65	2-4 mm
MQ; kg/mm	313,945	318,273	320.195	319.875	316.298	Min 250 kg/mm

Table 3.*AC-BC mixture examination results of nickel slag variation with Marshal Standard (2 x 75) collision test*

Characteristics of Mixture	Test results of nickel slag variation					Specification
	0.00 %	25%	50%	75%	100%	
VIM (%)	3.76	4.03	4.54	4.87	6.03	3.5 – 5.5
VMA (%)	15.22	14.36	14.49	15.87	15.87	Min 14
VFA (Kn,mm)	67.6	71.71	70.33	62.56	61.98	Min 65
Stability (Kg)	1796.21	1774.40	1730.76	938.10	763.57	Min 800
Flow (mm)	3.2	3.3	3.5	3.9	4.1	3.5 – 5.5
MQ; kg/mm	316,023	319.517	330.491	326.66	320.172	Min 250 kg/mm

According to the table 2 and 3 above, it can be seen that the stability value has increased in asphalt content of 5.0% and 5.5%. Meanwhile, asphalt content of 6.0% and 6.5% has decreased, but all the asphalt content meets the specifications. The stability value of nickel slag used as fine aggregate has increased as seen from the results of Marshall test with the addition of a stronger nickel slag. An increase in asphalt content with an air cavity value (VIM) has a strong correlation by using nickel slag as a fine aggregate characteristic of AC-BC asphalt fulfilling the specifications (35).

5.2 Comparison of Marshall VIM and Refusal VIM

Within a few years, the air cavity in the mixture after passing through the traffic began to decrease by about 1%, so there is a change in the plastic shape. Due to such condition, it needs a solution by making additional test, namely density Ultimate on samples with asphalt content obtained from VIM value of conventional Marshall testing until achieving absolute density (Refusal Density). The test results can be seen in table 4.

Table 4.*Examination results of AC-BC mixture of nickel slag variation with PRD (2 x 400) collision test*

Nickel slag variation	Marshall		PRD	
	Marshall Density	Marsahall VIM	Refusal Density	Refusel VIM
0.00 (%)	2.28	3.76	2.31	2.94
25 (%)	2.30	4.03	2.40	2.55
50 %	2.47	4.54	2.48	2.08
75 %	2.52	4.87	2.56	1.98
100 %	2.58	5.66	2.61	1.06

The density of an asphalt concrete mixture is generally associated with durability. The greater the density value, the denser the asphalt concrete mixture is.

5.3 Indirect Tensile Strength (ITS) testing on the use of nickel slag as a fine aggregate on AC-BC mixture

Indirect tensile strength is the ability of pavement layer to withstand the load in the form of a pull in the horizontal direction. The purpose of this experiment is to determine the possibility of cracks in the pavement. Value of the indirect tensile strength is used to determine the possibility of cracks in the pavement layers. The strain will be greater due to the decrease in bonding in the test sample. Table 5 shows the result of ITS (Indirect Tensile Strength) testing of concrete asphalt mixture with nickel slag as fine aggregate.

Table 5.*The correlation between strain and nickel slag*

Composition of Nickel Slag Mixture (%)	Sample Diameter (mm)	Horizontal Deformation (mm))	Strain (ε)
0.00%	93.00	1.430	0.02
25%	97.00	1.020	0.01
50%	97.00	0.907	0.01
75%	97.00	0.840	0.01
100%	97.00	0.860	0.01

Table 6.*The correlation between elastic modulus and nickel slag*

Composition of Nickel Slag Mixture (%)	Stress (Kpa)	Strain (ε)	Elastic Modulus (Kpa)
0.00%	10.866,63	0.01538	706710.68
25%	11.902,79	0.01052	1131931.78
50%	12.241.90	0.00935	1309703.12
75%	12.174.08	0.00866	1405815.97
100%	11.461.94	0.00887	1292800.64

The regression results are tested to find out the correlation between independent and dependent variables in asphalt concrete mixture with nickel slag variations in increasing tensile stress and elastic modulus toward load and temperature effects. Table 7 shows the results of linear regression.

Table 7.*Tensile stress variations of nickel slag with density of 2 x 400 collisions*

variations of nickel slag	F Hitung	Signifikansi	R Square	Adjust R square	Keterangan
0.00* Persentase	2.271	.247	.602	.341	Negative corelation
25.0* Persentase	2.401	.236	.615	.387	Negative corelation
50.0* Persentase	2.510	.227	.624	.376	Negative corelation
75.0* Persentase	2.211	.225	.566	.328	Negative corelation
100* Persentase	1.386	.373	.482	.134	Negative corelation

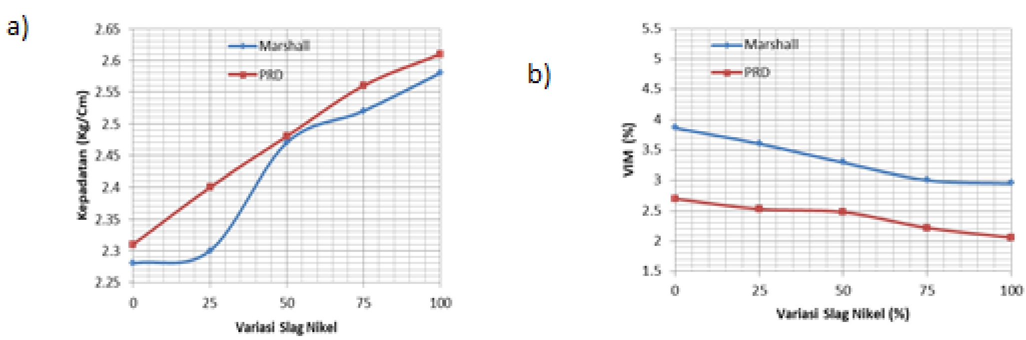

Figure 1.a) *Correlation between nickel slag variation and mixture density,* ***b)*** *Correlation between nickel slag variation and VIM (%)*

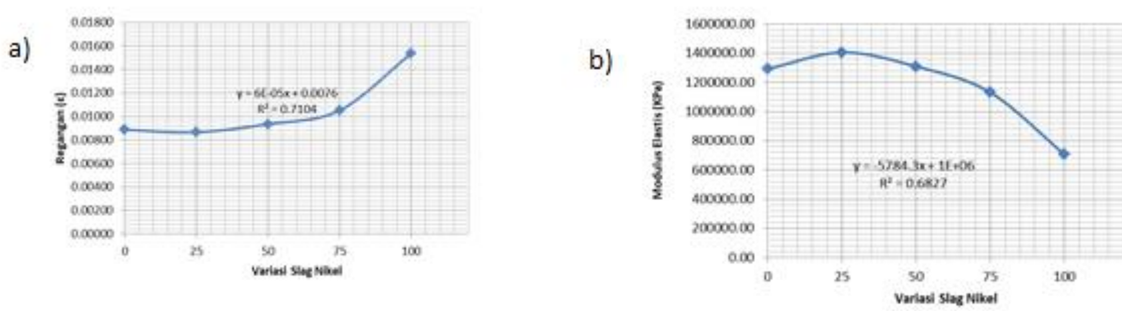

Figure 2.a) *Correlation between strain (ε) to Nickel Slag Variation based on KAO,* ***b)*** *Relationship of Elastic Modulus (E) to Nickel Slag Variation based on KAO*

Figure 1 shows that the Void In Mix (VIM) value decreases as the increase in the proportion of nickel slag both Marshall VIM and Refusal VIM, with the addition of the same number of nickel slag of smaller Refusal VIM value compared to Marshall VIM. The difference in value is influenced by the amount of collision density. The denser the VIM value, the smaller the value and the greater the density value. Superpave mixture design (PRD) using nickel slag as fine aggregate can be seen in table 4 with the addition of 50% nickel slag, which can penetrate the air cavity (VIM). Nickel slag can anticipate the use of natural aggregates in the mixture design of road pavement (36). Figure 2a) shows the effect of adding nickel slag as a fine aggregate to the strain. The percentage of nickel slag is 0%, 25%, 50%, 75%, 100%. The value of the strain has decreased in the addition of 25% nickel slag. The value increases when adding 50% nickel slag, equal to 100% nickel slag, and the value of strain increase. Figure 2b) shows the correlation between elastic modulus and nickel slag. In the addition of 25% nickel slag, elastic modulus value has increased, and then in the addition of 50% to 100% nickel slag, elastic modulus value has decreased.

6. Analysis and Discussion

As seen in the graph above, the use of nickel slag as a mixture in asphalt concrete clearly provides modification to the nature of asphalt concrete itself and contributes to the utilization of waste, which is considered dangerous to the environment. The characteristics of asphalt concrete modified with the addition of waste have a correlation to how much additional waste given to the composition of asphalt mixture depending on the shape and source of the waste (37), (38). The use of waste in concrete asphalt mixture to modify road pavement layers can result a better material performance by looking at the viscosity value in asphalt concrete mixture (39). It has been found that the pavement layers that have not been modified for stability, flow, and stiffness values for heavy traffic do not meet the requirements compared to the pavement layers modified with the addition of waste (40). Absolute density is the maximum density that can be achieved. The use of nickel slag as fine aggregate in asphalt concrete affects the value of density and volume of cavities in asphalt concrete mixture until the optimum limit of adding 50% nickel slag of fine aggregate. It can be seen in table 5 and 6 that the addition of nickel slag to asphalt mixture has the ability to increase tensile stress and is directly proportional to the mixture's passion ratio. Increasing the amount of density will change the asphalt concrete mixture to be tighter so that the plastic discharge decreases. Based on the results of calculation of multiple linear regression test (RLB) in table 7, R2 (R Square) value for ITS 0.0% nickel slag is 0.602 or (60.2%). This shows that the percentage of contribution of independent variable, which is nickel slag variation, on the dependent variable, which is tensile strength of 60.2%, has a strong correlation where the independent variable used shows a positive correlation. The value of 39.6% is influenced by other variables not included in the model in this research. Density of asphalt concrete mixture is applied to reduce the air volume in asphalt concrete mixture. Decreasing air cavity increases unit weight and can allow the mixture to occupy a smaller space (41)

Conclusion

The results of indirect tensile strength (ITS) testing of the mixture using nickel slag as a fine aggregate show improvement and performance of the mixture to the mechanical nature of nickel slag. The stiffness of nickel slag affects the increase of ITS value, where the higher positional ratio value is an indicator of flexibility level of the mixture based on the ratio of vertical deformation to horizontal deformation. The higher the value of the position ratio, the more flexible the mixture is. The correlation between the density of 2 x 400 collisions and nickel slag variation has stiffness nature with ITS value and high stiffness modulus. Increasing density load can increase the density of mixture and reduce the occurrence of shifts between the aggregate on the mixture due to traffic vehicle load. Maximum tensile stress and strain in the addition of 50% nickel slag of a fine aggregate can increase the average tensile stress by 10.29% by the density of 2 x 400 collisions. This shows that the use of nickel slag as a fine aggregate can significantly influence the increase in ITS values.

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