Analysis of Post-Combustion Concrete Study with The Addition of Superplasticizer

Rahmi Karolina*1, Deni Malik1

1Department of Civil Engineering, Universitas Sumatera Utara, Medan, Indonesia

*Email : rahmi.karolina@usu.ac.id

Abstract. This research explains that the use of superplasticizer admixture as an additional material in concrete mixes is expected to minimize concrete damage due to burning at high temperatures by increasing the quality of concrete in its mechanical properties which is compressive strength and physical properties which is concrete porosity. The variations in the addition of superplasticizer admixture used are 1%; 1.5%; and 2%, while variations in concrete combustion are 200ºC; 500ºC; and 800ºC. The test results show a decrease in compressive strength and increase in concrete porosity due to combustion at high temperatures. The tendency of concrete compressive strength will decrease along with the increasing temperature. At the temperature of 200ºC, a decrease of 7.14%; 40.57%; and 65.71% occurs, at the 500 ºC, decreased by 2.74%; 15.07%; and 65.75%, while at 800ºC decreased by 13.79%; 14.47%; and 53.95% of the initial strength of concrete without combustion. The porosity of concrete will rise along with the increasing temperature and the percentage increase will be greater along with the combustion temperature. At the temperature of 200ºC there is an increase in porosity of 7.41% - 11,853%, at 500ºC increased by 13,334% - 17,779%, and at 800ºC increased by 19.26% - 23.704%, from normal concrete porosity.

1. Introduction

Fires can cause damage to building structures, including concrete structures. When burning, concrete cannot produce fire but can absorb heat so that there will be excessive high temperatures which will result in changes in the concrete microstructure. At a certain temperature limit, heating will cause the stability of cement gel bonds in the concrete to be lost, expansion of gravel (aggregate), the release of cement bonds and expansion in granules, this will cause a decrease in the stability of the concrete unit itself so that the concrete strength drops. Changes or damage caused by fire are influenced by the height of the temperature, duration of combustion, type of materials forming the concrete mixture, and loading behavior.

The main problem faced in handling buildings after a fire is how to assess the strength of the rest of the building after a fire. Knowing the strength of the rest, we can make the most efficient remedial action to restore its original condition so that buildings that have experienced fires can be re-functioned. To date, buildings that have undergone fire are immediately demolished, even though there is a possibility that the burnt structural elements still have strength. Based on the description above, it is necessary to do research to find out the relation between the increase in temperature height, combustion time, and type of concrete-forming materials against the changes in the properties and characteristics of concrete due to fire on building structural elements so the residual strength can be identified from concrete material. Thus, it can be determined whether or not the structure of the building will be used again.

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd
2. Literature review
Concrete is a composite material (mixture) of several rock materials which are bonded by binding material. Concrete is formed from a mixture of aggregates (coarse and fine), cement, water with a certain ratio and can be added with certain mixtures if deemed necessary. Water and cement material are put together to form a cement paste which functions as a binding material while fine aggregate and coarse aggregate are as fillers. The strength, durability, and other properties of concrete depend on the nature of the basic ingredients, the comparison value of the ingredients, the method of stirring and how to work during pouring the concrete, the method of compaction, and the method of treatment during the hardening process (Gideon, 1993).

According to Tjokrodimumuljo (2000) basically concrete is not expected to be able to withstand heat above 250°C. Concrete that is heated to more than 800°C will experience degradation in the form of a significant reduction in strength which may not return (recovery) after the cooling process. The high loss of strength and whether or not the strength of the material returns to its original state is determined by the type of materials used, the severity of the fire process, and the length of combustion. The high level of severity (temperature) and the length of combustion time causes a reduction in the compressive strength of concrete material especially the emergence of internal shear stress as a result of differences in thermal properties between cement and aggregate.

2.1. Effect of high temperatures on concrete
The increase in temperature due to fire causes the concrete material to change its properties. The temperature that can be achieved in a burning building room is ± 1000°C with a fire duration generally more than 1 hour. Most structural concrete can be classified into three types of aggregates, which are carbonate, silicate, and light-weight concrete. Carbonate aggregates include limestone and dolomite and are included in one group because these two substances undergo changes in chemical composition at temperatures between 700°C to 980°C. Silicate aggregates which include granite, quartzite and sandstone do not experience chemical changes at temperatures commonly encountered in fires (Norman Ray, 2009).

A phenomenon that can be seen in concrete exposed to extreme heat (fire) is the occurrence of sloughing off (peeling), hair cracks and wide cracks, and the color of concrete. From visual observations, the temperature experienced by concrete can be estimated. (Nugraha, P., 2007) is set 17 point Times Bold, flush left, unjustified. The first letter of the title should be capitalized with the rest in lower case. It should not be indented. Leave 28 mm of space above the title and 10 mm after the title.

3. Methodology
The method used in this research is an experimental study which generally includes:

1. Provision of concrete constituent materials.
2. Examination of materials.
3. Mix Design.
4. Making of samples.
5. Examination of slump value.
6. Concrete compressive strength test at 28 days curing.
7. Concrete porosity test at 28 days curing.
8. Concrete combustion test at 28 days curing.
3.1. Making of samples
The making of samples consist of four mixture variations for the trial, which is the normal mixture without substitute materials and the mixture with the addition of superplasticizer admixture by 1%; 1.5%; and 2% of cement use.

3.2. Concrete mixture planning
Concrete mixture planning is intended to determine the composition or proportion of concrete constituent materials. The proportion of the constituent materials of this concrete is determined through mix design. This is done so that the proportion of the mixture can meet the technical requirements economically. In determining the proportion of mixtures in this research, the method of the Department of Public Works is used which is based on SK SNI T-15-1990-03.
The basic criteria for concrete design by using the Department of Public Works method is compressive strength and the relation with cement water factor. The complete mix design calculation can be seen in the attachment. From the results of the mix design calculation, the comparison of the concrete mixture between cement: sand: gravel: water = 1.00: 1.85: 2.83: 0.53.

3.3. Concrete combustion process
In this research, the combustion test of the concrete mixture is carried out with the addition of 1%; 1.5%; and 2% superplasticizer admixture compared to normal concrete. The combustion test, using a furnace machine, is carried out at the Mechanical Engineering Growth Centre Kopertis Laboratory of Region I Aceh-North Sumatra.

4. Results and discussion
4.1. Concrete compressive strength test
Concrete compressive strength test is done by using a Compressor Machine. The compressive strength of concrete can be obtained using a formula. Data from the test results of the concrete compressive strength with the addition of superplasticizer admixture for each combustion temperature are as follows:

| Sample             | Compressive Load (ton) | Compressive Strength (kg/cm²) |
|--------------------|------------------------|-------------------------------|
| 1% admixture concrete | 70                     | 311,111                       |
| 1.5% admixture concrete | 73                     | 324,444                       |
| 2% admixture concrete | 87                     | 386,667                       |

Table 1 shows the compressive load data obtained from the test results for concrete with the addition of 1%; 1.5%; and 2% superplasticizer admixture without combustion respectively, which are 70 tons, 73 tons and 87 tons. The three data show that the addition of superplasticizer admixture to the concrete mixture could increase the concrete compressive load.

Figure 2 shows the compressive load and compressive strength data for concrete with the addition of 1% superplasticizer admixture with combustion at temperatures of 200°C, 500°C, and 800°C, indicating that the increased maximum compressive load temperature that can be borne by concrete decreases its strength. This means that the concrete is getting weaker and the compressive strength of concrete has decreased by 7.14%, 40.57%; and 65.71% of the initial strength of concrete.

![Figure 2. Graph of 1% post-combustion admixture concrete compressive strength to the temperature](image-url)
Figure 3 shows the compressive load and compressive strength data for concrete with the addition of 1.5% superplasticizer admixture with combustion at temperatures of 200°C, 500°C, and 800°C, indicating that the increased maximum compressive load temperature that can be borne by concrete decreases its strength. This means that the concrete is getting weaker and the compressive strength of concrete has decreased by 2.74%; 15.07%; and 65.75% of the initial strength of concrete.

![Graph of 1.5% post-combustion admixture concrete compressive strength to the temperature](image)

**Figure 3.** Graph of 1.5% post-combustion admixture concrete compressive strength to the temperature

Figure 4 shows the compressive load and compressive strength data for concrete with the addition of 2% superplasticizer admixture with combustion at temperatures of 200°C, 500°C, and 800°C, indicating that the increased maximum compressive load temperature that can be borne by concrete decreases its strength. This means that the concrete is getting weaker and the concrete compressive strength has decreased by 13.79%; 14.47%; and 53.95% of the initial strength of concrete.

![Graph of 2% post-combustion admixture concrete compressive strength to the temperature](image)

**Figure 4.** Graph of 2% post-combustion admixture concrete compressive strength to the temperature

**Table 2.** Data summary of post-combustion concrete compressive strength with addition superplasticizer admixture

| Temperature (°C) | 1% admixture concrete | 1.5% admixture concrete | 2% admixture concrete |
|------------------|------------------------|-------------------------|-----------------------|
| 27               | 311,111                | 324,444                 | 386,667               |
| 200              | 288,889                | 315,556                 | 333,333               |
| 500              | 184,889                | 275,556                 | 297,778               |
| 800              | 106,667                | 111,111                 | 155,556               |
Table 2 is a summary of the data between the increase in temperature and the compressive strength of concrete with each addition of superplasticizer admixture by 1%; 1.5%; and 2%. The table shows the tendency that the compressive strength of concrete will decrease along with the increasing temperature. At a temperature of 200 °C decreased by of 7.14%; 40.57%; and 65.71%, at 500 °C decreased by 2.74%; 15.07%; and 65.75%, at 800 °C decreased by 13.79%; 14.47%; and 53.95% of the initial strength of concrete without combustion.

From Figure 5, it can be seen that the higher the temperature, the lower the compressive strength of the concrete. When the temperature is at 500°C with the addition of 1% superplasticizer admixture, the resulting compressive strength is 184.889 kg / cm², for the addition of 1.5% superplasticizer admixture, the compressive strength of the concrete is 275.556 kg / cm², and the addition of 2% superplasticizer admixture, the resulting compressive strength is 231.111 kg / cm². This result shows that the more concrete added with superplasticizer admixture, it will have a relatively high compressive strength. This happens because the concrete added by superplasticizer admixture has enough water to resist combustion heat even though water use is reduced by 10%-15% from the use of water in the making of normal concrete.

Water absorbed in the aggregate begins to evaporate, evaporation causes shrinkage of the cement paste. When the temperature is at 500°C to 800°C, a significant decrease of the compressive strength occurs, when the temperature of 800 °C for concrete with the addition of 1% superplasticizer admixture, the resulting compressive strength is 106.667 kg / cm², for the addition of 1.5% superplasticizer admixture, the compressive strength is 111.111 kg / cm², and for the addition of 2% superplasticizer admixture, the compressive strength is 155.556 kg / cm².

This decrease in compressive strength is caused by the cement paste which has been hydrated, decomposes \( \text{Ca (OH)}_2 \rightarrow \text{CaO} + \text{H}_2\text{O} \). CaO (lime) which is hygroscopic (absorbs water), while H\(_2\)O starts to evaporate at 100°C, causing dry and brittle concrete (Febrina, F., 2010).

In this case, it can be seen that the higher the combustion temperature, the lower the compressive strength of the concrete. When compared, the compressive strength value of the addition of superplasticizer admixture as much as 1%; 1.5%; and 2%, the resulting compressive strength of...
concrete decreases. For temperatures of 200 °C, the decrease can reach 2.74% - 13.79%, for 500 °C, it reaches 14.47% - 40.57%, for 800 °C, it reaches 53.95% - 65.75%, where at 800 °C with an additional admixture of at least 1%, it appears that the physical surface of the concrete has been peeled off and the inner structure is very fragile.

Lime from the combustion when added to water will expand and crack. Cement and water function as an adhesive and reinforce concrete. During the hydration process, the two most important components of the cement granules, C_2S and C_3S, react with H_2O and produce CSH and (CaOH)_2. C-S-H functions as a determinant substance of concrete hardness and aggregate binder. The hydration process is a process where the chemical composition of CaO cement is abbreviated C, SiO_2 is abbreviated S, Al_2O_3 is increased A, Fe_2O_3 is abbreviated F, reacts with water H_2O abbreviated (H).

The effect of this hydration process is then to make micro and nano-sized crystals called gels and Ca (OH) 2 which will continue to grow to fill the crystal cavities where the cavities contain water and grow into solid crystals as time goes by, stodging into crystal spaces that are still empty.

The decrease in compressive strength is due to the elements decomposition of of C-S-H (Calcium Silica Hydrate) which decomposes into free lime CaO and SiO_2 which have no power at all. C-S-H is the main element that supports the strength of concrete, so a great reduction in C-S-H will greatly reduce the strength of concrete. When the temperature is raised to reach 800 °C, there is a carbonization process which is the formation of Calcium Carbonat (CaCO_3), whitish in color so that it changes the color of the concrete surface to become brighter. Besides, at this temperature, there is a drastic decrease in the attachment between rocks and cement paste characterized by cracks and fragility of concrete (concrete can be easily broken down by hand).

4.2. Concrete porosity test
Concrete porosity test is carried out using scales. Each concrete is weighed before and after experiencing the combustion process. The porosity of the concrete can be obtained by using a formula for concrete porosity.

| Sample | Temperature (°C) | Porosity (%) |
|--------|-----------------|--------------|
| 1      | 27              | 5,925        |
| 2      | 200             | 17,778       |
| 3      | 500             | 23,704       |
| 4      | 800             | 29,629       |

Table 3 shows the average porosity data from the samples for concrete with combustion temperatures of 200 °C, 500 °C, and 800 °C with the addition of 1% superplasticizer admixture. It is seen that the higher the temperature, the porosity of the concrete load increases. This means that the concrete mass is reduced and the concrete is more fragile and porous. This resulted in the compressive strength of the concrete decreasing.

| Sample | Temperature (°C) | Porosity (%) |
|--------|-----------------|--------------|
| 1      | 27              | 2,962        |
| 2      | 200             | 16,296       |
| 3      | 500             | 22,222       |
| 4      | 800             | 28,148       |

Table 4 shows the average porosity data from the samples for concrete with combustion temperatures
of 200 °C, 500 °C, and 800 °C with the addition of 1.5% superplasticizer admixture. It is seen that the higher the temperature, the porosity of the concrete load increases. This means that the concrete mass is reduced and the concrete is more fragile and porous. This resulted in the compressive strength of the concrete decreasing.

**Table 5. Post-combustion concrete porosity data with the addition of 2% superplasticizer admixture**

| Sample | Temperature (°C) | Porosity (%) |
|--------|------------------|--------------|
| 1      | 27               | 2.962        |
| 2      | 200              | 13.333       |
| 3      | 500              | 19.259       |
| 4      | 800              | 25.185       |

Table 5 shows the average porosity data from the samples for concrete with combustion temperatures of 200 °C, 500 °C, and 800 °C with the addition of 2% superplasticizer admixture. It is seen that the higher the temperature, the porosity of the concrete load increases. This means that the concrete mass is reduced and the concrete is more fragile and porous. This resulted in the compressive strength of the concrete decreasing.

Figure 6 is a data summary between the increase in temperature and the porosity of the concrete with each addition of superplasticizer admixture by 1%; 1.5%; and 2%. The graph shows the tendency that the porosity of the concrete will rise along with the increase in temperature and the percentage increase will be greater along with the combustion temperature, at a temperature of 200 °C there is an increase in porosity of 7.41% - 11.853%, at 500 °C increasing to 13.334% - 17.779%, and at 800 °C increasing to 19.26% - 23.704%, from normal concrete porosity.

From the tests results above, it can be seen that the higher the combustion temperature, the greater the porosity of the concrete. This causes the concrete to become porous. This can be proven in Figure 6 where an increase in combustion temperature causes the number of concrete porosity to increase.

In the addition of superplasticizer admixture on post-combustion concrete, this is due to the fact that (H₂O) contained in the concrete will mostly evaporate. This condition is caused by the burnt concrete that will evaporate free water in large capillary pores, then followed by water in the gel pores.
that are smaller in size but more tightly bound by friction. The water molecules that will come out (migration) are blocked, then friction occurs with the pores of the concrete resulting micro cracks, so that the porosity of the concrete increases.

With increasing porosity, the compressive strength of the concrete will decrease and cause damage to the concrete structure. This is what to be overcome in the reason of adding superplasticizer admixture. With the addition of this type of admixture in the process of mixing fresh concrete allowing the concrete to be denser so that the density of concrete increases, indicating that the capillary pores in the concrete are so small that the porosity of the concrete due to combustion can be reduced which causes the concrete to still have sufficient residual strength. With the knowledge of residual strength, we can make the most efficient remedial measures to restore the condition to its original condition so that buildings that have experienced fires can be re-functioned. To date, buildings that have undergone fire are immediately crushed/destroyed (demolished action), even though the structural elements of the burnt building structure may still have strength.

4.3. Color and visual condition observation of concrete

| Temperature (°C) | Result of Visual Observation | Color of Concrete |
|------------------|-----------------------------|-------------------|
| 200              | Normal                      | Normal            |
| 500              | Cracking                    | Grayish-brown     |
| 800              | Crazing                     | Grayish-white     |

The first step in estimating the temperature experienced by concrete can be done through visual observation. The color of burnt concrete can indicate the level of fire, as presented in Table 4.6. The table shows the result of observing the difference in concrete color and the condition of the concrete surface after being burned. The color of the concrete that starts to brown to white indicates that the fire is quite severe. Aggregate or sand contains several iron compounds. Iron compounds produce cream, yellow, red, black and brown colors. Liconite is a very common iron compound that produces cream, yellow and brown. While hematite will give a red color. Silica iron compounds give a green color, mangaan compounds produce brown and carbon compounds give blue, gray, green or brown. The discoloration of the concrete begin to appear when the temperature is at 500 °C, which is grayish-brown in color. 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 800 °C, there is a carbonization process, which Calcium Carbonate (CaCO3) is formed that whitish in color so it changes the color of the concrete to become brighter. High temperatures in the concrete structure cause the concrete to experience fragility, and the visual signs that occur on the concrete are:

1. Discoloration of concrete
2. Transformation of concrete, such as:
   - Peeled off
   - Broken
   - Pore appearance

5. Conclusions
From the research data obtained and analysis of the data that has been done, it can be concluded that:

1. Fire phenomena in concrete structures will cause structural changes, including: cracks, damage / collapse, and changes in the color of the concrete surface. The color of the concrete will change along with the increasing temperature. The color change is caused by aggregates or sand which contains several iron compounds which can also cause corrosion.
2. Concrete will experience a decrease in strength along with the rising temperatures. In this case, it can be stated that temperature is very important in determining the mechanical properties of concrete.

3. The addition of superplasticizer admixture to the concrete mixture with 1% ; 1.5%; and 2% substitution of cement use can increase compressive strength and minimize damage to concrete after fire. This is because concrete with the addition of admixture has enough water to resist combustion heat even though the use of water is reduced by 10% -15% from the use of water in the manufacture of normal concrete.

4. The higher the combustion temperature, the greater the porosity of the concrete.

5. The addition of superplasticizer admixture to the concrete mixture with 1% ; 1.5%; and 2% substitution of cement use can reduce porosity in post-combustion concrete. Concrete compressive strength is inversely proportional to porosity. The smaller the porosity of the concrete, the greater the value of concrete compressive strength, this is because water (H2O) contained in the concrete will mostly evaporate. Increased porosity causes the compressive strength of the concrete to drop and cause damage to the concrete structure.

6. Suggestions
Some suggestions for further research are as follows:

1. It is expected that the next researcher can test the mechanical properties or physical properties of other post-combustion concrete such as: elasticity, tensile strength, or other post-combustion concrete properties that have never been studied before.

2. The next researcher is expected when testing porosity can measure samples after combustion to determine the impact of combustion on concrete porosity.

3. Tests for reinforced concrete can be carried out that focusing on reinforcement test.

4. The next researcher can test the mechanical or physical properties for other concrete qualities.

The next researcher conducts validation by examining the duration and temperature variations that have not been studied before. Should be avoided whenever possible. If required they should be used only for brief notes that do not fit conveniently into the text.

7. Reference

[1] ASTM, Annual Books of ASTM Standards, 1991. *Concretes and Aggregates*, Vol.04.02 Construction, Philadelphia-USA: ASTM,1991,PA19103-1187.

[2] Sutapa, Dede A A, 2011 Porositas, Kuat Tekan dan Kuat Tarik Belah Beton dengan Agregat Kasar Batu Pecah Pasca Dibakar, *Jurnal Ilmiah Teknik Sipil* 15 (1) Universitas Udayana-Denpasar.

[3] Bayuasri, Trisni, Indarto H., & Antonius 2006 Perubahan Perilaku Mekanis Beton Akibat Temperatur Tinggi, *Jurnal PILAR* 15 (2), Universitas Diponegoro-Semarang.

[4] Pujianto A, Putro Y S, Retno T and Ariska O 2006 *Beton Mutu Tinggi dengan Admixture Superplasticizer dan Aditif Silicafume*, Jurnal Teknik Sipil, Universitas Muhammadiyah Yogyakarta-Yogyakarta.

[5] Mulyono T, 2003, *Teknologi Beton*, Penerbit Andi, Yogyakarta.

[6] Murdock L J, and Brook K M 1986, *Bahan dan Praktek Beton*, Penerbit: Erlangga, Jakarta.

[7] Nugraha P and Antoni, 2007, *Teknologi Beton*, Penerbit Andi, Yogyakarta.

[8] Sagel R, Kole P, and Gideon K, 1993, *Pedoman Pengerjaan Beton*, Penerbit: Erlangga, Jakarta.