The Effects of Substitution of The Natural Sand by Steel Slag in The Properties of Eco-Friendly Concrete with The 1:2:3 Ratio Mixing Method

A Rahmawati¹, I N Saputro²
¹,²Department of Building Engineering Education, Faculty of Teacher Training and Education, Universitas Sebelas Maret, Indonesia

E-mail: anisrahmawati79@gmail.com

Abstract. This study was motivated by the need for the development of eco-friendly concrete, and the use of large quantities of steel slag as an industrial waste which is generated from the steel manufacturers. This eco-friendly concrete was developed with steel slag as a substitute for natural sand. Properties of concrete which used waste slag as the fine aggregate with the 1 cement: 2 sand : 3 coarse aggregate ratio mixing method were examined. That ratio was in volume. Then a part of natural sand replaced with steel slag sand in six variations percentages that were 0 %, 20 %, 40 %, 60 %, 80 % and 100 %. The compressive strength, tensile strength, and flexural strength of concrete specimens were determined after curing for 28 days. The research results demonstrate that waste steel slag can increase the performance of concrete. The optimal percentage substitution natural sand by steel slag sand reached of slag on the percentage of 20 % which reached strength ratios of steel slag concrete to the strength of conventional concrete with natural sandstone were 1.37 for compressive strength and 1.13 for flexural strength. While the tensile strength reached a higher ratio of concrete with steel slag sand to the concrete with natural sand on the 80% substitution of natural sand with steel slag sand.

1. Introduction
The development of eco-friendly and sustainable construction materials has gained major attention by the construction industry. One of the most significant activities stressed by the engineers and scientists related to construction industry especially in the concrete industry were aims to use raw materials with the possibility of improvement of cement characteristics and durability of concrete that will support the thought of green concept in concrete [1-2]. The three major objective behind green concept in concrete is to reduce greenhouse gas emission (carbon dioxide emission from cement industry, as one ton of cement manufacturing process, emits one ton of carbon dioxide), secondly to reduce the use of natural resources such as limestone, shale, clay, natural river sand, natural rocks that are being consume for the development of human mankind that are not given back to the earth, thirdly use of waste materials in concrete that also prevents the large area of land that is used for the storage of waste materials that results in the air, land and water pollution. This objective behind green concrete will result in the sustainable development without destruction natural resources [3].

Alternative materials can be used to substituted natural aggregates to support green concrete are industrial by-products that are easily available, require little or no pyro-processing and have inherent or latent cementitious properties. These materials are producing a greener concrete concerning
resource and energy consumption [4]. Such industrial by-products are commonly called as supplementary cementitious materials or mineral additives [5]. One of the wastes generated from industries were looked upon as possible alternatives to be used in concrete production is steel slag, which is a waste product generated from the steel industry. Steel slag is the inevitable by-product which is 15~20% of the production of crude steel in steelmaking process [6] or equivalent with 130 – 200 kg of slag from one ton of steel production, depending on the composition of the steel and on the steel production process [7]. Slag often appears as granulated materials containing large clusters, coarse and very fine particles. A significant amount of steel slag was always disposed of as waste which results in the waste of resource, environmental pollution even ecological destruction. That’s why the recycling of industrial waste slag is the core content of sustainable development. The recycling of steel slag will inevitably become an essential measure for the environment protection and therefore can lead to great social significance [8]. Steel slag can be seen as a potential alternative to natural aggregates. The uses of steel slag as an alternative material help save a large share of natural resources and protect the environment [9]. This study used steel slag as a substitute material in concrete productions.

Although there are many studies that have been reported by researchers on the use of steel slag in concrete mixture [6,10-16], not much research has been carried out in Indonesia and other countries concerning the mechanical properties of steel slag concrete which use the most simple and easy concrete mix design that is 1:2:3 ratio mixing method. Therefore, to generate specific experimental data on properties of steel slag as the natural sand replacement in the concrete mixture, the present study has been performed.

In Indonesia, there are many small steel industries located in several areas, one of which is in Klaten, Central Java. In this central of steel casting industrial, there are more than 50 small-medium industries which concerned in steel casting industry. The average of production capacity is 1000 ton/week which produces about 100 m³ steel slag. So far surrounding communities used steel slag as ground landfill, which can cause environmental pollution, especially water pollution. For this, this study conducted to study in using steel slag as substitute material of the natural sand in concrete with the 1:2:3 ratio mixing method. This method was chosen because it is a conventional method used by communities in around of this central of small steel industries. So the result from this study will be easier adopted by communities. Normal concrete used natural sand as fine aggregate, which usually comprises up to 30 percent of the total volume of concrete. Consequently, characteristics of sand significantly affect the performance of fresh and hardened concrete and have an impact on the cost-effectiveness of concrete [17].

The main objective of this research was to provide information about the effects of substitution of the natural sand by steel slag in the composition of concrete with the 1:2:3 Ratio Mixing Method to the mechanical properties of concrete. In this work, we have characterized the mechanical properties of concrete with steel slag sand regarding compressive strength, tensile strength, and flexural strength. These mechanical properties than compared to the performance of ordinary concrete.

2. Experimental

2.1. Materials
Portland Cement Composite (PCC) manufactured by HOLCIM was used. It’s confirmed to Indonesian specification of SNI 7064-2004 [18]. Coarse aggregate was taken from Merapi mountain’s quarry which crushed with the maximum size of 20 mm. Physical properties of coarse aggregate are presented in Table 1. The natural fine aggregate was taken from Merapi mountain’s quarry, which selected by sieving on sieves size and selected the fine gradation as shown in figure 1. Physical properties of fine aggregate are listed in Table 2. Steel slag took from the steel industries in Klaten, Central Java, Indonesia. The large clusters and coarse steel slag than crushed with the maximum size of 4.8 mm as shown in figure 2. The granulometric curves which comparing of natural sand aggregate and steel slag sand resulting from the previous granulometric adjustment are shown in Figure 1, while
the physical properties of steel slag are listed in table 3. The physical properties of all aggregates than compared with the standard from SNI 03-6861.1-2002 [19].

Table 1. The Physical Properties of Coarse Aggregate

| Property       | Point | Standard from SNI |
|----------------|-------|--------------------|
| Specific gravity | 3.85  | 2.5 – 2.7          |
| Abrasion       | 32.068 | <50%               |
| Fineness modulus | 3.48  | 2.5-3.8            |

Table 2. The Physical Properties of Fine Aggregates.

| Characteristic | Point | Standard from SNI |
|---------------|-------|--------------------|
| Water content | 0.13% | 1-3%               |
| Specific gravity | 2.58  | 2.5-2.7            |
| Fineness modulus | 3.44  | 2.5-3.8            |

Table 3. The Physical Properties of steel slag

| Characteristic | Point | Standard from SNI |
|---------------|-------|--------------------|
| Water content | 0.06% | 1-3%               |
| Specific gravity | 2.83  | 2.5-2.7            |
| Fineness modulus | 4.7   | 2.5-3.8            |

Figure 1. The gradation of aggregates
2.2. Mixing proportions of concrete
Concrete mixing method using 1 cement: 2 fine aggregate:3 coarse aggregate ratio is widely used in the concrete made by the unprofessional one due to it’s simple and easy way to be adapted. In this study, six concrete mixtures were designed. All concrete mixtures were prepared kept all cement (PC), sand, and coarse aggregate ratio constant that was 1pc: 2 sand:3 coarse aggregate. That ratio was in volume. Cement and coarse aggregate content were kept constant in all mixtures. All concrete mixtures used constant 0.8 water/cement ratio. The high water/cement ratio was obtained from the primary trial test of mixing concrete which produces a homogeneous mixture. Then the steel slag was substituted to the mixture with variations of concrete composition was listed in table 4. The concrete specimens prepared with mineral admixtures are summarized in Table 5.

**Table 4.** Variation of Composition of Steel slag in Concrete Mixture

| Mix code | 0 | 1 | 2 | 3 | 4 | 5 |
|----------|---|---|---|---|---|---|
| Cement   | 1 | 1 | 1 | 1 | 1 | 1 |
| Natural sand | 2 | 1.6 | 1.2 | 0.8 | 0.4 | 0 |
| Coarse aggregate | 3 | 3 | 3 | 3 | 3 | 3 |
| Steel slag sand | 0 | 0.4 | 0.8 | 1.2 | 1.6 | 2 |

**Table 5.** Mixing proportions of steel slag Concrete

| Mixing code | Cement content (m³/m³ mixture) | Natural sand content (m³/m³ mixture) | Coarse aggregate content (m³/m³ mixture) | Steel slag sand content (m³/m³ mixture) |
|-------------|--------------------------------|-------------------------------------|------------------------------------------|----------------------------------------|
| 0           | 0.17                           | 0.33                                | 0.50                                     | 0.00                                   |
| 1           | 0.17                           | 0.27                                | 0.50                                     | 0.07                                   |
| 2           | 0.17                           | 0.20                                | 0.50                                     | 0.13                                   |
| 3           | 0.17                           | 0.13                                | 0.50                                     | 0.20                                   |
| 4           | 0.17                           | 0.07                                | 0.50                                     | 0.27                                   |
| 5           | 0.17                           | 0.00                                | 0.50                                     | 0.33                                   |
2.3. Castings of concrete specimens
Castings of cylinder concrete specimens with dimensions were 300 mm in height and 150 mm in diameter, were prepared to determine the compressive strength and tensile strength of steel slag sand concrete. While the specimens for the flexural test was the beam (150x150x600mm). At first, steel slags, natural sands, and cement were mixed together in the dry state for about 3 minutes to obtain a uniform mixture. Next, the water was added to the blend slowly and mixed into a homogeneous mixture and then added the coarse aggregates and the residual water. The mixing was performed using a 350-litre mixer. The fresh concrete mixture was then poured into the molds and compacting manually using steel rod compactor. After casting, the specimens were covered with wet burlap and left in the casting room at a temperature of (20±5)°C for a period of 24 h. The specimens were then de-molded and submerged in water and measured at 28 d.

2.4. Testing
All concrete tested at 28 days age. Compressive strength was carried out on concrete cylinders using Compressive Testing Machine by following codes of SNI 1974-2011 [20]. The Tensile strength was determined using the standard of SNI 2491:2014 [21]. The flexural test using a simple beam with center-point loading was performed according to standard SNI 4154-2014 [22].

3. Results and Discussion

3.1. Compressive strength test results
The value of the considered compressive strength constitutes the average of the results from four specimens. The ratios of compressive strength used steel slag sand to the strength of conventional concrete with ordinary sandstone fine aggregate were illustrated in Figure 3. Results have shown that concrete with 20% substitution of fine aggregate by steel slag sand reached a highest compressive strength than others concrete mix.

![Figure 3. The Ratio of Compressive strength](image)

3.2. Tensile Strength test results
The ratios of tensile strength used steel slag sand to the strength of conventional concrete with natural sandstone fine aggregate were illustrated in Figure 4. It was average from four specimens for each type of concrete studied here. While the results have shown that the largest recorded value of the tensile strength was that of concrete with 80% substitution of natural sand with steel slag sand, which
reached 18% of tensile strength’s increasing. But the overall difference of tensile strength’s value from all concrete mixture in this study was not significant.

![Figure 4. The Ratio of Tensile strength](image)

**Figure 4. The Ratio of Tensile strength**

### 3.3. Flexural strength test results

The ratio of flexural strength used steel slag sand to the strength of conventional concrete with natural sandstone fine aggregate which came from the average of five samples tested specimens for each type of concrete studied here shown in figure 5. From the figure noted that concrete with 20% substitution natural sand with steel slag sand reached higher flexural strength than the other concrete mix.

![Figure 5. The Ratio of Flexural strength](image)

**Figure 5. The Ratio of Flexural strength**

The use of steel slag sand as 20% substitution of natural sand in concrete, increasing flexural strength by about 13%. Then more percentage of steel slag sand produced lower flexural strength.
3.4. Discussion

The test results indicated that concrete using steel slag as substitution material replacing a part of natural sand have a potential to produce better concrete performance than ordinary concrete. Theory said that steel slag concrete has lower strength at early ages. Therefore, steel slag can be used to control the hydration process so that concrete with high strength and good performance can be obtained [23]. According to recent studies, an increase in the compressive strength reported if steel slag used as a mineral admixture in the concrete mixture in term of EAF oxidizing slag aggregates [10-11], fine aggregate [12,13,14], partial replacement of sand [15], or fine and coarse aggregates [6,16]. Generally, using steel slag in concrete mix would improve the workability and compressive strength and does not give any deterioration as results of reaction with alkali in cement [21]. In this study, the highest compressive strength and flexural strength reached by 20% substitution natural sand by steel slag sand.

The increase in the compressive strength could be attributed to the high compactness of concrete achieved by adding sand slag in suitable proportions [24]. Steel slag sand used in this study have coarser gradation than the natural sand. Until the 20% substitution of steel slag, this coarser aggregate contributed to the higher compressive strength of the concrete. The improving of concrete performance also influenced by the shape of steel slag crushed sand. The shape and texture of steel slag crushed sand particles have a significant effect on the interlocking of paste and aggregate particles, providing good aggregate-binder bonding, which will lead to an improvement of strength of concrete [25,4]. After 20% substitution, then the higher percentage of steel slag sand produced lower compressive strength and flexural strength of concrete. The decrease in compressive and flexural strength with increasing steel slag sand after 20% substitution was believed to be due to the more existence of weak aggregate and paste interface due to the formation of the coating of calcite on steel slag surface which hinders the bonding between the paste and aggregates [26-27]. The thin coat of calcite cause steel slag’s surface similar with glass surface which has weak bonds between the particles and the cement paste [28]. More steel slag sands mean more aggregates and paste interfaces exist in the concrete mixture. Furthermore, aggregate with good gradation and fineness modulus will be able to result in maximum density and minimum porosity, which will generate higher compressive strength in concrete [29]. In this study, natural sand has finer grain size than the steel slag sand. The decrease of concrete strength also can be explained by the poor quality of granulated slag as sand due to its high degree of absorption [16]. Steel slag have more pores than the natural aggregate, that will absorb more waters from concrete admixture which caused less water available for cement hydration process.

4. Conclusions

In this work the effect of using steel slag sand as substitution of natural sand in the concrete mixture was preliminary studied to investigate the possibility of using a compound mineral admixture of steel slag as an additive material for concrete production with 1:2:3 ratio mixing method. From the test results and calculated strengths of the steel slag concrete, the following conclusions are drawn:

1. Concrete with good performance could be produced using compound mineral admixture of steel slag with 1:2:3 ratio mixing method
2. Compressive strengths of steel slag concrete reached the highest compressive strength by mixture ratio 1 Pc: 1.6 Sand: 3 Coarse aggregate: 0.4 steel slag which get 1.37 of ratio of concrete steel slag sand compressive strength than concrete with natural sand.
3. Tensile strengths of steel slag concrete reached the highest tensile strength by mixture ratio 1 Pc: 0.4 Sand: 3 Coarse aggregate: 1.6 steel slag which get 1.18 of ratio of concrete steel slag sand tensile strength than concrete with natural sand.
4. Flexural strengths of steel slag concrete reached the highest flexural strength by mixture ratio 1 Pc: 1.6 Sand: 3 Coarse aggregate : 0.4 steel slag which get 1.13 of ratio of concrete steel slag sand flexural strength than concrete with natural sand.
In brief, it can be said that the steel slag sand could be an alternative for use in concrete applications using 1:2:3 ratio mixing method which has higher strength than concrete with natural sand in substitution till 20%. Finally, the use of steel slag as building materials should be considered as a viable solution in terms of environmental conservation, which satisfies society’s current requirements.

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