Optimum combination of ferro-nickel slag (FeNi4) to the normal sand for the concrete compressive strength

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Abstract. Slag nickel is a by-product which causes environmental degradation and conventional slag is widely used as coarse aggregate in concrete. This research, therefore, used the newest slag type (FeNi4) from PT Antam Pomalaa as fine aggregate in natural sand and determine the effect of the combination on the optimum compressive strength of concrete. Moreover, the results obtained were compared with the use of only natural sand in concrete. The procedure involved varying the percentage of the slag mixed with the natural sand by weight at 0%, 25%, 50%, 75%, and 100% with each sample designed to have minimum compressive strength higher than 20 MPa at 28 days. Furthermore, a compressive strength test was conducted to determine the optimum combination to achieve the best value and the results showed 25% of nickel slag variation to be the best while other variations, 50%, 75%, and 100%, experienced a reduction of 8.96%, 11.85%, and 12.19% respectively in comparison with the normal concrete. This, therefore, means the use of Ferro-nickel slag (FeNi4) has the ability to increase the strength and reduce the weight of concrete.

1. Introduction
PT. Antam Pomalaa is currently one of the largest mining industries in Indonesia. Moreover, it has been discovered that approximately 1,000,000 tons/year [1] of nickel slag is produced as a by-product of the nickel mining industry with PT. Antam Pomalaa reported to currently have a new tool for nickel processing to produce FeNi4 type of slag which has a size distribution of matter in the sand unlike the previous variation which was generally in the form of gravel and boulders or coarse aggregate [2].

Government Regulation No. 101/2014 [3] regarding the management of hazardous and toxic waste (B3) recognizes nickel slag as one of the B3 wastes and this has been further reinforced by previous research which shows it to contain heavy metals such as Mercury, Arsenic, Cadmium, Lead, and Zinc which damage the environment and human organs when consumed. Several studies have also reported nickel slag material to be latent and unreactive when mixed only with water (H2O) but responds significantly when blended with calcium and other cement compounds. Moreover, the research by Romy et al. (2016) [4], stabilized heavy metals with cement in concrete through the formation of a new combination which is known as Ca(Zn(OH))2·2H2O (cement + zinc) and this shows the heavy metals in nickel slag become more stable when mixed with cement.

Current infrastructural development requires the availability of aggregates which meet technical requirements but not all regions have the potential materials needed in construction [5]. Meanwhile, concrete is increasingly required in construction due to its numerous and significant benefits with the standard aggregate requirement reaching 70-80% [6]. Sand is a significant element in concrete with the technically specified type generally obtained from the river but it is important to understand that some areas such as coasts and islands do not have this type, thereby, making it difficult to meet the standard
in terms of quality and quantity. This, consequently, makes concrete or other sand-based materials to be very costly in these areas.

Waste is currently being applied globally to preserve the environment through the application of 4R principles which means reduce, reuse, recycle, and replace. It is possible to reuse waste for several local purposes and these include being applied as a substitution for concrete components such as cement, fine aggregate, and coarse aggregate. This, therefore, means using FeNi4 nickel slag which is shaped like sand in a concrete mixture has the ability to provide several benefits to the environment, the science of concrete technology, and the availability of alternative building materials to replace natural sand.

One of the innovations that researchers often develop today is the use of industrial by product as construction agregat [7–9]. Many researchers have used previous type of nickel slag as an aggregate in the concrete and showed improved concrete strength [10,11]. Previous studies using FeNi4 nickel slag in concrete mixes focus only on using cement water content and additives [12]. The use of sand in concrete mixes, requires technical specifications including smoothness and roughness criteria [13,14]. Changes in physical properties and sand particle distribution due to the incorporation of nickel slag FeNi4 with natural sand were not much investigated. This study aims to obtain the optimal combination of natural sand (zone-3) and nickel slag FeNi4 sand (zone 1) achieving maximum compressive strength.

2. Research method

2.1. Properties of material used

The materials used in this study include Portland cement type I (Tonasa), PDAM water, split 1-2 cm from local materials in Kendari City, natural sand from local rivers in Kolaka district, and FeNi4 nickel slag (passed No.4 (5mm)) comes from PT. Antam Pomalaa, Kolaka district. The FeNi4 slag material from landfill location and the distribution particle of nickel slag FeNi4, however, presented in Figure 1 and Figure 2.

![Figure 1. Slag nickel FeNi4 material form PT. Antam Pomalaa](image1)

![Figure 2. Distribution particle of nickel slag FeNi4 (Passed sieve No.4)](image2)

The characteristics of coarse aggregate (split 1-2 cm), fine aggregate (river sand), and FeNi4 slag used in the study are shown in Table 1 while the gradations are presented in Figure 2.
Table 1. Properties of coarse and fine aggregate

| Properties of material | Coarse aggregate (split 1-2 cm) | Sand river (Sr) | Sand slag (Ss) |
|------------------------|----------------------------------|----------------|---------------|
| Gradation              | Zone-3                           |                | Zone-1        |
| SSD specific gravity   | 2.64                             | 2.48           | 2.88          |
| Bulk density, kg/l     | 1.34                             | 1.50           | 1.46          |
| Clay, Silt content, %  | 0.20                             | 1.25           | 1.25          |
| Moisture content, %    | 0.60                             | 0.60           | 0.05          |
| Absorption, %          | 0.74                             | 1.28           | 0.38          |
| Abrasion, %            | 30.28                            | -              | -             |

Figure 3. Sieve analysis of coarse and fine aggregate

These data were used to determine the composition of the standard concrete and slag concrete mixtures.

2.2. Properties of combination sand materials

Five combinations were used in this research and the physical properties of each are presented in Table 2 and Figure 4.

Table 2. Properties of combined sand materials

| Properties material | Proportion of sand river (Sr) / sand slag (Ss) |
|---------------------|-----------------------------------------------|
|                     | Com-1 (100/0) | Com-2 (75/25) | Com-3 (50/50) | Com-4 (25/75) | Com-5 (0/100) |
| SSD specific gravity| 2.48          | 2.63          | 2.73          | 2.83          | 2.88          |
| Bulk density, kg/l  | 1.50          | 1.34          | 1.57          | 1.54          | 1.46          |
| Clay, Silt content, %| 1.25          | 1.25          | 1.25          | 1.25          | 1.25          |
| Moisture content, % | 0.60          | 0.50          | 0.37          | 0.30          | 0.05          |
| Absorption, %       | 1.28          | 0.66          | 0.64          | 0.56          | 0.38          |
| Zone aggregat        | Zone-3        | Zone-2        | Zone 1        | Zone 1        | Zone 1        |
Figure 4. Sieve analysis of combined sand materials

These data were used to determine the concrete mixture's composition using a combination of river and slag sands.

2.3. Mix design of concrete

The planned composition of the concrete mixture was evaluated by calculating the concrete mix design $f'_c$ 20 MPa based on SNI 03-2834-2000 [15] and a water/cement ratio (w/c) of 0.5. The composition of the materials in each combination is shown in the following Table 3:

| Code of variation samples | Water (kg/m³) | Cement (kg/m³) | Sand river (Sr) (kg/m³) | Sand slag (Ss) (kg/m³) | Split 1-2 cm (kg/m³) |
|---------------------------|---------------|----------------|-------------------------|------------------------|---------------------|
| Comb-1 (control)          | 205           | 410            | 681.36                  | -                      | 1027.52             |
| Comb-2                    | 205           | 410            | 524.13                  | 174.71                 | 1084.49             |
| Comb-3                    | 205           | 410            | 352.05                  | 352.05                 | 1057.48             |
| Comb-4                    | 205           | 410            | 178.06                  | 534.19                 | 1069.46             |
| Comb-5                    | 205           | 410            | -                       | 719.64                 | 1081.45             |

2.4. Samples preparation

The samples were manufactured using a mechanical mixer while the slump value and fresh concrete weight were measured to determine to ensure they are according to plan. Meanwhile, the fresh concrete was left for 24 hours after which the mold was opened from the test object, marked, and treated in a soaking bath for 28 days.
2.5. Testing of specimens
The compressive strength was tested using a compression test machine and the method applied in the process was based on SNI 03-1974-1990 [16]. A uniaxial loading with a speed of 2–4 kg / cm² per second at the age of 28 days as well as a concrete cylindrical specimen with 150 mm diameter and 300mm height were also applied.

2.6. Analysis
The weight of the concrete volume and compressive strength value were calculated using equations (1) and (2) respectively.

\[ W = \frac{w}{v} \]  \hspace{1cm} (1)
\[ f'_c = \frac{P}{A} \]  \hspace{1cm} (2)

Where \( W \) is the volume by weight of concrete (kg/m³), \( w \) is the weight of concrete (kg), \( v \) is the volume of concrete (m³), \( f'_c \) is the compressive strength of concrete, \( P \) is the maximum load (kg), and \( A \) is the surface area of stress (m²).

3. Test results and discussion

3.1. Concrete volume weight
The concrete volume weight is the ratio between the weight and volume of cylindrical specimens used in research and the results are presented in the following table.

**Table 4. The results of the concrete volume weight analysis**

| Code of variation samples | Sand River (%) | Sand slag FeNi4 (%) | Weight of volume (kg/m³) |
|---------------------------|----------------|---------------------|--------------------------|
| Comb-1 (control)          | 100            | -                   | 2331.84                  |
| Comb-2                    | 75             | 25                  | 2329.24                  |
| Comb-3                    | 50             | 50                  | 2363.76                  |
| Comb-4                    | 25             | 75                  | 2363.36                  |
| Comb-5                    | 0              | 100                 | 2334.09                  |
Table 4 shows a decrease in the volume weight of concrete under normal concrete compared to FeNi4 slag by 25% while the use of FeNi4 slag above 25% increased the weight of the concrete compared to the normal concrete or control specimen. The reduction in the concrete weight is, however, beneficial considering the fact that it is lighter and safer to use as a construction material.

3.2. Compressive Strength
The compressive strength was tested on the 28th day using Equation (2) and the results for each specimen are presented in Table 5.

Table 5. Compressive strength of the concrete based on the variation of slag in the mixture

| Code of variation samples | Sand river (Sr), % | Sand slag (Ss), % | Zone of sand gradation | Compressive strength (MPa) |
|---------------------------|-------------------|-------------------|------------------------|---------------------------|
| Comb-1 (control)          | 100               | -                 | Zone-3                 | 26.33                     |
| Comb-2                    | 75                | 25                | Zone-2                 | 30.10                     |
| Comb-3                    | 50                | 50                | Zone-1                 | 23.97                     |
| Comb-4                    | 25                | 75                | Zone-1                 | 23.21                     |
| Comb-5                    | 0                 | 100               | Zone-1                 | 23.12                     |

Figure 6. Fresh concrete weighing

Figure 7. Result of the compressive strength test
According to Figure 7, there was an increase in the compressive strength with the use of 25% FeNi4 nickel slag by 14.32% in comparison with the normal concrete. This means the combination reduces the strength of the concrete compared to the normal concrete but meets the minimum of 20 MPa required by the standard. Meanwhile, the other samples including combination 3 (50/50%), combination 4 (25/75%), and combination 5 (0/100%) reduced by 8.96%, 11.85%, and 12.19% respectively compared to the normal concrete.

According to an earlier study by [17], which investigated the use of nickel slag as an aggregate and cement mixture for high-strength concrete, it was concluded that nickel slag aggregate improves the interface with its paste matrix, thus increasing the concrete strength. This shows that the treatment of chemical aggregates helps to improve concrete strength. A pozzolanic reaction between SiO2 from nickel slag and Ca (OH)2 from cement hydration was causing an increase in compressive strength. This pozzolanic reaction yielded more C-S-H gel than was formed from cement paste hydration [18]. The relation between the percentage of slag, strength and weight of concrete are presented in the following figure.

![Figure 8. Relation between the percentage of slag, strength and weight of concrete](image)

According to Figure 8, the increased strength of concrete in the use of FeNi4 nickel slag by 25% is due to the effect of the combination of natural sand and slag sand FeNi4, which can reduce the cavities and pores in the concrete mixture to produce the perfect combination to create a denser concrete mixture. The decrease in the strength of the concrete can occur due to the combination of fine natural sand and coarse FeNi4 nickel slag that is not balanced in the concrete mixture, thus creating a lot of air cavities and resulting in a less dense concrete mixture. In addition, the slag shape is slippery, and the absorption is small, it can be the cause of the reduced bond strength in the mortar, which makes the lower compressive strength of the concrete.

4. Conclusion
The combination of 75% river sand and 25% slag sand (FeNi4) was found to be the optimum mixture due to its ability to increase the compressive strength and reduce the volume of concrete compared to the normal or control specimen.
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