USE OF CEMENTITIOUS COMPOSITES FOR ENHANCING PERFORMANCE OF RC BEAMS AGAINST FIRE EXPOSURE

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ABSTRACT. The aim of this study is to evaluate the performance of RC beams against fire exposure using different cementitious composites. Total fourteen RC beams were cast. All beams were of size 150×150×1350 mm. Seven RC beams were exposed to fire at 900ºC for 1-hour duration. There were three control (CC) and three fire damaged (CCF) RC beams. Two control (CSMC) and two fire damaged (FSMC) RC beams were strengthened using Micro-Concrete. Two Control (CSSC) and two fire damaged (FSSC) beams were strengthened using UHPFRCC (Ultra High Performance Fiber reinforced Cementitious Composite). The UHPFRCC used was of compressive strength 109 MPa at 28 days. On the other hand, micro-concrete used was of compressive strength of 55 MPa at 28 days. All RC beams were tested under two-point loading. Change in load carrying capacity, deflection properties at mid-span, strain properties in concrete at center position of RC beam in top and bottom, failure modes were investigated for all the beams. The load carrying capacity of CCF beams reduced by 19.23% as compared to CC beams due to fire damage. Change in colour, spalling of concrete etc. is observed for CCF beams. The load carrying capacity of CSSC and CSMC beams increased by 73.08% and 22.12% respectively as compared to CC beams. The load carrying capacity of FSSC and FSMC beams increased by 84.52% and 33.33% respectively as compared to CCF beams. Strengthening using Micro-Concrete and UHPFRCC showed enhancement in performance of RC beams against fire exposure. UHPFRCC showed better performance as compared to Micro-Concrete for RC beams against the damage due to fire.

Keywords: RC Beam, Fire Exposure, Strengthening, UHPFRCC, Micro-Concrete.

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INTRODUCTION

The behaviour of reinforced concrete structure in fire condition is governed by different parameters like temperature and duration of fire, grade of concrete, age of concrete, cover to reinforcement, etc. Both concrete and steel undergo considerable change in their strength and other properties like deflection, strain etc. by the effects of heating, and some of these changes are not recoverable after subsequent cooling [1-5]. Chemical changes also occur due to heating. An understanding of these changes is essential in predicting or assessing the performance of the structure during fire and after cooling.

To maintain the serviceability of reinforced concrete structure after fire the restoration work is essential. There are several methods for strengthening fire damaged reinforced concrete members like Concrete jacketing, side plate bolting, use of fiber reinforced polymers etc. [8-9]. These methods have drawbacks like increase in existing member dimensions, difficulties of installations etc. Therefore, a new strengthening technique is required that is capable of enhancing the behaviour of reinforced concrete structure with minimal drawbacks. Use of different cementitious matrix having good mechanical and durability properties is also a good option for strengthening of reinforced concrete structure [10-14]. This paper presents the results of an experimental study, which is conducted for strengthening of RC beams against exposure of fire using Micro-Concrete and UHPFRCC.

EXPERIMENTAL INVESTIGATIONS

Specification of RC Beam

In the present study there were fourteen RC beams cast. The RC beams were designed are as IS:456 (2000) [17] and SP-16(1980) [18] provisions. The RC beam of size 150 mm×150 mm×1350 mm was used. The reinforcement of Fe 500 was used for both top and bottom bars. 2-10Ø bars in bottom, 2-8Ø bars in top and stirrups of 8Ø at 150 mm c/c was the reinforcement configuration for the RC beams used. The reinforcement detailing as per IS:13920 (2016) [19] is shown in Figure 1.

The concrete of grade M25 was used and it's mixture design was done as per codal provisions of IS:10262 (2009) [16]. Average Compressive strength of three cubes were evaluated at 7 and 28 days. Table 1 shows the mixture design adopted for M25 grade concrete. The 7 and 28 days compressive strength was 21.07 MPa and 31.56 MPa respectively.

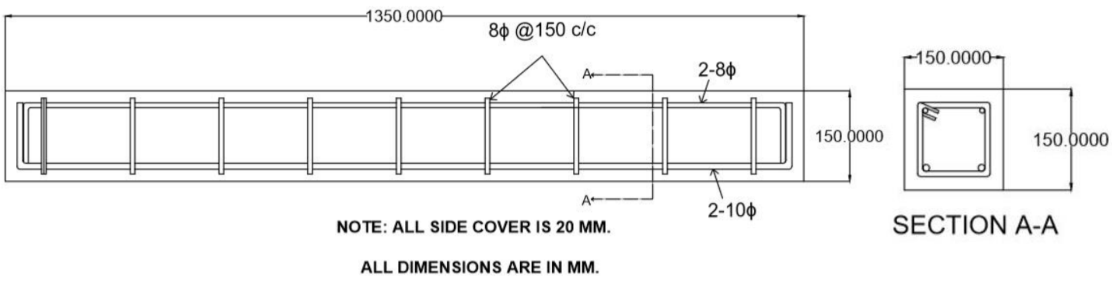

Figure 1 Reinforcement Detailing of RC Beam

MIXTURE DESIGN					
Cement (kg/m³)	Fine Aggregate (kg/m³)	Coarse Aggregate (kg/m³)		Water (lit/m³)	Superplasticizer (lit/m³)
		10 mm	20 mm		
359	833	438	692	158	3.23

Fire Exposure

Total 7 RC beams after 28 days of water curing, were given fire exposure of 900°C for 1-hour duration. The automatic gas fired furnace was used for fire exposure. The used gas fired furnace can attain maximum 1000°C using LPG gas as a fuel. The inner dimensions of gas fire furnace were 2.77 m × 0.6 m × 0.45 m. The interior surface of furnace was made of terra-wool coating that can resist temperature upto 1600°C. The furnace worked on principle of cut-off system i.e. after setting up a target temperature the burner automatically cut-off then inside temperature gradually reduces and at a point burner automatically ignites and the cycle repeats. During the fire exposure the temperature of specimen was measured using infrared thermometer that had maximum measuring capacity upto 1200°C using laser beamer. Figure 2 shows the time temperature curve as per IS:3809 (1979) [15], obtained in furnace and specimen. Time- temperature relationship as per IS:3809 (1979) [15] is as follows:

$$T-T_0=345\log(8t+1)$$

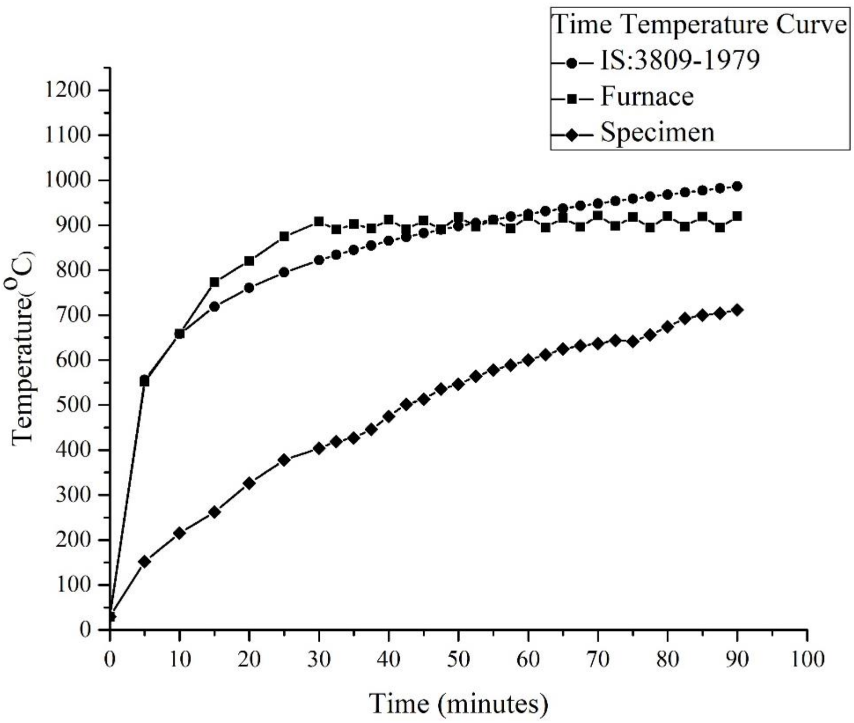

Figure 2 Time-Temperature Relationship

Strengthening Techniques Implemented

For strengthening of RC beams using Micro-Concrete and UHPFRCC, the cover concrete was chipped off and the chipped portion was strengthened with Micro-Concrete and UHPFRCC. After strengthening the beams were cured with water for 28 days.

Use of Micro-Concrete

Micro-Concrete used was blend of dry powder which requires addition of clean water to produce a free-flowing, non-shrink Micro-concrete with rapid hardening properties. The powder consists of Portland cements, graded aggregates and fillers, and additives which impart controlled expansion characteristics in the plastic state, while minimizing water demand. The Micro-Concrete is used for repairing for damaged reinforced components where access is limited and vibration is not possible. The w/b ratio was 0.16. Table 2 shows the compressive strength of Micro-Concrete obtained at different days.

Advantages of Micro-Concrete

- Gaseous expansion system compensates for shrinkage and settlement in the plastic state
- Can be pumped or poured into restricted locations
- Highly fluid to allow for placement without vibration
- Pre-packed to overcome site-batched variations
- Rapid strength gain to facilitate early reinstatement
- High ultimate strengths and low permeability of cured repair
- Contains no chloride admixture

Before strengthening using Micro-Concrete the surface should sound, free from loose material, water saturated. In case of corroded reinforcement, the corrosion and loosed material around reinforcement should be removed. The formwork should be properly sealed to avoid leakage. It should be placed immediately after continuous mixing of 5 minutes in a forced action mixture.

Table 2 Compressive Strength of Micro-Concrete

COMPRESSIVE STRENGTH			
1 Day	3 Days	7 Days	28 Days
16 N/mm^2	28 N/mm^2	42 N/mm^2	50 N/mm^2

Use of UHPFRCC

Seismocrete was the used UHPFRCC. It was a three component (powder, liquid, fiber) specially formulated cementitious product which had self-levelling rheology with exceptional mechanical and durability properties. It can be used thickness varying from 5 mm to 200 mm. It can be used for strengthening of heavy stressed machines, structural strengthening, seismic retrofitting, structural members subjected to repetitive loading etc. Table 3 shows the mechanical properties of used UHPFRCC obtained at different days.

Advantages of UHPFRCC used

- Exceptional high compressive strength of 48MPa after 24 hours.
- Excellent durability and resistance assistance to frost and thawing.
- Exceptional high tensile strength and value of sheared bond strength for strengthening jacketing to reinforced concrete substrates.
- Minimum thickness of application from 5-200mm ensures more adequate strengthening condition compared to other traditional reinforced concrete, having anti-carbonation barrier and anti-corrosion barrier properties.
- Provides very high resistance to fire.

The mixing at site is done using highly efficient vertical axes mixer. First mix powder and liquid and mix until a homogeneous mix is observed. After that fibers are gradually added and mixed until a homogeneous mix observed. It should be placed immediately after mixing as it has rapid hardening property. It possesses high heat of hydration. No extra bonding material is used while strengthening with said UHPFRCC.

Table 3 Mechanical Properties of UHPFRCC

MECHANICAL PROPERTIES				
Days	1 Day	3 Days	7 Days	28 Days
Compressive Strength	48 N/mm^2	78 N/mm^2	89 N/mm^2	109 N/mm^2
Split Tensile Strength	-	-	7 N/mm^2	9 N/mm^2
Flexural Strength	-	-	14 N/mm^2	19 N/mm^2

Test Setup

Figure 3 shows a common test setup used for all beams in the present study.

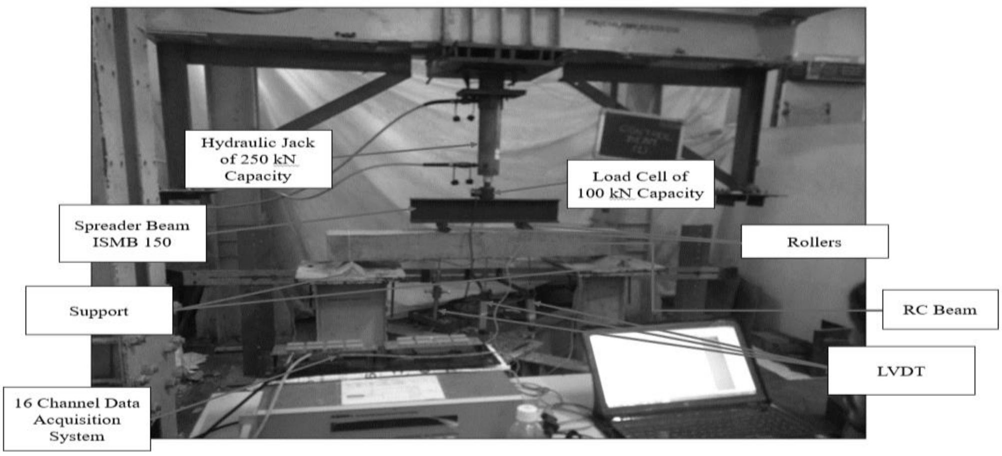

Figure 3 Test Setup for RC Beams

The Hydraulic jack of 250 kN was used for loading and a load cell of 100 kN was used for measuring load applied. There were three LVDT's attached, one at center of RC beam and other two 200 mm apart from center at left and right corner. Electrical resistance strain gauges of 90 mm length and 120Ω resistance were used to measure strain. Two strain gauges were attached one at the top center of beam surface and the other one at the bottom center of beam surface. The load was transferred to RC beams through spreader beams and rollers. The data acquisition system was for recording the strain and displacement results.

RESULTS AND DISCUSSIONS

Average Load Carrying Capacity

Figure 4 shows the average load carrying capacity of the all the beams. The results showed reduced average load carrying capacity for CCF beams compared to CC beams. The increased load carrying capacity was observed in strengthened control beams and strengthened fire damaged beams compared to control and fire damage beams. The beams strengthened with UHPFRCC showed increased load carrying capacity than beams strengthened with Micro-Concrete for both control and fire damaged beams. UHPFRCC proved to be a better strengthening technique.

The average load carrying capacity of CCF beams reduced by 19.23% as compared to CC beams due to effect of fire. The average load carrying capacity of CSMC, CSSC beams increased by 22.12%, 73.08% respectively, as compared to CC beams and average load carrying capacity of FSMC, FSSC beams increased by 33.33%, 84.52% respectively, as compared to CCF beams due to implemented strengthening techniques. Compared to CSMC, CSSC beams the average load carrying capacity reduced by 11.81%, 13.9% respectively, for FSMC and FSSC beams due to effect of fire. Compared to CSMC, FSMC beams the average load carrying capacity increased by 41.73%, 38.39% for CSSC, FSSC beams.

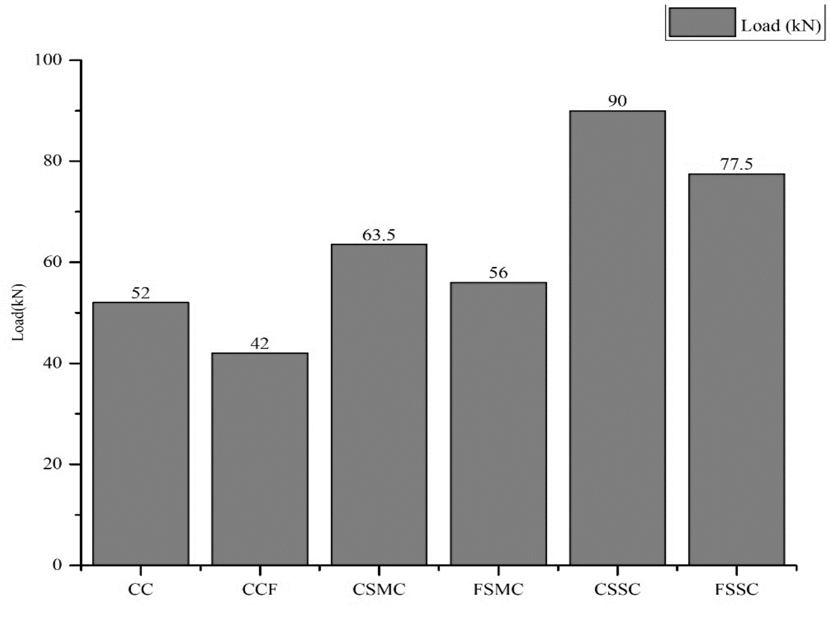

Figure 4 Average load carrying capacity of beams

Average Load v/s Deflection

Figure 5 shows the average failure load v/s deflection at mid-span for all the beams. The results showed increased mid-span deflection at average failure load for CCF beams compared to CC beams. The reduced mid-span deflection at average failure load was observed in strengthened control beams and strengthened fire damaged beams compared to control and fire damage beams. The beams strengthened with UHPFRCC showed reduced mid-span deflection at average failure load than beams strengthened with Micro-Concrete for both control and fire damaged beams. UHPFRCC proved to be a better strengthening technique.

At average failure load of CCF beams mid-span deflection of increased by 99.33% as compared to CC beams due to effect of fire. For CSMC, CSSC beams mid-span deflection reduced by 38.12%, 68.7% respectively, as compared to CC beams. For FSMC, FSSC beams mid-span deflection reduced by 61.19%, 65.75% respectively, as compared to CCF beams. For FSMC beams mid-span deflection increased by 57%, compared to CSMC beams. For FSSC beams mid-span deflection reduced by 70.74% as compared to FSMC beams. For FSSC beams mid-span deflection increased by 62.96%, as compared to CSSC beams. For CSSC beams mid-span deflection reduced by 69.7% as compared to CSMC beams.

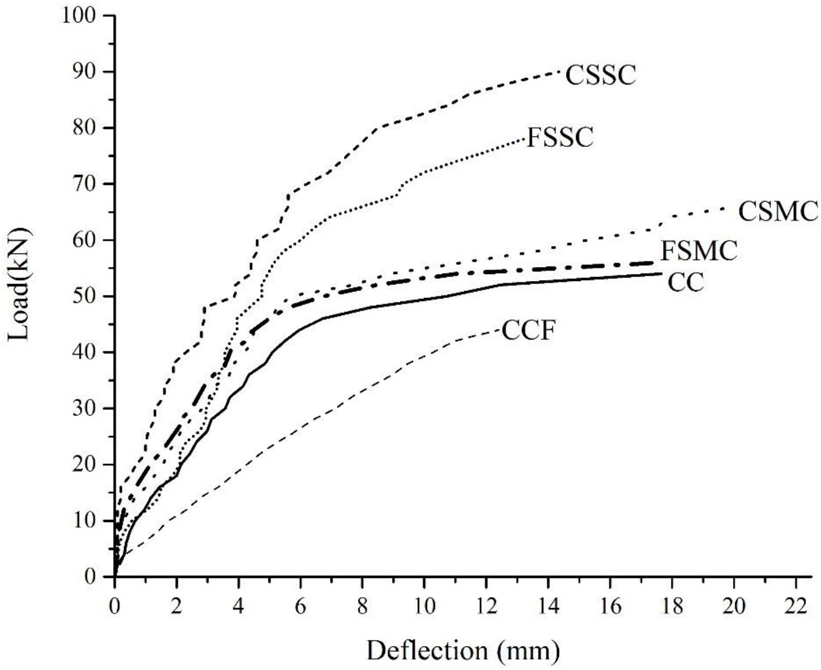

Figure 5 Average Load v/s Mid-Span Deflection of Beams

Average Load v/s Strain

Figure 6,7 shows the average load v/s strain at center position of RC beams at top and bottom. The results showed increased strain at average failure load for CCF beams compared to CC beams for both positions. The reduced strain at average failure load was observed in strengthened control beams and strengthened fire damaged beams compared to control and fire damage beams for both positions. The beams strengthened with UHPFRCC showed reduced strain at average failure load than beams strengthened with Micro-Concrete for both control and fire damaged beams for both positions. UHPFRCC proved to be a better strengthening technique.

At average failure load of CCF beams the strain at position-1 increased by 112.9% as compared to CC beams due to effect of fire. For CSMC, CSSC beams the strain at position-1 reduced by 36.25%, 46.8% respectively, as compared to CC beams. For FSMC, FSSC beams the strain at position-1 reduced by 61.19%, 65.75% respectively, as compared to CCF beams. For FSMC beams strain at position-1 increased by 57%, compared to CSMC beams. For FSSC beams strain at position-1 reduced by 70.74% as compared to FSMC beams. For FSSC beams strain at position-1 increased by 62.96%, as compared to CSSC beams. For CSSC beams strain at position-1 reduced by 69.7% as compared to CSMC beams.

Figure 9 shows the average load v/s strain at center position of RC beams at bottom. At average failure load of CCF beams the strain at position-2 increased by 27.03% as compared to CC beams due to effect of fire. For CSMC, CSSC beams the strain at position-2 reduced by 76.9%, 89.89% respectively, as compared to CC beams. For FSMC, FSSC beams the strain at position-1 reduced by 34.44%, 52.94% respectively, as compared to CCF beams. For FSMC beams strain at position-1 increased by 94.69%, compared to CSMC beams. For FSSC beams strain at position-1 reduced by 77.67% as compared to FSMC beams. For FSSC beams strain at position-1 increased by 11.15%, as compared to CSSC beams. For CSSC beams strain at position-1 reduced by 81.4% as compared to CSMC beams.

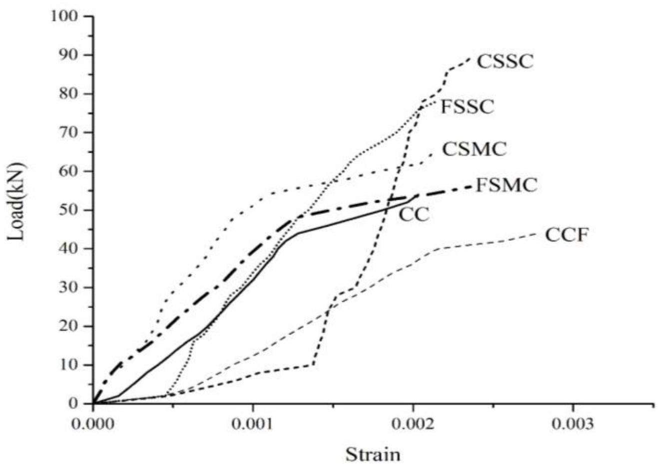

Figure 6 Load v/s Strain (Top Center) of Beams

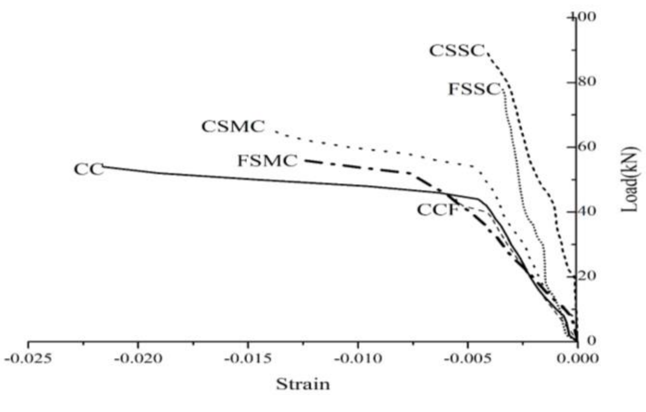

Figure 7 Load v/s Strain (Bottom Center) of Beams

Failure modes

In the following figures 8-10 the failure mode of different beams is shown. Failure mode changed shear in CCF beams due fire exposure. For CSMC, FSMC beams the flexure failure was observed. For CSSC, FSSC beams the flexure failure was observed but in these beams there were micro-cracks observed which indicated the presence of fibers.

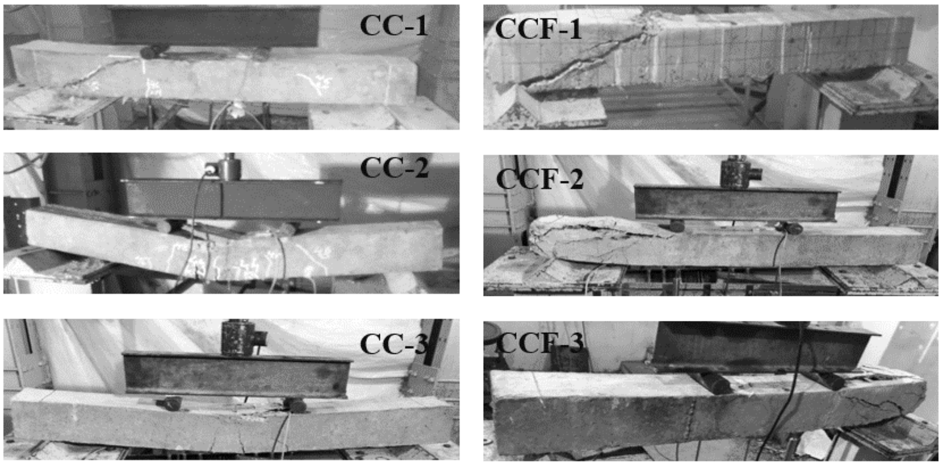

Figure 8 Failure Modes of Control and Fire Damaged Control RC Beams

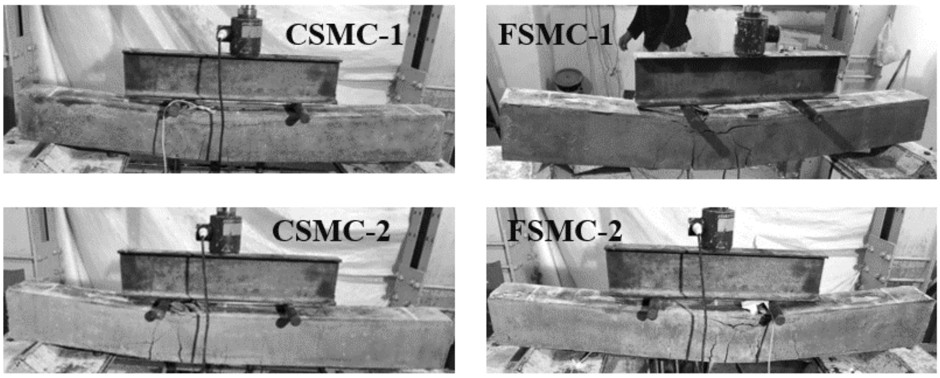

Figure 9 Failure Mode of Control and Fire Damaged Beams Strengthened with Micro-Concrete

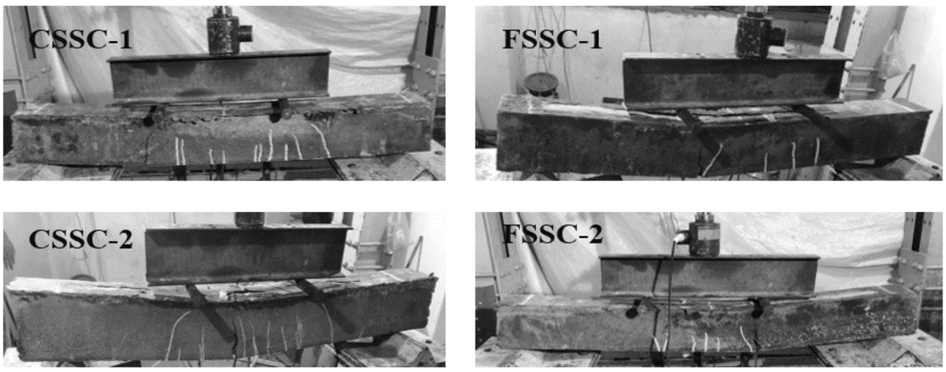

Figure 10 Failure Mode of Control and Fire Damaged Beams Strengthened with UHPFRCC

CONCLUSIONS

The conclusions from the present study are as follows:

- Effect of Fire on Concrete: After fire exposure change in color, cracks, spalling were observed on cubes. The compressive strength reduced by 40.21% and weight reduced 4.51%.
- Effect of Fire on RC Beams: After fire exposure change in color, cracks, spalling were observed on RC beams. The reduced load carrying capacity, increased mid-span deflection, increased strain at both positions were observed. The failure mode changed to shear due to effect of fire.
- Beams Strengthened using Micro-Concrete: For control and fire damaged RC beams strengthened using Micro-Concrete increased load carrying capacity, reduced mid-span deflection, reduced strain at both positions were observed compared to control and fire damaged beams. The failure mode control and fire damaged beams failure mode was flexure.
- Beams Strengthened using UHPFRCC: For control and fire damaged RC beams strengthened using UHPFRCC increased load carrying capacity, reduced mid-span deflection, reduced strain at both positions were observed compared to control and fire damaged beams. The failure mode control and fire damaged beams failure mode was flexure and micro-cracks were observed due to presence of fibers. The performance of control and fire damaged strengthened with UHPFRCC was better than control and fire damaged beams strengthened with Micro-Concrete.
- UHPFRCC proved to better a strengthening technique for fire damaged RC beams.

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