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Use of Nickel Slag Waste As Coarse Aggregate In Concrete

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Keywords

Coarse Aggregate; Nickel Slag; Compressive Strength; Normal Concrete.

Abstract

Indonesia is the largest nickel producer in the world. but from another aspect, the problem of ex-mining pits, combustion ash waste, nickel slag and others are environmental issues in the nickel mining industry (nikel.co.id, 2020). Currently, the Ministry of Industry through the research and development unit is trying to raise the potential of nickel slag or slag so that it can be used as industrial raw material that is in line with environmental management in the context of a sustainable economic program (antaranews.com, 2020). Based of this study was conducted on the use of nickel slag as a substitute for coarse aggregate in concrete. This research is an experimental study with the objectives of analyzing the physical and mechanical characteristics of nickel slag, analyzing the compressive strength of concrete using nickel slag as a substitute for coarse aggregate, and analyzing the optimal percentage of nickel slag used as a substitute for coarse aggregate. The results of this study indicate that the use of nickel slag as a substitute for coarse aggregate for 20 MPa concrete, and unable to achieve the planned average compressive strength of 20 MPa plus a margin of 12 MPa, resulted in a decrease in compressive strength and did not provide quality improvement. concrete. The application of nickel slag as a substitute for coarse aggregate in structural concrete with a design compressive strength ≥ 20 MPa is not recommended..

1. INTRODUCTION

Indonesia is the largest nickel producer in the world, but from another aspect, the problem of ex-mining pits, combustion ash waste, nickel slag and others is an environmental issue in the nickel mining industry (nikel.co.id, 2020). Currently, the Ministry of Industry through the research and development unit is trying to raise the potential of nickel slag or slag so that it can be used as industrial raw material that is in line with environmental management in the context of a sustainable economic program (antaranews.com, 2020).

In Southeast Sulawesi, there are several nickel smelters that produce nickel slag waste, including PT. Aneka Tambang in Pomala, Kolaka Regency, and PT. Virtue Dragon Nickel Industry (VDNI) in Morosi, Konawe District (Siti Harlina-detikFinance, 2019). Each mining industry company has a different age and technology in the calcination and reduction process in a reduction furnace to form matte and slag (analisis.id, 2020). so that differences in the shape and gradation of the slag produced also have the potential to occur.

Research on the use of slag as a partial replacement for coarse aggregates caused the bending strength of concrete to decrease and obtained normal concrete specific gravity at a variation of slag replacement of 80%, (Susilowati, Saputro, & Nurhidayati, 2013). Meanwhile, according to Ganti A. (2008) that, the use of low nickel slag as a substitute for coarse aggregates, can increase compressive strength by 12.32% and reduce abrasion by 24.17% and reduce shrinkage by 11.6% compared to normal concrete. Potential utilization of nickel slag (nickel slag) as aggregate up to 100% in concrete (Wijaya & Astutiningsih, 2021)

Several previous studies have been carried out such as (Jalali, Halim, & Salim, 2017), conducting research on the use of concrete paving blocks with variations of 0%, 25%, 75%, and 100%, where the average measurement results of paving blocks show that most of the test objects meet the requirements, especially the composition of a mixture of 1: 3 at all slag levels, compositions of 1: 4 and 1: 5 at slag levels of 0 and 25%; while the rest do not meet because they exceed the required size. The results of the compressive strength test

show that the higher the nickel slag content, the higher the compressive strength of the paving block, and the highest compressive strength is produced by the composition of the mixture of 1:3. Research on nickel slag as a concrete aggregate conducted by (Mustika, Salain, & Sudarsana, 2016), with the composition of cement, sand and gravel set at 1: 2: 3 in units of weight and the magnitude of the cement water factor which is also set at 0.5.

Another research by (Aprianto & Triastianti, 2018), namely the utilization of nickel slag solid waste, rice husks and fly ash into paving blocks, where in this study the use of slag was at most 45%. Characteristics of high-strength concrete with the substitution of steel slag and nickel slag as coarse aggregate (Suwindu, Parung, & Sandy, 2020). The effect of using nickel slag on the compressive strength and flexural strength of geopolymer concrete (Kaselle & Allo, 2021). Comparison of slag substitution in cement and sand in K-225 quality concrete mixture at PT IMIP Morowali Regency (Zainul, Djamaluddin, & Anwar, 2018). The design of non-sand concrete uses nickel vinyl aggregate slag type III (Taufiq, 2019). Effect of high temperature on the compressive strength of concrete using nickel slag as coarse aggregate (Hartono, Aswad, Mursidi, & Nurbaity, 2021). Experimental study of normal quality concrete with coconut shell aggregates and nickel slag (Aprilia, Phengkarsa, & Kusuma, 2021). In addition, the utilization of iron slag waste as a partial replacement material for sand in concrete production (Hijriah & Yunianti, 2021).

Based on the above, as well as to maximize the use of nickel slag waste, in addition to the location of the source material used is different, in this study there will also be a different composition formulation based on the specific gravity and weight of the aggregate content, as well as different variations in nickel slag substitution up to 100%, then in this study, it will be carried out with the title of the use of nickel slag waste as a coarse aggregate in concrete.

1.1 METHOD

1.2 Types of Research

The type of research carried out is experimental research, where the condition is made and regulated by the researcher by referring to the regulations of the Indonesian National Standard (SNI) and related literature. The type of test to be carried out is concrete aggregate testing, normal concrete compressive strength testing substituted for nickel slag material with variations of 0%, 10%, 25%, and 50% to 100%. The proportion of the concrete mixture is made concerning the guidelines of SNI 2834 of 2000. The number of specimens was made of 3 pieces for each of the compressive strength tests at concrete life of 1, 3, 7, 14, and 28 days.

1.3 Research Time And Location

This research was carried out in September 2020 and will end in June 2022 at the Materials and Concrete Laboratory of the Faculty of Engineering, Haluoleo University with material sources located at PT. Virtue Dragon Nickel Industry (VDNI) in Morosi, Konawe Regency, Southeast Sulawesi Province.

1.4 Stages of Research

The procedures and stages of research carried out include; observation and sampling of concrete constituent materials, testing of concrete constituent materials, mix design, making concrete specimens, pressing tests of concrete specimens, and data analysis.

From the observation of material sources, coarse aggregates in the form of nickel slag were obtained from PT. Virtue Dragon Nickel Industry (VDNI) in Morosi, Konawe County. Meanwhile, gravel is obtained from stone crushers produced by PT. Agung Beton Kendari. The river sand was obtained from the Pohara River of Konawe County.

The concrete constituent material tests carried out are tests of the characteristics of coarse aggregates (gravel and nickel slag), and the characteristics of fine aggregates (river sand) with feasibility conditions as shown in table 1 below:

Table 1. Types of testing of aggregate characteristics and specifications required.

No.	Characteristics of coarse aggregates	Specifications	Characteristics of fine aggregates	Specifications
1	Sludge content	Max 5 %	Sludge content	Max 5 %
2	Wear	< 40%	Organic content	< no. 3
3	Moisture content	0,5% - 2%	Moisture content	2% - 5%
4	Volume weight		Volume weight	
	a. Loose condition	1.4-1.9 kg/ltr	a. Loose condition	1.4-1.9 kg/ltr
	b. Solid conditions	1.4-1.9 kg/ltr	b. Solid conditions	1.4-1.9 kg/ltr
5	Absorption	Max 2%	Absorption	Max 2%
6	Specific gravity:		Specific gravity	
	a. Bulk	1.6 - 3.3	a. Bulk	1.6 - 3.3
	b. SSD	1.6 - 3.3	b. SSD	1.6 - 3.3
	c. Apparent	1.6 - 3.3	c. Apparent	1.6 - 3.3
7	Fine modulus	5.50-8.50	Fine modulus	2.50-3.20

(Source: SII 0052-1980)

Mix design of concrete is carried out by referring to the guidelines of SNI 2834 of 2000 concerning procedures for making a normal concrete mixture plan. The targeted average plan compressive strength of 30.48 MPa, was obtained using equation (1). In equation (1) $f'cr$ is the average plan of compressive strength, $f'c$ is the required compressive strength, which is 19.3 MPa, K is the multiplier factor coefficient, which is 1.64 and S is the standard deviation, which is 7 MPa. Variations of concrete mixtures with nickel slag substitutions are complete in table 2.

$$f'cr = f'c + K.\mathrm{S} \tag{1}$$

In equation (2), $f'c$ is the compressive strength with the unit *MPa* which is an indicator of the quality of concrete. *P* is the maximum load of the compressive test equipment with Newton units *(N)* and *A* of the cross-section of the concrete test piece specimen by unit *(mm²)*.

$$f'c = \frac{P}{A} \tag{2}$$

Compressive testing of concrete specimens was carried out at the age of 1 day, 3 days, 7 days, 14 days, and 28 days with variations in nickel slag substitution of 0%, 10%, 25%, 50,% and 100%. Given the need to know the model of the trend of increasing the strength of concrete from the age of 1 day to the age of 28 days in concrete specimens with this slag aggregate, while the limited capacity of the concrete mixer is only 0.3 m³ into to avoid the inhomogeneous of the mixture in each variation, as well as the magnitude of the deviation of compressive strength, the number of samples of concrete cylinder specimens is onlaremade 3 pieces for each age and variation of the mixture. The full testing and variation of concrete mixtures can be seen in table 2 below.

Table 2. Variation of the mixture and testing life of concrete

Variations of Concrete Mix	Types of Testing	Number of Test Objects and Concrete Life				
		1 Day	3 Days	7 Days	14 Days	28 Days
Concrete 0% Slag	Compressive strength	3	3	3	3	3
Concrete 10% Slag	Compressive strength	3	3	3	3	3
Concrete 25% Slag	Compressive strength	3	3	3	3	3
Concrete 50% Slag	Compressive strength	3	3	3	3	3
Concrete 100% Slag	Compressive strength	3	3	3	3	3

(Source: Research Plan 2020).

At the data analysis stage, an analysis of the test results of the characteristics of coarse aggregates (crushed stone and nickel slag), compressive strength and composition of the concrete mixture was carried out. Then analyze the correlation between the characteristics of the coarse aggregate and the resulting compressive strength of the concrete.

2. DISCUSSION



Figure 1. Concrete material under study *(Source: Observations, 2020).*

The results of the Pohara fine aggregate (river sand) test were processed data on the physical condition of the sand, among others; Sludge content is 4.00%, organic content is in category number 2, water content is 3.80%, loose volume weight is 1,401 kg/liter and solid volume weight is 1,525 kg/liter. water absorption 1.781%, bulk specific gravity 2.58 kg/liter, dry specific gravity 2.46 kg/liter and surface dry specific gravity 2.51 kg/liter, and sand smoothness modulus 2.99.

The test results of coarse aggregates (crushed stone) processed data on the physical condition of the sand, among others; sludge content of 1.45%, Wear 33.14%, moisture content of 1.69%, loose volume weight of 1.66 kg/liter and solid volume weight 1.83 kg/liter, water absorption 2.84%, bulk specific gravity (real) 2.75 kg/liter, dry specific gravity 2.55 kg/liter and surface dry specific gravity 2.62 kg/liter and smoothness modulus which is 9.18. Meanwhile, from the test results of nickel slag as a substitute for coarse aggregates, the following characteristic data were obtained: slag sludge content of 0.47%, slag hardness of 2.40%, average volume weight of 1.73 kg/liter, water absorption of 0.91%, surface dry specific gravity of 2.95 kg / ltr, bulk specific gravity 3.01 kg/liter and apparent specific gravity of 2.93 kg/liter, and slag fineness modulus 7.02.

From the results of compressive testing on concrete with normal materials (crushed stone aggregates) and concrete using nickel slag as a substitute for partially or completely broken stone, an average compressive strength was obtained at a variation of 0% nickel slag aged 28 days of 30.77 MPa with a standard deviation of 1.16, at a variation of 10% nickel slag average compressive strength of 30.26 MPa with a deviation of 0.62, compressive strength of 30.1 MPa at a variation of 25% nickel slag with a deviation of 0.3, compressive strength of 30.13 at a variation of 50% nickel slag with a deviation of 0.68 and a compressive strength of 30.38 MPa, and a variation of 100% nickel slag with a deviation of 0.15.

Based on the strength of the 28-day lifespan, concrete without nickel slag obtained a compressive strength of 30.77 MPa, concrete with substitution of 10% nickel slag of 30.26 MPa, concrete with substitution of 25% nickel slag of 30.10 MPa, concrete with substitution of 50% nickel slag of 30.13 MPa and in concrete with 100% nickel slag compressive strength of 30.38. Concrete compressive strength data from each of the other slag substitution variations as in table 3 below:

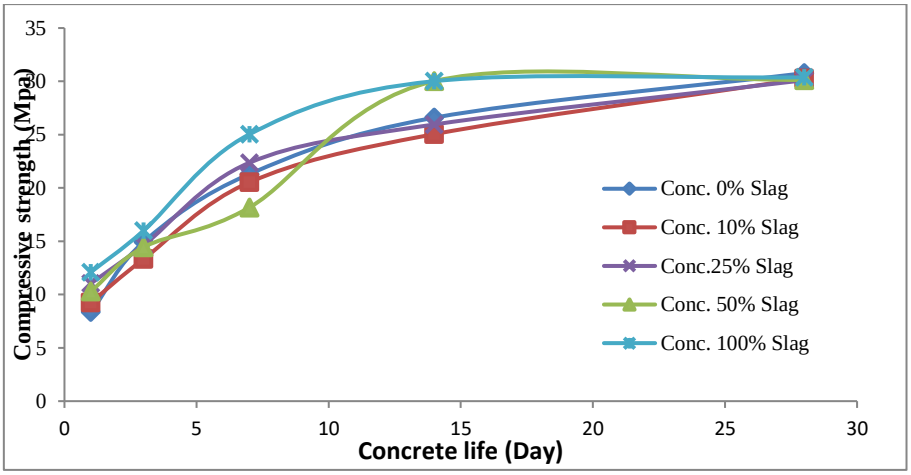
Table 3. Compressive strength of concrete with nickel slag substitution

Variant	Sample	Crushed load (kN) / Compressive strength (Mpa)									
		1 Day		**3 Days**		**7 Days**		**14 Days**		**28 Days**	
	1	145.6	8.2	268.8	15.2	376.4	21.3	469.6	26.6	532.6	30
Concrete 0% Slag	2	150.4	8.5	258.0	14.6	383.8	21.7	455	25.7	572.3	32.4
	3	148.0	8.4	265.5	15.0	370.6	20.9	485.4	27.5	529.5	29.9
Average			***8.37***		***14.94***		***21.30***		***26.59***		***30.77***
	1	178.9	10.1	171.7	9.7	325.0	18.4	348.8	19.7	520.5	29.47
Concrete 10% Slag	2	145.2	8.2	269.2	15.2	394.2	22.3	493.0	27.9	565.0	30.99

Variant	Sample	Crushed load (kN) / Compressive strength (Mpa)									
		1 Day		**3 Days**		**7 Days**		**14 Days**		**28 Days**	
	3	166.5	9.4	265.8	15.0	368.6	20.9	485.5	27.5	535.5	30.32
Average			***9.26***		***13.34***		***20.53***		***25.05***		***30.26***
	1	220	12.46	243.8	13.8	404.2	22.9	535.5	30.3	526.0	29.78
Concrete 25% slag	2	167.2	9.47	277	15.7	395.0	22.4	400.8	22.7	538.6	30.49
	3	198	11.21	254.4	14.4	385.8	21.8	439.0	24.9	530.5	30.04
Average			***11.04***		***14.63***		***22.36***		***25.96***		***30.10***
	1	235.4	13.33	266.80	15.11	293.40	16.61	488.50	27.66	560.20	30.72
Concrete 50% Slag	2	165.4	9.36	229.80	13.01	294.20	16.66	505.50	28.62	515.40	29.18
	3	145.2	8.22	269.20	15.24	375.10	21.24	597.00	33.80	538.50	30.49
Average			***10.30***		***14.45***		***18.17***		***30.03***		***30.13***
	1	197.30	11.17	245.60	13.91	476.00	26.95	590.50	33.41	540.20	30.59
Concrete 100% Slag	2	232.20	13.15	320.20	18.13	428.00	24.23	520.00	29.44	535.00	30.29
	3	211.85	11.99	282.00	15.97	422.40	23.92	480.50	27.21	552.20	30.26
Average			***12.10***		***16.00***		***25.03***		***30.02***		***30.38***

(Source: Observations, 2020).

The previous table shows that normal concrete (without the addition of slag instead of crushed stone) can achieve the planned compressive strength of concrete which is 30.48 MPa of which the compressive strength is obtained by 30.77 MPa. However, in the variation of nickel slag substitution, 5%, up to 100%, only the highest compressive strength of 30.38 MPa was obtained.



Gambar 3. Grafik Peningkatan Kuat Tekan Beton Slag Nikel*(Sumber: Hasil Analisa, 2020)*

The graph of the increase in compressive strength of each concrete life shows that there is an increase in compressive strength in the use of nickel slag instead of crushed stone. In the variation of 50% and 100% nickel slag aged 1 day to 14 days, there is a tendency to increase the compressive strength significantly, the maximum strength is achieved faster but stagnant at the compressive strength below the compressive strength of the plan.

The characteristics of the river sand used qualify as fine aggregates on concrete. The sludge content of 4.04% which is almost close to the limit is 5%, is linear with a large amount of feldspar content of 77% where the compound consists of the elements sodium (Na), Potassium (K) Aluminum (Al) and silicon (Si). The elements sodium and potassium, are reactive alkali metals that are soft, light and easily react with water, resulting in a greater difference in the weight of sand before washing after washing. While aluminum (Al) is a type of heavy metal with a density of 2.70 grams/cm^3, and silicon ica which is a non-metallic element (metalloid) with a mass of 2.57 grams/cm^3 found in dust and sand. Elements of aluminum and silicon oxidized with oxygen will have the potential to increase the level of sludge in the sand. The density of the elements that

make up the chemical compounds in river sand particles will determine the specific gravity, volume weight, and absorption power of the sand.

In portland cement, it consists of 71.59% lime minerals, 20.42% clay, 0.91% iron sand, and 7.07% coal with compound content SiO_2, Al_2O_3, Fe_2O_3, Ca,O, and MgO on each of these minerals (Botahala & Pasae, 2020). In the concrete hydration process, the presence of silicate and aluminate compounds with the specified concentration is found in cement, the hydration reaction occurs for 1-3 hours (cement paste is still plastic or workable condition). Tricalcium aluminate C_3A, then tricalcium silicate C_3S resulting in setting time or hardening to be fast due to the hot temperature, while gypsum ($CaSO_42H_2O$) slows down the time setting process. So that the high content of sludge results in an excess concentration of aluminate in cement paste and mortar, thereby reducing the binding power of cement paste to coarse aggregates.

Overall the characteristics of nickel slag are better than that of crushed stone, except for the weight of the volume. The low volume weight and high percent crushed (5 mm filter pass) on crushed stone due to the impact load of the steel ball of the Los Angles tool, are caused by the presence of cavities in the grains and the level of smoothness of nickel slag 9.8 is higher than the smoothness of crushed stone grains which is only 7.02. While the specific gravity and absorption of nickel slag are better than crushed stone, it is closely related to the content of chemical elements contained in nickel slag and crushed stone. Nickel slag which is 78% dominated by the content of elements magnesium, ferrite, and silicon, Mg 1.80 Fe 0.20 SiO 4 which are transition metals and alkali metals with density Fe 7.86 grams/cm³ and Mg 1.74 grams/cm³, while crushed stone which is 70% dominant contains basalt, sodium (anorthite, sodian, syn) Na 0.45 Ca 0.55 Al 1.55 Si 2.45 O8, with a lighter density, resulting in a higher density or specific gravity of nickel slag than that of crushed stone. The specific gravity of the slag is higher, making the water absorption of the nickel slag lower, while the low specific gravity of crushed stone results in high water absorption. Although in nickel slag some pores or cavities allow it to absorb water, nickel slag which is resulting from high-temperature combustion, the lack of oxygen in the granules, and the surface of the slag grain becomes more waterproof.

From the characteristics of nickel slag above, it is indicated that it contributes to the low compressive strength, this is in line with research (Rahmawati & Suhendro, 2017), which suggests that the wear of linear aggregates against the compressive strength obtained. In addition, the shape of nickel slag grains that tend to be round also results in a lower compressive strength obtained, this is strengthened by research (Masril, 2020), which found that the compressive strength of concrete using crushed stone is higher than the compressive strength with natural gravel as a coarse aggregate, which is 264.237 kg/cm² compared to 246.91 kg/cm².

The correlation and effect of nickel slag substitution on compressive strength can be seen in the correlation analysis and linear regression in the following table.

Table 4. Correlation and effect of nickel slag on compressive strength

Nickel Slag Variations (%) Variable X	Compressive Strength (Mpa) Variable Y
0	30.77
10	30.26
25	30.10
50	30.13
100	30.38
R	-0.258
R^2	0.067

(Source: Analysis results, 2020)

From the correlation analysis, an R-value of 0.25 was obtained, which means that the substitution of nickel slag with the resulting compressive strength of the concrete, has a strong relationship. Meanwhile, from the results of linear regression analysis on the substitution of nickel slag against the compressive strength, a value

of R^2 0.067 was obtained. A graph of the linearity between the variations of nickel slag against compressive strength can be seen in the following chart.

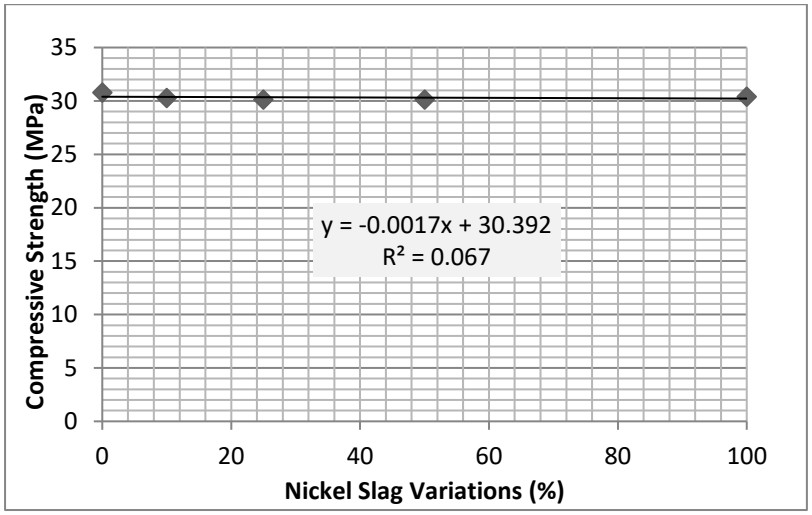


Figure 4. Linear regression model correlation of nickel slag substitution to the compressive strength of concrete

The graph above shows that the substitution of nickel slag does not affect compressive strength. The absence of the effect of replacing crushed stone with nickel slag as a coarse aggregate, either partially or completely does not provide an improvement to the compressive strength of the concrete produced.

3. CONCLUSIONS

The results of this study showed that the use of nickel slag as a substitute for coarse aggregates for 20 MPa quality concrete was not able to achieve the planned average compressive strength of 20 MPa plus a margin of 12 MPa. The use of nickel slag as a substitute for coarse aggregates results in low compressive strength obtained. The low correlation of nickel slag substitution in coarse aggregates to concrete compressive strength indicates the lack of improvement in concrete quality due to the experiment. Thus the use of nickel slag instead of coarse aggregate on structural concrete with a plan compressive strength of ≥ 20 MPa is not recommended for use.

4. ACKNOWLEDGMENTS

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