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Influence of Fiber on Shear Behavior of Concrete Exposed to Elevated Temperature

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A B S T R A C T

Fire accidents are inevitable and it is one of the significant hazards, which causes loss of life and valuables. The present investigation focused to study the influence of fibers on shear strength of concrete exposed to elevated temperature as per ISO 834. The fibers used in the study were Basalt, Carbon, Glass, Polypropylene and Poly vinyl alcohol. M20, M30, M40 and M50 grades of concrete were used for the investigation. The results revealed that the shear strength is declined with increase in temperature. The shear strength is enhanced by the addition of fiber in the reinforced concrete beams exposed to elevated temperature. Carbon fiber reinforced concrete specimens exhibited better residual shear strength than the other specimens. Addition of carbon fiber and basalt fiber in concrete reduced the micro cracks in the specimens exposed to elevated temperature. Addition of polypropylene fiber and poly vinyl alcohol fiber reduced the spalling but the crack propagation was not prevented in the specimens exposed to high temperatures.

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NOMENCLATURE

T	Furnace temperature at time t	PVAFRC	Poly vinyl alcohol FRC
T_0	Initial furnace temperature	t	Duration heat exposure (min)
°C/t	Rate of heating	°C/min.	Degree celcius per minute
°C/hr	Degree celcius per hour	RC	Reinforced Concrete
CC	Control Concrete (without fiber)	E	Young’s modulus (GPa)
FRC	Fiber Reinforced Concrete	L	Length (mm)
CFRC	Carbon FRC	T_m	Melting point (°C)
BFRC	Basalt FRC	Vol/%	Dosage of fiber (%)
GFRC	Glass FRC	P	Load
PPFRC	Polypropelne FRC	ϕ	Diameter (mm)

1. INTRODUCTION

Fiber Reinforced Concrete (FRC) is known for many property enhancements in conventional concrete. There are numerous studies carried out during last three decades to overcome the weak tensile behavior of concrete. The performance of concrete is always associated with its compressive strength and tensile strength. These two properties are much important that decides the characteristics of concrete. The fibers added in concrete helps to reduce the brittleness of the concrete by bridging the micro cracks and thus prevented the macro crack development [1]. Only limited studies have been carried out on the effects of elevated temperature on the shear strength of FRC. Majority of the investigations focused on the effect of steel fibers and PolyPropylene Fiber (PPF) on the shear strength of the concrete. Considering FRC in terms of fire resistance, some tests have been conducted to identify the effect of fibers in resisting the fire related damages that occurs in concrete structures [1, 2]. Mainly, these are emphasized on the effect of fibers on the basis of its shape, type and the percentage of addition (quantity) on the strength parameters of concrete. Commonly the experiments are carried out in

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terms of compressive strength, tensile strength and modulus of elasticity [1–5]. Widely used fibers in the concrete industry are synthetic fibers such as PPF and Poly Vinyl Alcohol Fiber (PVAF), Steel Fibers (SF), and hybrid of SF and PPF. There are also a few examinations, which tested concrete with Carbon Fibers (CF), and Glass Fibers (GF) [4, 5].

Kurup and Senthil-Kumar [6] found that addition of PVC fibers improved the ductility behavior of concrete and reduced the brittle failure of concrete. Shear strength values were reduced in the case of fiber reinforced concrete with respect to the addition of PVC fibers and silica fibers (0.6 to 1%) [6]. Bae et al. [7] concluded that, an increase in shear strength according to inclusion of steel fiber was more effective than the four times volume fraction of shear reinforcement. Based on experimental results of the study conducted by Abdi Moghadam and Izadifard [8] it is found that although the inclusion of steel fibers decreased the compressive strength, it has improved the shear strength of plain concrete at 28 days of curing. Smith et al. [9] experimentally investigated the shear strength of fire affected (622℃) beam specimens. The rate of heating was 10℃/min. It was found that 30% reduction in shear strength occurred. Cai et al. [10] studied the residual shear strength of concrete beam specimens after exposure to ISO 834 time temperature curve and the reduction in shear strength was found. For the exposure time of 30 min., 60 min. and 90 min the shear strength reductions were 15, 23 and 26%, respectively. Yusuf [11] examined the residual shear strength of concrete push off specimens after exposure to 200℃, 350℃ and 500℃ with a rate of 17℃/h. heating. The residual strengths after the specimens exposure to 200℃, 350℃ and 500℃, were 26%, 41% and 66%, respectively. Concrete with PP fibers showed the negative performance on improving the mechanical properties beyond the critical temperature (more than 500°C). It was due to the loss of bond between the fiber and cement matrix. It may be due to the development extra pores during melting of PPF [12–14]. Information are limited on the effect of fibers on shear strength of concrete exposed to elevated temperature.

The shear strength is a significant property, which enables concrete to withstand against the fatigue forces. It is considerably less than the compressive strength, because the micro cracks developed in concrete can spread and widen under bending loads. When exposed to fire, bending strength of concrete is reduced due to the spalling that occurs within concrete elements [15–17].

Information on the residual shear strength of FRC with CF, Basalt Fiber (BF), GF, PPF and PVAF exposed to standard fire curve (ISO 834) was found to be missing in the literature. Effect of elevated temperature on FRC with different strength grades are to be evaluated. Hence, it is necessary to understand the influence of different types of fibers on the strength and surface defects of concrete when exposed to elevated temperature. An attempt has been made to study the key factors such as type of fibers, grade of concrete and intensity of temperature, which affect the residual shear properties of concrete.

This paper investigates the shear response of FRC exposed to elevated temperature. The fibers used in the study are BF, CF, GF, PPF and PVAF. The study was conducted in M20, M30, M40 and M50 grades of concrete. Residual shear capacity of different grades of concrete with different fibers are presented in this work.

The main objective of the investigation is to examine the influence of fibers on the shear strength of concrete after exposure to elevated temperature.

2. EXPERIMENTAL INVESTIGATION

2. 1. Materials The ordinary Portland cement of grade 53 conforming to IS: 12269–2013 and Manufactured sand (M-sand) as fine aggregate (Zone II) as per IS: 383:2016 were used. Crushed granite stones of size 20mm confirming to IS 383:2016 were used as coarse aggregate. The quality of water was found to satisfy the requirements of IS 456:2000. Considering the properties of materials, the mix proportion of concrete was designed as per IS 10262:2019. A water reducing agent Master Glenium SKY 8233 was used to control the workability (slump cone test) of all concrete mixtures. The water reducing agent maintained the workability of the mix in between 75 and 100mm even after the addition of fibers into the mix without affecting the water cement ratio. Fe 500 steel bars were used as reinforcement. Table 1 shows the details of fibers.

2. 2. Preparation of Specimens and Test Procedure Singly reinforced FRC beams were cast and used for testing the shear behavior after exposure to elevated temperature. 700 x 150 x 150mm size beams were used for the investigation considering the limitation of the furnace size. Two numbers of 6mm diameter bars were used at top and bottom of the specimens. In order to ensure shear failure, two legged 6mm diameter stirrups are provided at supports and loading points only to hold the main bars (Figure 1). With respect to the proposed

TABLE 1. Details of fibers

Fibers	L (mm)	E (GPa)	σt (MPa)	T_m (℃)	Vol/%
PPF	12	165	317	165	0.25
PVA	12	220	396	220	0.25
GF	12	77	2050	1500	0.25
BF	12	100	3100	1400	0.25
CF	12	240	3500	1200	0.25

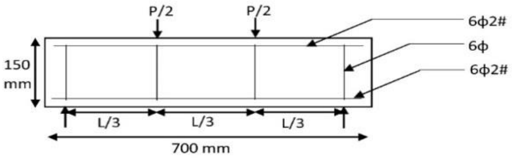

Figure 1. Details of RC beam

beam size molds were made with cast iron. The two-point loading arrangement was adopted from IS 516:1959.

After 24 hours of casting, the sides of the formwork were removed and the specimens were cured in water for 28 days. After curing, specimens were dried and heated following stranded fire curve.

A computer controlled electrical furnace with inner dimensions of 700 × 400 × 400 mm having the capacity power of 100kW was used to heat the specimens (Figure 2). The maximum operating temperature of the furnace is 1200°C, with a capability to set the standard fire temperature curve (Equation (1)). Type K thermocouples connected to a microprocessor based data acquisition unit were used to monitor the temperature inside the furnace.

$$T - T_0 = 345\log_{10}(8t + 1) \tag{1}$$

Concrete specimens were exposed to heating durations of 30 min (821°C), 60 min (925°C) and 90 min (986°C) as per standard fire curve (Figure 3) following ISO 834. Heated specimens were cooled in ambient condition before the test. The furnace temperature of the heated specimens and its surface cooling rate are shown in Figure 3. The investigation was carried out for different grades of concrete such as M20, M30, M40 and M50. After cooling in air, the shear resistance of Reinforced Concrete (RC) beams were tested using a computerized Universal Testing Machine (UTM) of capacity 1000 kN. Two-point load was applied with appropriate test setup to ensure constant shear in the specimens. The loading gauge was connected with the digital testing machine that records the failure load of the specimens. After curing, cube specimens were exposed to 90 minutes of elevated temperature (986℃) to observe the surface defects. Figure 4 shows the methodology adopted.

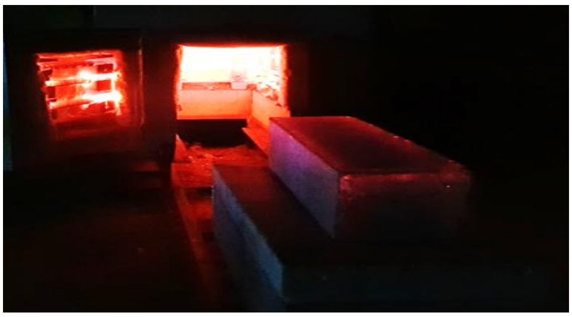
Figure 2. View of furnace and heated specimens

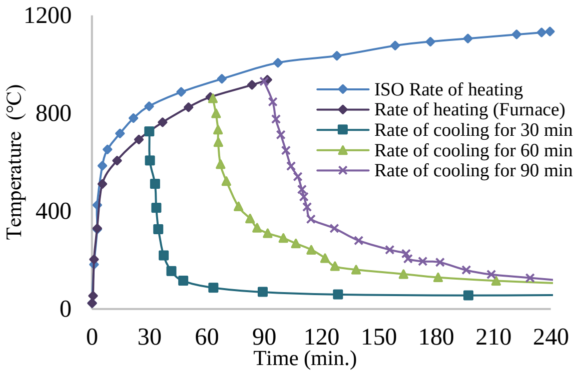

Figure 3. Heating and cooling regime of specimen

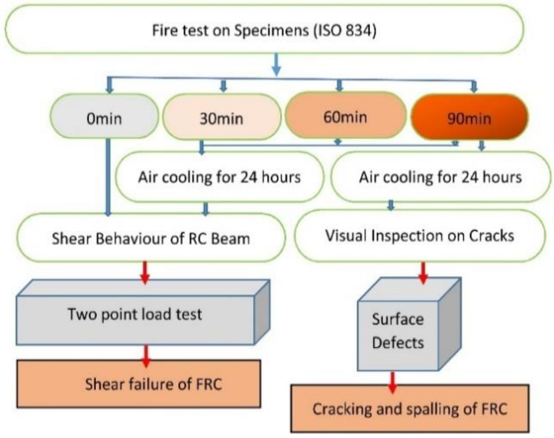

Figure 4. Methodology

3. RESULTS AND DISCUSSION

3. 1. Shear Strength

During loading, shear failure was observed in the beam specimens and it is confirmed by the diagonal cracks developed near the support (Figure 5). The ultimate load was delayed according to the type of fibers added in the concrete specimens. For the RC specimens exposed to elevated temperature, the shear resistance decreased with the increase in the duration of elevated temperature.

Figure 5. Shear failure of specimen and inset view of crack

3. 1. 1. Effect of Fiber Type on Unheated FRC Tables 2 to 5 summarized data for the shear failure load of different FRC specimens. It is evident from the results, that all the FRC specimens exhibited more shear capacity than the control concrete (CC). The increment of shear resistance of FRC with respect to CC were found to vary according to the fibers added in the concrete. In the case M20 grade unheated CC specimens (Table 2), carbon FRC (CFRC) exhibited 1.7 times the shear resistance of CC. This was followed by Basalt FRC (BFRC) (1.6 times) and Glass Fiber Reinforced Concrete (GFRC) (1.5 times). The significant increase in the shear strength may be due to the high tensile load carrying capacity (Table 1) of CF, BF and GF [18]. Poly Vinyl Alcohol FRC (PVAFRC) and Polypropylene FRC (PPFRC) specimens exhibited a marginal increase (1.2 times) in shear strength with respect to CC. All FRC specimens exhibited more shear resistance than the CC specimens for M20, M30, M40 and M50 grades after exposure to elevated temperature for 30, 60 and 90 minutes of exposure duration.

Figure 6 depicts the increment in shear resistance of unheated M20, M30, M40 and M50 grade specimens with respect to unheated CC. It is evident that the increment of shear resistance is depended on the elastic modulus and tensile strength of fibers added in the concrete. The results proved that fibers with high tensile strength (CF) has the highest ratio of shear resistance in an unheated condition (1.7 for M20 grade CFRC, 1.5 for M30 grade CFRC, 1.7 for M40 grade CFRC and 1.6 for M50 grade CFRC). This was followed by BFRC, GFRC, PVAFRC and PPFRC specimens that have a lower shear strength (Tables 2-5).

3. 1. 2. Contribution of Fibers in Concrete Exposure to High Temperatures Figures 7 - 10 show the comparison of the shear resistance of M20 (Figure 7), M30 (Figure 8), M40 (Figure 9) and M50 (Figure 10) grade heated FRC specimens with respect to the heated M20 grade CC, M30 grade CC, M40 grade CC and M50 grade CC specimens. This was calculated by taking the ratio of shear resistance of any specimen with the shear resistance of control concrete (CC) of a same grade exposed to same elevated temperature. It can be seen from the figures that, M20 grade CFRC, M30 grade CFRC, M40 grade CFRC and M50 grade CFRC exhibited the maximum shear resistance when exposed to elevated temperature for durations of 30, 60 and 90 minutes. These figures clearly indicate the contribution of fibers in improving the shear resistance of FRC exposed to higher temperature. The fibers in the heated M20 grade CFRC specimens exhibited almost similar contribution in the shear resistance (1.8 times) even after exposed to 30, 60 and 90 minutes. Similar phenomenon was visible on shear resistance of M30 grade CFRC, M40 grade CFRC and M50 grade CFRC specimens.

TABLE 2. Shear resistance (kN) of M20 RCC specimens

t	CC	CFRC	BFRC	GFRC	PPFRC	PVAFRC
00	70.09	116.11	110.82	105.08	84.60	85.08
30	62.57	112.60	97.67	89.92	80.87	81.53
60	51.33	92.69	78.84	71.78	62.52	62.98
90	46.04	81.52	69.91	56.06	48.88	49.10

TABLE 3. Shear resistance (kN) of M30 RCC specimens

t	CC	CFRC	BFRC	GFRC	PPFRC	PVAFRC
00	84.58	125.45	120.33	108.82	92.35	94.69
30	72.54	120.12	110.65	95.45	82.95	82.10
60	60.29	98.85	88.24	76.54	63.00	64.10
90	51.50	83.71	73.69	59.21	52.45	52.12

TABLE 4. Shear resistance (kN) of M40 RCC specimens

t	CC	CFRC	BFRC	GFRC	PPFRC	PVAFRC
0	101.5	170.52	161.60	155.68	146.25	147.55
30	86.54	152.37	138.21	120.43	109.54	109.99
60	70.54	122.16	111.05	83.58	82.37	83.02
90	55.00	94.35	85.75	61.58	57.15	57.90

TABLE 5. Shear resistance (kN) of M50 RCC specimens

t	CC	CFRC	BFRC	GFRC	PPFRC	PVAFRC
0	119.6	192.54	175.55	167.55	155.57	156.83
30	94.57	163.55	150.54	136.13	129.54	130.02
60	81.07	135.25	128.46	101.25	90.68	92.51
90	66.00	108.55	102.55	72.46	68.25	69.55

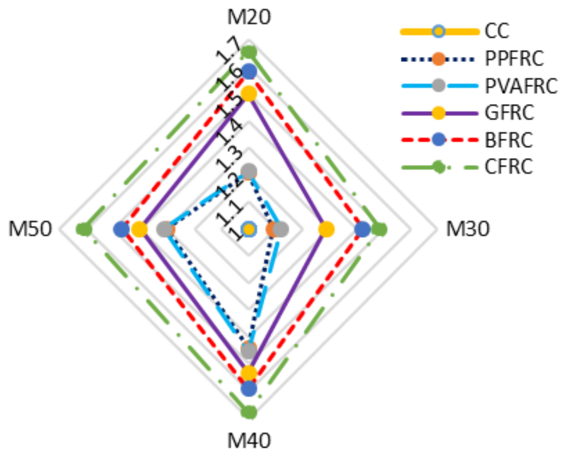

Figure 6. Ratio of shear resistance for unheated specimens

The shear resistance of M20 grade BFRC specimens were found to be 1.5 times that of the M20 grade CC specimens at elevated temperature conditions (30, 60 and 90 minutes). In addition, M30 grade BFRC (1.5 times), M40 grade BFRC (1.6 times) and M50 grade BFRC (1.6 times) exhibited similar behavior in the case of temperature exposed conditions. There was a sudden drop in the shear resistance of M20 grade GFRC specimens (1.4 times to 1.2 times) when exposed to 90 minutes of elevated temperature. M30 grade GFRC, M40 grade GFRC and M50 grade GFRC also exhibited a similar pattern. It may be due to the loss in tensile strength of glass fiber when exposed to elevated temperature [19]. With prolonged heat exposure, the shear resistance of the specimens declined but it can be strengthened by increasing the tensile strength of concrete [10].

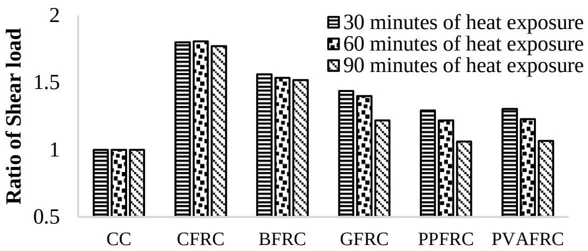

Figure 7. Shear resistance of M20 heated FRC specimens

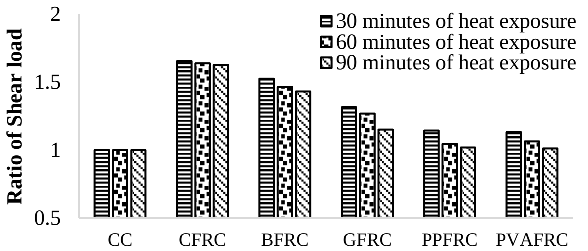

Figure 8. Shear resistance of M30 heated FRC specimens

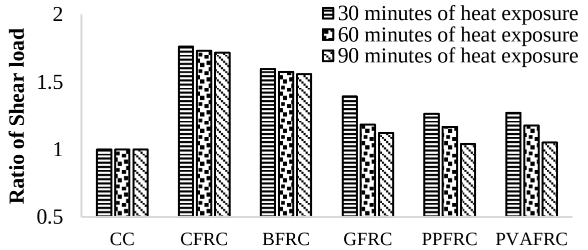

Figure 9. Shear resistance of M40 heated FRC specimens

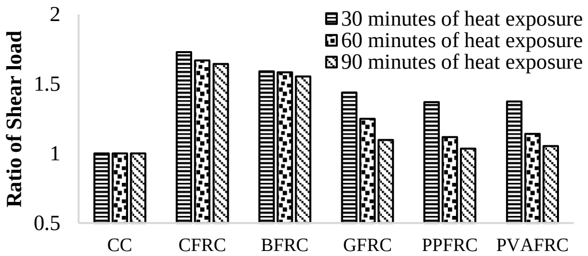

Figure 10. Shear resistance of M50 heated FRC Specimens

In the case of M20 grade PPFRC and M20 grade PVAFRC specimens, a sudden drop (1.2 times to 1.06 times) was observed on the shear resistance of concrete, when exposed to 60 and 90 minutes. In the case of PPFRC and PVAFRC, the similar pattern is observed for other grades (M30, M40 and M50) of concrete. It may be because of the low melting point of these fibers which causes melting of fibers inside the specimens when exposed to elevated temperatures. This reduced the tensile strength of fibers in heated specimen compared to CC. The melting of fibers leads to the creation of pore holes in concrete specimens, which helps to reduce the crack propagation [20, 21]. Hence it shows better shear resistance capacity (1.1-1.2 times) than CC.

3. 2. Thermal Crack Formation Figure 11 (11A, 11B, 11C, 11D, 11E, 11F) shows the surface view of M20 grade specimens heated up to 90 minutes. It is evident from the figures that the M20 grade CC had more surface pitting than the BFRC, CFRC, GFRC, PPFRC and PVAFRC specimens. For PPFRC and PVAFRC specimens, only surface pitting was observed. This is because of reduction in pore pressure through pore channel created when these specimens exposed to elevated temperature [20] GFRC, BFRC and CFRC specimens had less thermal cracks than CC. It may be due to the bridging effect of high melting point fibers (GF, BF and CF) [22]. The GFRC have small amount of progressive cracks. This is because of the reduction in the tensile capacity of GF, when it is exposed to elevated temperature [19]. Hence reduction in bridging effect between cement matrixes occurs.

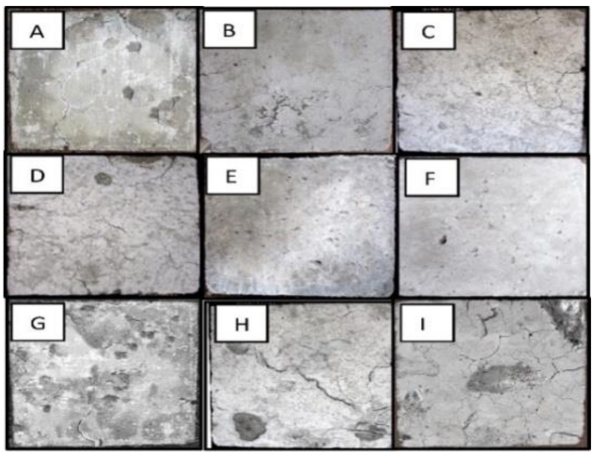

Figure 11. Surface view of specimens: A. M20 CC, B. M20 PPFRC, C. M20 PVAFRC, D. M20 GFRC, E. M20 BFRC, F. M20 CFRC, G. M30 CC, H. M40 CC and I. M50 CC

Also Figure 11 (11A, 11G, 11H, 11I) shows the surface view of the M20 grade CC, M30 grade CC, M40 grade CC and M50 grade CC specimens after being exposed to 90 minutes of heat exposure. From the visual inspection, it is identified that M50 grade CC has the maximum surface damage when compared to M20 grade CC specimens. This may be due to the high density of concrete (M50 grade CC) with less porosity [2]. When the specimens were exposed to elevated temperature, the pore pressure developed within the concrete is high in higher-grade concrete and this induced more surface cracks.

4. CONCLUSIONS

FRC specimens were exposed to elevated temperature up to 90 minutes' duration of heating following the standard fire curve. Shear resistance of FRCs were analyzed before and after heating. The higher grade concrete (M50) is found to retain high shear strength. Addition of fibers improved the shear strength of concrete. The effect of fibers on concrete in terms of shear strength and crack control after being exposed to elevated temperature are concluded below:

- The concrete specimens with CF show better residual shear strength in all grades and at different temperature levels. For 90 minutes of heat exposure, CFRC retained 116 and 91% shear strength of the unheated CC specimen for M20 grade and M50 grade, respectively.
- Concrete specimen with BF (99 - 86%) and GF (80 - 61%) also exhibited high shear strength after exposure to 90 minutes of elevated temperature but the shear strength was found to be lower than that of concrete specimens with CF.
- The residual shear strength of the PPFRC and PVAFRC specimens after exposure to 30 minutes, were found to be 115% (M20) - 108% (M50) and 116% (M20) - 109% (M50), respectively. From 60 minutes of heat exposure onwards, residual shear strength was found to be decreasing. In addition, at 90 minutes of heat exposure, PPFRC and PVAFRC specimens exhibited marginal increment in shear strength than control concrete specimen. It is proved that fibers improve the shear resistance of concrete exposed to elevated temperature. Also addition of fibers prevented the spalling of concrete specimens.
- The concrete specimens with CF and BF were found to have minimum micro cracks even after exposure to elevated temperature. Addition of PPF and PVAF reduced the spalling but the crack propagation could not be prevented at high temperatures. The specimens with GF had more cracks and more surface damage after the exposure. Concrete with higher strength grade (M50) had high rate of crack propagation.

The results of the research are applicable for RC beams exposed to standard fire following ISO 834 fire curve. In case of external fire curve, the behavior of fiber reinforced concrete may change. In addition, there is a scope to compare the performance of different FRC with the corresponding optimum volume fraction of fibers.

5. ACKNOWLEDGEMENT

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Persian Abstract

چکیده

سوانح آتش سوزی اجتناب ناپذیر است و یکی از مهمترین خطراتی است که باعث از بین رفتن جان و اشیاء با ارزش می شود. تحقیق حاضر به بررسی تأثیر الیاف بر استحکام برشی بتن در معرض دمای بالا طبق استاندارد ISO 834 پرداخته است. الیاف مورد استفاده در این تحقیق شامل بازالت ، کربن ، شیشه ، پلی پروپیلن و پلی وینیل الکل بودند. بتن از M20، M30، M40 و M50 استفاده شد. نتایج نشان داد که با افزایش دما مقاومت برشی کاهش یافته است. استحکام برشی با افزودن الیاف در تیرهای بتن مسلح که در معرض دمای بالا است افزایش می یابد. نمونه های بتن مسلح با فیبر کربن نسبت به سایر نمونه ها مقاومت برشی باقیمانده بهتری نشان دادند. افزودن الیاف کربن و بازالت در بتن باعث کاهش ریزگردها در نمونه های در معرض دمای بالا می شود. افزودن الیاف پلی پروپیلن و پلی وینیل الکل باعث کاهش فاصله می شود اما از انتشار ترک در نمونه هایی که در معرض دمای بالا قرار دارند ممانعت نخواهد کرد.