Behavior of Concrete Burned with High Temperature

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Abstract. This study aims to determine the compressive strength of concrete after a fire and to determine the properties and characteristics of concrete after the fire. This study used an experimental method using cube concrete specimens and concrete quality K 175, where each of the 5 samples was treated burned and not burned. Concrete was treated by curing for 28 days. The fuel test used an electric furnace with the combustion temperature used was 1000ºC with a duration of 6 hours at the age of 35 days. Furthermore the test sample was cooled at room temperature for 24 hours. Changes that occurred in post-burn concrete include changes in the color of the concrete to gray-white, crazing, spalling, release of aggregate grains, occur shrinkage and increased porosity. The results of post-burn concrete press test also showed a decrease in compressive strength by 70%. The average percentage of post-burn shrinkage is 13.79%. The average value of post-burn porosity of concrete is 31.91%.

1. Introduction
Concrete is one of the building components that are resistant to fire. However, the behavior of concrete such as shrinkage, cracking and the value of compressive strength will be different if the concrete has been in post-combustion conditions with high temperatures, for example in a building fire situation.

In some experimental testing of reinforced concrete structures, proven fire can dramatically reduce the strength of these reinforced concrete structures [1,2]. Assessment of the behavior of concrete at high temperatures can be carried out by various tests carried out on specimens of different sizes, especially testing concrete samples which have undergone burning at high temperatures to reach 1000ºC [3]. The influence of high temperatures can affect concrete behavior, such as color changes, stress-strain relationships, compressive strength, and elastic modulus [4,5,6,7,8].

This experimental study aims to study the compressive strength of concrete and its behavior after the concrete fixes high temperatures. The study was conducted using several samples of concrete cubes at temperatures over 1000ºC, then starting with testing compressive strength. Several visual observations and measurements were made to determine the differences in concrete before it was burned or after it was burned.

2. Method
This study used an experimental method using K-175 quality concrete test samples (fc ‘= 15 MPa) in the form of cubes with a size of 15 cm x 15 cm x 15 cm by 10 pieces, each of which 5 samples was treated burned and not burned. The fuel test using an electric furnace with the combustion temperature used is 1000ºC with a duration of 6 hours at the age of 35 days. Then the test sample was cooled at room temperature for ± 24 hours. Concrete mix design used SNI 7656-2012, and compressive strength test
referred to SNI 03-1974-1990 [9]. Details of concrete test samples and mix design composition can be seen in Tables 1 and 2.

| Sample Number | Amount |
|---------------|--------|
| Without burning |     |
| No. 1         | 1     |
| No. 2         | 1     |
| No. 3         | 1     |
| No. 4         | 1     |
| No. 5         | 1     |
| No. 6         | 1     |
| No. 7         | 1     |
| With burning |     |
| No. 8         | 1     |
| No. 9         | 1     |
| No. 10        | 1     |
| Total         | 10    |

### Table 2. Mix Design Composition.

| No. | Material | Mixed Composition (kg/m³) | Mixed Composition per 50.625 L (kg) |
|-----|----------|---------------------------|-------------------------------------|
| 1   | Water    | 254.400                   | 12.879                              |
| 2   | Cement   | 332.385                   | 16.826                              |
| 3   | Sand     | 913.743                   | 46.263                              |
| 4   | Split    | 933.400                   | 47.258                              |

### 3. Results and Discussion

From the results of concrete combustion testing at a temperature of 1000ºC, after observing lighter colored post-burn concrete, namely grayish white. The color comparison between the concrete burned and not burned can be seen in Figure 1. The color change in the concrete begins to appear when the temperature is 500ºC, which is grayish-brown. This occurs because of the presence of iron salt compounds in aggregates or concrete sand, which causes the concrete to change color. If the temperature reaches 750ºC there is a carbonization process that is formed Calcium Carbonate (CaCO₃) which is whitish in color so that the color of the concrete becomes brighter [9,13,16].

There are also hair cracks/crazing and surface peeling/spalling on concrete (Figure 2). Post-combustion concrete also becomes porous (Figure 3) and very fragile, this is evidenced by the easy release of grains (Figure 4) on the concrete when touched even without being touched. Spalling is a symptom of removing part of the concrete surface in the form of a thin layer. Crazing is a symptom of crumbling on the concrete surface like the breakdown of eggshells. [17]. Basically, concrete is not expected to be able to withstand heat up to above 250ºC [18]. As a result of the heat, the concrete will crack, spall, and lose strength. Power loss occurs because of the gradual change in chemical composition of the cement paste.
Based on the testing of compressive strength, the concrete compressive strength values obtained as listed in Table 3 below are obtained. Based on the table, it can be seen that the average value of concrete compressive strength in the sample that was not burned was 211.20 kg/cm². While the average value of concrete compressive strength in the sample burned was 63.29 kg/cm². The remaining percentage of compressive strength = 63.29 / 211.20 x 100% = 29.97% ≈ 30%, while the percentage loss of compressive strength = 100% - 30% = 70%. The occurrence of high temperature changes, such as those that occur during a fire event, will affect the structural elements. Because in this process there will be an alternating cycle of heating and cooling, which will cause complex physical and chemical phase changes, this will affect the quality/strength of the concrete structure and will cause the concrete to become brittle [15]. The decrease in compressive strength is caused by the hydrated cement paste decomposes Ca (OH)₂ → CaO + H₂O. CaO (lime) which is hygroscopic (absorbs water), while H₂O begins to evaporate at a temperature of 100°C due to heat causing concrete dry and brittle [9,10,13,16] (see Figures 3 and 4).
In this study, after the concrete was burned to a temperature of 1000ºC for 6 hours, it was proven that the concrete became very dry, the concrete also became very fragile and easily destroyed and could even be broken by hand and the release of grain on the outer parts of the concrete. Cement and water are the most important things as concrete adhesives and reinforcement [9, 10]. When concrete is burned at high temperatures, evaporation of water occurs, resulting in cement that has reacted with (hydrated) water to decompose into free lime which loses its strength altogether. This is what causes a significant reduction in compressive strength in the burned concrete. In this test, there is a shrinkage of dimensions and a reduction in the mass of concrete when compared to the concrete before being burned. From the table, it can be seen that the average shrinkage of each specimen is 13.7%.

Porosity is the ratio of pore volume (volume occupied by fluid) to the total volume of concrete (volume of the test object). Evaporation in the combustion process causes water that has filled the concrete parts to evaporate out so that empty spaces occur in the concrete. In addition, the pores in the concrete are also caused by the insistence of the deepest part of the concrete during evaporation, causing larger gaps such as hair cracks. The higher the combustion temperature, the greater the porosity of the concrete, this results in porous concrete. This is because H₂O contained in the concrete evaporates. Water molecules that will migrate (migration) are blocked, then friction occurs with the concrete pores as a result of micro-cracks, so that the porosity of the concrete increases. With increasing porosity the
compressive strength of the concrete drops and causes damage to the concrete structure [18,19]. The amount of porosity that occurs can be seen in Tables 3-5.

**Table 3. Value of Compressive Strength of Concrete Test Sample.**

| Sample Number | Pressure (kg/cm²) | Average (kg/cm²) |
|---------------|------------------|------------------|
| 1             | 222.67           |                  |
| 2             | 208.89           |                  |
| 3             | 208.89           | 211.20           |
| 4             | 215.56           |                  |
| 5             | 200.00           |                  |
| 6             | 57.78            |                  |
| 7             | 63.11            |                  |
| 8             | 60.00            | 63.29            |
| 9             | 75.56            |                  |
| 10            | 60.00            |                  |

**Table 4. Percentage of Post-burn Concrete Shrinkage.**

| Sample | Dimension (mm) | Pre-Burn (gr) | Post-Burn (gr) | Difference (gram) | Shrinkage (%) |
|--------|----------------|---------------|----------------|-------------------|---------------|
| 6      | p 152.00 l 152.80 t 152.40 | 7835          | 6730           | 1105              | 14.10         |
| 7      | p 151.10 l 154.00 t 152.20 | 7868          | 6781           | 1087              | 13.82         |
| 8      | p 153.35 l 152.00 t 152.00 | 7870          | 6788           | 1082              | 13.75         |
| 9      | p 152.00 l 153.30 t 150.80 | 7705          | 6663           | 1042              | 13.52         |
| 10     | p 150.60 l 153.50 t 150.90 | 7758          | 6689           | 1069              | 13.78         |

**Table 5. Percentage of Post-burn Concrete Porosity Value.**

| Sample | Mass | Porosity (%) |
|--------|------|--------------|
| 6      | Early 7835 | 32.74       |
|         | End  6730 |              |
| 7      | Early 7868 | 32.21       |
|         | End  6781 |              |
| 8      | Early 7870 | 32.06       |
|         | End  6788 |              |
| 9      | Early 7705 | 30.87       |
|         | End  6663 |              |
| 10     | Early 7758 | 31.67       |
|         | End  6689 |              |
4. Conclusion
Based on the testing of the K-175 quality concrete sample (fc' = 15 Mpa) in the form of a cube which was burned at a temperature of 1000°C for 6 hours it can be concluded that fire causes physical changes in concrete such as discoloration into grayish-white, crazing, spalling, brittle concrete, aggregate granules more easily released, concrete shrinkage (13.79%) and increased porosity (31.91%), which ultimately causes a decrease in compressive strength (70%). Concrete buildings that have been burned at high temperatures are not recommended for reuse.

Acknowledgement
Acknowledgments are given to Anes who helped complete this research responsibly. Hopefully, similar research on fires can be continued in future studies.

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