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Research Paper

STUDIES ON POST PEAK FLEXURAL STRENGTH OF CONCRETE UNDER SUSTAINED ELEVATED TEMPERATURES

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Concrete behavior upon exposure to high temperature or fire is determined by cement matrix, aggregate, moisture content, pore structure, and applied loading in addition to temperature increase rate as well as maximum temperature reached. Plain concrete mixtures exposed to heat showed evidence of surface spalling and cracking. The manifestation of such effects was exacerbated by low permeability and high brittleness of the low water-cement ratio concrete mixture used. Effect of heat and temperature upon concrete is attributed to internal pressure caused by water evaporation. Typically, water vapor is not drained through concrete pours at a fast rate so that internal pressure below the point of potential damage to the microstructure is reduced. Incorporation of Polypropylene fibers in Concrete, reduces the spalling and cracking. This was achieved via melting and consequently, creating added escape routes for vapor pressure. In this work an attempt has been made to study the effect of exposure to elevated temperature upon fibrillated polypropylene fiber reinforced concrete. The percentage of fiber considered for these investigations are 0.0%, 0.1%, 0.2% and 0.3% by volume of concrete mix at 100°C, 150°C, 200°C and 250°C for a sustained duration of 2 h, 4 h and 6 h, of exposure. The tests have been carried out as per recommended procedures of relevant codes and previous investigators. The results are compared and conclusions are arrived.

Keywords: Flexural strength, Fiber Reinforced Concrete, Polypropylene fiber, Sustained elevated temperature

INTRODUCTION

Concrete has been widely used as construction materials in buildings and other industrial structures for a long time. The recent technological advances have extended its use to special applications like aircraft engine test cells, tube jet runways, nuclear reactor vessels and missile launching pads, which have to endure higher temperatures. Elevated temperatures are also encountered in normal structures in cases of accidents like fire.

Plain Concrete possesses a very low tensile strength, limited ductility and little resistance to cracking. Internal micro cracks are inherently

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present in the concrete and its poor tensile strength is due to the propagation of such micro cracks, eventually leading to brittle fracture of the concrete.

It has been recognized that the addition of small, closely spaced and uniformly dispersed fibers to concrete would act as crack arrester and would substantially improve its static and dynamic properties.

REVIEW OF LITERATURE

Gowripalan *et al*. (1997) reported that high temperatures on the high strength concrete mixture, containing silica fume reaching a residual compressive strength of 90% when heated to 250°C.The drop in the residual strength above 250°C.The substantial up to 50% and 15% opted 1000°C. The tensile strength, modulus of elasticity and ultrasonic velocity through the material shows the reduction up to 750°C or 1000°C.

Roy and Parker (1983), reported that of the three days the strength development of blends is equivalent to that of pure Portland cement at normal temperatures, but this stage is achieved more rapidly at elevated temperatures, while a very fine pore structure is developed with longer time.

Sujit Ghosh and Karim W Nasser (1996) reported that, the compressive strength and static elastic modulus of 20 and 60%

Fly ash and 10% silica fume concrete decreased with a rise in temperature from 21.4 to 232°C for all three pressures.

Abrahams (1971) indicated that one of the important factors which affects concrete strength when heated is the type of aggregate used. He determined the compressive strength of concrete made with different types of aggregate, that is, light weight, siliceous and carbonate respectively, specimens were heated to test the temperature while stressed too and then tasted hot, where, is the 28 day moist cured compressive strength levels during heating of 0.25-0.55 fee had little effect on the strength obtained.

Loncard *et al.* (1967) tests found that the strength decreased with increase in moisture content. Bertera and polivika reported similar feelings at 150°C. They also saw that the mode of compression failures is brittle when the concrete is dry, but ductile when the concrete is wet. Free moisture in concrete can cause a significant deterioration in strength.

Harada *et al*. (1970) carried out tests using cylindrical specimen, 5 cm diameter and 10 cm diameter. The specimens were heated gradually in an electric furnace. Test results showed the linear reduction in strength with temperature rise, becoming approximately 60% at 400°C. Pumicite concrete had less strength reduction about 80% remaining at 400°C. High alumina cement concrete showed a severe strength loss compared with normal Portland cement concrete retaining approximately 50% at 200°C. He showed that siliceous aggregate concrete has a higher compressive strength as compared to the same concrete having high alumina cement.

Ziad Bayas *et al*. (2002) reported that, ultimate bending strength as well as post peak flexural strength decrease with increasing exposure temperature, duration or both. Furthermore, exposure to temperatures below 100ºC does not seem to significantly affect the flexural behavior of polypropylene fiber reinforced concrete.

George *et al*. (2000) reported that there is a slight improvement in residual strength at 200ºC exposure. At exposure when compared to 100ºC exposure. At exposure temperatures of 300ºC and higher, there is a significant loss of strength. At temperatures of 900°C and greater, all the concretes essentially had no structural integrity. The residual strength of High Strength Concrete (HSC) at exposure temperatures of 300°C or higher not significantly different than residual strengths for Normal Strength Concrete (NSC). The addition is polypropylene fibers to HSC to reduce the amount of explosive spalling in a rapid heat rise fire have structurally no beneficial or adverse effects on the residual strength.

RESEARCH SIGNIFICANCE

Concrete undergoes significant changes when exposed to high temperatures resulting in changes in structural properties. These observations are based on literature review with reference to time temperature curves. The question whether to retain or demolish the structure after it has been subjected to high temperatures will be based on assessment of structural properties, in addition to economic considerations. In the normal circumstances during the accidental fire, the structure will be subjected to very high temperature for a short duration. The laboratory studies based on the standard time, temperature curves approximately simulate conditions of fire.

However, when the temperature is sustained for long duration, the reliable research results on the effect of the sustained elevated temperature on concrete is limited and warrants a detailed study.

Examination of the structures after it has been subjected to sustained elevated temperature show extensive cracking, spalling, excessive deformation, especially in flexural members such as beams, slabs and column. This clearly indicates that there is change in structural properties the behavior of structural members may differ from the original after the exposure.

Therefore, for the assessment to be proper, the properties of the concrete after it has been subjected to sustain elevated temperature have to be assessed properly so that the prediction of the behavior can be done in a scientific way. In the circumstances mentioned above it was felt necessary to study the changes in properties of concrete after it has been subjected to sustained elevated temperature.

EXPERIMENTAL PROGRAMS

Test Variables

The following variables were considered for studies

a) Maximum temperature

b) Exposure time at maximum temperature

Properties of Materials

Cement - Portland Pozolana cement of 53 grade was used. Coarse Aggregate - 10 mm maximum size broken granite, metal of igneous origin was used. Specific gravity is found to be 2.9. Fine Aggregate - Fine river sand was used. Specific gravity is found to be 2.54. Water - Clean potable water was used for mixing mortar and concrete. Table 1

Concrete mix Details, Table 2 shows Chemical and Physical Properties of Polypropylene fiber – fine fibrillated and Table 3 shows the details of the specimens.

Casting and Testing of Specimens

All the specimens were cast in steel moulds unless and otherwise specified. After 24 h of casting they were de moulded and placed in a curing tank for 28 days. The specimens were removed and air cured in one day at room temperature till they were taken for

Table 1: Concrete Mix Details

Grade of Concrete	Mix Proportions	W / C
M 50	1:1.41:1.12	0.28

Table 2: Physical and Chemical Properties of Polypropylene fibre

Absorption	Nil
Fiber length	12mm
Melt Point	162°C
Thermal conductivity	Low
Acid and salt resistance	High
Specific gravity	0.91
Modulus (young's)	0.5 (3.5 KN/mm^2)
Ignition Point	590°C
Alkali Resistance	Alkali Proof

Note: * from NINA INDUSTRIES, MUMBAI.

Table 3: Details of Specimen

Temperature	Exposure	% of fiber considered	Number of Samples
Room Temperature	0	0.0%,0.1%,0.2%,0.3%	12
	2 h	0.0%,0.1%,0.2%,0.3%	12
	4 h	0.0%,0.1%,0.2%,0.3%	12
	6 h	0.0%,0.1%,0.2%,0.3%	12
	2 h	0.0%,0.1%,0.2%,0.3%	12
	4 h	0.0%,0.1%,0.2%,0.3%	12
	6 h	0.0%,0.1%,0.2%,0.3%	12
	2 h	0.0%,0.1%,0.2%,0.3%	12
	4 h	0.0%,0.1%,0.2%,0.3%	12
	6 h	0.0%,0.1%,0.2%,0.3%	12
	2 h	0.0%,0.1%,0.2%,0.3%	12
	4 h	0.0%,0.1%,0.2%,0.3%	12
	6 h	0.0%,0.1%,0.2%,0.3%	12
Total number of samples			156

experimentation. These specimens were kept inside the oven and the required temperature of 100ºC or 200ºC or 300ºC was set. Depending on the number of specimens kept inside the oven, the time taken to reach the steady state was found to vary between 2 to 6 h. After the steady state is reached the specimens were sustained for a predetermined duration of time 2 h or 4 h or 6 h at the end of which the specimen were cooled to room temperature and tested for their residual characteristics using a proper experimental setup.

RESULTS AND DISCUSSION

General Observation is made in Concrete after subjected to sustained elevated temperatures.

Physical changes were observed in general by visual inspection in concrete when examined after exposing to sustain elevated temperature. The changes that occurred are mainly due to color.

Visual examinations of the test specimens confirm that the color of the concrete gradually changed as the temperature and exposure hour are increased. The visual observation conducted on the specimen is presented in Tables 4 and 5 experimental test results of Residual Flexural Strength.

For sustained elevated temperature of 100ºC for 2 h of duration of exposure there is

Table 4: Results of Visual Inspection of Specimens

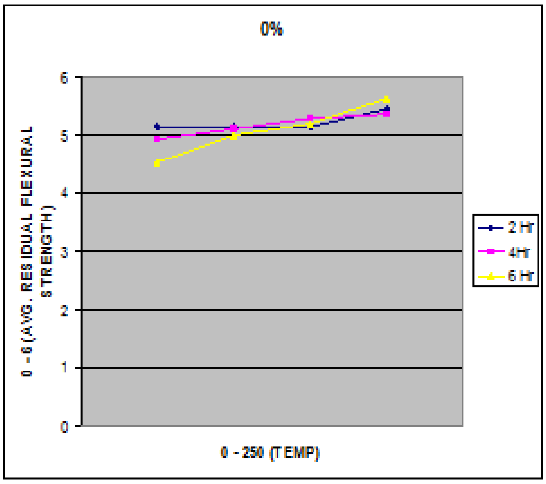
Temperature in ºC	Duration of Exposure in Hours	Color as Observed	Color as Observed After Exposure Temperature
Room Temperature	0	Grey	Grey
100ºC	2,4,6	Grey	Grey
150ºC	2,4,6	Grey	Grey
200ºC	2,4,6	Grey	Grey
250ºC	2,4,6	Grey	Grey

Table 5: Experimental Test Results of Residual Flexural Strength

Temperature	Exposure	% of fiber considered	Number of Samples
Room Temperature,	0 hr.	0.0%,0.1%,0.2%,0.3%	4x3=12
100ºC	2hrs,4hrs, 6hrs.	0.0%,0.1%,0.2%,0.3%	3x4x3=36
150ºC	2hrs,4hrs, 6hrs.	0.0%,0.1%,0.2%,0.3%	3x4x3=36
200°C	2hrs,4hrs, 6hrs.	0.0%,0.1%,0.2%,0.3%	3x4x3=36
250°C	2hrs,4hrs, 6hrs.	0.0%,0.1%,0.2%,0.3%	3x4x3=36
Total number of samples			156

Figure 1: Overview of Tested Specimens

Figure 2: Shows Residual Flexural Strength Vs. Temperature for Plain Concrete



a marginal reduction of 19.56%, 3.31%, 2.45%, 6.44% in residual flexural strength when the addition of 0%, 0.1%, 0.2% and 0.3% of Poly Propylene fiber in concrete.

When the sustained elevated temperature 100°C for 4 h, duration of exposure, the residual flexural strength is reduced to 23%, 17.45%, 17.62%, 9.66% to 0%, 0.1%, 0.2% and 0.3% of Poly Propylene fiber inclusion in plain concrete respectively.

Figure 3: Shows Residual Flexural Strength Vs Temperature for 0.1% of Polypropylene Fibre Inclusion in Plain Concrete

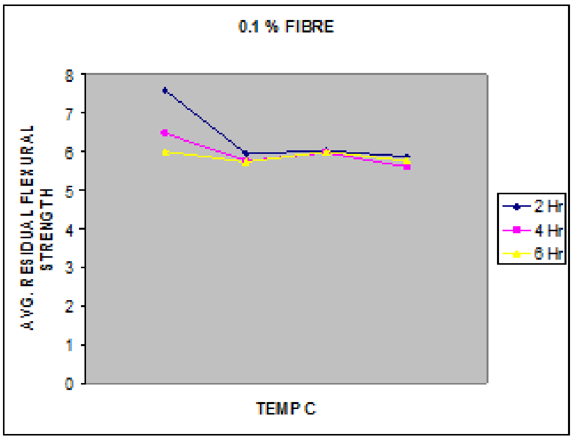
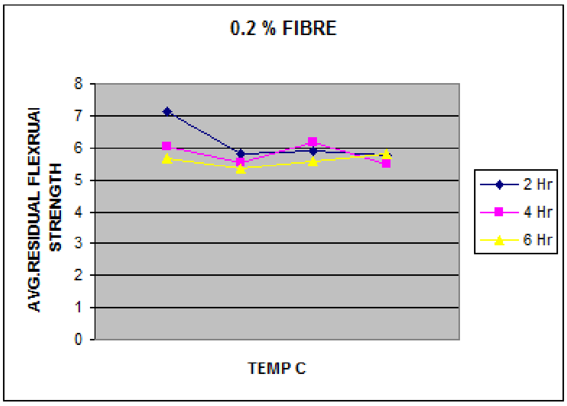


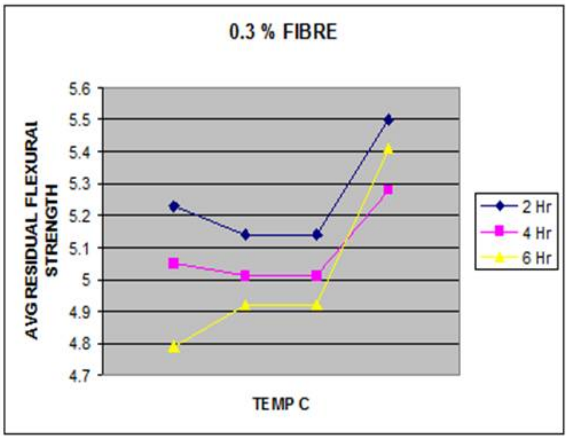
Figure 4: Shows Residual Flexural Strength Vs Temperature for 0.2% of Polypropylene Fiber Inclusion in Plain Concrete



When the sustained elevated temperature 100°C for 6 h, duration of exposure, the residual flexural strength is found to decrease to an extent of 29.26%, 23.69%, 22.40%, 14.31% for plain concrete, 0.1%, 0.2% and 0.3% of Polypropylene fibre concrete respectively.

For sustained elevated temperature of 150°C for 2 h of duration of exposure there is

Figure 5: Shows Residual Flexural Strength Vs. Temperature for 0.3% of Polypropylene Fiber Inclusion in Plain Concrete



a marginal reduction of 19.56%, 24.33%, 20.62%, 8.05% in residual flexural strength when the addition of 0%, 0.1%, 0.2% and 0.3% of Polypropylene fiber in concrete.

When the sustained elevated temperature 150ºC for 4 h, duration of exposure, the residual flexural strength is reduced to 20.18%, 26.75%, 24.31%, 10.37% to 0%, 0.1%, 0.2% and 0.3% of Polypropylene fiber inclusion in plain concrete respectively.

When the sustained elevated temperature 150ºC for 6 h, duration of exposure, the residual flexural strength is found to decrease to an extent of 21.75%, 27.13%, 26.77%, 11.98% for plain concrete, 0.1%, 0.2% and 0.3% of Polypropylene fiber in concrete respectively.

In a sustained elevated temperature of 200ºC for 2 h of duration of exposure there is a marginal reduction of 19.56%, 23.18%, 19.53%, 8.05% in residual flexural strength when the addition of 0%, 0.1%, 0.2% and 0.3% of Polypropylene fiber in concrete.

When the sustained elevated temperature 200ºC for 4 h, duration of exposure, the residual flexural strength is reduced to 17.37%, 23.82%, 15.84%, 10.37% for 0%, 0.1%, 0.2% and 0.3% of Polypropylene fiber inclusion in plain concrete respectively.

When the sustained elevated temperature 200ºC for 6 h, duration of exposure, the residual flexural strength is found to decrease to an extent of 18.77%, 23.69%, 23.63%, 11.98% for plain concrete, 0.1%, 0.2% and 0.3% of Polypropylene fiber concrete respectively.

For sustained elevated temperature of 250ºC for 2 h of duration of exposure there is a marginal reduction of 14.71%, 25.47%, 21.31%, 1.61% in residual flexural strength when the addition of 0%, 0.1%, 0.2% and 0.3% of Polypropylene fiber in concrete.

When the sustained elevated temperature 250ºC for 4 h, duration of exposure, the residual flexural strength is reduced to 16.11%, 28.78%, 25.0%, 5.54% for 0.0%, 0.1%, 0.2% and 0.3% of Polypropylene fiber inclusion in plain concrete respectively.

When the sustained elevated temperature 250ºC for 6 h, duration of exposure, the residual flexural strength is found to decrease to an extent of 11.89%, 26.62%, 20.62%, 3.22% for plain concrete, 0.1%, 0.2% and 0.3% of Polypropylene fiber concrete respectively.

CONCLUSION

The following conclusions are presented based on experimental results.

a. The residual flexural strength of concrete is decreased to (19.56%, 3.31%, 2.45%, 6.44%), (23.0%, 17.45%, 17.62%, 9.66%) and (29.26%, 23.69%, 22.4%, 14.31%) for plain concrete and 0.1%, 0.2%, 0.3% of Polypropylene fiber concrete at 2 h, 4 h and 6 h of temperature exposure for 100ºC temperature respectively.

b. The residual flexural strength of concrete is decreased to (19.56%,24.33%,20.62%,8.05%), (20.18%, 26.75%, 24.31%, 10.37%) and (21.75%, 27.13%, 26.77%, 11.98%) for plain concrete and 0.1%, 0.2%, 0.3% of Polypropylene fiber concrete at 2 h, 4 h, and 6 h of temperature exposure for 150ºC temperature respectively.

c. The residual flexural strength of concrete is decreased to (19.56%, 23.18%, 19.53%, 8.05%), (17.37%, 23.82%, 15.84%, 10.37%) and (18.77%, 23.69%, 23.63%, 11.98%) for plain concrete and 0.1%, 0.2%, 0.3% of PolyPropylene fiber concrete at 2 h, 4 h and 6 h of temperature exposure for 200ºC temperature respectively.

d. The residual flexural strength of concrete is decreased to (14.71%, 25.47%, 21.31%, 1.61%), (16.11%, 28.78%, 25.0%, 5.54%) and (11.89%, 26.62%, 20.62%, 3.22%) for plain concrete and 0.1%, 0.2%, 0.3% of PolyPropylene fiber concrete at 2 h, 4 h and 6 h of temperature exposure for 250ºC temperature respectively.

Also, it is concluded that the incorporation of Polypropylene fiber in concrete may arrest the extensive cracking, spalling and deformation of concrete when it is subjected to sustained elevated temperatures. Hence the use of Polypropylene fibre in concrete is recommended for structures which may fails due to fire exposure conditions.

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