Effect of nickel slag as a sand replacement in strength and workability of concrete

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Abstract. Concrete containing cement, sand, gravel, nickel slag, water and superplasticizer were processed using normal intensive mixing. The strength of concrete is determined by the interfacial zone between binder paste and aggregates. Due to the weathering of natural aggregates with time, a morphology with rounded edges is obtained, reducing the interlocking with the paste. Hence, it is interesting to investigate the use of nickel slag as a sand replacement in concrete since this material has sharp angular edges, which can improve the cohesion of the concrete. This research investigates the use of nickel slag as the replacement of sand in concrete. Various concrete samples were produced with the increasing nickel slag content from 0% to 50% every 10%. A water-cement-ratio of 0.35 was chosen in this study. Concrete mixes were assessed for their compressive strength and workability. The obtained results showed that the strength of the concrete increases together with the increasing nickel slag content in the concrete mixture. Also, the results demonstrated that the slump increases with rising nickel content. In addition, there was no bleeding in fresh concrete mixture in this research.

1. Introduction

In recent decades, concrete has grown to be the most popular material for infrastructure projects to complete steel structure. It is estimated that the annual worldwide concrete production achieves about twenty-five billion tons [1]. Fine aggregate, as one of the ingredients of concrete besides coarse aggregate, cement, and water, occupies about 20%-30% of concrete volume. It can be estimated that annually, the production of concrete for construction projects all over the world requires about 6.25 billion tons of fine aggregate. This number implies that natural resources are depleting substantially, it will cause environmental degradation. As natural resources become increasingly scarce in the near future, the alternative way to protect the environment is to utilize the waste material from industry in concrete production.

Nickel slag is one of the by-product materials from smelting nickel [2]. In this process, the raw material is dried into a rotary dryer and sent to the reduction kiln for sulfidation. Afterwards, the material was transferred to an electric furnace for the next treatment. In this stage, the slag was generated and the ore was transferred to the converter for purification. In the last stage, the ferronickel, which contains about 80% iron and 20% nickel was generated, and also the slag. In Indonesia, about 4 million tons of nickel slag is produced annually and only utilized for landfilling. Nickel slag contains harmful elements such as Pb, Zn, As, Cd, Co, and Cu, [3] which cause hazards for human health. A possible breakthrough for both environmental problems can thus be sought in exploiting nickel slag within the concrete production. Looking into literature, nickel slag was investigated by several researchers as cement
replacement in concrete [2–4]. In addition, there is limited literature available regarding the use of nickel slag as a sand replacement, which is only reported by [5]. The subject of the current research is the effect of nickel slag as sand replacement in strength and workability of concrete.

2. Materials and methods

2.1. Cement
The used materials in this study were purchased from an Indonesian Company. As the cement, an Ordinary Portland Cement type 1 (OPC I) was used throughout all experiments. This cement contains moderate C₃A, which can increase the compressive strength at longer curing ages, as suggested by [6, 7]. The chemical compositions of OPC are tabulated in table 1.

| Constituents | OPC  |
|--------------|-----|
| SiO₂         | 19.86 |
| Al₂O₃        | 5.33  |
| CaO          | 64.14 |
| Fe₂O₃        | 3.03  |
| MgO          | 2.39  |
| SO₃          | 1.9   |
| C₃S          | 51    |
| C₂S          | 24    |
| C₃A          | 6     |
| C₄AF         | 11    |
| Blaine permeability (cm²/g) | 3350 |

Table 1. Chemical compositions and fineness of OPC I.

2.2. Nickel slag
Nickel slag used in this study is a by product obtained from FeNi IV Plant of Aneka Tambang Company (Indonesia). This plant produces solid-granulated nickel slag with less porosity. Besides this, the nickel slag has angular particles with varying sizes. The physical properties of slag nickel are given in table 2.

| Test                | Sand | Gravel | Nickel slag |
|---------------------|------|--------|-------------|
| Specific gravity (g/cm³) | 2.62 | 2.37   | 2.93        |
| Water absorption (%)  | 1.43 | 0.89   | 0.50        |

Table 2. Physical characteristics of aggregates and nickel slag.

2.3. Aggregates
In Indonesia, aggregates that are used in concrete production are generally natural aggregates. The fine aggregate can be found in the river basin with a round texture and smooth surface. The gravel used in this study is obtained from the erosion of rocks, which is crushed using a stone crusher to obtain the desired gradation. The physical properties of aggregates are shown in table 2.
2.4. Superplasticizer

In this study, a new generation of polycarboxylic ether (PCE) based superplasticizer was used throughout all experiments. This superplasticizer has long side chains, which disperse the cement particle at the beginning of the mixing process to obtain the slump life and the desired workability at a low water-to-cement ratio. As the superplasticizer cannot be mixed directly to the mixture during the mixing process, the superplasticizer is dozed in a plastic container containing about 10% water and poured in the mixing pan after the 90% water mixing period.

2.5. Mix design

The water-to-cement ratio used in this research was 0.35. Nickel slag was used as a sand replacement with the proportions of 0%, 10%, 20%, 30%, 40%, and 50% by weight. Due to the different specific gravity between sand and nickel slag, in which nickel slag is heavier than sand, the total volume of concrete containing nickel slag will decrease. Therefore, other materials such as cement, coarse aggregate, and water will compensate to obtain 1 m³ of the total volume of concrete containing nickel slag. The detail of concrete compositions is shown in table 3.

| Material         | Ref | 10% | 20% | 30% | 40% | 50% |
|------------------|-----|-----|-----|-----|-----|-----|
| Cement           | 449.0 | 449.1 | 449.2 | 449.3 | 449.4 | 449.5 |
| Nickel slag      | 0.0  | 57.6 | 115.2 | 172.9 | 230.6 | 288.4 |
| Sand             | 576.0 | 518.6 | 461.1 | 403.6 | 346.1 | 288.5 |
| Coarse aggregate | 1117.0 | 1117.5 | 1117.9 | 1118.4 | 1118.8 | 1119.4 |
| Water            | 157.0 | 157.4 | 157.7 | 158.1 | 158.5 | 158.9 |
| Superplasticizer | 9.9  | 9.9  | 9.9  | 9.9  | 9.9  | 9.9  |

2.6. Workability and compressive strength

The workability of fresh concrete was determined using a mould with the following dimensions: diameter of base (200 ± 2 mm); diameter of top (100 ± 2 mm), and height (300 ± 2 mm) according to BS EN 12350-2:2009. The slump test was conducted in a triplicate to evaluate the workability of concrete containing nickel slag as sand replacement.

After curing in a water bath with a temperature of 25 ± 2 °C, the cylinder (100 mm diameter x 200 mm length) were taken out and then left at ambient temperature for two hours. The cylinders were tested in triplicate to evaluate the compressive strength at the age of 7 and 28 days. A compression machine with a capacity of 150 tons-force was used.
3. Results

3.1. Workability of fresh concrete

The results of the slump test of concrete are shown in figure 2. It is clear that the increase in nickel slag content in concrete also enhanced the workability of the fresh concrete. This result can be explained by the fact that nickel slag has a low water absorption compared to sand, as explained in table 2. It may cause surplus water content in concrete. In addition, the workability of concrete also depends on the particle size and particle shape of aggregate [5]. In this study, the particle size of nickel slag is coarser than sand as shown in figure 1. It means that the surface area of nickel slag is lower than sand so that the amount of water needed to wet the surface area of nickel slag is also lower than sand. In the end, it may trap excessive water in concrete mixture which is not used to wet the surface area of nickel slag. This is another reason for the increased workability of concrete containing nickel slag. In this study, no bleeding is observed in the fresh concrete mixture.

![Figure 2. Workability of concrete (the values represent three replicates).](image)

3.2. Compressive strength

![Figure 3. The strength evolution of concrete containing nickel slag as sand replacement (the average values represent three replicates).](image)

The evolution of compressive of concrete containing nickel slag as sand replacement is attached in figure 3. In general, it can be seen that the strength of concretes increase with the increasing nickel slag
content in the concrete mixture. The highest compressive strength was achieved for 40% nickel slag, which increased about 10.8% compared to the reference mixture, as shown in figure 4. For early curing days (7 days), the compressive strength of concrete at the replacement level of 10% and 50% was slightly lower and similar to the reference mixture, respectively. For longer curing periods (28 day), the compressive strength of concrete containing 10% and 50% nickel slag was similar and slightly higher compared to the reference mixture, as seen in figure 3. It seems that the use of nickel slag as sand replacement gave positive effect to the compressive strength. These results confirm the findings of Saha and Sarker [5]. They found that the compressive strength increases up to 50% substitution of nickel slag, and then decreases with an increase in nickel slag content. This result can be explained by the fact that nickel slag has sharp angular edges and rough surface, which can improve cohesion and slip resistance between aggregate and paste. However, the particle size of nickel slag is bigger than sand, as shown in figure 1. It means that the sand can fill more pores in concrete than nickel slag. So that at higher replacement level of nickel slag, the number of unfilled pores in concrete matrix increased due to the reduced fine particles in concrete matrix. This is the reason for the decreased compressive strength of concrete at 50% nickel slag substitution, as shown in figure 3 and figure 4. From this result, it can be concluded that the replacement level of 40% nickel slag gives the lowest porosity in concrete matrix, generating an increase in the compressive strength of concrete.

![Figure 4](image_url)

**Figure 4.** Enhancement in strength (concrete containing nickel slag versus reference) at 7 days and 28 days.

### 4. Conclusions
Concerning the effect of nickel slag as the sand replacement in strength and workability of concrete, the following conclusions can be drawn:

1. There is an increase in the workability with increasing nickel slag content in a concrete mixture. This might be due to the effect of the low water absorption and low surface area of nickel slag.
2. The use of nickel slag for up to 40% sand replacement in concrete gave a positive effect on the compressive strength. The replacement level of 40% nickel slag content provides the lowest porosity in a concrete matrix.

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