Thermal behavior of Concrete subjected to elevated temperature: Case Studies

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Abstract. Fire presents a significant danger to the survival of the building and inhabitants, adverse effects at the structural level. In view of this, several researchers have measured the fire efficiency and behavioural characteristics of concrete under varying temperatures. Using indirect measures such, water permeability, as chloride ion permeability absorption and sorptivity, the resilience of concrete after fire exposure is assessed. In most previous literature, residual mechanical properties mentioned may be overvalued, where cooling was typically employed. Proper assessment of concrete fire resistance requires more experimental data found under different cooling environments, such as water spraying or water quenching. Design considerations and analytical methods are provided to determine the reaction of reinforced concrete structures to elevated-temperature settings. Related studies in which reinforced concrete structural components have being exposed to cyclic loading. The purpose of this review is to provide a description of the elevated temperature characteristics of the performance of concrete ingredients and structures. The impacts of high temperatures on high-strength concrete materials are observed and their quality is compared to standard concrete strength.

1. Introduction
In seeking a more rational approach with concrete of different types of aggregate subjected to sustained elevated temperatures show a variation in compressive strength. After the levels of the temperature are increased for the same continued duration, will vary in its compressive strength to a large extent. The properties and the strength characteristics of recycled aggregate concrete were deficient when related to the specimens that were by the natural aggregate[1]. Kaveh reported similar findings at 200°C, which deteriorate rapidly because of removal of a substantial amount of water of crystallization and transformation of quartz, which is accompanied by a sudden expansion of the material[2]. Differences between the data on normal dense concrete are primarily due to differences in the experimental techniques and to some level to, a different quality of material used[3][4]. Aggregates may also depreciate at this temperature level. Then some aggregates can be deteriorated even at lower temperature levels. For
example, quartz expansion has occurred at a higher rate of about 300°C [5][6]. Experiments were conducted by heating a specimen to high temperatures without loading, stabilizing the temperature and applying a load until failure occurred. Tang stated that there are variations in the thermal and mechanical properties of materials due to degradation due to elevated temperatures: it suggested that the form of aggregate used [7] is one of the important factors influencing concrete strength when heated. The strength was found to decrease as the humidity content amplified [8][9]. Sheng conveyed that differences in the thermal and mechanical characteristics of materials ensuing to degradation due to high temperatures: water loss in concrete, mineralogical transformations and internal micro rapid [10]. Findings were published at 150 °C[11]. Abbas has also shown that when the concrete is dry, the compression failure mode is brittle, but ductile when wet. Free moisture in concrete can cause the strength to deteriorate significantly[12]. Concrete that has been heated at a temperature below 500 °C can hydrate and gradually recover much of its power, according to research by Yang. Experiments show that strength has recovered to more than 90% of the strength prior to heating after around one year[11].

Yaragal Silica aggregate concrete has been shown to have greater compressive strength compared to the same concrete with a high alumina content [13]. The influence of loading and cement to the aggregate ratio on the compressive strength for concrete made with Portland cement, and fine aggregate consisting of flint shows that the loss of compressive strength is slower for the concrete with higher aggregate content and loading of the specimen during heating[14]. The differences in compressive strength between specimens that were tested in a heated state (without loading during the heating) and other tested after slow cooling down to 20°C. It shows that the strength of cooled concrete is less than that of hot concrete[15][16]. The concrete was made with Portland cement and with aggregate consisting of while Jura limestone, basalt, Rhine sand and crushed clinker. It illustrate that the aggregate has a important consequence on the variation of the compressive strength with temperature, especially temperature below 500°C[17].

2. Mixture proportioning

Recycled aggregate concrete has shown a decrease in the enduring compressive strength up to 20% for the entire range of temperature and exposure. Hence, it is not recommended to use recycled aggregate concrete for structures which are visible to sustained higher temperatures[18]. The concrete with 20% replacement of magnesite has shown a steady increase in the residual compressive strength up to 10 to 15%. Thus, plain concrete with a partial replacement of magnesite aggregate is suitable for structures subjected to elevated temperatures for a prolonged duration. The comparison of the different types of aggregates has shown that concrete with vermiculite, low strength aggregate and partial replacement with magnesite aggregate has better resistance to sustained elevated temperature[19].

![Figure 1. Impact of temperature on the compressive strength of binary and ternary HPSCC mixtures (Data From[20]).](image-url)
Test results showed a linear decline in intensity with an upsurge in temperature of about 60 percent at 400 °C. With approximately 80 percent loss compared to standard Portland cement concrete maintaining approximately 50 percent at 200 °C[21], Pumicite concrete had less strength reduction. The concrete was manufactured with Portland cement and with Jura limestone, basalt, Rhine sand and crushed clinker aggregate. It illustrates that the aggregate has a significant effect on the temperature change in the compressive power, especially at temperatures below 500 °C. It has been detected that the decrease in compressive strength of concrete is greater for any specific heating duration, the higher the concrete grade [22]. The lasting compressive and tensile strengths for high-strength concrete with cement mix after heating to 800 °C with ordinary Portland cement were 44 percent [23][24]. In the 100 °C to 300 °C range, HSC showed a 15 percent to 20 percent loss of compressive strength, while NSC showed no such loss of strength [25]. The compressive strength of concrete has been observed to increase by up to a maximum of 4 percent at 100°C over a 6-hour exposure period relative to that at room temperature. At 300 °C for 6 hours of exposure, the compressive intensity decreases by 22 per cent. HSC loses at 400 °C a large quantity of its compressive strength and at 800 °C achieves a strength damage of around 75 percent. The change in intensity in the 100-400 °C temperature range is marginal [26]. The studies were primarily focused on concrete strength, which is commonly defined as standard strength concrete (SSC).

3. Test procedure and instrumentation
Gai carried out tests using a cylindrical specimen, which has 5cm diameter and 10cm height. The specimens were heated gradually in an electric furnace (rate of temperature rise 1.5°C/minute). Test results showed a linear decrease in intensity with an increase in temperature of about 60 percent at 400 °C [27]. Different nations and codes have built time-temperature curves to assess the fire endurance of concrete structural elements based on temperature history [28][29]. It has been recorded that when exposed for 4 hours and 40 percent when exposed to 300 °C for 6 hours for M15 concrete, both plain and reinforced [30], the decrease in concrete strength is around 28 percent.

The influence of loading and cement to the aggregate ratio on the compressive strength for concrete made with Portland cement, and fine aggregate consisting of flint shows that the loss of compressive strength is slower for the concrete with higher aggregate content and loading of the specimen during heating [30]. The differences in compressive strength between specimens that were tested in a heated state (without loading during the heating) and other tested after slow cooling down to 200°C. It shows that the strength of cooled concrete is less than that of hot concrete [31]. The plain concrete will have a reduction in residual strength up to 30% for a duration of exposure 6 hours at 300°C.

4. Time-Temperature Curves
The experiments were conducted by heating a specimen to high temperatures without loading, stabilizing the temperature and applying a load until failure occurred. Due to degradation due to elevated temperatures, variations in the thermal and mechanical properties of materials are reported: water loss in concrete, mineralogical transformations and internal micro cracking [32][33]. Between 100 °C and 200 °C [34], the initial effects of a slow increase in concrete temperature may occur. Tests performed at CBRI up to an exposure temperature of about 400 °C, then the strength dramatically decreases and decreases to 25 to 30 per cent of the initial strength [35]. At these temperature levels, evaporation of free moisture occurs. The reduction in intensity is in the range of 15-40 percent at 300 °C. Compressive strength at 550 °C reduction m will range from 55-70% of its original value. After the 400 °C to 500 °C exposure temperature [36]calcium hydroxide dehydration took place. At these temperature levels, evaporation of free moisture occurs. The reduction in intensity is in the range of 15-40 percent at 300 °C. Compressive strength at 500 °C reduction m will range from 55-70% of its original value. After the 400 °C to 500 °C exposure temperature, calcium hydroxide dehydration took place. At this temperature stage, aggregates might also deteriorate. But, even at lower temperature levels, some aggregates will deteriorate. For example, at a higher rate of about 300 °C [37], quartz expansion...
occurs. High exposure to temperature led to a decline in both ordinary concrete and high-performance concrete strength. After 500 °C, the loss of compressive strength was important. The tensile strength losses were greater from 22 °C to 500 °C than those of compressive strength [38]. In most experimental projects, these curves are followed in order to compare the outcomes of experimental programmes at various locations in the same country or with different methods of the Three Fire Test[39].

In addition, experiments on the effects of both NSC and HSC and other forms of concrete subjected to elevated temperatures are examined and the disparity in their structural properties is contrasted with the literature available[40]. Emmanuel has stated that concrete heated to a temperature below 500 °C rehydrates during cooling and gradually recovers most of its strength[41]. In several nations, research has been performed on recycled aggregates. At temperatures above 200 °C [42], the decrease in residual strength is relatively linear. The leading studies carried out in concrete under elevated temperatures are shown in Table 1.

| Authors                     | Year | Citations |
|-----------------------------|------|-----------|
| K. H. Tan, Y. Yao           | 2004 | 56        |
| M Z Jumaat et.al.,          | 2015 | 21        |
| Mohamad J. Terro et.al.,    | 2016 | 17        |
| Hu et.al.,                  |      | 15        |
| Subhash C. Y. et.al.,       | 2010 | 9         |
| Borvorn et.al.              | 2016 | 6         |

5. Residual compressive strength

Microstructural properties of the concrete and hydration of cement paste contributes to the strength properties of concrete [43][44]. Gen indicated that one of the important factors affecting concrete strength when heated was the type of aggregate used and discovered that the strength decreased with an increase in moisture content [45][48]. Pumice concrete had less strength reduction, with approximately 80 per cent loss compared to regular Portland cement concrete retaining approximately 50 per cent at 200 °C. It showed that silica aggregate concrete, relative to the high alumina content of the same concrete, has a higher compressive strength [49].

The concrete with vermiculite aggregate has shown a better resistance to elevated temperature up to 200 °C for 4 hours of exposure and retains the strength at room temperature and more to the extent of 18%[46]. The concrete with vermiculite aggregate can be used for non-load bearing structures where it is exposed to an elevated temperature of 200°C up to 4 hours of exposure. The high strength aggregate concrete has shown a drastic reduction in residual compressive strength for all the levels of temperature from 100°C to 300°C and duration of exposure from 2 to 6 hours[47]. The Residual Compressive Strength is has been observed that at 100°C for the duration of 2 to 4 hours, there is an increase in residual compressive strength (85.91% to 98.77%), and then residual compressive strength decreases at 6 hours (93.36%)[48][49]. At temperature beyond 400°C the percentage drop in strength is sharp. The Residual Strength Index (RSI) is the ratio of the strength after firing to the strength before fire[50].
The specimens were exposed to 200°C, there is an increase in residual compressive strength up to 4 hours (82.16% to 90.87%), and then the residual compressive strength decreases beyond 4 hrs (79.66%). When the specimens were exposed to 500°C, for the duration of 2 to 6 hrs, there is a reduction in compressive strength as the duration increases. It has been observed that residual compressive strength varies from 85.49% to 69.30%[51][52]. The concrete surface exposed to fire may lose its compressive strength at 1200°C [53]. Concrete with low strength aggregate has shown a steady increase in the residual compressive strength from 20 to 30% on an average for all levels of temperature from 100° to 500°C and duration of exposure 2 to 6 hrs. Thus, the concrete with low strength aggregates may be recommended for concrete perceptible to an elevated temperature for a longer duration.

6. Conclusion
The following findings were drawn on the experimental investigations performed on concrete undergoing sustained elevated temperature with various forms of aggregate. When both the temperature and exposure time are raised, there is a decline in residual compressive strength in plain concrete. In buildings that would be exposed to elevated temperatures for a longer time, concrete with a high strength aggregate can be avoided. Owing to the removal of a large amount of water from crystallization and quartz conversion, which is followed by a sudden expansion of the material, all concretes deteriorate quickly at temperatures above 500 °C. Concrete undergoes substantial changes due to elevated temperature resulting in changes in structural properties such as compressive strength, tensile strength, flexural strength, etc. These findings are made based on literature review with regard to curves of time temperature. It also shows factors such as the W / C ratio, aggregate forms, specimen age, heating intensity, heating length, load during exposure temperature and specimen cooling. The strength of concrete at high temperatures is determined by the cement mix and moisture content.

It was also found that studies were performed based on time-temperature curves for concrete with various aggregate forms. On the basis of the standard time temperature curves, the laboratory experiments approximately model the state of fire. However, when the temperature is maintained for a long period of time and warrants a detailed analysis, the reliable research results on the consequence of sustained elevated temperatures on concrete with different types of aggregates are minimal. The behaviour of the structural members can vary for concrete of different aggregate types after exposure. Aggregates have a greater effect on the concrete's compressive strength when the concrete is exposed to prolonged elevated temperatures. Exposure time is important in determining the residual strength of concrete for different
temperature levels; therefore, priority must be given to measuring this factor, and studies can be extended in this direction. The studies can be carried out further to analyse the temperature levels at which the concrete with various types of aggregate.

7. References
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