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Tensile strength of normal and high strength concrete with polypropylene fibers at elevated temperature

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***Abstract*—This paper investigates the effect of thermal loading on the tensile strengths of normal and high strength concrete with and without polypropylene fibers. The unstressed residual split and flexural tensile strength of concrete is determined by testing cylinder and prism specimens. The specimens were subjected to single heating-cooling cycle with a hold period of 3 hours at 200^{0}C and were cooled in the furnace before testing the specimens for the residual split and flexural tensile strength of concrete. Similar treatment was carried out on the specimens at 400^{0}C, 600^{0}C and 800^{0}C and their residual tensile strength's were determined. Specimens were also prepared for determining the tensile strengths at room temperature. It has been observed that with the increase in the thermal loading or temperature, the flexural and split tensile strength experienced significant losses. The loss was found to be higher for stronger concretes. Flexural tensile strength was observed to experience a sharp loss at low temperatures that became gradual later at high temperatures. Split tensile strength, however, experienced a gradual loss, with the increase in temperature. The results indicated that the effect of high temperature is more severe on flexural tensile strength as compared to split tensile strength. The polypropylene fibers show an increase in the ductility, fire resistance and enhancement of the tensile properties of the material.**

***Keywords*—High temperature; normal strength concrete; high strength concrete; polypropylene fibers; split tensile strength; flexural tensile strength**

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I. Introduction

The reinforced concrete structures with adequate structural detailing, e.g. minimum dimensions and cover thicknesses of the reinforcement usually achieved satisfactory fire resistance without any additional fire protection. However after the fire has been extinguished the heat penetration into the cross section may continue for hours, and is inverted during the cooling phase leading to thermal stress and cracks [1]. With the development of concrete technology, high strength concrete (HSC) has been commonly utilized in many concrete structures around the world. HSC offers more strength and durability compared to normal strength concrete (NSC). Numerous researches are carried out to elucidate the behavior of NSC and HSC under elevated temperatures, especially its mechanical properties. Kodur and Sultan [2] compared the results of normal strength concrete (NSC) and high strength concrete (HSC) subjected to high temperature and concluded that the temperature between 400^{0}C and 800^{0}C was critical to the large percentage of strength loss of concrete. The effect of high temperature on the mechanical properties of high-strength mortar was studied by Cülfik and Özturan [3]. They concluded that specimens exposed to elevated temperatures showed higher decrease in flexural strength than compressive strength. Li et al. [4] examined the compressive, splitting tensile and bending strength of NSC and HSC after exposure of high temperature. They concluded that the relative tensile strength of concrete reduced with increase in temperature. Xiao and Gert [5] investigated the effect of high temperature on the mechanical properties mechanical properties of normal strength concrete (NSC), high strength concrete (HSC) etc. and concluded that the high temperature effect on the mechanical properties of concrete degrades with increase of temperature. Songa et al. [6] carried out the comparative study between the compressive, split tensile and flexural tensile strength of two concretes made with nylon and polypropylene fibers exposed to high temperature. They found that the nylon fiber concrete outperformed its polypropylene fibers companion in the upgrading of compressive, split tensile, flexural tensile strength. Noumowe´ [7] studied the effect of elevated temperature on the mechanical properties of high strength concrete with and without polypropylene fibers. He found that neither the compressive behavior nor tensile behavior was significantly modified with the addition of the polypropylene fibers at 200^{0}C. Kodur and Phan [8] reported that the type of fire, the fire size and heat output has significant influence on the fire performance of a concrete structural system. Aydın et al. [9] determined the effects of high temperatures on the compressive strength, flexural strength, modulus of elasticity, with different curing conditions with polypropylene (PP) and steel fibers. It has also been concluded that PP fibers inclusion caused some reduction in flexural tensile strength under autoclave curing before high temperature exposure. Noumowe´ et al. [10] presented experimental investigations on the effect of elevated temperature on the compressive, split tensile strength and permeability of high-performance concrete incorporating polypropylene fibers. It was revealed that the addition of 2% of polypropylene fibers to high performance concrete did not have significant effect on the compressive and splitting tensile strength of concrete. Suhaendi [11] explained the effect of hybrid fibers on the residual properties of HSC mainly its permeability, modulus of elasticity, splitting tensile and compressive strength after being exposed to high temperature. Substantial reduction in modulus of elasticity, splitting tensile and compressive strength has been observed for specimens heated up to 200^0C.

The literature revealed the tensile strength is important for greater comprehension of the structural behavior of concrete. Therefore, the present research takes into consideration the tensile strength investigation of NSC, HSC and high strength fibrous concrete (HSFC) subjected to elevated temperatures, as measured in terms of flexural and split tensile strength tests. The research in the field of tensile strength of HSC with and without fibers under elevated temperature is quite scarce, so that in the present study the most effort to investigate the behavior of HSC with and with out polypropylene fiber and its differences with that of NSC.

II. Experimental Program

A. Material Properties

Ordinary Portland Cement 43 grade (OPC 43) was used throughout the investigation. The physical properties of cement confirmed with the recommendations of IS-4031 [12]. The commercially available micro silica of grade 920 U (silica content of more than 92 percent) was used in the present investigation. Locally available river sand with fineness modulus of 2.43 was used as fine aggregate and locally available crushed granite stone of maximum size aggregate of 20 mm was used as coarse aggregate. The specific gravity of the aggregate was 2.65 g/cm^3. Washed aggregate was used throughout the study. The physical properties of fine and coarse aggregate confirmed with IS-383 [13]. The commercially available polypropylene (PP) fibers with a length of 12 mm were used in the study. The potable water was used for mixing and curing which was free from injurious amount of deleterious materials as recommended by IS: 456 [14]. The commercially available superplasticizer, Glenium 51, which is based on unique carboxylic ether polymer, was used as chemical admixture for workability of concrete.

B. Mix Proportioning

Three concrete mixes were prepared as per the guidelines of IS: 10262 [15] at an ambient temperature of 25^0C and relative humidity of 60%. The normal strength concrete (NSC) mix for 20 MPa compressive strength of concrete at 28-days and trial mixes were conducted for HSC and HSFC to obtain the target strength about 60MPa at 28-day. The NSC and HSC mixes have no PP fiber, while HSFC mix prepared with 2 Kg/m^3 PP fibers. Super plasticizer with 2 percent of cement weight was used in HSFC mix for workable concrete. The details of the mix proportions are shown in Table 1.

TABLE I. CONCRETE MIX PROPORTION

Mix	Cement (Kg/m^3)	Water (liter)	CA (Kg/m^3)	FA (Kg/m^3)	SF (Kg/m^3)	Super plastis izer (litre)	PP fiber (Kg/m^3)
NSC	450	211.5	675	1350	-	-	-
HSC	600	204	624	1050	49.8	12	-
HSFC	600	204	624	1050	49.8	12	2

C. Casting and Testing Procedure

The standard prisms of size 100×100×500 mm and cylinders of size 150×300 mm were cast to determine the flexural and spilt tensile strength of concrete at 28 days and tests were performed according to IS: 516 [16] and IS: 5816 [17] respectively. One thermocouple per specimen was inserted just after casting the specimens into moulds. The specimens were demoulded after 24 hours and cured under water for the period of 28 days. After 28 days of curing, the specimens were prepared for testing at room and at elevated temperatures for single heating-cooling regimes.

D. High Temperature Furnace

The electric furnace shown in Fig. 1 was fabricated for testing of cubes and cylinders at different thermal loading. The heating elements were fixed at the two opposite sides and on the top side of the furnace, with refractory lining on all six faces. The internal dimensions of the furnace are 1000×760×510 mm (length × width × height). A 40 mm diameter hole was provided in front of the furnace for the release of fumes and used for placing thermocouples in the furnace. The electric furnace has the rating of 1150^{o}C with a programmable microprocessor temperature controller attached to the furnace power supply. The temperature history in the furnace is controlled by a designated fire curve, typically those of “standard fires”. Usually, furnaces are equipped with devices to measure temperatures, and deformations, and to load test specimens.

E. First phase of study: specimens subjected to a single heating-cooling cycle

The specimens were heated at elevated temperatures i.e. at 200^0C, 400^0C, 600^0C and 800^0C after the curing age of 28 days. The specimens were heated for three hours holding time keeping in view that concrete must have a fire test rating of at least two hours in order to insure that structural damage will not result in a collapse, before buildings are evacuated, and for safety of firefighters. Public life-safety codes do not allow structures to be built unless they have two hours fire ratings and insurances companies will not insure structures that have less than two hours fire rating.

Figure 1. *Details of furnace.*

The furnace was completely closed during heating and cooling process. Fig. 2 shows the details of single heating-cooling cycle up to target temperature 'T'. After completion of one cycle, the specimens were tested for split and flexural tensile strength.

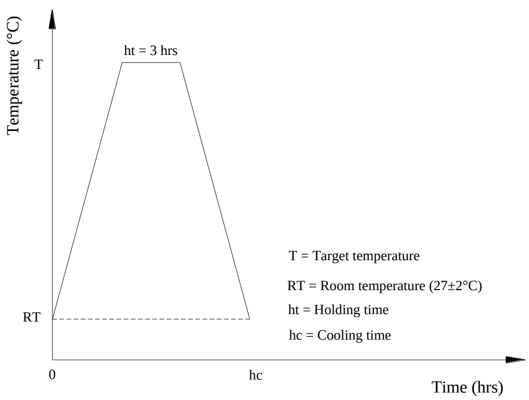

Figure 2. Single heating-cooling cycle curve.

III. Results and Discussion

A. *Inner Heating Temperature*

In single heating-cooling cycle, the maximum temperatures of the core of specimens have been measured using the thermocouples which have been placed in the core of the cylindrical specimens. Fig. 3 shows that for all temperatures for which the study is carried out, the temperature of the NSC is observed to be higher than that of HSC and HSFC core. At all elevated temperatures, the difference between the temperature of the surface and the core of NSC concrete specimens is marginal. By comparing the temperature of the core of NSC, HSC and HSFC specimens, at all elevated temperatures, it may be said that the denser the concrete, the lesser is its core temperature. Fig. 3 also shows that the temperature of HSFC core is observed to be higher as compared to that of HSC. HSFC is not as dense as HSC due to its PP fibers content which melts and provides channels for vapors to escape when subjected to elevated temperature and make the temperature of HSFC core higher. As HSC specimens are dense specimens as compared to NSC. The temperature of the core of the HSC concrete mix has shown the least core temperature during all the thermal cycles.

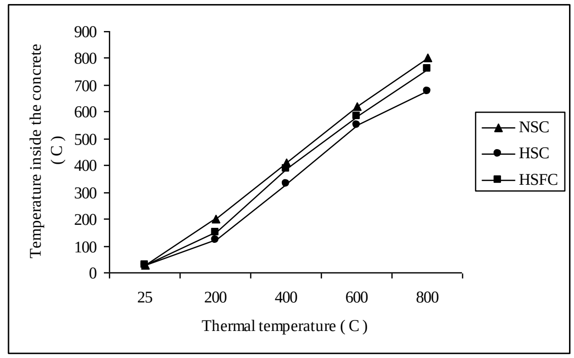

Figure 3. *Core temperature in different concrete specimens.*

B. *Effect of Single Heating-Cooling Cycle on Flexural Strength of Concrete*

Flexural tensile strength has a direct relation with ductility. With increase in the compressive strength of concrete, generally its brittle behavior also increases, causing reduction in tensile strength. The variations of residual flexural tensile strength of all the concrete mixes before and after exposure to high temperature are shown in Fig.4. The loss of residual tensile strength is such that none of the concrete mixes showed any flexural tensile strength after 600^{0}C. The flexural tensile strength of HSC and NSC is very close at room temperature while the strength of HSFC is higher than NSC and HSC. High compressive strength of HSC makes it brittle, but by adding some fibers its brittle behavior can be reduced to some extent. At elevated temperatures reduction of tensile strength is observed in all the concrete mixes. The tensile strength decreased slightly in HSC and HSFC up to 200ºC as compared to NSC. At 200^{0}C, the loss of flexural tensile strength in NSC, HSC and HSFC is 65%, 12.7% and 9.9% respectively as compared to flexural tensile strength of concrete at room temperature. After 200ºC, the loss of tensile strength is rapid in HSC and HSFC as compared to NSC. HSC and HSFC have experienced their sharpest reduction in tensile strength between 200 to 400°C. After 200^{0}C, it is found that the PP fibers totally melted and extensive cracking is observed in HSFC. On application of the tensile load, these cracks and channels created have lead to early collapse of concrete. The brittle behavior of HSC and the cracks observed, follow a similar phenomenon. NSC has shown a marginal flexural tensile strength at about 300ºC and found no tensile strength at around 400^{0}C. The tensile strength of HSC and HSFC is close at 400^{0}C temperature. The loss of strength at 400^{0}C in HSC and HSFC is about 87.8% and 84.4% respectively as compared to room temperature strength. The loss of strength in HSC and HSFC is marginal up to 600ºC. All the mixes have shown no residual tensile strength at 800^{0}C temperature.

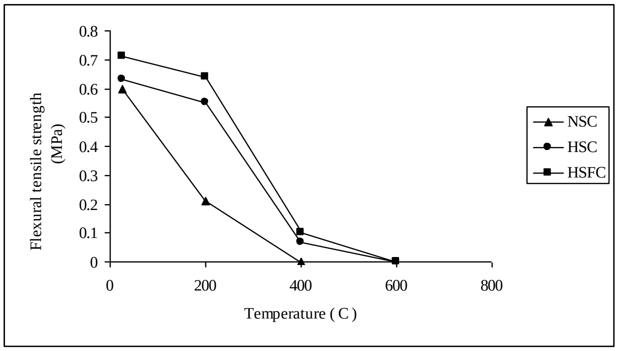

Figure 4. *Residual flexural tensile strength of different concrete mixes at elevated temperature.*

C. Effect of Single heating-Cooling Cycle on Split Tensile Strength of Concrete

The splitting tensile strength of NSC, HSC and HSFC cylinder specimens at elevated temperature is shown in Fig.5. With the increase in temperature, loss of splitting tensile strength is observed in all of the concrete mixes. It is observed that all the concrete mixes have shown better split tensile strength as compared to flexural tensile strength. The rate of reduction in the split strength is slower as compared to that of flexural tensile strength in all the concrete mixes. Although the HSFC shows more ductility but HSC shows the better split tensile strength at room temperature. It can be said that for better split tensile strength, higher strength can be more helpful than higher ductility.

The splitting tensile strength of NSC has the least value at room temperature as well as elevated temperatures. The splitting tensile strength of HSC mix is the highest at most of temperatures. But the split tensile strength of HSC decreased more sharply as compared to the other mixes. At 200^{0}C, the splitting tensile strength of HSC and HSFC is very close. At 400^{0}C, the splitting tensile strength of HSFC has the highest value as compared to that of other mixes. With increase in temperature, HSFC shows severe effect after 400^{0}C and the splitting tensile strength of HSFC decreased very sharply and it is close to that of NSC specimens. The severe strength loss may be attributed not only to the decomposition of the hydration products but also due to the thermal incompatibility between aggregate and cement paste.

D. Loss Comparison between Flexural and Split Tensile Strength of Concrete at Elevated Temperature

The loss of strength has also been compared between the flexural and splitting tensile strength in all of the concrete mixes. The flexural strength loss (FSL) and splitting tensile strength loss (STSL) of NSC mix is shown in Fig. 6. NSC had some split tensile strength up to 600°C and the flexural tensile strength just up to 200°C. At 200°C, the loss of flexural and split tensile strength is about 65% and 23% respectively. The loss of flexural tensile strength is about 3 times the reduction of splitting tensile strength at the same temperature. Loss of split tensile strength of NSC is approximately 36% at 400°C. At 600°C this loss is about 84%.

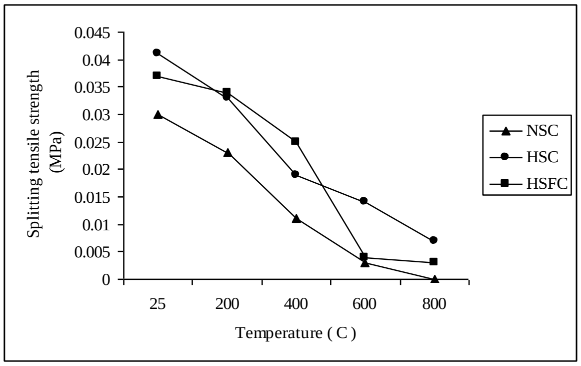

Figure 5. *Residual splitting tensile strength of different concrete mixes at elevated temperature.*

Fig. 7 shows the loss comparison between flexural and split tensile strength of HSC. It is observed that the loss of strength is lower in HSC as compared to NSC at all temperatures. HSC has shown lesser reduction in flexural and split tensile strength at all temperatures. At 200°C, splitting tensile strength has shown the sharpest reduction as compared to that of flexural strength. The reduction in flexural and split tensile strength is approximately 13% and 20% respectively. The percentage loss of flexural tensile and split tensile strength of HSC is 89% and 53% at 400°C respectively. At this temperature, the loss of flexural tensile strength in HSC is very sharp as compared to that of split tensile strength. Unlike NSC, HSC has shown some flexural tensile strength at 400°C. Flexural tensile strength has its sharpest reduction in HSC and is at its least at 400°C, which is about 3 times the loss in split tensile strength of HSC. At 800°C the percentage loss of split tensile strength is about 83%.

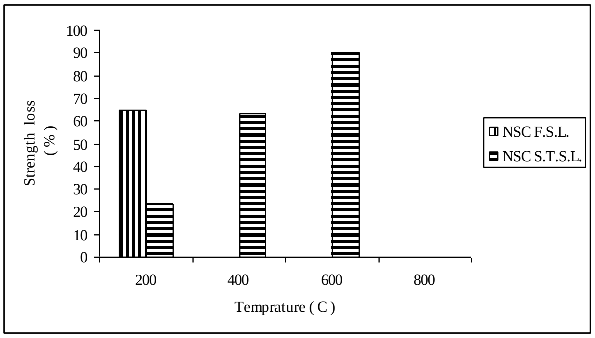

Figure 6. *Comparison between loss of flexural and split tensile strength of NSC at elevated temperature.*

The loss of flexural and split tensile strength of HSFC has been shown in Fig. 8. The percentage reduction in flexural and split tensile strength of HSFC is 10% and 8% respectively has been observed at 200°C temperature. The percentage reduction of about 86% and 32% respectively is observed at 400°C. The difference between the loss of flexural tensile strength at 200°C and 400°C in HSFC is same as that observed in HSC.

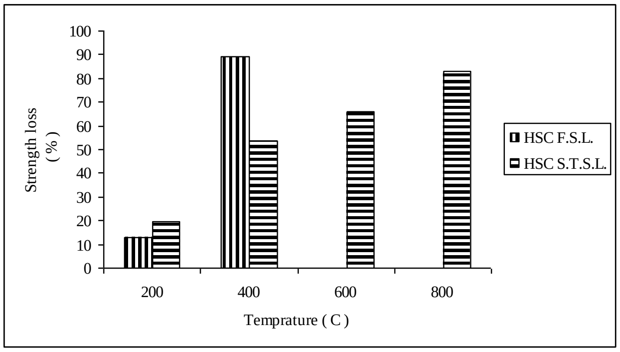

Figure 7. *Comparison between loss of flexural and splitting tensile strength of HSC.*

The percentage loss of flexural tensile strength in HSC is more than 2 times of that in HSFC. HSFC has shown no flexural tensile strength after 400°C. Unlike HSC, the loss in flexural tensile strength in HSFC is to some extent more than that in split tensile strength. At 600°C the percentage loss of split tensile strength is about 89%. HSFC is the only mix that has shown same split tensile strength at the ultimate temperature to which it has been tested. The reduction of split tensile strength is about 92% at 800°C. By comparing all the three mixes, it can be said that the loss of tensile strength is least in HSFC as compared to that of NSC and HSC up to 400°C. After 400°C the loss of tensile strength is least in HSC.

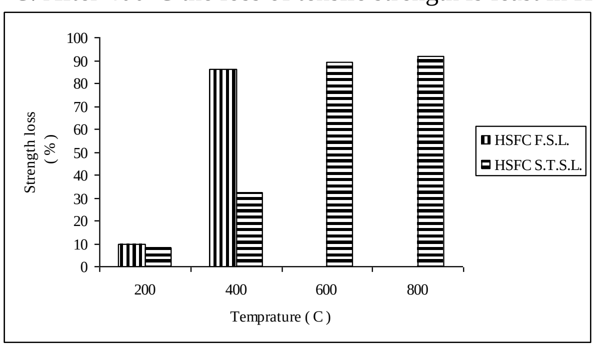

Figure 8. *Comparison between loss of flexural and splitting tensile strength of HSFC.*

It is observed that the loss of split tensile strength has a higher value in all of the mixes. The reason of severe strength loss in split tensile strength may be same that due to the decomposition of the hydration products and the thermal incompatibility between aggregates and cement paste.

IV. Conclusions

Based on the above experimental investigations, the following conclusions have been drawn:

1. In NSC, HSC and HSFC exposed to high temperature, flexural and split strength decreases with the increase of temperature.
2. The reduction of the flexural tensile strength in all concrete mixes has been observed to be higher as compared to that of split tensile strength at the same elevated temperature.
3. When exposed to 200^0C, NSC showed losses up to 65% in flexural strength, while HSC showed a loss of 13%. At 400^0C, HSC losses reached up to 89% of the initial flexural strength while HSFC have shown 86% flexural strength. When the temperature increased up to 800^0C, almost all of the flexural strength is lost.
4. After 400^0C, HSFC has experienced a substantial reduction in its split tensile strength. When exposed to 600^0C, NSC showed losses up to 95% in split tensile strength, while HSC showed a loss of 67%. At 800^0C in HSC losses reached up to 83% of the initial split tensile strength while HSFC have shown 92% of its split tensile strength.
5. HSC has shown the better split tensile strength at room and most of the considered elevated temperatures. It can be said that, to have the better split tensile strength, higher strength can be more helpful than higher ductility.

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