Effect of temperature rise against durability and behaviour of ground granulated blast furnace slag concrete

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Abstract. Concrete which affected with high temperature will lost its strength significantly by 60%. To overcome this problem is utilizing steel industry waste, that is Ground Granulated Blast Furnace Slag (GGBFS) which is used as a substitute for cement in concrete mixtures. The properties of GGBFS which is cementitious same as cement, so that it can fulfil the function of cement. In this research, GGBFS concrete and normal concrete with strength of concrete is 30 Mpa and both types of concrete will be burned at a temperature of 600˚C for 2 hours. After that, characteristics strength of concrete will be tested to GGBFS concrete and normal concrete in each concrete before being burned and after being burned. The result of this research, there was an insignificant increase in strength of concrete with GGBFS as a substitute for cement by 40%. The average compressive strength of GGBFS concrete before and after being burned was 30.48 MPa and 11.16 MPa, compared to normal concrete which was 30.06 MPa and 9.76 MPa. Increasing also happened at the result of flexural test, which is initial crack at GGBFS concrete occur in greater deflection and load than normal concrete.

1. Introduction
Fire is one of the disasters that cause the structure failure of concrete construction. Usually it occurs in the construction of office buildings, house and factories. However, it does not rule out the possibility of a fire that can occur in the area around the bridge so that the fire contact with the concrete and cause the concrete structure run into extreme high temperature rises, although the chances of that possibility are small. For example of a fire that occurred was the burning of the ship under the Ampera Bridge on 20 December 2018, where there was contact between the fire from the burning of the ship against the beam concrete in the bridge.

Physical and mechanical properties in concrete will be decrease if exposed to high temperatures from fire. This is due to physical changes in aggregate and chemical composition of cement. High temperatures cause a decrease in durability, mass loss, reduction in compressive strength and modulus of elasticity and cracks in the girder beam. Damage to the concrete due to increased temperatures caused by fire disasters has a level of damage that can be caused by the duration and temperature of the fire with a percentage of concrete compressive loss of 60% [1,2].

To overcome this, waste from the steel industry such as Ground Granulated Blast Furnace Slag (GGBFS) can be used in concrete mixtures as a substitute of cement which aims to reduce damage caused by high temperatures from fires such as spalling on concrete surfaces, concrete carbonation and cracks in concrete. Forming element of GGBFS are lime, silica and alumina, which have cementitious properties like cement so they can replace the portland cement function with a replacement ratio of 10%
- 70% [3]. The results indicate that the use of GGBFS has been shown to improve some strength characteristics so as to reduce damage to concrete. Concrete structures containing up to 50% GGBFS as cement replacement material are considered suitable for the use of building structures, roads and bridges [4].

Therefore, a study was conducted which examined the effect of GGBFS as a substitute for cement in concrete on the mechanical properties or strength of the concrete, and investigated the strength and resistance of GGBFS concrete to high temperatures due to fire. Furthermore, this study aims to determine the strength comparison between GGBFS concrete and normal concrete in order to obtain a comparison of concrete properties and strength between GGBFS concrete and concrete without GGBFS before and after exposed with high temperature. Things to note from the results of this test are compressive strength, flexural strength, mass loss and modulus of elasticity.

2. Methods
The research method is experimental method, in which the concrete mix design method used was American Concrete Institute (ACI) 211.1-91 with a compressive strength of concrete is 30 MPa.

The research began with testing specimens in the form of cylindrical concrete to obtain optimum levels of GGBFS mixture in concrete mixes. The ratio of GGBFS content used in this test specimen is from 20% to 60%. Concrete cylinder will be tested its compressive strength. GGBFS content ratio as a substitute for cement which produces the highest compressive strength value will be used as the optimum level of GGBFS. Details of the test specimen to be tested can be seen in Table 1.

| Dimension of specimen | Ratio of GGBFS | Amount pcs |
|-----------------------|----------------|------------|
| Cylinder (cm)         | %              |            |
|                       | 20             | 3          |
|                       | 30             | 3          |
| 15 × 30               | 40             | 3          |
|                       | 50             | 3          |
|                       | 60             | 3          |

After the optimum level is obtained, that level used in concrete mixes for test specimens that will be reviewed for physical and mechanical properties before and after combustion. Test specimens are divided into two dimensions, cylinder and beam. Then the test specimens were also grouped into two test specimens, there are normal concrete and GGBFS concrete, each of which contained specimens that were burned and not burned. Details of the test specimen can be seen in table 2.

| Dimension of Specimen | Quality of Concrete (MPa) | Unburned Specimen | Burned Specimen |
|-----------------------|--------------------------|-------------------|-----------------|
|                       | SNI 03-6429-2000         | SNI 4431: 2011    | SNI 03-6429-2000| SNI 4431: 2011 |
| Cylinder (Ø15×30)     | 30                       | 3                 | 3               |
| Beam (15×15×75)       | 30                       | 3                 | 3               |

In table 2, cylinder specimen have to be weighed before and after combustion. The specimens in table 2 are also included for normal concrete and GGBFS concrete specimens. The test is explained on the cylindrical concrete in the form of mass loss after combustion, compressive strength and modulus of elasticity. Whereas concrete beams are tested for their flexural strength. Concrete compressive strength testing refers to SNI regulation 03-6429-2000. Flexural strength testing refers to SNI 4431: 2011 regulations with loading system that is two point load. The flexural strength testing scheme can be seen in Figure 1.
Concrete combustion process refers to the regulations of the American Standard Testing and Material (ASTM) E119-2000, with a burning duration of 2 hours at 600 °C.

3. Results and discussion
Proceed by testing the specimens to obtain optimum levels of GGBFS, the results of the tests can be seen in Table 3.

| GGBFS % | Dimension of Specimen D | Weight T | Age of Con | Max. Load kN | Compressive Strength (f'c) | Ave rage |
|---------|-------------------------|----------|-------------|--------------|-------------------------|---------|
| 20      | 15.20 3.85 12206        | 15.60 30.00 12214 | 15.04 30.00 1220 | 28 | 514.2 28.35 | 29.81 |
|         | 15.00 30.04 12253.3     | 15.05 30.25 1224.5 | 15.04 30.00 1231.6 | 28 | 588.4 33.31 | 31.46 |
| 30      | 15.00 31.26 1233.4      | 14.98 30.00 1224.1 | 15.20 29.98 199.7 | 28 | 760.8 43.19 | 39.33 |
|         | 15.00 30.00 1231.4      | 15.00 30.34 1214.3 | 15.26 30.00 1206.5 | 28 | 594.0 33.53 | 31.57 |
| 50      | 15.00 31.50 1200.5      | 15.00 31.00 1210.9 | 15.04 30.48 1197.1 | 28 | 510.4 28.90 | 24.31 |

From Table 3, the compressive strength of GGBFS is obtained. The optimum levels of GGBFS as a substitute for cement in GGBFS concrete can be seen from Figure 2.
In Figure 3, that the optimum levels of GGBFS as a substitute of cement were obtained at 40% with an average compressive strength is 39.33 MPa, compared to 30% and 50% of the GGBFS whose compressive strength only increased to 31.46 MPa and 31.57 MPa, only a slight increase in strength from the design of compressive strength is 30 MPa. In the use of GGBFS as much as 60% of the total weight of cement, concrete compressive strength decreases to 24.31 MPa. So, the optimum level of GGBFS as a substitute of cement is 40%.

Followed by testing cylindrical specimens, where normal concrete and GGBFS concrete that was burned and not burned were tested for compressive strength and modulus of elasticity. Results can be seen at Table 4.

**Table 4.** Results of compressive strength and modulus of elasticity test between normal and GGBFS concrete.

| No | Code of Specimen | Combustion Temperature | First Weight gr | Weight after burned gr | Compressive strength MPa | Average of Comp. Strength MPa | Actual Modulus of Elasticity MPa |
|----|------------------|------------------------|-----------------|------------------------|--------------------------|-------------------------------|---------------------------------|
| 1  | BNTB-1           | -                      | 11951.2         | 29.76                  | 30.06                    | 15507.60                      |
| 2  | BNTB-2           | -                      | 11867.3         | 29.89                  |                          |                               |
| 3  | BNTB-3           | -                      | 11734.7         | 30.54                  |                          |                               |
| 4  | BGTB-1           | -                      | 11823.1         | 35.82                  |                          |                               |
| 5  | BGTB-2           | -                      | 11921.1         | 33.20                  |                          | 27455.60                      |
| 6  | BGTB-3           | -                      | 11895.6         | 34.12                  |                          |                               |
| 7  | BNB-1            | 600°C                  | 11909.2         | 10600.9                | 9.24                     | 9.76                          | 2615.30                        |
| 8  | BNB-2            | 600°C                  | 11942.4         | 10927.5                | 11.25                    |                               |
| 9  | BNB-3            | 600°C                  | 11893.5         | 10787.4                | 8.79                     |                               |
| 10 | BGB-1            | 600°C                  | 12724.1         | 11461.9                | 11.31                    |                               |
| 11 | BGB-2            | 600°C                  | 11809.9         | 11003.5                | 10.98                    | 11.16                         | 4103.20                        |
| 12 | BGB-3            | 600°C                  | 12109.8         | 10862.7                | 11.18                    |                               |

BNTB : Normal Concrete Unburned  
BGTB : GGBFS Concrete Unburned  
BNB : Normal Concrete Burned at 600°C  
BGB : GGBFS Concrete Burned at 600°C  

**Figure 3.** Load vs deflection graph between GGBFS and normal concrete.

From the graph above shows that GGBFS concrete has more strength than normal concrete. Which is initial crack of GGBFS concrete occur at a deflection of 0.895 mm with a load of 21.01 kN. While initial crack of normal concrete occur at a deflection of 0.49 mm with a load of 8.21 kN. Furthermore, it can be seen in Table 4, that the compressive strength and modulus of elasticity of GGBFS concrete are greater, that is 34.48 MPa and 27455.60 MPa greater than normal concrete that is 30.6 MPa and 15507.60 MPa.
Figure 4. Load vs deflection graph between GGBFS and normal concrete (Burned at 600°C).

From the graph above shows that the concrete that has been burned, GGBFS concrete still has more strength than normal concrete. Which GGBFS concrete initial crack at 1,15 mm with a load of 11 kN. While normal concrete initial crack occur at a deflection of 1 mm with a load of 7,55 kN. Furthermore, it can be seen in Table 4, that the compressive strength and modulus of elasticity of GGBFS concrete are greater, namely 11,16 MPa and 4103,2 MPa greater than normal concrete which is 9,76 MPa and 2615,3 MPa.

With a further increase in temperature up to 600°C, the relative of compressive and flexural strength between GGBFS and normal concrete decrease drastically, furthermore the reduction in the strength of the concrete was significantly larger. The effect of GGBFS was not significant on the loss in mass of concrete exposed to elevated temperature, so the decrease in strength due to elevated temperature between GGBFS and normal concrete is not much different [5]. However, GGBFS concrete has a greater compressive and flexural strength than normal concrete.

4. Conclusion

With a further increase in temperature up to 600°C, the compressive strength of GGBFS concrete and normal concrete decreased drastically, by losing its strength up to 70%. By 600 C, the reduction in the compressive strength of concrete was significantly larger. The decomposition of C-S-H was considered significantly influenced the strength loss of concrete above 600°C [6].

The modulus of elasticity was calculated and compared between a normal and GGBFS concrete which it is burned and not. It is evident that the modulus of elasticity of all concrete decreased with the increase in temperature. The effect of temperature on the loss in modulus of elasticity is very pronounced, which is different from the gradual loss in mass and compressive strength [7].

Furthermore, this also affects the beam test specimen, where the initial crack and peak load in the flexural strength test of the GGBFS concrete occur at a greater load than the normal concrete [5,8].

Results of this test it can be concluded that the effect of GGBFS as a substitute for cement in concrete can affect the strength of the concrete, which the effect of GGBFS in increasing the strength of concrete increases significantly in the case that the concrete is not burned and burned.

Acknowledgment

This opportunity to express gratitude to all of the Department faculty members of Civil Engineering Politeknik Negeri Bandung for their help and support. Also thank to PT Krakatau Semen Indonesia for the GGBFS so that this research could be carried out well. Its a big grateful too to my partner who supported me through this venture.
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