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Investigation On Strength Retention Characteristics Of Hybrid Fibre Reinforced Concretes At Elevated Temperatures

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Abstract— Concrete is the versatile and economical building material in contemporary construction and engineering projects. Concrete is a poor conductor of heat, but suffer considerable damage when exposed to elevated temperatures. The relative properties of fire exposed concrete are of prime importance due to serviceability, durability and strength considerations of concrete structures. The history of concrete heat exposure is important to determine whether a fire-exposed concrete structure and its components are still structurally sound or not. In this experimental investigation, concrete cubes of 100 mm size of various compositions were cast and 28 days water cured and later exposed to elevated temperatures of either 200°C or 400°C or 600°C and or 800°C with a retention period of 2 hours. This study discusses the strength retention characteristics of hybrid fibres reinforced concrete mix compositions.
Keywords- Fibre reinforced concrete; Steel fibres; polypropylene fibres ; Residual compressive strength; Elevated temperature .

I. INTRODUCTION

Concrete is possibly exposed to elevated temperatures during fire accidents or when it is near to furnaces or reactors. The most important effects of elevated temperature on concrete are dehydration of cement paste, porosity increase, modification in moisture content, thermal expansion, alteration of pore structure, strength loss, thermal cracking due to incompatibility, thermal creep and thermal spalling due to excessive pore pressure. There is a thermal incompatibility between the aggregate phase and hardened paste phase, which initializes the cracking process when concrete is heated [8]. With increasing temperature, loss of elastic modulus is quicker than the compressive strength [7]. The rate of loss in strength of concrete is highly dependent on the type of cooling regimes [5]. Fibres limit the crack development and propagation in structural concrete, improving its ductility, toughness and mechanical properties [4].
The residual compressive strength of steel fibre reinforced concrete gradually increases up to 200-250°C and starts decreasing as temperature exceeds 300°C [9]. In the hybrid fibre system, the stiffer steel fibres improves the first crack stress and ultimate strength; while the flexible and ductile PP fibres lead to improved ductility and post-cracking toughness [3]. An optimum level of fiber hybridization improves the concrete workability, uniform fiber dispersing-ability with low cost [1].
The strength deterioration characteristics of hybrid fibre reinforced normal strength concretes at elevated temperatures are investigated in this study. Attempts have been made to find the suitable

combination of steel-polypropylene hybrid fibres , that could significantly enhance the performance of hybrid fibre reinforced concrete at high temperatures.

II. MATERIALS

Ordinary Portland Cement (OPC) 43 grade was used and its properties are tabulated in Table 1. Coarse aggregate was crushed stone with a maximum size of 20 mm. Locally available natural river sand conforming to zone III (IS 383-1970 grading requirements) was used as fine aggregate. Physical properties of fine and coarse aggregates are presented in Tables 2. Potable quality water is used. Sulphonated naphthalene polymer based High Range Water Reducing Admixture (HRWRA); 'CONPLAST 430' of FOSROC was used. The specific gravity of HRWRA was 1.18. Steel fibres (density=7850 Kg/m^3 , length = 26 mm, diameter = 0.57 mm and aspect ratio of 45) and polypropylene fibres (density = 0.9 Kg/m^3, melting point 160-170°C, fibre length 3-19 mm and tensile strength is around 400 MPa) were used in this experimental investigation. Figure 1 shows the photographs of steel fibres and polypropylene fibres, used in this work.

Figure 1. (A) Steel fibres (B) Polypropylene fibres

Table 1. Physical properties of ordinary Portland cement

Sl. No.	Property	Result obtained			Requirements as per IS code			Remarks
1	Specific gravity	3.12			--			ACC cement 43 Grade
2	Normal consistency	29%			--			Satisfies IS-4013-1968 requirements.
3	Setting times, minutes	Initial 65 Final 270			Not less than 30 Not more than 600			
4	Fineness, m^2/Kg	330			Not less than 300			
5	Soundness, mm	2.50			Not more than 10 mm			
6	Compressive strength, Mpa	3 Days	7 Days	28 Days	3 Days	7 Days	28 Days	
		34	51	61	22	33	43	

Table 2. Properties of aggregates

Properties	Specific gravity	Bulk density	Moisture content
fine aggregates	2.65	Loose: 1463 Kg/m^3 Compact: 1661 Kg/m^3	Nil
coarse aggregates	2.77	Loose: 1360 kg/m^3 Compact: 1527 kg/m^3	Nil

III. EXPERIMENTAL METHODOLOGY

The compositions of various concrete mixes used in this experimental study are presented in Table 3. For reference mix1, nominal concrete mix (1 : 1.5 : 3) is used, that neither has steel nor polypropylene fibres. The slump was 50 mm ± 15 mm for all the concrete mixes. For concrete mixes with fibres, 6 ml per Kg of cement of super plasticizer is used to maintain the acceptable range of slump. For each mix, 15 Nos. of cubes were cast. So that, 3 cubes from each mix shall be available for the particular temperature exposure.

After 28 days of water curing, the cubes were removed from the curing tank, and were allowed to dry in the air for 12 hours. The concrete cubes were subjected to elevated temperature in an electric furnace with target temperature range from 200°C to 800°C in increment of 200°C. The retention time was 2 hours and specimen were furnace cooled. The temperature built up is gradual at the rate of 7 °C/min. The time required for reaching 200°C, 400°C, 600°C and 800°C is about 20, 60, 90, 150 minutes respectively. After reaching the designated temperature the specimen were retained at that temperature for period of 2 hours, for soaking. The furnace is switched off after the completion of retention, and then the specimen were left in the furnace until the interior of the furnace reached room temperature. Later they are removed from the furnace and were tested for residual compressive strength as per IS 516-1959 (reaffirmed 1999), after visual inspection for cracks and spalling etc. if any.

Table 3. Composition of various mixes

Mix	**SF** (%)	**PPF** (Kg/m^3)	**C** (Kg)	**FA** (Kg)	**CA** (Kg)	**W** (Kg)	**SF** (Kg)	**PPF** (Kg)
Mix 1	-	-	384.4	576.6	1153.3	192.2	-	-
Mix 2	1	0.4	380.5	570.7	1141.5	190.3	78.5	0.4
Mix 3	1	0.9	380.5	570.7	1141.5	190.3	78.5	0.9
Mix 4	1	1.4	380.5	570.7	1141.5	190.3	78.5	1.4

(SF-Steel Fibres, PPF- Polypropylene Fibres, C-Cement, FA- Fine Aggregates, CA-Coarse Aggregates, W- Water)

IV. RESULTS AND DISCUSSION

4.1. Physical observations

No visible cracking or spalling was observed in samples, up to 400°C. Hairline cracks begin to appear extensively at approximately 600°C and continued to grow as the temperature increased up to 800°C. In case of concrete mixes 2, 3, and 4, small amount of spalling at the edges and corners of the specimen at 600°C and above was observed. However, Mix1 showed considerable amount of cracks and spalling after temperature of 600°C and above. The concretes containing PPF experience least amount of spalling, than those without Polypropylene fibres. This result is attributed to the formation of network of micro-channels as a consequence of PPF getting melted and vaporizing, with increase in temperature. Thus, greater vapour tension in the capillaries can be released, which may be the reason of less explosive spalling in Fibre Reinforced Concretes (FRC) at elevated temperature. The studies carried out by [2] have also reported that FRC shows very less explosive spalling (edges and corner separation) compared to plain concrete, after heat exposure.

4.2. Residual compressive strength

Figure 2 shows the variation of residual compressive strength with elevated temperatures for all concrete mixes. Residual compressive strength gradually increases up to 200°C and thereafter decreases with the increase in temperature. According to [6], the initial increase in residual compressive strength up to 200°C temperature range can be attributed to rehydration and moisture migration. The overall tendency of strength reduction with increasing temperature was similar for the concrete without fibres (Mix 1) and the concrete with fibres (Mix 2, Mix 3 and Mix 4).

The most considerable reduction in compressive strength occurred between 400°C and 800°C in all the mixes. Addition of hybrid fibres has not shown significant effect on high temperature compressive strength of concrete. The similar results are obtained by [6]. The slower degradation of strength at early stages in concrete Mix 1 can be attributed to its higher stiffness as compared to FRC's (Mix 2, Mix 3 and Mix 4). PPF melts at an around 170°C, so there is degradation in its microstructure resulting from increased porosity. As temperature rises up to 800°C, residual compressive strength of all concrete mixes deteriorates progressively from 100% at ambient temperature to around 40% at 800°C. Among all the mixes, concrete Mix 2 and Mix 4 retain highest (52%) and lowest (37%) compressive strengths respectively. Concrete Mix 4 shows, 5% lower residual compressive strength than that of Mix 1 at the temperature of 800°C. Therefore, 1.4 kg/m^3 dosage of polypropylene fibres along with 1% of steel fibres (Mix 4) has adverse effect on the residual compressive strength. Researchers [3] have also reported that the residual compressive strength of the concrete deteriorates with excess PPF dosage.

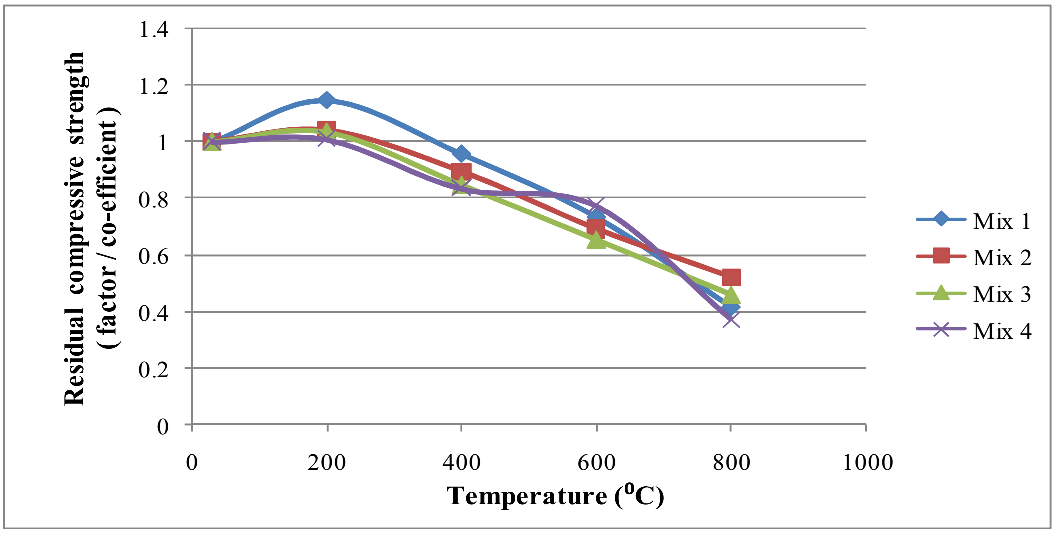

Figure 2. Variation of residual compressive strength V/s temperature

Concrete containing hybrid fibres shows a reduction in residual compressive strength compared with their plain (Mix 1) counterpart, in the temperature range of 200-400°C. While at the temperature 600°C residual compressive strength for concrete Mix 4 shows an increase of 3% over that of Mix 1. Similarly, at the temperature of 800°C residual compressive strength for concrete Mix 2 shows an increase of 10% in comparison to that of Mix 1. Among concrete mixes having combination of steel and polypropylene fibres, Mix 2 (1% SF and 0.4 Kg/m^3 PPF) and Mix 4 (1% SF and 1.4 Kg/m^3 PPF) show highest and lowest residual compressive strength at 800°C respectively. Amongst the hybrid fibre compositions, Mix 2 performs better at 800°C, with strength retention increase of 10%.

V. CONCLUSIONS

- The concretes containing PPF experience lesser amount of cracks, than those without polypropylene fibres.
- Addition of hybrid Steel and polypropylene fibres, to a small extent improve residual compressive strength at elevated temperatures.
- 1% volume fraction of Steel fibres and 0.4 Kg/m^3 of Polypropylene fibre tends to improve strength retention performance of hybrid fibre reinforced concrete at elevated temperatures (above 600 °C).

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