

The Residual Strength for Different Shaped High Strength Concrete Specimens at High Temperature

Rahel Khalid Ibrahim¹ & Hiba Muhammed Muhammedemin²

¹Faculty of Engineering, Koya University, Koya, Iraq

²Near East University, Faculty of civil Engineering, Nicosia, Cyprus

Correspondence: Rahel Khalid Ibrahim Koya University, Koya, Iraq.

Email: rahel.khalid@koyauniversity.org

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Abstract: Fire can be considered as a destructive hazard that attacks concrete structures. Exposing to high temperature causes deterioration in strength and spalling for high strength concrete members. In this research the effect of high temperature on the different high strength concrete specimen shapes is studied as a represent of circular and rectangular column sections. For this purpose, cube and cylindrical shaped specimens were made from polypropylene fiber contained high strength concrete, as well as the plain high strength concrete. After moist curing periods for 7, 28 and 90 days, the specimens were subjected to high temperatures of 450 and 650°C, and their residual compressive strength were evaluated. Cube specimens exhibited higher residual strength than cylindrical specimens and the superior stability of rectangular section columns compared to circular ones at high temperatures is concluded.

Keywords: High Strength Concrete, High Temperature, Polypropylene Fibers, Specimens' Shape, Residual Strength

1. Introduction

Controlling the sensitivity of concrete to its unstable spalling behavior during fire is one of today's major issues in the design and construction of concrete structures. Spalling of concrete can have serious structural and economic consequences and is a phenomenon that should be taken into account when designing for fire since it results in crack formation and high reduction of strength. This paper emphasizes on changing the geometrical design of column sections rather than the material to become more stable against the exposure to high temperatures. The aim of this paper is to compare residual strength for cube and cylindrical high strength concrete specimens to determine the shape effect on the residual strength and the sensitivity towards spalling of high strength concrete after exposure to fire.

2. Literature Review

Studying the fire resistance of high strength concrete (HSC) has become of a great importance in the last years due to the high usage of this material in high-rise structures. According to the high-rise structure designers, in the designing procedure the challenge is fire resistance. Although, concrete has a better resistance to high temperature than the steel, still fire represents an important threat for the damage or even collapse of many structures (Buchanan, 2002). Besides, some high

strength concrete structures like; coal gasification vessels, electrical power plants and nuclear power plants are continuously exposed to high temperatures.

A well-hydrated cement paste generally consists of calcium silicate hydrate, calcium hydroxide and calcium sulphate aluminate hydrate. A saturated paste also contains a large amount of free water, capillary water and gel water (chemically bonded water). When concrete is heated to 300°C, the free water and some of the chemically bonded water of hydration products are lost. Exposure to 500°C results in further dehydration due to the decomposition of calcium hydroxide. A complete decomposition of calcium silicate hydrate occurs at temperatures beyond 900°C (Klieger & Lamond, 1994). A number of studies in the same manner have shown that an increase in temperature in cement pastes causes the release of physically absorbed water, chemically bonded water and the decomposition of hydration products (Ye et al., 2007).

Through the increasing usage of high strength concrete in columns, fire resistance properties that with respect to spalling have become more considerable (Caldarone, 2008). Surface spalling occurs when a low permeable paste is subjected to a high rate of heating. This phenomenon occurs when the vapor pressure in the pores develops stresses greater than the material's tensile strength (Buchanan, 2002). The internal stresses in compression members make them more vulnerable to spalling. High strength concrete is more susceptible for spalling than the conventional concrete due to its lower permeability. High strength concrete is of a low porosity, the interrupted moisture in the capillary pores among the temperature rise cannot escape and result a vapor pressure in concrete. This pressure reaches 8 MPa, almost twice the tensile strength of concrete at 300°C (Phan, 1997). Even if the spalling doesn't occur the excessive vapor pressure in the system due to high temperature causes micro-cracks which by turn leads to a significant decrease in strength (Ibrahim et al., 2012). The strength deterioration of concrete exposed to high temperature may be due to several factors: temperature level, rate of heating, heating time, cooling method, applied load, type of aggregate, type of mineral admixture and air humidity (Bingöl & Gül, 2009; Khoury, 2000). Therefore, there are broadly variable results regarding the exposure of concrete to elevated temperature (Neville, 2005). The strength deterioration for high strength concrete at elevated temperatures is more pronounced than in normal strength concrete (Behnood & Ziari, 2008), whereas some researchers have showed that high strength concrete performs better than normal strength concrete at elevated temperatures (Ibrahim et al., 2011).

To overcome the spalling effect of high strength concrete it is necessary to add polypropylene fibers to the concrete mixes. Polypropylene fibers melt at around 160°C and become capable of producing moisture escape channels to release the vapor pressure. Researchers showed that, 1 kg of polypropylene fiber per one cubic meter of concrete mix is sufficient to eliminate the spalling effect (Ibrahim et al., 2014; Kalifa et al., 2001). Many authors emphasized that, using polypropylene fibers up to 2 kg/m³ do not have negative effect on the strength of high performance concrete (Noumowe, Siddique, & Debicki, 2009). In this research, to alleviate the spalling effect of the specimens, polypropylene fiber is used in amount of 1 kg/m³ for mortar and concrete mixes.

3. Materials and Methods

Portland cement, coarse aggregate, fine aggregate, super plasticizer and polypropene fiber and is used in this research. Ordinary Portland cement type I (42.5 Mpa) obtained from Mass Company. Fine aggregate was obtained from Bogid which has specific gravity of 2.7 and located under the second zone. Also, Gravels having the maximum size of 12.5mm and specific gravity of 2.67

obtained from Bogid pit were used as a coarse aggregate. Tap water was used for mixing and curing purposes. The superplasticizer used in this research was high performance polycarboxylic based, under the trade name of Hyperplast PC175. The polypropylene fibers is obtained from Timuran Engineering and holding a brand name of Fibrillated polypropylene fiber. They were white in color, having a length of 12.19 mm with a specific gravity of 0.9 and the melting point of 160 to 170 °C. The tensile strength for the fibers was 0.36 kN/mm². The material was used for those specimens that were subjected to high temperatures. The recommended dosage of material usage is 1 to 2 Kg/m³ of concrete.

A concrete mixture containing 1Kg polypropylene fiber per one cubic meter of concrete was prepared beside the control mixture. The water cement ratio for all mixtures were fixed to (0.38), to keep this rate constant super plasticizer was used for attaining proper workability. The mix proportion for 1m³ of concrete is shown in the Table 1.

From each concrete mix 27, (100*100*100mm) cubes and 27 (100*200mm) cylinders were casted. The cube and cylinder specimens where put in water for 7, 28 and 90 days as a moist curing. From each concrete mixture and curing regime at least 3 cubes and 3 cylinders were taken out from water, surface dried and exposed to high temperatures of 450 and 650 °C for 2hrs at a heating rate of 9°C/min. The heated specimens were cooled to room temperature and subjected compression test beside the controlled non heated specimens. The compression test was performed according to (EN, 2009) and (ASTM, 2015) standards of compression test for cubes and cylinders respectively.

Table 1: The Mix Proportions per One-Meter Cube of Concrete

Mix Code	Cement Kg.	Gravel Kg.	Sand Kg.	Water Kg.	Alum sludge Kg.	Super plasticizer Kg.	Polypropylene Fiber Kg/m ³	Slump mm	Flow mm
P	480	930	870	180	0	5	0	240	550
PP	480	930	870	180	0	5.5	1	240	550

4. Results and Discussion

4.1 Compressive Strength before Exposure to High Temperature

Table 2 shows the compressive strength results for P (cubes), PP (cubes containing polypropylene fiber), C (cylinders) and CP (cylinders containing polypropylene fiber) 7, 28 and 90 days respectively before and after exposure to high temperature. It can be observed that cub specimens shows higher strength than the cylinder ones for all curing periods. A compressive strength of 56.68 MPa was recorded for 28 day cube specimens, While, cylinder specimens had 54.89 MPa compressive strength. From these results the produced concrete can be categorized under high strength concrete. Both cube and cylinder specimens exhibited gradual increase in strength by increasing the moist curing periods

Maximum compressive strength of 59.55 MPa and 55.18 MPa was recorded for 90 days from cured cube and cylinder specimens respectively. The incorporation of polypropylene resulted in a slight decrease in strength for both cube and cylinder specimens for all curing periods.

Table 2: Compressive Strength for Different Curing Regimes and Different Exposure Temperatures (MPa)

Specimens	Compressive strength for different curing regimes and different exposure temperatures (MPa)								
	7 Days			28 Days			90 Days		
	26 ^o C	450 ^o C	650 ^o C	26 ^o C	450 ^o C	650 ^o C	26 ^o C	450 ^o C	650 ^o C
P	50.09	39.06	20.44	56.68	48.47	26.61	59.55	48.05	29.29
PP	46.82	35.37	17.48	51.44	48.45	26.59	56.29	49.04	30.03
C	45.16	22.27	10.48	54.89	32.13	14.79	55.18	32.79	16.50
CP	41.22	23.71	12.95	48.94	35.60	16.44	52.68	37.26	18.34

4.2 Compressive Strength After 450^oC

The exposure to 450^oC resulted in a decrease in compressive strength for both cube and cylinder specimens with respect to non-heated specimens. Cube specimens showed superior residual compressive strength than cylinder ones in both polypropylenes contained and non-polypropylene contained specimens for all curing periods.

The incorporation of polypropylene fibers resulted in enhances of residual strength for both cube and cylinder specimens with respect to non-polypropylene contained specimens for all curing regimes. The effect of polypropylene fibers on the residual strength of cylinders is more pronounced than cubes. Polypropylene fibers melt at 200^oC, so they provide open channels for the vapor pressure to release; hence reducing the micro cracks an increasing the residual compressive strength. The incorporation of polypropylene fibers enhanced the residual strength for cylinders by nearly 2 MPa with respect to non-polypropylene contained cylinders. Maximum residual compressive strength of 49.04 MPa was recorded for 90 day from cured polypropylene contained cube specimens.

4.3 Compressive Strength After 650^oC

The exposure of the specimens to 650^oC resulted in a dramatic decrease in compressive strength. Once again, cube specimens showed superior residual strength than cylinder specimens. The higher residual strength for cube specimens than the cylinder ones is most probably due to that the shape of cubes provides shorter escape path for vapor to escape than the cylinder specimens due to higher surface area of cubes. The incorporation of polypropylene fibers enhanced the residual strength for cylinders by nearly 2MPa with respect to non-polypropylene contained cylinders. Maximum residual compressive strength of 30 MPa was recorded for 90 day cured polypropylene contained cube specimens.

4.4 Visual Inspections

Some non-polypropylene contained cylinder specimens spalled explosively after exposure to 450^oC (Fig.1) while, no spalling were observed for non-propylene contained cube specimens. This phenomenon is due the excessive build up vapor pressure generated in cylinder specimens with compared to cube ones, which can be explained by higher surface area of cubes that provides more

vapor release than in cylinders. No spalling was occurred in cylinder and cube specimens when polypropylene fibers were added to the concrete mix.



Figure 1: Spaling of cylinder specimens after exposure to 450°C.

Figure 2 shows the change in color for non-polypropylene (P) and polypropylene (CP) contained cylinder specimens before and after exposure to high temperatures. The green color of concrete at 26°C turns to light grey after exposure to 450°C and the color becomes even lighter after exposure to 650°C due to the decomposition of hydration products to lime which have a lighter color. Cracks can be seen on the specimens surface after exposure to 650°C.

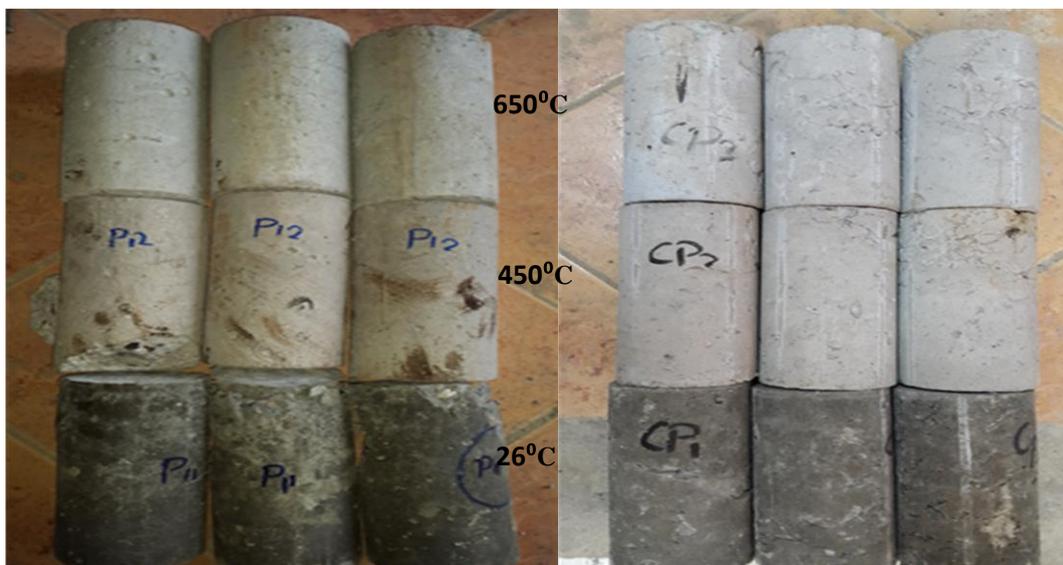


Figure 2: Non-polypropylene (P) and propylene (CP) contained cylinder specimens after exposure to different temperatures

The images of non-polypropylene (P) and polypropylene (PP) cube specimens after exposure to different temperatures are shown in figures 3 and 4 respectively. The higher the exposure temperature the lighter the color of the specimens becomes. The exposure to 650°C induced in visual cracks on the specimens' surface

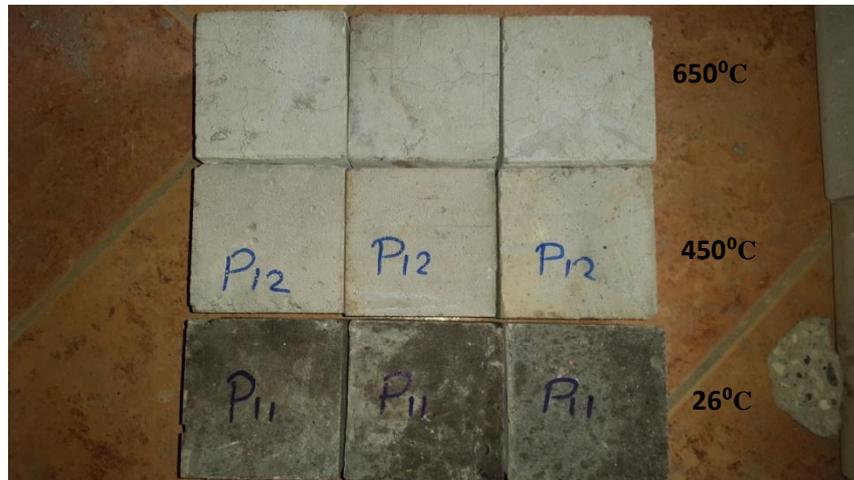


Figure 3: Non-polypropylene contained cube specimens after exposure to different temperatures



Figure 4: Polypropylene contained cube specimens after exposure to different temperatures

5. Conclusions

From this research the following conclusions can be drawn:

- It is possible to produce high strength concrete having 90 day compressive strengths up to 59.55 MPa for cubes and 55.18 MPa for cylinders.
- Maximum residual compressive strength of 49.04 MPa was recorded for 90 day cured polypropylene contained cube specimens after exposure to 450°C
- Maximum residual compressive strength of 30 MPa was recorded for 90 day cured

polypropylene contained cube specimens after exposure to 650°C.

- The incorporation of polypropylene fibers enhances the residual strength for both cube and cylinder specimens after exposure to high temperature.
- The rectangular sections are more resistible to the exposure to high temperature than the circular ones.
- The exposure to 650°C induced in visual cracks on concrete surface.

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