Applicability of steel slag as replacement aggregate on characteristic of self-compacting concrete

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Abstract. This paper aims to apply steel slag as replacement aggregate on the characteristics of Self-Compacting Concrete (SCC). The experimental study was conducted by mixing fresh SCC using partial substitution of coarse aggregate and fine aggregate slag, which were gained from a steel mill by PT Barawaja in Makassar. Two types of cement binder, such as Portland Composite Cement (PCC) and Silica Fume (SF), were used in the SCC mixture. The mix composition of SCC was designed according to The European Guidelines for Self-Compacting Concrete (EFNARC). The criteria requirements of SCC were evaluated by filling ability, viscosity, and passing ability of fresh concrete with testing by Slump-flow, V-funnel, and L-box apparatus. Specimens of concrete cylinders and concrete prisms were also prepared. After curing in water at 28 days, specimens were tested in compressive strength, flexural strength, and tensile strength according to Indonesian Standard (SNI). The results showed that replacement aggregate of steel slag could be applied in SCC concrete production based on SCC requirements. In addition, test results in compressive strength and flexural strength were obtained 60.70 MPa and 8.61 MPa, respectively.

1. Introduction

Globally, concrete is the most used a construction material, which is about 30 billion tons of concrete produced annually in the world [1]. Accordingly, concrete is broadly utilized on the earth with an annual consumption of 1 m³ per person [2]. Aggregate is mainly material for concrete production, which are approximately achieved proportion of 75% - 80% aggregate in concrete [3]. It means, at least about 20 billion tonnes of aggregate were used in concrete production each year.

Steel slag is a solid waste material, which are produced by the steel smelting industry, which can be produced more than ten tons a month. For instance, a steel-mill by PT Barawaja in Makassar can generate wasted slag material about annual 160 tons. The particle size of slag can be fabricated same as usually size of natural aggregate, and slag material has rough textured surface. Moreover, the chemical compound properties of steel slag are nearly similar to cement-based material [4]. Based on these the explanation to be clear that steel slag can potentially be used as an alternative material to replace natural aggregate in concrete. Applicability of steel slag as a replacement aggregate in concrete production can be obtained a concrete of environmentally friendly, cheaply, and sustainably.

The researches on the utilization of steel slag aggregate for the production of concrete have been reported by several studies [4-7]. However, a study on the applicability of steel slag aggregate on the characteristics of Self-Compacting Concrete (SCC) is not entirely revealed. The unique problem of slag aggregate when used in concrete is the ability of concrete to flow owing to a higher density compared with commonly natural aggregate. Therefore, the applicability of steel slag aggregate on characteristics of SCC were investigated. The goal of this study is to apply of steel slag aggregate on the characteristics of SCC. In addition, the mechanical properties such as compressive strength, flexural strength, and tensile strength of self-compacting steel slag concrete are also discussed.
2. Material and method

2.1. Materials

In this study, two types of the binder were used, such as Portland Composite Cement (PCC) and Silica Fume (SF), which were complied with Indonesian Standard (SNI 15-7064) and American Standard Testing and Material (ASTM C 1240), respectively. The chemical properties for both binders measured by Scanning Electron Microscopy Energy Dispersive X-Ray Spectroscopy (SEM-EDS) are shown in Table 1. Meanwhile, Table 2 describes the physical properties of natural aggregate and steel slag aggregate, which were tested according to Indonesia Standard (SNI). The source of steel slag fine aggregate (slag sand) and steel slag coarse aggregate (ladle slag stone) were taken up from steel mill by PT Barawaja in Makassar, Province of South Sulawesi, Indonesia.

| Binder | Composition (%) |
|--------|----------------|
|        | Na₂O MgO Al₂O₃ SiO₂ SO₃ K₂O CaO TiO₂ MnO FeO |
| PCC    | 0.11 2.34 3.40 21.49 1.87 1.57 67.02 - - 1.82 |
| SF     | 4.50 4.16 0.87 87.00 1.08 1.10 0.49 - - - |

Table 1 Chemical properties of a binder

| Physical properties | Natural aggregate | Steel slag aggregate |
|---------------------|-------------------|---------------------|
|                     | River sand (S)    | Crushed stone (G)   |
| Density (Kg/ltr)    | 1.43              | 1.40                |
| Specific gravity, SSD | 2.52             | 2.58                |
| Water absorption (%) | 2.48            | 3.44                |
| Aggregate Abrasion (%) | -              | 24.01               |
| Aggregate Crushing, ACV (%) | -           | 29.69               |

Table 2 Physical properties of aggregate

2.2. Proportion of mixture

The mixture proportion of the Self-Compacting Steel Slag Concrete (SCSSC) was used in this research, as demonstrated in Table 3. The concrete mixture composition was designed according to The European Guidelines for Self-Compacting Concrete (EFNARC) [8]. The replacement of natural aggregate (river sand and crushed stone) by slag aggregate (slag sand and slag stone) was 50% of volume of aggregate with a maximum size of coarse aggregate was used 20mm. Further, PCC cement was also replaced by 10% SF of the cement weight. The replacement of PCC by SF were conducted in order to meet the requirements for the maximum cement content of 600 kg/m³ in the SCC concrete mixture [8]. This research was not yet conducted replacing 100% of slag aggregate to inhibit possibly segregation occurrence of SCSSC specimens due to a higher density of slag aggregate.

| Unit content (kg/m³) |
|----------------------|
| W                     |
| PCC  SF  S  S-slag  G  G-slag  Sp |

Table 3 Mix proportion of SCSSC specimens
2.3. Test methods

2.3.1. Method of self-compacting concrete. The mixing procedure of the Self-Compacting Steel Slag Concrete (SCSSC) was carried out following Indonesian Standards (SNI 2493). After mixed concrete for three minutes, the fresh SCSSC specimen was measured the main characteristics for filling ability, viscosity, and passing ability as specified in requirements of the European Guidelines for Self-Compacting Concrete (EFNARC 2005). The SCC characteristics of filling ability, viscosity, and passing ability of SCC concrete were measured by the Slump-flow, V-funnel, and L-box apparatus as illustrated in Figure 1, Figure 2, and Figure 3. The test of fresh SCC concrete was conducted three times in order to specify the characteristics of SCSSC specimens.

2.3.2. Mechanical properties.

In this research, the strength characteristics of SCSSC specimens were observed to evaluate the compressive strength, flexural strength, and tensile strength (splitting test). Concrete cylinder specimens in size of φ100x200mm and concrete prism specimens of 100x100x400mm were prepared. Twenty-four hours after cast, concrete specimens were demoulded, then they were cured in water (tap water curing). All cured concrete specimens were placed in an indoor building at room temperature of approximately 25°C. After a curing period of 28 days, concrete specimens were tested in compressive
strength, flexural strength, and tensile strength according to Indonesian Standards of SNI 1974, SNI 4431, SNI 2491, respectively. Minimally, the average strength of fifteen concrete specimens was determined as the strength of concrete specimens.

3. Results and discussion

3.1. Characteristics of SCC

The test results of the SCSSC specimen characteristics were conducted three times by methods of Slump-flow, V-funnel, and L-box are depicted in Table 4. It was observed that the flow time of the fresh SCSSC specimens to reach a flow to the 50cm diameter ($T_{50cm}$) was obtained at 3.75 seconds. It means that the flow time of $T_{50cm}$ was in ranging with 2s-5s as required according to The European Guidelines for Self-Compacting Concrete (EFNARC 2005). Similarly, results of the Slump-flow (final slump) were attained 680mm in an average slump-flow, which were meet the requirements for the filling ability of SCC ($\geq 520mm, \leq 700mm$). Both results suggest that fresh SCSSC specimen fulfills the requirements of filling ability of SCC concrete properties.

Further, the result of viscosity characteristics of SCSSC specimens was tested by the V-funnel method showed the average flow time was gained in 2.07 seconds, which was less than 10 seconds ($\leq 10$ seconds). It means that the viscosity of the SCSSC specimens satisfies the specification requirements of SCC concrete properties. Moreover, based on result of the L-box measurement method, it was found that the ratio of H2/H1 was 0.82. It showed that result was more significant than the minimum requirements of 0.75. The result of the L-box method exhibits that the SCSSC specimen could meet the criteria of SCC concrete by passing ability characteristics. In addition, phenomenon of concrete segregation did not occur based on the visual observation, although segregation test method of SCSSC specimens was not undertaken in this research. Generally, the results of characteristics by filling ability, viscosity, and passing ability of the fresh SCSSC specimen are summarized in Table 5. Based on the evaluation result, it can be revealed that the utilization of steel slag as a replacement aggregate meets the requirements properties of the SCC mixture. In other words, steel slag aggregate can be applied as a replacement aggregate in SCC production. This finding to be clear that the effect of slag characteristics on particle size and physical properties, that slag aggregate may replace natural aggregate role in SCSSC production.

| Characteristics of SCC | Method of Testing | Results of observation | Specification criteria for SCC | Remark |
|------------------------|-------------------|------------------------|-----------------------------|--------|
| Filling ability        | Slump-flow        | 670mm                  | $\geq 520mm, \leq 700mm$    | Eligibly |
|                        | $T_{50cm}$        | 3.75s                  | 2s - 5s                     | Eligibly |
| Viscosity              | V-Funnel          | 2.10s                  | $\leq 10$s                  | Eligibly |
| Passing ability        | L-Box             | 0.82                   | H2/H1 $\geq 0.75$           | Eligibly |
3.2. Mechanical properties

The recorded data of the compressive strength (fc) and the unit weight of the twenty-five concrete cylinder specimens are described in Figure 4. The result denoted that the hardened SCSSC specimens were obtained 60.70 MPa in average compressive strength at 28 days. It means that the concrete of SCSSC can be classified as high-strength concrete under compressive strength, which is more than 50 MPa in compressive strength. This result is the same as the tendency in compressive strength reported by previous researchers, not SCC [9]. It indicates that utilization of steel slag aggregate improves the compressive strength of concrete. Regarding unit weight of concrete specimens, it was observed that the average density of SCSSC specimens was acquired at 2490 kg/m³. It expresses that steel slag aggregate does not have a significant effect on increasing the unit weight of SCC. As well-known, the normal weight of concrete is commonly 2400 kg/m³.

![Figure 4 Result of compressive strength of SCSSC specimens](image)

The average flexural strength (fr) at 28-day of the fifteen concrete prism specimens was achieved 8.61 MPa, as illustrated in Figure 5. Meanwhile, the ratio of flexural strength to compressive strength (fr/fc) was obtained 14.2%. Result exhibits that SCSSC specimens can probably be applied in concrete road construction, which is at least flexural strength of 10% by compressive strength. Furthermore, it was found that the average tensile strength of fifteen concrete cylinder specimens was 4.72 MPa, as shown in Figure 6. The result was also observed that the ratio of tensile strength to compressive strength (ft/fc) and tensile strength to flexural strength ratio (ft/fr) were 7.8% and 54.8%, respectively. Based on the results of SCC characteristics and mechanical properties, it is evident that natural aggregate replaced by slag may be applied to SCSSC production.

![Figure 5 Result of flexural strength of SCSSC specimens](image)

![Figure 6 Result of tensile strength of SCSSC specimens](image)
4. Conclusion
The potential applicability of steel slag aggregate on the characteristics of Self-Compacting Concrete has been revealed, and the following conclusions can be drawn:

- Based on the requirement of SCC concrete related to filling ability, viscosity, and passing ability, steel slag aggregate can be applied as replacement aggregate in SCC concrete production.
- Based on the results of mechanical properties of SCSSC specimens, it was found 60.70 MPa and 8.61 MPa for compressive strength (fc) and flexural strength (fr), respectively.

Acknowledgments
The authors would like to express gratefulness to the Ministry of Research, Technology, and Higher Education of the Indonesian government for their financial support in this research. Also, the authors fully appreciate and be grateful to PT. Barawaja in Makassar for their support and assistance during the process of this research.

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