Characteristic of melted slag from wrought iron industry as green concrete material

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Abstract. Utilization waste material on concrete ingredients or its manufacturing that did not harm the environment is the need for the environment sustainability. It is the background of research in concrete design for more environmental friendly as often called green concrete. This work aims to investigate the usability of the melted slag, obtained from local wrought iron industry, as aggregates replacement according to waste material utilization. In particular, it focused on studying the feasibility of replacing the aggregates using melted slag by investigating the basic physical characteristic. Slag is known have a high percentage of silica and ferric oxides, which gives pozzolanic activities that suitable to use as cement blended product. Slag waste used in this work is obtained from the wrought iron industry from Pakis district, Magelang Regency, Central Java, Indonesia. The slag chunk extracted from the furnace then crushed to smaller particle sizing as fine aggregates and coarse aggregates. The aggregates characteristic is observed in relation to gradation test, specific gravity, bulk density, clay lumps percentage, and Los Angeles abrasion value. All of observation parameters are taken consecutively based on SNI and ASTM specification to evaluate its compatibility as concrete aggregates. The current work remarks that the fine and coarse aggregates generated from wrought iron slag do not reveal complete fulfilment in the aggregate specifications of any standard. Even though, the slag fine aggregates could be used in standard or lightweight concrete with further treatment such as crushing to smaller particle size, washing to minimize the clay lumps, and mixing with natural aggregates.

1. Introduction

Concrete is the most used building material worldwide with global production at about 12 billion per year. It is estimated that the average consumption at about 1.8 tonnes per year per every living human being, which much higher compared to steel (roughly 0.19 tonnes/year per person) [1]. There are many reasons why concrete was remarkably reliable, such as high strength, high durability, and environmentally low impact compared to steel [2]. However, due to its massif production volume (12 billion/year), the total carbon emissions of concrete become significant than steel or other materials [1].

The essential ingredients of concrete are aggregates, portland cement, and water, are considered having an environmental impact. The extraction of aggregates having land use implication, while the manufacturing of cement is facing a carbon (CO2) emission issue [3,4]. The portland cement was responsible for 74 % to 81 % of the total CO2 emissions of concrete. Globally, cement industries contribute about 5 % of the global (CO2) carbon emissions [5]. Emissions number of cement processing are coming from energy consumption of the kiln process and the chemical reaction (CaCO3→CaO + CO2) to decompose limestone. The chemical reaction itself contributes about 0.5 tonnes of CO2 per tonne CaO produced [5]. This reason encourages the need for concrete that is more environmentally friendly as often called green concrete.
Green concrete expressed as concrete that utilizes waste material on its ingredients, or its manufacturing did not harm the environment [6]. Green concrete can be easily identified using such parameters: the amount of cement substitution materials, manufacturing process, and life cycle analysis [7]. As reported in previous studies, there are two significant ways to produce green concrete. First, expand the use of residual or waste product, then the utilization of new types of cement which have lower CO2 emissions [8].

Since the 1990s, the use of waste material was encouraged to reduced cement and natural aggregates [9]. The use of Fly ash waste confirmed an excellent result to cut down the amount of portland cement used in concrete [7]. Furthermore, the by-product of foundries (foundry sand and cupola slag), glass, wood ash, sludge successfully introduced as substitution material for aggregates replacement [9,10]. The use of new cement materials such as alkali-activated cement, magnesia cement, polymer cement, and sulfoaluminate cement was found later [7].

However, proper treatment of slag waste still a big task for Indonesia, due to its classification as toxic and hazardous waste (B3). The study case is a local wrought iron industry in Pakis district, Magelang Regency, Indonesia, which produces about 3 tonnes slag waste/week from the heating process of wrought iron. Currently, slag waste was just thrown away as a landfill, which creates groundwater pollution. Thus, there is a need to utilize slag waste as a useful product to solve this environmental problem altogether giving added value to a particular product.

Based on the presented reason, this work aims to investigate the usability of the melted slag, obtained from local wrought iron industry, as aggregates replacement. In particular, it focussed on studying the feasibility of replacing the aggregates using melted slag by investigating the basic physical characteristic.

2. Application of slag

Slag defined as a by-product of steel manufacturing that originated from the molten steel that separates from dirt in the furnace. Steel slags categorized as a non-metallic residue that remains in when the molten steel has extracted from the furnace [11]. The slag consists of calcium silicates, calcium aluminoferrites, and oxides of some minerals (calcium, iron, magnesium, and manganese) [12]. However, along with the technological development, the term "slag" has been expanded. Slag is not only associated with steel manufacturing waste but also represents slag that originated from molten waste material (indicated in Fig.1) [13]. Thus, new kind of slag has developed, such: de-sulphurization slag from metal processing, and synthetic slag extracted from municipal solid waste incineration [14].

![Figure 1. Classification of slag](image)

The chemical composition depends on the types of furnace used in steel manufacturing, such: blast furnace (BF), Electric-arc Furnace (EAF) and Basic oxygen furnace (BOF) [15, 13]. Both of BOF and
BF slag have a high percentage of silica and ferric oxides, which gives pozzolanic activities that suitable to use as cement blended product [16]. In contrast, EAF slag possess low pozzolanic activity and having expansive nature of the aggregates, which is causes crack to use on the cement-based product [11, 16].

The use of BF slag as aggregates replacement on concrete gives improvement on freezing, thawing, sulfuric acid, and salt attack resistance with the strength that conforming Japan standard [17,18]. Furthermore, along with the addition of ash filler, the utilization of BF slag could produce high strength concrete [19]. Previous research also presented that EAF slag has successfully used on concrete pavements [20], hot mix asphalt, and bituminous treated sub-base [11]. Even though EAF slag has an expansion problem, it proved that the use of EAF aggregates replacement could produce higher compressive strength of concrete than natural aggregates [16, 21].

3. Experimental Methods

Slag waste that being assessed obtained from the wrought iron industry from Pakis district, Magelang Regency, Central Java Indonesia (Fig. 2). The slag chunk extracted from the furnace then crushed to smaller particle sizing as fine aggregates and coarse aggregates. The aggregates characteristic assessed for such parameter: gradation test, specific gravity, bulk density, clay lumps percentage, and Los Angeles abrasion value. All the parameter investigations are taken consecutively based on SNI and ASTM norm [22-25]. The evaluated parameter then compared to ASTM [22,23] and SNI [24] specification of concrete aggregates to know whether it was suitable to use as concrete aggregates or not.

4. Result and Discussion

The use of grained material on concrete has prescribed on ASTM [22-23] for normal and lightweight concrete. Locally, there is also Indonesian Standard or SNI [24] that regulate the specification of aggregate for regular concrete for application in Indonesia. All three standards focus on establishing measures of acceptance regarding grading, physical properties, abrasion resistance, and deleterious material content. The value of those parameters of aggregates should comply with the limit listed on the norm. However, due to aggregates heterogeneity, there is a possibility that it will fit several parameters and fail to meet some criteria in a particular standard. Hence, the codes ensure that the use of the fails aggregates was not prohibited. This exception applies if the concrete strength made from fails aggregates has not a significant difference compared to concrete from adequate aggregates.

4.1. Aggregates grading

The grading of aggregates being examined to ASTM [22-23] to check the conformity to standard concrete specification (Table 1 and 2). Figure 3(a) reveals that the slag fine aggregates gradation curve

![Figure 2. Wrought iron slag waste](image-url)
was not fit with the ASTM C33 [22] range for normal concrete. The evidence addressed by the percentage of the granules which passed in 1.18 and 2.36 mm sieve below the lower limit of ASTM C33 (Table 1). Thus, according to Kosmatka et. al. [26], this gradation curve could be classified as gap-graded aggregates, as several particle sizes are missed (1.18 and 2.36 mm particles) from the range. The use of gap-graded aggregates could lead to concrete that is likely to segregate or honeycomb [26]. Consequently, it needs higher cement volume to produce the concrete compared to well-graded aggregates. Contradiction with ASTM [22], toward Indonesian standard [24], the slag fine aggregates fortunately categorized as coarse sand class and still can be applied for 15-20 MPa concrete constituent.

![Figure 3](image.png)

**Figure 3.** Gradation curve of (a) slag fine aggregates and (b) slag coarse aggregates compared to ASTM C33 specification

| Table 1. Slag fine aggregates gradation |
|----------------------------------------|
| Sieve | Percent passing (%) |
|       | ASTM C33 requirement | Fine slag agg. |
| 9.5 mm | 100                   | 100             |
| 4.75 mm | 95 - 100            | 99.4            |
| 2.36 mm | 80 - 100            | 66.4            |
| 1.18 mm | 50 - 85             | 46.0            |
| 600 μm  | 25 - 60             | 30.3            |
| 300 μm  | 5 - 30              | 18.4            |
| 150 μm  | 0 - 10              | 11.2            |
| 75 μm   | 0 - 3               | 7.0             |

| Table 2. Slag coarse aggregates gradation |
|------------------------------------------|
| Sieve | Percent passing (%) |
|       | ASTM C33 requirement | Coarse slag agg. |
| 37.5 mm | 100                    | 100             |
| 25 mm   | 90 - 100               | 99.1            |
| 19 mm   | 40 - 85                | 75.4            |
| 12.5 mm | 10 - 40                | 33.4            |
| 9.5 mm  | 0 - 15                 | 11.1            |
| 4.75 mm | 0 - 5                  | 5.5             |

4.2. **Physical parameters**

As shown in Table 3 and Table 4, the physical properties for the fine and slag coarse aggregates do not conform to ASTM [22,23] and Indonesian standard (SNI) [24] specification. However, not all the obtained result was evaluated cause the norm does not give the exact limitation of some aggregates parameter. Only four parameters that could be compared to ASTM and SNI, such as fineness modulus, Los Angeles abrasion, clay lumps, and bulk density.

The slag fine aggregates exhibit that the number of fineness modulus is about 4.21, which categorized as coarse sand. This finding in line with the gradation analysis delivered earlier. Nevertheless, the
fineness modulus does not comply with any limit given by the codes (Table 3). This result means that the slag gradation still too coarse to be classified as fine aggregates. Therefore, to be used as fine aggregates, the slag aggregates must be further treated. The treatment that possible to carry on is combining the slag aggregates with natural fine aggregates or crushing the slag to smaller grain size.

### Table 3. Physical characteristic of slag fine aggregates

| Parameters            | Slag fine aggregates | Code specification limit |
|-----------------------|----------------------|--------------------------|
|                       |                      | ASTM C33, concrete agg.  | ASTM C330, lightweight conc. | SNI 04 1989, concrete agg |
| Fineness modulus      | 4.213                | 2.3 - 3.1                | -                          | 1.5 - 3.8                 |
| Clay lumps            | 8.51 %               | 3%                       | 2%                         | 5%                        |
| Bulk density          | 1.158 gr/cm³         | > 1.120 gr/cm³           | < 1.120 gr/cm³             | -                         |
| Water absorption      | 13.63 %              | -                        | -                          | -                         |
| Bulk specific gravity | 1.76                 | -                        | -                          | -                         |
| SSD specific gravity  | 2                    | -                        | -                          | -                         |
| Apparent specific gravity | 2.3               | -                        | -                          | -                         |
| Moisture content      | 6.276%               | -                        | -                          | -                         |

Table 3 also stated that slag fine aggregates retain a high amount of clay (about 8.51 %) which the standard gives a 2 - 5 % limit. This fact points out that the quality of the bond between aggregates and cement paste will be affected. Furthermore, the bulk density and water absorption (Table 3) gives an illustration that the fine aggregates is very porous and tends to comply with ASTM C33 (standard concrete).

### Table 4. Physical characteristic of slag coarse aggregates

| Parameters            | slag coarse aggregates | Code specification limit |
|-----------------------|------------------------|--------------------------|
|                       |                        | ASTM C33, concrete agg.  | ASTM C330, lightweight conc. | SNI 04 1989, concrete agg |
| Fineness modulus      | 3.747                  | -                        | -                          | 6 - 7.10                 |
| Los Angeles abrasion   | 35.0 %                 | 50                       | -                          | -                        |
| Clay lumps            | 2.8 %                  | -                        | 2%                         | 1%                       |
| Bulk density          | 1.017 gr/cm³           | > 1.120 gr/cm³           | < 0.880 gr/cm³             | -                        |
| Water absorption      | 5.102 %                | -                        | -                          | -                        |
| Bulk specific gravity | 1.89                   | -                        | -                          | -                        |
| SSD specific gravity  | 1.986                  | -                        | -                          | -                        |
| Apparent specific gravity | 2.555               | -                        | -                          | -                        |
| Moisture content      | 1.122 %                | -                        | -                          | -                        |

In contrast with the data presented in Table 3, the physical characteristic in Table 4 shows that the slag coarse aggregates have extremely smooth particles (FM around 3.74) compared to Indonesian standard (FM between 6-7.10). Nevertheless, concerning that the ASTM standard does not give any restriction to Fineness modulus, the slag coarse aggregates still comply with the ASTM rule. Furthermore, the slag coarse aggregates exhibit a remarkable result concerning abrasion value with the Los Angeles resistance is about 35 % (ASTM limit 50%).
5. Concluding Remark

This paper presents the properties of slag waste from the wrought iron industry that were experimentally examined based on the specification standard of concrete aggregates. According to the result of conducted experiments, the followings concluded:

1. The fine and coarse aggregates obtained from wrought iron slag does not reveal complete fulfilment in the aggregate specifications of any standard.
2. The slag fine aggregates could be used in standard or lightweight concrete with further treatment such as crushing to smaller particle size, washing to minimize the clay lumps, and mixing with natural aggregates.
3. The slag coarse aggregates pose a satisfactory result to be used as concrete aggregates. However, the manufacturers should give proof that the strength of concrete made from these aggregates has a similar strength to concrete with natural aggregates.

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