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IMPROVING THE PERFORMANCE OF LASTON AC-WC PADDING WITH THE UTILIZATION OF NICKEL SLAG WASTE

FALDERIKA*, NUR FITRAH

Departemen Teknik Sipil, Universitas Komputer Indonesia, Indonesia
*Corresponding Author: falderika@email.unikom.ac.id

Abstract

Utilization of waste as part of the road pavement material is an important issue. This is caused by the decreasing availability of natural materials as road raw materials and the increasing costs for procurement as well as the process of obtaining aggregates. As a result, alternative materials are needed and one of them is nickel slag. Nickel slag is categorized as Toxic and Hazardous waste (B3), so testing is needed to determine the content of the hazardous substances. The value of the Toxicity Characteristic Leaching Procedure (TCLP) test is smaller and meets the requirements, the results of testing the physical characteristics of nickel slag also meet the requirements used in road construction materials. The purpose of this study is to analyse the effect of using nickel slag on the performance of the Laston mixture (AC-WC). The tests were carried out based on the empirical method with the Marshall test which refers to the provisions of the properties of the Laston mixture (AC-WC) General Specifications for Roads and Bridges of Highways, Bina Marga, 2018. Variations in Reference Asphalt Content (KAA) used are 5%, 5.5%, 6%, 6.5%, and 7%. Based on the analysis results of the Marshall test, it is known that the use of nickel slag has better performance in terms of the higher Marshall stability value of 1803 kg compared to 1660 kg in a mixture without nickel slag. From the results of the tests and analyses carried out this nickel slag waste can be used as a new material in the asphalt mixture so that the impact is that the waste can be reused.

Keywords: Laston AC-WC, Marshall, Nickel slag.

1. Introduction

Nickel slag waste is a by-product produced as waste from the steelmaking industry that is widely recycled in many countries around the world for decades. Approximately 160 kg of steel slag is produced per tonne of steel produced. Common chemical compounds in steel slag are SiO2, CaO, Fe2O3, Al2O3, and MnO. The recovery of these metals not only safe to dispose but also cheap to clean up [1]. Waste is recycled as aggregate for asphalt pavements to reduce the landfill area available for slag disposal and reduce the cost of disposing these metals as waste and save natural resources. Steel slag is a valuable resource to replace natural stone and reduce the environmental impact of extracting virgin resources [1-5]. Indonesia has the number 1 nickel reserve in the world which reaches 72 million tons or 52% of the world's total reserves. Indonesia's nickel ore production in 2019 was 800 thousand tons or about 30% of the world's total production [6].

According to Wang et al., laboratory studies and actual use of nickel slag showed strong potential for suitability of slag as a Hot Mix Asphalt (HMA) aggregate, as well as in granular base and subbase applications [3]. Measurable laboratory evaluation and usability criteria are essential for use of a full range of slags. Steel slag provides a strong and dense aggregate with favourable properties for use in construction [4]. When incorporated into HMA, its rough shape and surface texture increase affinity with asphalt and stripping properties and provides high stability and resistance to rutting and fatigue cracking [7-9]. Meanwhile, according to Prezzi et al., the use of steel slag aggregate in HMA may have some disadvantages due to potential volume expansion, increased asphalt content, and the overall high cost due to the dense material, resulting in lower asphalt volumes for the same unit weight of conventional aggregate and increased transportation costs [10].

In another study, it was stated that steel slag aggregate also has high abrasion and polishing resistance with improved slip resistance when used in surface materials compared to conventional aggregates, with the ability to retain its properties over the life of the pavement [8, 9]. The use of slag nickel as a substitute for natural aggregate is still obstructed due to Government Regulation No. 101 of 2014 which states that nickel slag is one of the materials that fall into the category of Hazardous and Toxic waste (B3) [7]. Flexible pavement is the most popular pavement layer for road construction. Most use non-renewable materials and industrial products such as aggregate, bitumen, cement, lime, and other additives used during road construction and maintenance [6].

One of the uses of nickel slag in asphalt mixtures is as a filler in a Hot Rolled Sheet (HRS) mixture whose strength depends on the strength of the mortar; a mixture of fine aggregate, filler, and asphalt. At 1% filler slag content, the Optimum Asphalt Content (OAC) is obtained of 6.75% with a better stability value than using extinguished lime filler [1]. In contrast, the use of fine nickel slag III with 9% filler obtained OAC 6.54% and filler 11.2% obtained OAC 7.023% [8]. In another study, for a mixture of AC-WC nickel slag used as an additive for fine aggregate, the optimum nickel slag content was 10% with a maximum tensile strength value of 79,147.74 KPa and the tensile strength value decreased after the addition of nickel slag above 10% [11-14].

Laston AC-WC mixture using nickel slag as a substitute for coarse aggregate with a reference asphalt content of 5%, 5.5%, 6%, 6.5%, and 7% can be used with characteristics that meet the requirements of Highways. In this paper, research has been carried out on the construction of the binder course as part of a literature review of the evaluation study of asphalt mixtures using waste slag as a substitute for coarse aggregate. The utilization of nickel slag waste provides economic benefits and has an environmentally friendly impact. This aggregate derived from nickel slag is available locally in Indonesia and has the potential to be used in high-value construction applications.

2. Research Method

The design of the hot asphalt mixture starts from testing the characteristics of the material used with the gradation used. The material and the gradation act as intermediate layer in Laston AC-WC, as specified in the General Specifications for Roads and Bridges of Highways, Bina Marga, 2018. Likewise, the standard reference mix used refers to the provisions of the mixed properties of the intermediate layer Laston AC-WC General Specifications for Roads and Bridges of Highways, Bina Marga, 2018. On the other hand, slag testing is still based on testing natural aggregates, it is necessary to first determine the aggregate gradation in making the mix design. The type of mixed design gradation refers to the combined aggregate gradation envelope for the AC-WC asphalt mixture. This test was carried out in the Bandung Institute of Technology Laboratory for five months, starting by testing the properties of aggregates, asphalt, and nickel slag waste materials. Because of the specific gravity of nickel slag with the density of natural aggregate > 0.2, in the mixed design, the unit volume is used. Figure 1 shows the gradation used in this research.

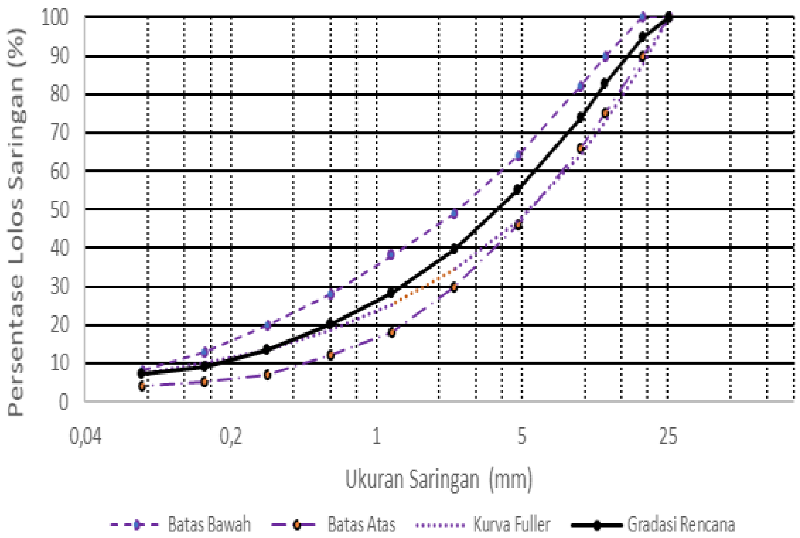


Fig. 1. Mixed gradient [2].

Materials

The main materials used in this research include asphalt, aggregates, steel slag, Portland cement, and sand. Asphalt type 50-60 with the physical specification shown in Table 1 was used. The aggregates that were used in this study are mixed from crushed aggregates and crushed steel slag which is divided into coarse aggregate in the range of 4.75 - 19 mm and fine ranges of 0.0075 - 4.75 mm according to the specification of road and bridge as shown in Table 2 [1]. Natural crushed aggregate (available locally-Badra site) with a maximum size of 19 mm was used for all mixes as suitable for the binder layer of flexible pavement (SORB/R9) [15,16].

i) Asphalt

Asphalt is a brownish black material that has water-resistant properties and anti-adhesive properties, which at a certain temperature will be solid but when heated to a certain temperature it will turn into a liquid or soft so that it can be used to wrap aggregate articles during road construction. It is a sticky liquid or solid consisting of hydrocarbon compounds or their derivatives, which are dissolved in trichloro-ethylene, non-toxic, volatile, and softens gradually when heated. [2]. In short asphalt is a thermoplastic material that has solid to slightly dense texture at room temperature and is one of the mixed materials used as a binder for aggregates in road pavements. Due to the fact it can harden when the temperature decreases, it is very suitable to be used as a binder.

ii) Aggregate

Aggregate is the main material for road structure. It is a collection of crushed stone grains and sand, or other minerals, both natural and artificial, which are the main determinants of the carrying capacity of a pavement. Based on the grain size, it is divided into three, namely coarse aggregate, fine aggregate, and filler. The Bina Marga specification states that coarse aggregate consists of crushed stone and crushed gravel that is retained on a No. 4 sieve or 4.75 mm sieve, while fine aggregate is material that passes a No. 4 sieve or 4.75 mm sieve. Filler is a mixed material that fills the space between fine and coarse aggregate to increase density. Stone dust and added fillers must be dry and free from lumps, and when tested by sieving according to SNI 03-1968-1990 shall contain material that passes the No. 200 sieve or 75 m sieve not less than 75% by weight [3]

iii) Nickel Slag

Slag is an industrial waste that is often found in the metal smelting process. Slag is in the form of residue or waste, in the form of lumps of metal, of low quality because it is mixed with other materials that are difficult to separate. The slag occurs due to the agglomeration of silica, potassium, and soda minerals in the metal smelting process or the melting of these minerals from the smelting container material due to high heat processes.

Nickel slag is an aggregate of residual waste from the combustion of electric furnaces produced by nickel mining. The results of the initial testing of slag waste showed that the main content of the waste was the minerals clinoenstantite (±90%) and magnetite (±9%). The use of nickel slag as a concrete mixture to replace aggregate in concrete or mortar from the lateritic nickel ore smelting process in Sulawesi is classified as high Fe and has the potential to be used as an alternative material for coarse or fine aggregate in concrete and mortar [3].

Table 1. TCLP Test Results

No.	Parameter	Unit	Results	Requirements TCLP -A	TCLP -B
1	Lead	Mg/1	<0,04	3	0,5
2	Cadmium	Mg/1	<0,05	0,9	0,15
3	Mercury	Mg/1	<0,002	0,3	0,5
4	Arsenic	Mg/1	<0,004	3	0,5
5	Antimony	Mg/1	<0,06	6	1
6	Molybdenum	Mg/1	<0,06	21	3,5
7	Zinc	Mg/1	0,18	300	50
8	Selenium	Mg/1	<0,004	3	0,5
9	Copper	Mg/1	0,02	60	10
10	Nickel	Mg/1	<0,01	21	3,5
11	Silver	Mg/1	<0,006	40	5
12	Barium	Mg/1	<0,03	210	35
13	Chromium Hexavalent	Mg/1	<0,01	15	2,5
14	Chloride	Mg/1	5.38	75000	12500
15	Boron	Mg/1	0,001	150	25
16	Nitrate	Mg/1	0,32	15000	2500
17	Nitrite	Mg/1	0,19	900	150
18	Cyanide	Mg/1	0,01	21	3,5

3. Results and Discussion

After conducting research and processing laboratory data, it is found that the comparison value of Marshall parameters for Nickel Slag and Split Stone is as follows (Table 2):

Table 2. Marshall test results 100%

MARSHALL (100%)							
No.	**Rate Asphalt**	**Density**	**VIM %**	**VMA %**	**VFA %**	**Stability Kg**	**Flow mm**
1	5.0%	2.30	8.814	16.898	47.838	1558.67	**2.590**
2	5.0%	2.29	9.332	17.370	46.274	1645.91	**3.120**
3	5.0%	2.35	6.931	15.182	54.344	1765.85	**2.900**
Average		2.32	8.359	16.483	49.485	1656.81	**2.870**
1	5.50%	2.37	5.548	14.969	62.934	1803.75	**3.740**
2	5.50%	2.38	5.227	14.680	64.391	2033.83	**2.720**
3	5.50%	2.37	5.477	14.904	63.255	1870.45	**2.970**
Average		2.37	5.418	14.851	63.527	1902.68	**3.143**
1	6.0%	2.40	3.522	14.200	75.198	1855.61	**3.790**
2	6.0%	2.38	4.522	15.089	70.032	1518.84	**4.740**
3	6.0%	2.39	4.090	14.705	72.188	1657.91	**3.620**
Average		2.39	4.045	14.665	72.473	1677.45	**4.050**
1	6.50%	2.42	2.049	13.947	85.306	1400.20	**3.200**
2	6.50%	2.40	2.902	14.696	80.253	1372.15	**3.680**
3	6.50%	2.40	3.144	14.909	78.914	1408.73	**3.470**
Average		2.41	2.698	14.517	81.491	1393.69	**3.450**
1	7.0%	2.41	1.795	14.769	87.846	1461.62	**4.230**
2	7.0%	2.41	1.752	14.732	88.106	1384.30	**3.900**
3	7.0%	2.42	1.582	14.584	89.153	1224.37	**3.900**
Average		**2.42**	**1.710**	**14.695**	**88.368**	**1356.76**	**4.010**

Marshall parameters:

i. Void In Mix (VIM): VIM, is the number of pores in a mixture (Fig. 2).
ii. Flow (flow): Fatigue is the magnitude of the change value a mixed effect load gives (Figs. 3 and 4).
iii. Stability: Stability, is the ability of pavement to mix when receiving traffic load without having to happen periodic changes such as waves, grooves, or bleeding (Fig. 5).
iv. Voids in Mineral Aggregate (VMA): VMA, is the number of volume pores in the mixture (Fig. 6).
v. Marshall Quotient (MQ): Marshall Quotient (MQ) is the result division of the value of stability and flow, which is used as an indicator of the potential flexibility of racks/fractures (Fig. 7).

a) Density

Comparison of density values between 0% variation and 100%. In this variation, 0% has a value of density lower than 100% variation.

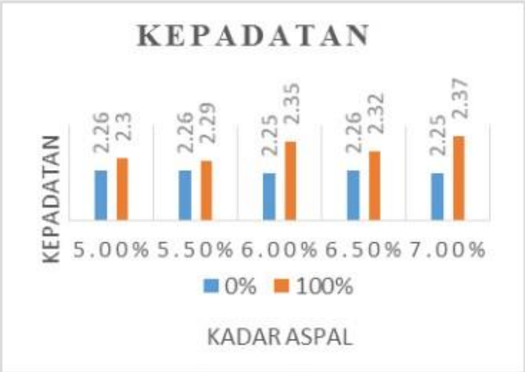


Fig. 2. Summary density.

b) Flow

Comparison of flow value between 0% variation and 100% found flow value at 100% variation larger this is influenced by the asphalt content on a mix of 100% more variations based on the calculation results of the Job Mix Formula.

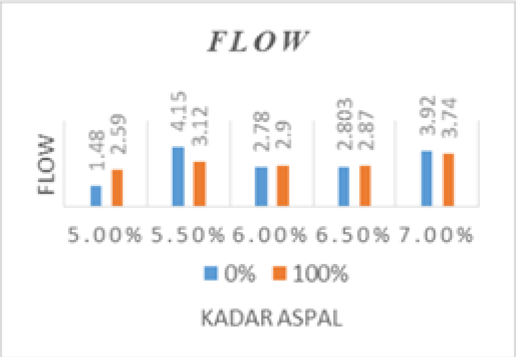


Fig. 3. Summary flow.

c) Void Filled with Asphalt

Comparison of VFA values between 0% and variations of 100%, found the average VFA value variation 100% greater this is due to the value of attachment aggregate to asphalt for nickel slag was found to be 95%

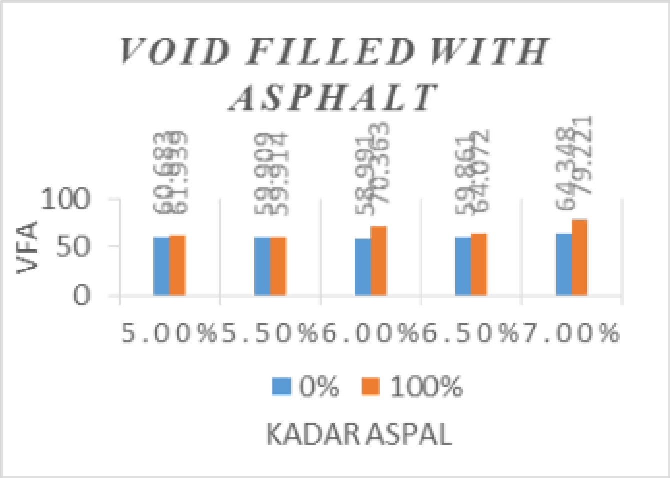


Fig. 4. Summary VFA.

d) Stability

This is influenced by the value of the specific gravity of Nickel Slag is greater with a value e 2.9255 compared to the specific gravity of Split stone with a value of 2.5181

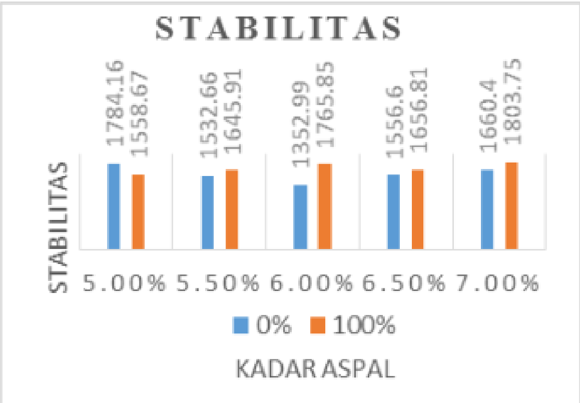


Fig. 5. Summary stability.

e) Void in mineral aggregate

Comparison of VIM values between 0% and variation 100% found the average VIM value variation 100% smaller than the 0% variation. This matter proves that the density value at a mixture of 100% is greater than 0%

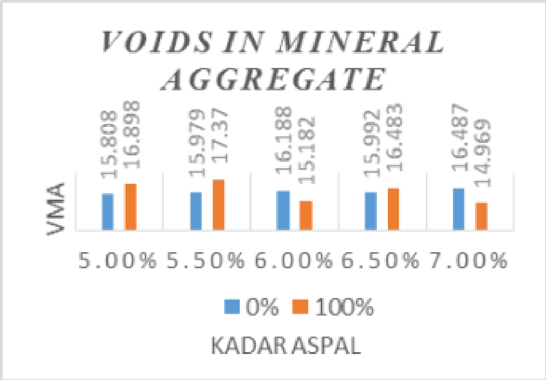


Fig. 6. Summary VIM.

f) Marshall Quotient

Comparison of MQ values between 0% variation and 100% obtained the average in the mixture of 100% larger, this can be seen in the value of high stability and more Flow value small so that the MQ value at 100% greater variation. This results in fracture potential at 100% variation mixture greater than the 0% variation.

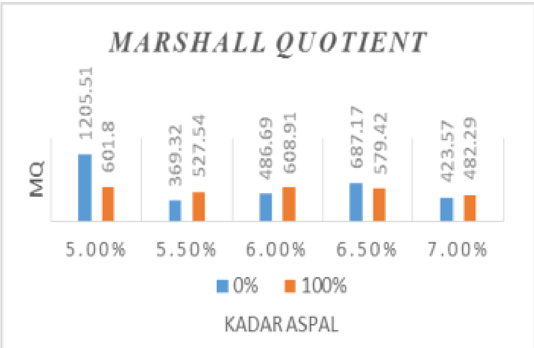


Fig. 7. Summary MQ.

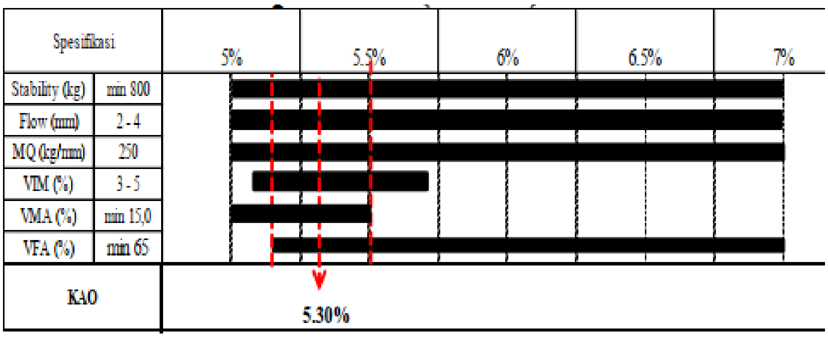
Optimum asphalt content variation aggregate content 0% and 100%.

Table 3. Determination of asphalt content optimum (0%).

Spesifikasi		5%	5.5%	6.0%	6.5%	7.0%
Stability (kg)	min 800					
Flow (mm)	2-4					
MQ (kg/mm)	250					
VIM (%)	3 - 5					
VMA (%)	min 15.0					
VFA (%)	min 65					
KAO				6.1		

Source: Laboratory Data Processing Results

Table 4. Determination of Asphalt content optimum (100%).



Source: Laboratory Data Processing Results

4. Conclusion

In conclusion, the use of 100% nickel slag and effective at 7% asphalt content makes the density of the mixture high. This resulted in smaller voids in the mixture which increase the stability. Stability is an empirical parameter to measure the ability of asphalt mixtures to withstand deformation caused by a loading. Thus, the use of nickel slag can provide economic value because it can reduce the use of new aggregates.

Acknowledgement

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