The behaviour of self-compacting concrete (SCC) with nickel slag as fine aggregate towards seawater curing

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Abstract. This paper is a continuous study that outlines Self Compacting Concrete (SCC) behavior on high strength concrete with nickel slag as fine aggregate. The percentage of nickel slag substitution as fine aggregate varies from 0% to 100% with an increase of 25%. This laboratory study aims to obtain the effect of seawater curing on the concrete compressive strength. The specimens immersed in seawater for 220 days will provide a SCC behavior assessment towards seawater immersion. The results obtained show that concrete with 25% nickel slag gives the most maximum effect. Compared to concrete without slag, SCC with 25% nickel slag has a higher compressive strength of 17%. Besides, the slump test also showed good condition. All specimens using nickel slag in seawater immersion show greater strength when compared to non-slag concrete. This means that concrete is very suitable at a curing age of 220 days when substituted with nickel slag. The mixture using nickel slag of 100% (SCC100 specimen) illustrates a reasonably stable strength from 28 days of immersion.

1. Introduction

The use of various waste for concrete manufacture become a common phenomenon due to climate change and sustainability concern in the construction sector [1]. Nickel slag is a waste product produced by a company of PT Antam Pomalaa. In 2018, PT. ANTAM produced 1,023,111 tonnes of slag. Slag from the ferronickel processing plant of PT. ANTAM in Pomalaa, Southeast Sulawesi, is currently being used as a substitute for fine aggregate raw material for construction and a concrete construction material called Pomalaa Beton (Poton). In addition, slag is also used as a substitute for aggregate (sand and gravel) in cast concrete mix of PT. ANTAM. Nickel slag can be processed into concrete construction materials such as POTON or Pomalaa Beton. To note, as of semester I 2019, this company nickel production has reached 4.79 million wet metric tons (wmt) or an increase of 27% compared to the same period in 2018, 3.77 million wmt. ANTAM's efforts in managing ferronickel factory waste are a reflection of the Company's commitment to sustainable development. This effort can decrease environmental effects and mitigate climate change [2]. The concrete compressive strength test results showed an increase in slag levels of 20 and 40%, but decreased at levels of 60 and 80% [3].

Seawater cannot be separated from development, especially coastal areas, coastal structures such as piers, and various structures[4]. This paper describes the effect of concrete using nickel slag as the base material for fine aggregates. It is crucial to be investigated to describe the behavior of sea immersion. Concrete has been widely used for construction material due to its characteristics of availability, low cost, and durability [5]. Currently, Self-Compacting Concrete has become widely demanded in the construction sector due to its technical and economic benefits [6]. Furthermore, SCC (Self Compacting Concrete) is used as a method of making concrete to make it easier to work, where the concrete can solidify itself without vibrator. On high strength concrete with a small slump value
which causes difficulties when making it so that superplasticizer liquid is used to make the concrete flow. High-quality concrete has a large water-cement viscosity factor value, which makes it very complicated cast. In this case compaction, a method is needed to make it easier by using SCC, which can self-compact and has high workability. The quality of the compressive strength that is planned should not experience a decrease in strength due to the presence of the SCC as an added material. Also, Dehn et al. [7] said that in the production of SCC concrete, the composition of coarse aggregate and fine aggregate must be considered. The more significant the proportion of fine aggregate will increase the flowability of fresh concrete. Still, if too much fine aggregate used, it will decrease the resulting compressive strength value.

Conversely, if too much coarse aggregate can increase the risk of segregation of concrete. The use of superplasticizers can improve the quality of concrete [8][9][10]. This study uses an added material in the form of a Master Glenium Sky 8851 superplasticizer at 1% of the weight of cement. The SCC concrete mix design method used is the System Department of Environment (DOE) for normal concrete mix design. In testing the slump value of several variations in the use of slag, it shows that the greater the addition of slag to high strength concrete mixtures, the greater the travel time in T500 mm compared to concrete without slag [11].

2. Materials and Methods

2.1. Seawater

This paper presents an experimental method to determine the effect of seawater curing on the strength of high strength concrete using nickel slag as a substitute for fine aggregate. Some of the compositions used for nickel slag variations are 0%, 25%, 50%, 75%, and 100% for sand. The seawater used comes from the local area (Kendari City in Southeast Sulawesi Province). In this study, we did not calculate the effect of seawater content on concrete; however, it only explains the strength of concrete against curing with seawater. The concrete soaking method with seawater is 220 days (5.5 months) by comparing several variations.

2.2. Coarse Aggregate

The coarse aggregate used in the manufacture of SCC concrete, namely crushed stone with a maximum aggregate size of 20 mm, is obtained as follows:

| Table 1. Analysis of Coarse Aggregates |
|----------------------------------------|
| No  | Materials Test Types     | Results          |
| 1   | Sieve Analysis           | Pass 3/4"        |
| 2   | Moisture content (%)     | 0.10             |
| 3   | Specific gravity         |                 |
|     | - Bulk (gr/cm³)          | 2.65             |
|     | - SSD (gr/cm³)           | 2.67             |
|     | - apparent (gr/cm³)      | 2.71             |
| 4   | Fill weight (gr/cm³)     | 1.55             |
| 5   | Absorption (%)           | 0.89             |
Based on Table 1, the results of the analysis of coarse aggregate testing with a maximum grain limit of 20 mm meet the standard presentation of passing the coarse aggregate sieve and can be used as coarse aggregate in the concrete mixture.

2.3. Fine Aggregate
The fine aggregate used in this study is sand, as shown in Table 2.

Table 2. Analysis Results of Fine Aggregate

| No | Materials Test Types | Results |
|----|----------------------|---------|
| 1  | Sieve Analysis       | Zone III|
| 2  | Moisture content (%) | 0.80    |
|    | Specific Gravity     |         |
| 3  | - Bulk (gr/cm³)      | 2.55    |
|    | - SSD (gr/cm³)       | 2.56    |
|    | - apparent (gr/cm³)  | 2.57    |
| 4  | Solid fill weight (gr/cm³) | 1.59 |
| 5  | Absorption (%)       | 0.28    |

The test results for fine aggregate meet the Indonesian National Standard (SNI) of Zone Category III, where the zone categorized the zone as slightly fine sand, which can be utilized in high strength concrete mixtures.

2.4. Nickel Slag
Nickel slag derived from feni 3 was used in this study as a substitute for fine aggregate in the manufacture of SCC concrete. The parameters of fine aggregate tested include sieve analysis, moisture content, density, and absorption.

Table 3. Results of Nickel Slag Testing Analysis

| No | Testing types       | Results |
|----|---------------------|---------|
| 1  | Sieve Analysis      | Zone II |
| 2  | Moisture Content (%)| 1.32    |
|    | Specific Gravity    |         |
| 3  | - Bulk (gr/cm³)     | 2.85    |
|    | - SSD (gr/cm³)      | 2.87    |
|    | - apparent (gr/cm³) | 2.89    |
| 4  | Solid fill weight (gr/cm³) | 1.45 |
| 5  | Absorption (%)      | 0.38    |

As shown in Table 2 and Table 3, the results of the test analysis of nickel slag and sand meet the predetermined standards as fine aggregate. Therefore, the composition of sand and slag as a substitute for sand can be seen in Table 4.

2.5. Slump Flow
Slump Flow measurement is carried out to determine the workability of the SCC concrete mix. SCC concrete agility is a measure of the ease with which the mixture can be stirred, transported, poured, and compacted without causing segregation of the constituent materials of the concrete. The level of discomfort is influenced by the composition of the mixture, the physical conditions and the type of
mixing substance. The following are the results of the SCC concrete slump flow test for several variations of the use of nickel slag as a substitute for fine aggregate. According to Nini et al. [12], the slump flow value of SCC concrete with a superplasticizer concentration of 1.5% of the cement weight obtained a slump flow of 715 mm with a flow time of 4 seconds and no segregation occurred.

The compressive strength of concrete is the maximum compressive load that can be borne by a large unit of concrete until crushed. This test is carried out to determine the concrete’s quality from the design results, whether meeting the requirements or not. Besides, the compressive strength of concrete is used to assess and control the quality of concrete work in the field to meet specification requirements. The method used to check the compressive strength of concrete is to use a compression machine. The principle of testing the compressive strength of concrete with a compressive machine tool is to measure the amount of load that can be borne by one unit of concrete area (test object) until the test object is destroyed/damaged.

After passing the treatment or immersion period, the specimen needs to be removed to prepare for the cylinder compressive strength test according to its day-age (3, 7, 14, and 28 days) and 220 days.

The formula for determining the compressive strength of the test object:

\[
f'c = \frac{P}{A} \text{ (MPa)}
\]

Where \( P \) is a maximum load (N/mm\(^2\)) and \( A \) cross-sectional area (mm\(^2\))

2.6. Methods

This study uses material originating from the Southeast Sulawesi Area. As for the coarse material comes from Moramo, South Konawe district. The fine aggregate comes from Pohara, Konawe district and nickel slag from ANTAM Pomalaa. Seawater used was from Kendari Bay. Figure 1 illustrates the methodology for testing cylindrical specimens where the cylinder size used is 30 cm high and with a diameter of 10 cm.

The slump test shall be performed on a flat (Figure 2), nonabsorbent base plate. The mold should be positioned on the base plate so that it is fully supported. Filling the mold with concrete, then opening the smaller mold face down, in the middle of a flat wet base plate or concrete surface. Using a suitable container, fill the entire mold continuously. The inner surface is leveled. Then remove the concrete from the mold around the base of the mold to prevent interference with the flowing concrete movement. Wait for the concrete to stop flowing and then measure the largest diameter of the resulting circular concrete spread to 1/4 in (5 mm). observed to produce circular flow concrete forming a diameter, measure the diameter of the flow concrete circle [13].

![Flow Chart of the Method](image-url)
2.7 Mix Design of Self Compacting Concrete

SCC concrete mix planning follow DOE (Department of Environment) standards. The composition of coarse aggregate and fine aggregate used is 55% and 45% in accordance with the maximum limit recommended by EFNARC [13]. The cement water factor used was uniform, namely 0.3. Compressive strength is planned at 45 MPa at 28 days of age with the use of Superplasticizer (SP) of 1% of the weight of cement type Masterglenium sky 8851.

| No. | Specimen Code | Cement (Kg) | Water (Ltr) | Coarse Aggregate (Kg) | Sand (Kg) | Nickel Slag (Kg) | SP (ml) |
|-----|---------------|-------------|-------------|-----------------------|-----------|-----------------|--------|
| 1   | SCC0          | 750         | 225         | 743.6                 | 608.4     | -               | 7.5    |
| 2   | SCC25         | 750         | 225         | 743.6                 | 456.3     | 152.1           | 7.5    |
| 3   | SCC50         | 750         | 225         | 743.6                 | 304.2     | 304.2           | 7.5    |
| 4   | SCC75         | 750         | 225         | 743.6                 | 152.1     | 456.3           | 7.5    |
| 5   | SCC100        | 750         | 225         | 804.4                 | -         | 658.1           | 7.5    |

3 Results and Discussion

The following are the SCC concrete test results using variations in the use of nickel slag as a substitute for fine aggregate, respectively 0%, 25%, 50%, 75%, and 100% slag with the same immersion treatment on all specimens for 220 days using seawater. It shows that aggregate distribution is proportional so that the resulting compressive test results meet the design strength of 45 MPa. At 0% variation (without slag), the strength is the same as the 100% slag composition, namely 37.58 MPa. With 25% slag, the strength increased to 46.88 MPa while in 50% slag the compressive strength declined to 38.75%.
Figure 3. Aggregate distribution in concrete

The test object shows a proportional distribution of aggregates so that the resulting compressive test results meet the designed strength of all 45 MPa, as shown in Figure 3. Therefore, a typical crack cross-section of the three types tested, that all fractured parts of all were similar to each other and according to plan, both the result of the compressive strength and the modulus of elasticity of the concrete (Ec) at **28 days** [14].

Figure 4. Concrete compressive strength test results (a) SCC0 (b) SCC25 (c) SCC50 (d) SCC75 (e) SCC100

From the figure, it can be seen that brittleness is the strength produced after curing with seawater. According to the SCC25 test specimen in Figure 3b 25% slag produces the highest strength, then 50% slag, 75% slag, 100% slag and finally in Normal concrete without slag. This behavior is also shown in the graph of the stress against the immersion age in each of the specimens in Figure 5.
Figure 5. The relationship between stress and concrete age

The graphic image above shows that in general, concrete with nickel slag mixture has stable strength after 28 days of immersion. The stress given during 220 days of immersion using seawater is found in concrete with a nickel slag content of 25%, the quality of the concrete reaches 46.88 MPa, an increase of 2% from the age of 28 days, while the value of the strength of concrete with a slag composition of 25% against concrete without slag (SCC0) increased by 14.14%. This shows that nickel slag as a substitute for sand gives a greater strength contribution than without nickel slag.

The addition of rice husk ash added to high-quality concrete 28 days old with seawater curing can increase the tensile strength value and modulus of rupture compared to high-quality concrete curing in plain water [15]. The following explains the slump value carried out as in the graph below with reference to the standard procedure test method slump value [16]. Also studied the strength of high strength concrete using SCC with the addition of a mixture of 1.5% superplastizer to provide the best strength value and with the addition of a superplasticizer to increase its strength [12].

Figure 6. The relationship between the value of slump flow and the average compressive strength of concrete, aged 220 days.
Based on Figure 6, the results of the analysis of the modulus of elasticity of concrete at 28 days show that the elasticity of concrete has the same value with the same compressive strength. This is clearly seen in the modulus of elasticity because the relationship between the compressive strength of concrete and the modulus of elasticity is directly proportional. At the age of 28 days, concrete experiences maximum strength, both elasticity and strength value, namely at 75% variation with a value of 49.38 MPa, 20% strength is more excellent than concrete without slag variations. It shows that 75% and 25% slag substitution of sand in concrete with the use of Master Glenium Sky 8851 Superplasticizer additives gives maximum results, which is due to the composition ratio of the sieve analysis to fine aggregate, namely in Table 2 the composition of zone III is 25%, Pohara sand aggregate and in Table 3. Zone II 75% of slag sand aggregate with a water absorption capacity value meets the standards and produces the maximum concrete compressive strength.

4. Conclusion
This paper outlines Self-Compacting Concrete (SCC) behavior on high strength concrete with nickel slag as fine aggregate by using laboratory study. The percentage of nickel slag substitution as fine aggregate varies from 0% to 100%, with an increase of 25%. The results obtained from 5 variations of the mixture show that the use of nickel slag of 25% gives the maximum results. When compared with normal quality (Concrete without slag), on the test object with 25% slag has an increase of 17% of the strength, the visualization of the slump flow test results shows very good conditions. All specimens using slag in seawater immersion show greater strength when compared to non-slag concrete. This means that concrete is very suitable at a curing age of 220 days when substituted with nickel slag. The mixture using nickel slag of 100% (SCC100 specimen) illustrates a fairly stable strength from 28 days of immersion.

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