Residual Compressive Strength Of Normal And High Strength Concrete At Elevated Temperatures

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Abstract

In this study, the residual strength of normal and high strength concrete at elevated temperatures were evaluated. The concrete specimens were subjected to varying elevatedtemperatures (200°C – 800°C)for two (2) hours. The specimens were then cooled in air and quenched in water. The test results showed that the residual compressive strength of both types of concrete decrease with increase in temperature and this is more for concrete quenched in water. An effective approach other than quenching with water after a fire is imperative.

1Introduction

The fire resistance of concrete for most applications is adequate. However, when subjected to elevated temperatures, the strength and durability properties are significantly affected due to physical and chemical changes (Erai Fed and Zhi – Sham 2008, Topcu and Demio 2007, Mehta and Moteiro 2007). These changes are the loss of various forms of water (free, adsorbed and chemically bound) and the hydro thermal reactions that cause the progressive breakdown of cement-gel structure and consequent loss in load – bearing capacity (Khoury 1992; Handoo et al 2002).

Apart from load – bearing capacity, exposure to elevated temperature affects properties and behavior of normal and high strength concrete differently in two main areas: First, strength loss in the intermediate temperature range (100°c – 400°C); and secondly, occurrence of explosive spalling in high strength concrete (HSC) at similar range of temperatures (Phan 2007). There is structuralimplication for these material behavioral differences. First, the occurrence of explosive spalling at relatively low temperature frequently observed for HSC (Sanjayan and Storks, 1993) is an indication that the reinforcement or any structural elements is likely to be exposed directly to heating due to early loss of concrete cover, leading to premature loss of overall structural capacity. Secondly, the difference in relative strength loss (if any) between HSC and NSC at elevated temperatures raise questions on the validity of existing design rules' applicability to HSC. This is because these design rules were based primarily on tests of normal strength concrete. These rules may or may notbe applicable for structures built with High strength concrete .

Degradation of concrete strength at elevated temperatures has attracted the attention of researchers from time immemorial (Abrams 1971; Malhotra 1956; Schneida 1983 and 1985).

Sanjayan and Storks (1993) studied NSC and HSC at elevated temperatures and observed spalling of HSC at high temperature. They concluded that HSC appears to be more prone to spalling in a fire than NSC. Almeida (1998) tested normal strength concrete at elevated temperatures and observed that significant reduction in compressive strength begins at 300°C and recorded about 20% loss. Galleto and Meneguini (2000)'s study confirm Almeida's result and show that conventional concrete heated to 300°C and slowly cooled had a 24% loss in compressive strength in relation to its original un heated strength.

Petrucci (1987) reported a 50% reduction in compressive strength for NSC subjected to 600°C. Nevile (1997) authenticated Petrucci;s findings after working with cylindrical test specimens, 100mm and 200mm and subjected to varying temperatures (200°C – 600°C) at a rate of 5°C/min in a muffle furnace for two hours, cooled in air and quenched in a water tank. He obtained resultswhich are in agreement with that of Petrucci.

Galleto and Meneguini took the study further when they tested each group of six test specimens subjected to a temperature of 300°C, 600°C and 900°C. Heating was at a rate of 15°C/min, starting from an ambient temperature of 25°C for all the test specimens for two hours, gradually cooled in air and quenched in water. Their findings revealed that at 900°C, the specimens deteriorated completely.

Suji et al (1996) took the study to a new dimension when they introduced partial replacement of Opc with pozzolanicmaterials and observed their behavior at elevated temperature. They used 20%, 60% fly ash and 10% silica fume. Their findings revealed that the compressive strength of concrete decreased with rise in temperature from 21.4°C – 232°C. This was attributed to a gradual deterioration of the binding matrix with rise in temperature. The decrease was not compared with that of concrete with no pozzolana neither was the extent of decrease in strength for both types of concrete compared.Srinivassa et al (2006) studied the effect of elevated temperatures (50°C – 250°C) on the compressive strength of HSC made with both OPC and PPC (Portland Pozzolana cement).The residual compressive strength was evaluated at different ages. The result showed that at latter ages HSC made with PPC performed better by retaining more residual compressive strength compared to concrete made with OPC.Apeh and Ogunbode (2012) studied the residual strength of laterized concrete at elevated temperature and concluded that it maintained less proportion of its relative residual strength than plain concrete when quenched in water and more when cooled in air.

Ravindrarajah (1998) attempted a comparative study of the residual strength of NSC and HSC. He heated HSC with blended cement to 800°C and quenched it in water and also with NSC but without blended cement. His findings revealed that the residual strength of HSC with blended cement was 31% while that of NSC with no blended cement was 44%. Hoff et al (2000) in line with Ravindrarajah studied the compressive strength of HSC with blended cement.The specimens were heated to 800°C and quenched in water. The residual strength is about 31%. This agrees with Ravindrarajah's findings.In the same line of thought, Phan et al (2002) studied the influence of silica fume on the strength of HSC at elevated temperature and concluded from their findings that silica fume apparently has no significant effect on strength of HSC at elevated temperatures. This was strengthened by Tolentino et al (2000) when they analyzed the residual performance of HSC of 45 and 60Mpa, heat – treated at 600^{o}C and then cooled to room temperature. They observed a decrease in residual compressive strength with a rise in temperature as a result of heat–induced material degradation.They concluded thatresidual mechanical properties of concrete are dependent on their original non heat- treated values.

Hoff et al (2000b) conducted research on HSC at elevated temperature. The test specimens were subjected to 100^{o}C – 900^{o}C and observed slight improvement in residual strength at 200^{o}C, significant loss at 300^{o}C and no structural integrity at 900^{o}C. When compared with similar results on NSC, they concluded that residual strength of HSC at elevated temperatures of 300^{o}C or higher differ significantly from that of normal strength concrete.

From the findings of researchers so far, it is apparent that the behavior of HSC and NSC at elevated temperatures differs (Phan 1996; Phan and Carino, 2001). The implication(s) of these differences in behavior for both types of concrete on structural elements is yet to be investigated.

1.1 Aim and Objectives of the study

The study aimed at the determination of residual strength of normal and high strength concrete. This was achieved by producing samples concrete cubes of normal and high strength concrete. On curing, they were subjected to elevated temperatures (200^{o}C – 800^{o}C) and their residual strengths determined. These were then compared and their implication(s) on structural elements highlighted.

1.2 Significance of the study

It is imperative to note that results or findings obtained from this study added to those obtained in previous researches help in forecasting the degree of decay a structure or structural element can attain after a fire. This aspect is of utmost importance in designing for the recovery or reinforcement for retrofitting of such structure or structural element.

1.3 Materials and Methods

The study was carried out by means of laboratory tests. The unstressed residual property test method was adopted for the study. The specimens for both test series were made with the same materials but different mixture proportions. For NSC, the mix I was used while Mix II and III were used for HSC. Table 1.0: Mix Proportions for test specimens

	Mix I(C25)	Mix II (C60)	Mix III (C45)
	(w/c = 0.6)	(w/c = 0.39)	(w/c = 0.39)
Cement Kg/M^3	376	596	542

Water Kg/M^3	213	199	199
Coarseagg.	854	846	790
Fineagg. Kg/M^3	868	734	628

Preliminary tests (specific gravity, sieve analysis) were performed on the aggregates (river sand and crushed granite) in accordance with Bs 812 and workability tests on the fresh concrete to determine their suitability. Burham, locally produced cement which conforms to BS 12 was used for the study.

Normal strength concrete (NSC) of grade 25 and high strength concrete (HSC) of grade 45 and 60 sample cubes of 100mm x 100mm x 100mm were cast and cured for 28 days. On curing, they were air – dried and subjected to varying temperature (200^{o}C – 800^{o}C) for 2 hours at 2^{o}C/min in a muffle furnace. They were allowed to cool in the furnace to ambient temperature at2^{o}C/min. Before heating, samples were reserved and used as controls. The control and simulated samples were then tested for compressive strengths using a universal compressive strength machine.**The residual strength of the cube sample is the ratio of the compressive strength at temperature, ϴ^{o}C to that at ambient temperature.** A graph of residual strength (Rs) versus temperature was plotted to study the behavior of type of concrete at varying temperatures.

2. Experimental Results and Discussion

2.1 Preliminary Test Results

The results of the Preliminary tests performed on the materials used for the study is shown below.

Table 2.0 - Preliminary test results.

Material	Sp. gravity	f. Modulus	Slump
Fine Agg	2.65	2.35	
Coarse Agg	2.51	2.72	
Fresh Concrete			42mm

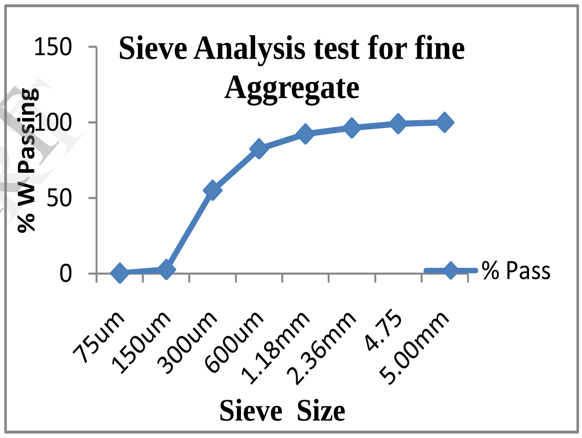

Figure 1- Sieve analysis test for fine aggregate

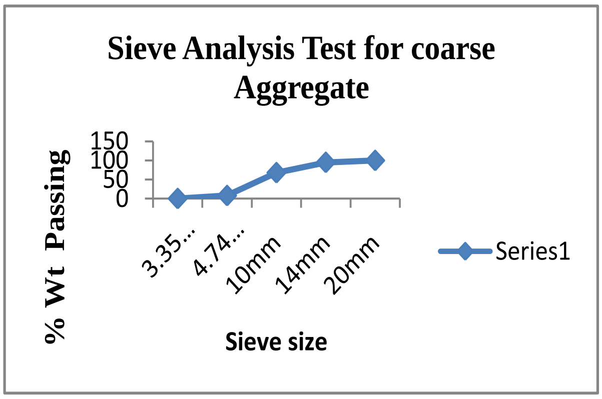

Figure 2 – Sieve analysis test for coarse aggregate

Figure 1 and 2 show the sieve analysis test results for fine and coarse aggregates. Figure 1 is a well graded fine aggregate sample which falls into zone iv while figure 2 is a well graded coarse aggregate sample which has a maximum size of 20mm since 8% pass through sieve no 4.75mm (IS:383).

2.2 Residual Strength (Rs)

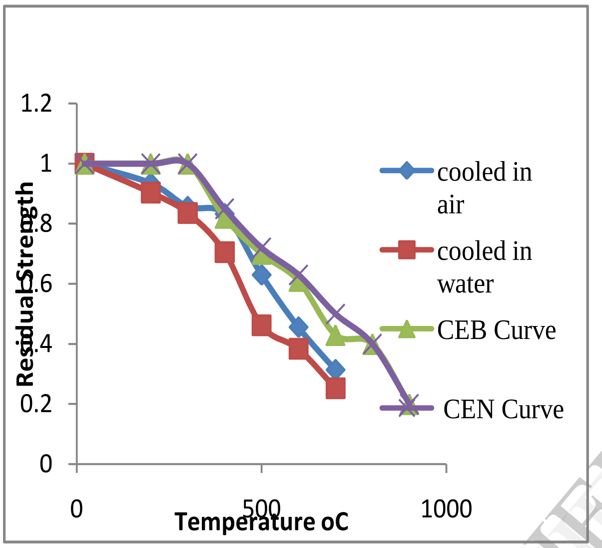

Figure 3- Residual strength of NSC concrete with CEB/CEN Design Curve

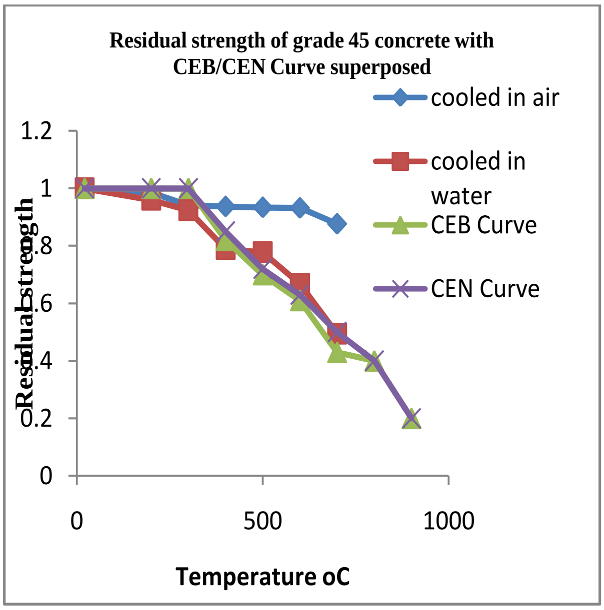

Figure 4- Residual strength of HSC concrete with CEB/CEN Design Curve

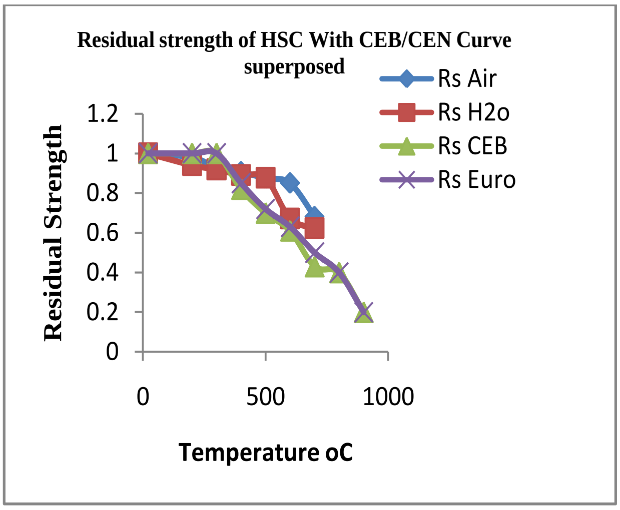

Figure 5- Residual strength of HSC concrete with CEB/CEN Design Curve

Plate I – Specimen inside the furnace

Figure 3 show the residual strength of normal strength concrete at varying temperatures while figure 4 and 5 show that for high strength concrete. The figures show that for both types of concrete (irrespective of concrete grade), concrete cooled in air has higher residual strength compared to that cooled rapidly in water. This is true because the faster the cooling rate produced, the greater would be the thermal gradient set up in the concrete, as a result of strength weakening (Mohamadbhai, 1986; Chan et al 1999).

At 200°C, the specimens showed slight reduction in residual strength varying from 6% (air cooled) to 10% for cooling in water. At 400°C, a farther decrease in residual strength was observed ranging from 12% (air cooled) to 29% (water cooled). At 500°C, 27% (air cooled) and 54% for water cooled was observed. At 600°C, the specimens were found to have a residual strength less than 50% of their ambient temperature value. Beyond this temperature level, less than 30% residual strength was observed.

These results are similar to that of Husem (2006), Souza and Moreno (2010). Their findings further revealed that at 600°C concrete loses not only free water but also the water contained in the gel, thus causing a high level of surface cracking on structural elements. Bazant and Kaplan (1996) opined that this surface cracking is also due to thermal in -compatibility of the hardened cement paste and aggregate which increases porosity and decrease strength.

However, the result of this study is in contradiction with that of Luo et al (2010) because of the latter's specimens which contain high cement content. In this case, for water cooled specimens, they would have reabsorbed water to undergo re-hydration and which led to slight retirement of strength.

Comparing figure 3with figure 4 and 5, the residual strength for HSC is higher as the temperature level increases. This also agrees with Husem (2006).As reported by Zhang et al (2000), this phenomenon show that more energy is required to break the surface of concrete and to overcome the cohesive force due to the aggregate bridging, aggregate interlocking, frictional forces and other mechanisms in the integration process zone of HSC than that of NSC specimens as the temperature level increased.

For design purposes, mechanical properties of concrete at elevated temperature may be obtained using design curves prescribed by CEN and Euro code. These design curves were based on results of fire tests on NSC (Phan and Carino, 2000). It is imperative to validate their applicability to HSC. This is achieved by superposing these curves on the results of this study (Figures 3 – 5). Comparing these curves with results of this study, the CEN Euro code and the CEB design curve are applicable to NSC (Figure 3) but un conservative to HSC (Figure 4 and 5) because their estimates of mechanical properties (residual strength) of HSC is underestimated. This is not out of place since the curves were derived from test results on NSC as aforementioned (Phan and Carino, 2000).

3 Conclusion

The concrete constituent materials used for the study met suitability requirements of relevant codes. Irrespective of concrete grade, concrete cooled in air has higher residual strength compared to that cooled in water. Forboth concretesresidual strength loss increase with increase in temperature. The CEN Euro code and the CEB design curve are applicable to NSC but not applicable to HSC which needs further attention. An effective approach other than quenching with water for a structure after a fire is imperative.

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