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Mechanical Characteristics of Concrete with Addition of Nickel Slag Waste as Aggregates

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ABSTRACT

Ferronickel slag is a waste product of the nickel metal smelting industry. PT. Virtue Dragon Nickel Industry is a company located in Konawe, Southeast Sulawesi Province, which is the first ferronickel and stainless-steel industrial area in Indonesia. Since 2017 until now, the capacity of the ferronickel smelting industry in the company is 600,000 tons. From the ferronickel smelting process, slag waste of around 3 million tons has also been produced which has not been processed or utilized. Slag waste is feared to disrupt the environment if not managed or utilized properly. This study aims to study the utilization of nickel slag waste as a substitute for fine and coarse aggregate in concrete. This study compares the mechanical properties of concrete using nickel slag material with the use of natural materials in the form of gravel and sand taken from the Konaweha River. The study was started with the preparation of nickel slag in the size of coarse aggregate 10-20 mm, and fine aggregate that passes 20 mesh. Nickel slag was tested for its content or composition. Slag was mixed into a concrete mixture containing sand, gravel, cement with a certain composition. The slag content was added at 0, 10, 20 and 30%. The stirred mixture was then tested for slump with an Abrams cylinder with a lower diameter of 20 cm, an upper diameter of 10 cm and a height of 30 cm. The mixture was molded in the form of a cube measuring 15 cm x 15 cm x 15 cm for density testing and compressive strength testing after 28 days. The test results showed that the largest slag content was silica and iron. The addition of nickel slag provided a slump value that was still included in the type of mixture with good performance. The addition of nickel slag up to 30% increased the density and compressive strength of concrete. The density of concrete increased by 6.7-21.9%. The increase in concrete compressive strength ranges from 8.43 to 33.79%. The mixture with the addition of 20% fine slag has the highest compressive strength of 33.23 MPa.

1. Introduction

Infrastructure development in a country cannot be stopped. Nowadays, there is an increase in world construction projects by 6%-9% per year [1]. The shortage of raw materials for construction work is an increasing problem worldwide. Thus, the conservation and use of sustainable materials have become an interesting field of research. In construction work with different aggregate sources such as ferronickel slag waste, recycled construction waste, reclaimed pavement waste, burnt brick waste, treated soil and so on [2], [3], [4]. The amount of ferronickel waste steel slag has increased with the rapid growth of the steel industry [5], [6], [7]. The abundance of ferronickel mineral

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resources in Indonesia has resulted in an increasing number of processing plants in various regions [8][9].

Referring to data from the Ministry of Energy and Mineral Resources in 2019, Indonesia was the world's largest nickel ore mining producer. Of the total world nickel production of 2,668,000 tons of Ni, 800,000 tons of Ni came from Indonesia. Sulawesi Island is the largest nickel reserve area in Indonesia, one of which is Southeast Sulawesi province. PT. Virtue Dragon Nickel Industry is a company located in Konawe, Southeast Sulawesi Province, is the first ferronickel and stainless steel industrial area of Jiangsu Delong Nickel Industry Co., Ltd. and China First Heavy Industry Group of China located in Indonesia. The first phase is to build a 600,000-ton ferronickel smelting project (VDNI), with three major projects including a smelter, a power plant and a dock, with a total investment of 1 billion US dollars. The production line was put into operation in 2017 (Ministry of Energy and Mineral Resources, 2019). The utilization of resources and safe disposal involved in heavy metal slag has attracted increasing attention worldwide, if the slag accumulates for a long time without treatment, it can have a very detrimental effect on the environment [10], [11]. The use of ferronickel slag is considered safe because the amount of heavy

metals in the leachate is much lower than the permissible limit. Concrete using ferronickel slag as a partial replacement for sand has mechanical properties that can be improved, such as compressive strength, tensile strength and modulus of elasticity, compared to control specimens [12], [6]. This nickel smelting process produces a very large amount of ferronickel slag waste that needs to be handled or utilized properly because it has the potential to cause environmental pollution. So far, ferronickel slag has only been used for road embankments [13], [3], [5]. On the other hand, the need for high-quality concrete is increasing along with the progress of development. High-quality concrete is usually used for buildings that bear quite large loads. Buildings that bear quite large loads require concrete that has very high concrete compressive strength, the ability to withstand cracks that occur and withstand cracks against weather conditions. The use of various types of solid waste from industry as a substitute for fine and coarse aggregates in concrete mixtures has been widely carried out, including fly ash [14], copper slag [15], iron slag [16], and also nickel slag [17] [18]. Research on the utilization of nickel slag has begun, therefore this study will study the utilization of nickel slag (ferronickel slag) from nickel smelter waste, which is currently still limited in its use and most of it is only stockpiled. The use of nickel slag for concrete aggregates is expected to provide a solution to the problem of nickel slag waste, and provide added value to nickel slag waste.

2. Research Methodology

2.1. Materials

Siever Machine, Crusher, Sieve, Scales, Measuring Cup, Bucket, Abrams Cone, Electric Mixer, Large Shovel, Small Shovel, Pounding Stick, Ruler, Block Mold, Pressure Gauge Machine. Portland cement from PT. Semen Indonesia, Coarse Aggregate in the form of crushed stone (split) from Kendari, sand measuring 4.8 mm from the Konaweha River, water, Nickel Waste (Ferronickel slag) from PT. VDNI, Morosi District, Konawe Regency, Southeast Sulawesi Province.

2.2. Procedures

2.2.1 Determination of Concrete Mix Composition

The composition of the concrete mixture used is a concrete mixture with a weight ratio of cement: fine aggregate: coarse aggregate in various compositions. Nickel slag is prepared as a substitute for coarse aggregate and fine aggregate. Nickel slag is crushed to a size of 1-2 cm for coarse aggregate, while for fine aggregate, it is sieved and taken that passes 20 mesh. Variations in composition include variations in the percentage of nickel slag waste as a substitute for coarse aggregate, by 0%, 10%, 20%, 30% of the weight of coarse aggregate in a concrete mix unit, and also by 0%, 10%, 20%, 30% of the weight of fine aggregate.

Table 1 Concrete Composition for fine slag

Composition	**% material**			
Fine sand	40	30	20	10
Coarse sand/gravel	50	50	50	50
Fine Slag	0	10	20	30
Cement	10	10	10	10

Table 2 Concrete Composition for coarse slag

Composition	% material			
Fine sand	40	40	40	40
Coarse sand/gravel	50	40	**30**	20
Fine Slag	0	10	20	30
Cement	10	10	10	10

2.2.2 Concrete Mix Making

The making of this concrete mix begins with the preparation of samples used in the form of coarse aggregate, fine aggregate, cement and water as well as ferronickel slag samples as coarse and fine aggregates, then testing the characteristics of the aggregates used based on the relevant SNI method including testing water content, mud content, volume weight, specific gravity and water absorption. The aggregate gradation in the mixture is determined and designed to meet the mixture specifications for a maximum aggregate size of 4 mm.

2.2.3 Slag and Concrete Testing

a) Slag content analysis

The slag content was analyzed at the PT. VDNI Laboratory, Morosi District, Konawe Regency, Southeast Sulawesi Province. The analysis includes the content of elements contained in nickel slag.

b) Slump value testing

Slump testing is carried out with an Abrams mold, which is a cone-shaped mold with a lower diameter of 20 cm, an upper diameter of 10 cm and a height of 30 cm. Slump value testing on fresh concrete follows SNI standards (SNI 03-1972-1990) [19]. Slump testing is carried out with the following steps:

a. The concrete mixture is put into the Abrams mold with 3 layers, each layer consists of the same material, and each layer is pierced with a steel stick 25 times.
b. The top surface is leveled using a cement trowel and waited for 60 seconds.
c. The Abrams cone is carefully pulled up, so that the concrete mixture will drop.
d. The slump value is obtained by measuring the amount of subsidence of the concrete mixture from its original height.

c) Concrete density testing

In density testing, the mixture is molded in a cube mold measuring 15cm x15cm x15cm. Concrete density testing follows SNI 1973:2008 [20]. Density can be obtained by weighing fresh concrete compacted in a standard container of known mass [21][22].

d) Concrete compressive strength testing

There are 2 types of test objects in concrete compressive strength tests that are often used, namely cubes and cylinders. The test objects used in this study were in the form of cubes measuring 15cm x 15cm x 15cm. The test objects were soaked in water for 28 days before the compressive strength test was carried out [20]. The test specimens were dried and then the test specimens were subjected to a compression test procedure according to SNI standards for compressive strength in accordance with SNI 03-1974-1990 [19].

3. Results and Discussion

3.1. Chemical compound content of slag

The results of the composition test in the Laboratory showed that the chemical compound content in PT. VDNI slag was silica (Si), iron (Fe), alumina (Al), and magnesium (Mg). The test results are shown in table 3.

Table 3 Chemical compound content of ferro-nickel slag PT.VDNI

Compound	%
SiO_2	30.49
Al_2O_3	6.38
CaO	1.75
MgO	11.1
Cr_2O_3	1.17
Ni	1.35
Fe	23.44
P	0.0101
S	0.44
Burn Reduction	7.65
Silicon magnesium Ratio	2.75

The average value of SiO_2 content in the slag used as aggregate is 30% and the average Fe is 23.44% which increases the compressive strength of the concrete quite high, so that it can improve the mechanical properties of the concrete. The nickel slag used is included in the low slag group obtained from the furnace [23]. In general, nickel slag contains silica (Si), iron (Fe), alumina (Al), and magnesium (Mg) with levels that are varies (Wang, 2016). The nickel slag content is almost the same as the nickel slag content from the Pomalaa area, the main content of which is silica (Si), alumina (Al), and iron (Fe) [24]. The nickel slag content is also similar to the nickel slag from the Sorowako_East Luwu area, the highest element content is iron (Fe) between 50-60%, Silica (Si) between 11-35%, and Magnesium between 1-15% [25].

3.2. Slump Value

The size of the slump value depends on the amount of water mixed into the mixture. The more water used in the mixture, the thinner the mixture, causing the greater the slump value, the large slump value can result in a decrease in the compressive strength of the concrete. Slump testing was carried out using an Abrams cone, which is a cone-shaped mold with a lower diameter of 20 cm, an upper diameter of 10 cm and a height of 30 cm. The use of this method is based on the ASTM C-143 standard [19], [26]. The test results obtained are shown in Table 4 and plotted in Figure 4.

Table 4 Concrete mix slump test results

Slag Variation	Fine Slag Slump Value (cm)	Coarse Slag Slump value (cm)
0%	8	8
10%	8.4	7.9
20%	9	8.3
30%	9.2	8.1

Table 4 shows the results of the research conducted. The test results show varying slump values. The largest slump value is 9.2 at 30% coarse aggregate. If seen from the slump value obtained, the workability of the concrete can be known, where from various variations in % slag is a mixture of materials that are not included in the group of thin mixtures. The slump values obtained from various types of mixtures can all be used for non-reinforced footings, underground construction, road construction. The test results in general show that both types of nickel slag, both fine and coarse, have good performance. The slump value ranges from 8-12 cm, including the group of concrete mixtures with good performance [19]. A slump value below 8 cm indicates that the concrete mixture is too coarse, while a slump above 12 cm indicates that the concrete mixture is too soft to be applied. In general, the lower the slump value, the mixture will be difficult to pour and has the potential to cause air cavities and cracks in the concrete [26], [27], [28].

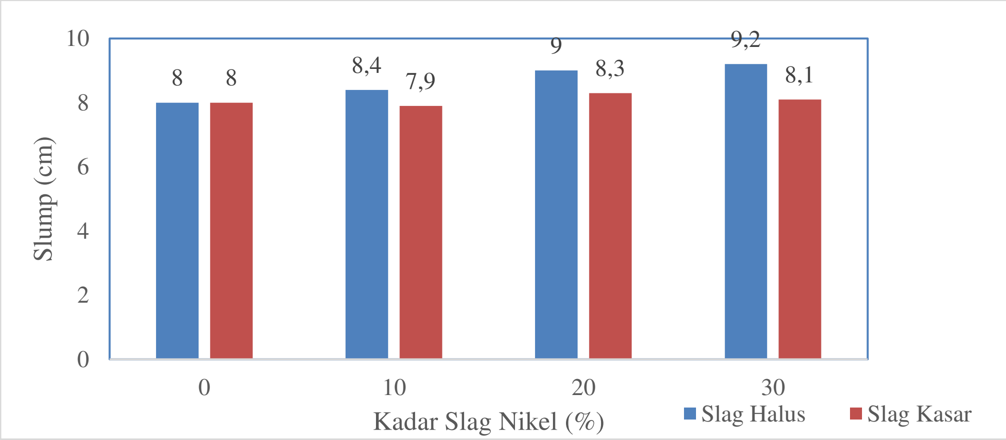

Fig. 1 Slump of concrete at various levels of fine and coarse slag

3.3. Concrete Density

Concrete density is a measure of the density of concrete that directly affects its weight. Higher density means more mass per unit volume, resulting in heavier concrete. This is important in construction, because weight affects structural stability, load-bearing capacity, and foundation requirements. The results of measuring the compressive strength of concrete with both fine and coarse slag substitution are shown in Figure 2.

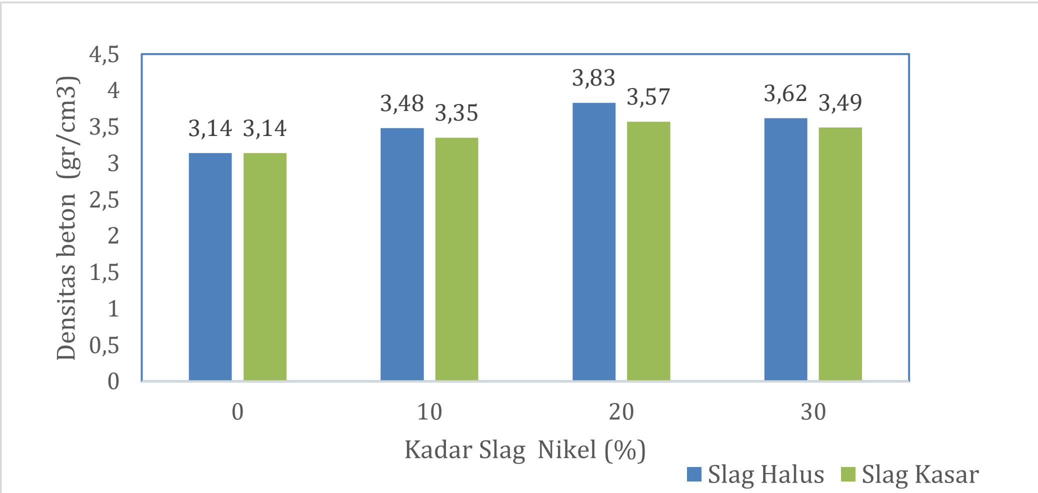

Fig. 2 Density of concrete at various slag levels

In measuring the specific gravity of concrete at 0% aggregate without slag on a block molding tool with dimensions of 15cm x 15cm x 15cm, each obtained a specific gravity of 3.14 gr/cm³, in a mixture of 10% fine aggregate obtained a specific gravity of 3.48 gr/cm³ and coarse aggregate obtained a value of 3.35 gr/cm³. In the substitution of 20% fine nickel slag aggregate, a specific gravity of 3.83 gr/cm³ and coarse aggregate 3.57 gr/cm³ were obtained, and in a mixture of 30% fine aggregate obtained a specific gravity of 3.62 gr/cm³ and coarse aggregate 3.49 gr/cm³. The largest specific gravity is in the sample of 20% fine aggregate with a value of 3.83 gr/cm³.

Concrete made with or without slag additions shows high-density concrete, according to the criteria for concrete density greater than 2800 kg/m³ or 2.8 g/cm³ [29], [30]. The addition of nickel slag provides an increase in concrete density of 6.7-21.9%. The highest increase in the addition of fine slag is 20%.

The increase in concrete density with the addition of nickel slag is in line with the results of previous studies which also obtained results of an increase in density with the addition of nickel slag [18]. The density value of concrete will generally correlate with the compressive strength of concrete proportionally.

3.4. Concrete Compressive Strength

The compressive strength of concrete was tested at various mixture compositions with the substitution of fine sand aggregate with fine nickel slag and the substitution of coarse gravel aggregate with coarse nickel slag. The results of the compressive strength test are shown in Figure 3.

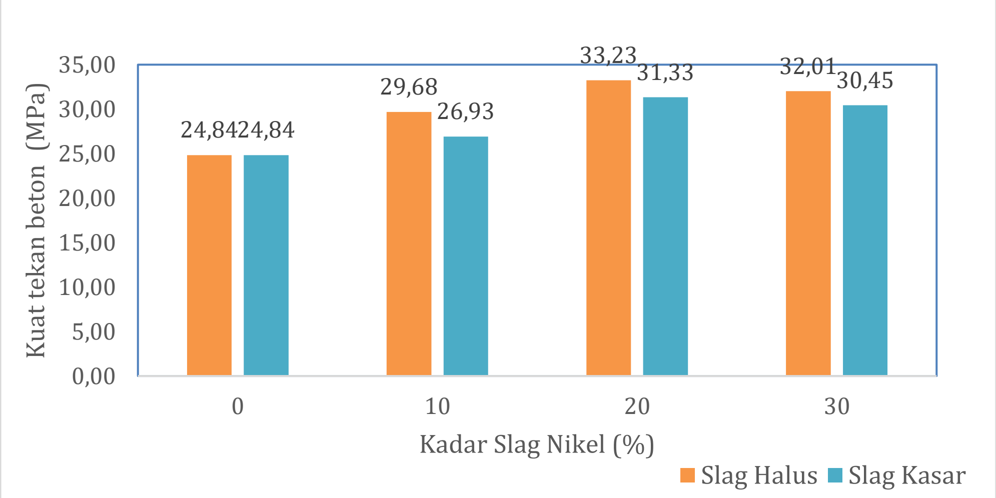

Fig. 3 Concrete compressive strength at various slag levels

Based on the compressive strength graph, 0% concrete has a higher compressive strength value, namely 24.84 MPa. The addition of 10% slag increases the compressive strength to 29.68 MPa, for fine slag and 26.93 MPa for coarse slag. The addition of 20% slag produces concrete with a compressive strength of 33.23 for fine slag and 31.33 MPa for coarse slag. With the addition of 30% slag, the compressive strength becomes 32.01 MPa for fine slag and 30.45 MPa for coarse slag.

The addition of fine or coarse slag increases ive the impact of heat on the increase in concrete compressive strength. The increase in concrete compressive strength ranges from 8.43-33.79%. The lowest increase occurred with the addition of coarse slag of 10%, while the highest increase in compressive strength occurred with the addition of fine slag of 20%. In general, the addition of fine slag provides a greater increase in compressive strength than coarse slag.

The increase in compressive strength in concrete using fine or coarse slag is in line with previous studies. Previous studies have shown that concrete with nickel slag has an increase in compressive strength of around 21% compared to concrete without nickel slag [17]. Research on the addition of fine nickel slag from the blast furnace process to a concrete mixture of 25% showed an increase in compressive strength of around 11.50% [18].

Other studies have treated the addition of nickel slag as a substitute for sand in a concrete mixture of 20-40%. Substitution of sand with nickel slag has increased the compressive strength, but the addition of slag above 40% actually decreases the compressive strength of the concrete. The highest increase in compressive strength is in the addition of nickel slag of 40% [31].

4. Conclusion

The nickel slag content of Morosi, Konawe is mostly silica (Si) and iron (Fe). The slag composition is almost the same as the slag composition from other areas in Central Sulawesi. The addition of fine nickel slag increases the slump value, but is still within the limits that still meet the good slump standards for concrete. The addition of coarse slag has only a slight effect on the slump value. The slump of concrete with the addition of nickel slag is still within the normal limits for a good concrete mix with a slump value ranging from 8-12 cm. The addition of nickel slag increases the density of the concrete. All concrete mixes produced are included in the high-density concrete classification. The density of concrete with the addition of nickel slag increases by 6.7-21.9%. The concrete mix with the addition of 20% fine nickel slag has the highest density of 3.83 gr/cm^3. The addition of nickel slag increases the compressive strength of the concrete. Fine slag provides a greater increase in compressive strength compared to coarse slag. The compressive strength of concrete with the addition of nickel slag ranges from 26.93-33.23 MPa. The increase in compressive strength of concrete with the addition of nickel slag ranges from 8.43-33.79%. The mixture with the addition of 20% fine slag has the highest compressive strength of 33.23 MPa. The addition of fine or coarse nickel slag up to 10-30% has improved the quality of concrete.

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