Effects of Ground Granulated Blast Furnace Slag and Recycled Coarse Aggregates in Compressive Strength of Concrete

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Abstract. Innovations in concrete technology are developing and increasing rapidly. Modifications were made in concrete research to produce concrete that is strong, economically valuable, and environmentally friendly. This can be done by using concrete waste as a concrete substitution material -which is coarse aggregate- and slag waste as a concrete substitution material for cement. In this research, the characteristic properties of these materials and the effects of their use on the strength of concrete will be studied. The compositions of Ground Granulated Blast Furnace Slag (GGBFS) varied by 0%, 25%, 50%, 75% with the coarse aggregate composition of 40% against natural aggregate. The use of 50% GGBFS gave the compressive strength of 24.8 MPa. The use of GGBFS will result the economic value of concrete and reduce CO₂ emissions.

1. Introduction
Concrete is the most widely used construction material. This concrete has the advantage of materials that are easily obtained, arranged, and the price is still cheap with treatment and maintenance that is not too complicated. Concrete forming material is cement. Cement is a material used to bind to other concrete-forming materials. The main raw materials for making cement are quicklime from limestone, silica from the soil, alumina from clay [1-4].

Solid concrete waste is the result of demolition from buildings that are damaged or waste sample testing in the laboratory. While fresh concrete waste is removed from the waste due to excess production at the batching plant. Recycled aggregates are produced from the re-preparation of mineral waste materials, with the largest source being construction and demolition waste [2, 5-6]. At 56 days, concrete with a mixture of 40% recycled aggregates has a compressive strength with other mixtures, with a 16.9% increase in normal concrete [4, 7].

This steel production waste is sand slag waste produced by blast furnaces from steel mills. This slag waste still contains silicate and calcium aluminosilicate which can be used as cement formers with the right composition [8].

Ground Granulated Blast Furnace Slag (GGBFS) was classified by ASTM C 989 as a nonmetallic product, consisting of calcium silicates and aluminosilicates and other bases developed in accordance with fuel requirements by tan in blast furnaces in the iron production process [9]. At the same 28 days strength, replacement of Portland cement containing 65% slag can reduce compressive strength by almost half in 2 days.
2. Methods and materials
In this research, the composition of the mixture was obtained from mix design. While the tests carried out on concrete are fresh concrete testing and compressive strength testing. Then results obtained from the test will be studied.

The compressive strength test had used five variations of GGBFS consist of 0%, 25%, 50%, and 75% of the cement composition. The composition of recycled aggregate used is 40% of the total gross aggregate. The specimens will be tested under the compressive test at 3 days, 7 days, 28 days and 56 days.

The mixed design has been formulated based on ACI 211.1 for $f_{c'} = 21.5$ MPa. The water-cement ratio used was 0.425. The mix design for 1 m$^3$ concrete is shown in Table 1, where the amount of recycled aggregate is 40% of the total coarse aggregate.

| Name                      | Quantity  |
|---------------------------|-----------|
| Water                     | 195 kg    |
| Cement                    | 458.82 kg |
| Fine Aggregate            | 694.80 kg |
| Natural Coarse Aggregate  | 612.13 kg |
| Recycled Aggregate        | 408.09 kg |
| Superplasticizer          | 1.15 kg   |

The materials used in this study are natural coarse aggregates, recycled coarse aggregates, GGBFS, fine aggregates, cement, and water.

2.1. GGBFS and cement
GGBFS is formed as a liquid at 1350-1550° in the manufacture of iron; limestone reacts with material rich in $\text{SiO}_2$ and $\text{Al}_2\text{O}_3$ associated with the ore or present in ash from the coke. The slag is cooled very rapidly and solidifies as a glass. The granulated slag is poured into a large excess of water (100 m$^3$/t of slag) or subjected to spraying jets under 0.6 MPa pressure. After the treatment, the water content of slag (≤ 30 per cent) is largely eliminated in dryer mills or filter basins [10-11].

A slag containing 35-50% lime, 30-40% silica, 10-18% alumina and small amounts of magnesia, and manganese and iron oxides, except for its lower lime content, similar in composition to Portland cement. If mixed with the necessary quantity of limestone, its composition can be brought to that required in a Portland cement raw mix [10, 12]. The material of GGBFS is shown in Figure 1.

$\text{Al}_2\text{O}_3$ content above 13% tended to increase early strengths but to decrease late strengths. In Table 2 showed that the $\text{Al}_2\text{O}_3$ content of GGBFS is greater than cement, so it will to increase early strength and decrease late strength. MgO in amounts up to 11% was quantitatively equivalent to CaO. Minor components were found to have important effect: that of MnO was always negative [13].

|          | $\text{SiO}_2$ | $\text{Al}_2\text{O}_3$ | CaO | MgO | S  | $\text{Fe}_2\text{O}_3$ | MnO | others |
|----------|----------------|------------------------|-----|-----|----|------------------------|-----|--------|
| Cement (%)| 20.5           | 5.4                    | 63.9| 2.1 | 3.0| 2.6                    | 1.4 | 1.1    |
| GGBFS (%)| 36             | 12                     | 35.5| 13.5| 1.45| 0.8                    | 0.6 | 0.15   |
The characteristics of fine aggregate used in this study is shown in Table 3, and all values are satisfied except water absorption that exceeds the standard.

### Table 3. Characteristics of fine aggregate.

| Characteristics             | Magnitude          |
|-----------------------------|--------------------|
|                            | Fine Aggregate     | ASTM Standard |
| Bulk density (Kg/m³)        | 1495               | 1300 - 1900   |
| Specific gravity            | 2.78               | 2.3 - 3.1     |
| Water absorption (%)        | 3.73               | 2.3           |
| Grading zone                | Zone 2             |               |
| Sludge content (%)          | 0.3                | 0.2 - 6       |
| Organic content             | No. 1              | Maximum No.3  |

2.3. Natural coarse aggregate

Natural coarse aggregate used in this study was 60%, while the remaining 40% will use the recycled aggregate.

2.4. Recycled aggregate

Recycled aggregate used here is the concrete waste with a strength of 30-35 MPa which is crushed with a crushing machine (Figure 2). The results of this fraction are divided into four compositions, namely 30-20 mm, 20-10 mm, 10-5 mm, and smaller than 5 mm. The recycled aggregate used for this study was 25 mm, so that the aggregate used was 20-10 mm and 10-5 mm [6].

Figure 2. Crushed concrete from crushing machine.
The characteristics of recycled coarse aggregate have a bulk density value smaller than natural aggregate because mortars that are still attached with the recycled coarse aggregate. So that their weight is lighter than natural aggregate. And the absorption value is higher, so it can absorb more water. Characteristics of natural and recycled aggregate is shown in Table 4.

**Table 4. Characteristics of natural coarse aggregate.**

| Characteristics          | Natural Coarse Aggregate | Recycle Aggregate | ASTM Standard |
|--------------------------|--------------------------|-------------------|---------------|
| Bulk density (kg/m³)     | 1500.32                  | 1190              | 1400-2200     |
| Specific gravity         | 2.59                     | 2.36              |               |
| Water absorption (%)     | 1.99                     | 5.4               | Maximum 4     |
| Maximum size (mm)        | 25                       | 20                |               |
| Abrasion (%)             | 25.04                    | 31.6              | 15-50         |

2.5. Water

The water used is raw water that does not contain hazardous materials and not contaminated with chemicals that can damage the strength of cement [14].

2.6. Superplasticizer

Superplasticizer here is used to reduce water absorption in concrete and increase concrete slump [15].

3. Test and results

3.1. Fresh concrete test

Fresh concrete tests have been taken from AASHTO T 199-99. The test carried out is a slump test with a slump cone as a test tool. From the results of the fresh concrete test, all slump test results meet the slump target. The results of lump test are shown in Table 5.

**Table 5. Slump test.**

| Mix | Cement (%) | GGBFS (%) | Slump (mm) | Slump Target (mm) |
|-----|------------|-----------|------------|-------------------|
| 1   | 100        | 0         | 92         | 80-100            |
| 2   | 75         | 25        | 93         | 80-100            |
| 3   | 50         | 50        | 80         | 80-100            |
| 4   | 25         | 75        | 84         | 80-100            |

3.2. Compressive strength

The compressive strength test on concrete is carried out at 3 days, 7 days, 28 days and 56 days. In 28 days compressive strength testing for the 0% GGBFS mixture has a value of 32 MPa. Whereas the mixture of 25% GGBFS decreased to 28.4 MPa. For a mixture with 25% GGBFS without superplasticizer has a value almost the same as the composition of 25% GGBFS using superplasticizer which is 27.3 MPa. The mixture or replacement of 50% cement using GGBFS has decreased to 24.8 MPa. In the mixture of 75% GGBFS decreased by MPa to 19.2 MPa or decreased by 37.4% against the mixture of 0% GGBFS. At an early age the mixture of 25% GGBFS has a higher strength than other mixes. But, the late age the mixture of 0% GGBFS has a higher strength than other mixes. The compressive test results are displayed in Table 6 and Figure 3.
Table 6. Compressive strength.

| Mix | Cement (%) | GGBFS (%) | Compressive strength in MPa |
|-----|------------|-----------|-----------------------------|
|     |            |           | 3 days | 7 days | 28 days | 56 days |
| 1   | 100        | 0         | 13.8   | 23.0   | 32.0    | 35.1    |
| 2   | 75         | 25        | 13.9   | 23.3   | 28.4    | 31.1    |
| 3   | 50         | 50        | 11.4   | 20.3   | 24.8    | 25.7    |
| 4   | 25         | 75        | 8.6    | 12.4   | 19.2    | 19.9    |

Figure 3. Compressive strength with the variation of GGBFS.

4. Conclusion

Based on the results and analysis of material testing and initial compressive strength testing regarding the use of recycled coarse aggregate in concrete, the following conclusions can be obtained:

- Recycled aggregate has almost the same characteristics as natural coarse aggregate. The value of recycled aggregate abrasion is quite good at 31.6%. Absorption of water (absorption) is quite high at 8.23%. For the weight of the contents of the recycled coarse aggregate has a smaller value than the natural coarse aggregate which is 1190 kg/m³. Specific Gravity SSD recycled coarse aggregate is 2.36 smaller than the natural coarse aggregate of 2.59.

- Compressive strength testing for the 0% GGBFS mixture has a value of 32 MPa. Whereas the mixture of 25% GGBFS decreased to 28.4 MPa. For a mixture with 25% GGBFS without superplasticizer has a value almost the same as the composition of 25% GGBFS using superplasticizer which is 27.3 MPa. The mixture or replacement of 50% cement using GGBFS has decreased to 24.8 MPa. In the mixture of 75% GGBFS decreased by MPa to 19.2 MPa or decreased by 37.4% against the mixture of 0% GGBFS.

- The concrete compressive strength relationship with the composition of GGBFS shows an inverse relationship between the compressive strength of concrete with GGBFS replacement of cement. The equation shows the greater the use of GGBFS, the smaller the compressive strength produced.

- The use of GGBFS up to 50% of cement replacement reached the optimum compressive strength results. By using the composition of 50% GGBFS, it can reduce the use of cement, so that the concrete mixture can give economic value and reduce CO₂ emissions.
5. References

[1] Afriandi R F 2018 Pengaruh Faktor Umur terhadap Perbandingan Kuat Tekan Beton Normal, Beton Mutu Tinggi dan Beton Ringan (Mataram: Universitas Mataram)

[2] Akbar A F 2015 Studi Pengaruh Penggunaan Agregat Halus Daur Ulang dari Limbah Padat dengan Mutu K350-K400 dengan Admixture Conplast SP 337 Terhadap Kuat Tekan, Kuat Lentur, dan Susut (Depok: Universitas Indonesia)

[3] Andiani P 2011 Identifikasi Komposisi Limbah Konstruksi Pembangunan Struktur Bangunan Bertingkat Tinggi (Depok: Universitas Indonesia)

[4] Marastuti P 2014 Studi Penggunaan Agregat Kasar Daur Ulang Dari Limbah Beton Padat Dengan Mutu K350-K400 Terhadap Kuat Tekan, Kuat Lentur dan Susut Pada Susut (Depok: Universitas Indonesia)

[5] Saleh C 2016 Pemanfaatan Limbah Ready Mix Sebagai Bahan Agregat Kasar Beton Normal (Bogor: Universitas Pakuan)

[6] Swamy R N 1983 New Concrete Materials (London: Surrey University Press)

[7] Sangeetha S P 2018 Strength and flexural behaviour of reinforced concrete with ground granulated blast furnace slag Int. J. Pure and Appl. Math. 118 pp 867-879

[8] Apriliando B A 2013 Effects of Steel Slag Substitution in Geopolymer Concrete on Compressive Strength and Corrosion Rate of Steel Reinforcement in Sweater and Acid Rain (Depok: Universitas Indonesia)

[9] Krishnan D, Ravichandran P T and V K Gandhimathi 2017 experimental study on properties of concrete using ground granulated blast furnace slag and copper slag as a partial replacement for cement and fine aggregate Rasayan J. Chem. 10 600-605

[10] Hewlett P 2004 Lea’s Chemistry of Cement and Concrete (UK: Butterworth-Heinemann)

[11] Prasanna K, Anandh K S and Ravinshankar 2017 An experimental study on strengthening of concrete mixed with ground granulated blast furnace slag (GGBFS) ARPN J. Eng. Appl. Sci. 12 2439-2444

[12] Kaur M and Sanjeev N 2012 Performance of ground granulated blast furnace slag concrete with partial replacement of sand by saw dust IOSR J. Mech. Civ. Eng. 2 22-30

[13] Nilson A and George W 1979 Design of Concrete Structures (USA: Halliday Lithograph)

[14] Raina, V K 1993 Concrete for Construction (London: Tata McGraw-Hill)

[15] Nawy E 2001 High-Performance Concrete (New Jersey: John Willy and Sons)

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