The influence of Ground Granulated Blast Furnace Slag (GGBFS) as Portland Composite Cement (PCC) substitution in improving compressive strength of concrete

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Abstract. Concrete is a construction material that is extensively used to build various Infrastructures. The increasing of basic human facilities and the resulting Infrastructures in increasing needs of concrete and cement concrete as the material forming. Many problems in the concrete producing industry are not sustainable. Because of concrete production uses enormous natural resources and the main binding material in concrete is cement. Cement is the result of calcination of lime roackets in the process results in the release of carbon dioxide (CO2). To mitigate this problem and for sustainability concrete, many researches have been done to find a replacement for cement. Geopolymer concrete is an alternative to reduce part of cement. Ground Granulated Blast Furnace Slag (GGBFS) that consist of silica and alumina can be used as a binder to replace part of the Portland Composite Cement (PCC). In this study, concrete compressive strength tests were carried out on 48 specimens of concrete cylinder 15x30 cm. The ratio of substitution GGBFS/PCC used were 0/100, 40/60, 50/50 and 60/40. The specimens were cured at room temperature then tested at the age of 7, 14, 21 and 28 days. The results show that the average compressive strength of concrete at the age of 28 days that GGBFS/PCC ratio of 0/100, 40/60, 50/50 and 60/40 were 26.50, 23.01, 26.65 and 22.56 MPa, respectively. Based on the analysis, 50% substitution of GGBFS can be used to partially replace cement because has the same as normal compressive strength of concrete and can be classified as environmentally friendly or green concrete.

1. Introduction
Currently, the process of burning raw materials for cement is the biggest of CO2 gas, which is one of the causes of environmental impacts that need attention. CO2 emissions are the main causes of global warming and climate change. Besides fly ash and silica fume, another material can be used as cement replacement is slag [1]. Partial replacement of cement can be used as an alternative to reducing CO2 emissions by means of partially substituting cement with waste ground granulated blast furnace slag (GGBFS). GGBFS is still categorized as hazardous and toxic material waste where produce, containers, transporters and users are limited by very strict regulations and permits (KSI,2018).

GGBFS a by-product in the manufacture of the processing of iron and the amounts of iron and slag obtained are of the same order. The slag is a mixture of lime, silica and alumina, the same oxides which
has a similar chemical composition of cement, so it can replace most the mass of cement with a specific ratio to the production of environmentally friendly concrete [2,3]. Usually the composition of blast-furnace slag consists of silicon, calcium, aluminum, magnesium and oxygen constitute 95% or more of the blast-furnace slag [4].

In Hogan and Meuseul research, the cementitious and pozzolanic behavior of GGBFS is essentially similar to that high-calcium fly ash at 40%, 50% and 65% cement replacement by weight [5] and Mehta found that up 3 days of age, strength contribution from slag to ASTM C 109 that mortar was low, however strength similar to the reference cement was achieved at 7 days, and higher strength thereafter [6]. ASTM C 989 explain that slag activity index (SAI) as the percentage ratio of the average compressive strength of slag cement are 50:50%.

Efficiency factor of GGBFS on concrete was reported that overall strength that combination of the two factors are the general efficiency factor and the percentage efficiency factor [7]. Oner and Akyuz have used Bolomey and Feret equation and was calculated the optimum content of fly ash to maximize strength as 40% [4].

In this research, an experimental investigation of optimum usage of GGBFS as substitution of PCC cement in concrete. The optimum values of GGBFS were determined for concrete with various cement dosages by the compressive strength.

2. Research methods
Concrete-making materials such as an aggregate, cement and GGBFS were tested first.

2.1. Materials

2.1.1. Cement. In this research the cement used was Portland Composite Cement (PCC) has specifications according to Indonesian Standards (SNI 15-7064-2004), Europe Standards (EN 197-1:2000) and American Standards (ASTM C 595-03). Specific gravity of PCC used was 2,9. The blaine specific surface area was 500 m²/kg.

2.1.2. Ground granulated blast furnace slag. In this research used of GGBFS from PT. Krakatau Semen Indonesia has specification analysis are specific gravity of 2,89, amount retained sieve 45 µm (no.325) is 3,06% and the blaine specific surface area was 332 m²/kg. GGBFS and PCC chemical content are given chart below, Table 1.

| Compound | Oxide : % weight |
|----------|------------------|
|          | PCC  | GGBFS |
| CaO      | 63   | 43.95 |
| SiO      | 22   | 36.27 |
| Al₂O₃    | 7    | 14.93 |
| Fe₂O₃    | 3    | 0.54  |
| SO₃      | 2    | 0.68  |
| MgO      | 2    | 1.02  |
| K₂O      | 0.59 | -     |
| Na₂O     | 0.27 | -     |

(Sources: Balai besar bahan dan barang teknik Bandung).

2.1.3. Aggregates. In this research the coarse aggregate with a density 2.7 gr/cm³ with a maximum particle size of 19 mm, fineness modulus of 5.6 and have specific gravity of 2.67. The fine aggregate was crushed limestone powder with a density of 2.6 gr/cm³, fineness modulus of 2.25 and specific gravity of 2.54.
2.2. Preparation and curing of specimen
In total 48 concrete cylinders of 15x30 cm with substitution ratio GGBFS/PCC of 0/100 (normal concrete), 40/60, 50/50 and 60/40 were tested for compressive strength at the age of 7, 14, 21 and 28 days. The curing method used to treat the specimen stored at room temperature (± 25°C). Number and Designation of Concrete sample are given chart below, Table 2.

| Designation | Type of Beam Concrete | Number |
|-------------|-----------------------|--------|
| BN          | Concrete without GGBFS| 12 samples |
| BG-40       | Concrete with 40% GGBFS| 12 samples |
| BG-50       | Concrete with 50% GGBFS| 12 samples |
| BG-60       | Concrete with 60% GGBFS| 12 samples |
| Total       |                        | 48 samples |

3. Results and discussion
The test result of concrete compressive strength test specimens with and without substitution GGBFS is given in the chart below, Figure 1.

![Figure 1. Graph of concrete compressive strength PCC concrete and GGBFS.](image)

| No. Test objects | Results to-Day Compressive Strength |
|------------------|------------------------------------|
|                  | 7       | 14       | 21       | 28       |
| BN               | 25.20   | 26.05    | 26.25    | 26.50    |
| BG-40            | 19.49   | 22.99    | 22.99    | 23.02    |
| BG-50            | 21.69   | 25.25    | 25.69    | 26.65    |
| BG-60            | 20.01   | 22.40    | 22.55    | 22.56    |
Based on Figure 2 and Table 3 shows that the normal concrete and substitution GGBFS concrete have a compressive strength value continues to increase with age. In normal concrete compressive strength values tend to be stable, in concrete with GGBFS substitution have a low value at the beginning of age concrete but continues to increase even predicted to continue after the age of 28 days. As the previous research by Gidion Turuallo, that the compressive strength of concrete with a level of 50% ggbfs at the age of 32 days increased by 84.99% [8]. The compressive strength of normal concrete at early age is higher than concrete with GGBFS substitution. Normal concrete as control specimen at the age of 28 days had the compressive strength of 26.5 MPa. At 40% substitution of GGBFS have a lower compressive strength value of 23.02 MPa, then the concrete compressive strength increased at the of 50% substitution of GGBFS with almost the same compressive strength value even increased 1% that is equal to 26.65 MPa, then at 60% substitution of GGBFS have a value of compressive strength is 22.56 MPa.

4. Conclusion

The optimum content of use GGBFS in this study as a partial replacement of PCC cement at 28 days is at 50% content of GGBFS produce compressive strength value of 26.65 MPa or increase about 1% of normal concrete so GGBFS can partially replace cement in concrete manufacture. Concrete with GGBFS substitution can also be categorized as environmentally friendly concrete because it can reduce the use of cement. In this study the authors have limited time, so the authors suggest further research testing the compressive strength more than 28 days in order to determine the compressive strength of concrete GGBFS are predicted to continue increase.

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