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Investigation on Impact Strength of Fiber Reinforced Concrete Subjected to Elevated Temperature

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Abstract: The effect of elevated temperature on impact strength of Fiber Reinforced Concretes (FRC) is investigated in this paper. Cylinder specimens are used with different types of fibers such as Aramid, Basalt, Carbon, Glass, Polypropylene and PVA. All the specimens were exposed to elevated temperature as per standard fire curve following ISO 834. After heating the specimens are cooled by natural air prior to impact strength test. The tests are conducted as per ACI committee 544. Test result reveals that addition of fiber enhances the impact strength of concrete specimens. Concrete with Carbon fiber and Basalt fiber exhibits better performance than concrete with other fibers. In unheated condition Carbon fiber shows 5.9 times increase in impact resistance with respect to reference specimen. For 90 minutes of heat exposure, all FRCs except concrete with Aramid fiber shows 2 times better impact resistance than that of reference specimen.

Index Terms: Fiber Reinforced Concrete, Impact Strength, Elevated Temperature, Carbon Fiber, Basalt Fiber

I. INTRODUCTION

Concrete is a brittle material due to its higher rigidity. During the past few decades, several experiments had been conducted to improve the ductility of concrete [9-13]. Presently Fiber Reinforced Concretes (FRC) is used in construction industry to overcome the deficiencies regarding the tensile strength of concrete. For better usage of fibers in cement composites, different types of fiber products are also developed [1]. Toughness is an important mechanical property, FRC exhibits higher toughness when subjected to different type of loads. Impact strength can be calculated based on the toughness of the material under impact loads. Previous researches indicates that several investigations and tests have been conducted to analysis the impact resistance of concrete specimens [2- 8]. This paper evaluates the impact resistance of different FRC specimens by impact test and the results are evaluated in terms of ultimate failure impact energy.Concrete structures are affected by a many of risks during their life span, such as earth quake, fire and impact loading etc. When concrete structures are loaded repeatedly as a function of time, severe damages may occur. Blast induced impact and fire always happen concurrently on structural members thereby encircled with a risk of impact load with fire load [14, 15].Few research works carried out on impact resistance of FRC after the heat exposure. Though some studies have considered mechanical properties of blast induced impact and fire load of concrete structures [14-16], it was not reported the impact resistance of different types of fiber reinforced concrete after exposed to heat. The objective of the investigation is to evaluate the impact resistance of plain concrete (Reference specimen) with different strength grades after exposed to elevated temperature by standard fire curve [19]

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II. MATERIALS AND TEST METHODS

A. Materials and Mix Proportioning

Table 1: Properties of Fiber

Fiber	Melting Category	Density (g/cu.cm)	Melting point (^{O}C)
AF	Low	1.44	150
BF	High	2.65-2.8	1400
CF	High	1.6	1200
GF	High	2.6	1500
PPF	Low	0.90 -0.91	160 - 170
PVA	Low	1.29	220

Concrete specimen used for this investigation consists of plain concrete with fibers. Ordinary Portland Cement (OPC) of 53gradeswas used to cast all the specimens. Crushed stones of size 20mm were used as coarse aggregate. The 12mm length short fibers which are supplied in bunch are dispersed in concrete mix. Table 1 shows the properties of Aramid (AF), Basalt (BF), Carbon (CF), Glass (GF), Poly Propylene (PPF) and Polyvinyl Alcohol (PVA) fibers that were used in specimens. The volume fraction used for all fibers were 0.25%. A water reducing agent Conplast SP430 was used to improve the workability of the concrete mixtures.

B. Test specimens

Concrete specimen of 150mm diameter and 64mm height were cast. After casting the specimens were kept in the curing tank for 28 days [17, 18] (figure 1).

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After curing the specimens were dried for 24 hours prior to the test. Specimens were heated up to 30 minutes, 60 minutes and 90 minutes (821^0C, 925^0C and 986^0C) respectively as per Standard fire curve [19]. Heated specimens were cooled by natural air before testing.

The investigation has been carried out for M20, M30, M40 and M50 grades of concrete.

Figure 1: Specimens in Curing Tank

C. Test procedure

Drop weight impact test was carried out on specimens as per the guidelines of ACI committee 544 [17]. Figure 2 shows the concrete specimen and equipment for conducting the drop weight impact resistance test. The equipment consists of a standard manually operated 4.45 kg compaction hammer with a height of 457mm drop on a hardened steel ball of 63.5mmdiameterwhich is resting on a flat base plate with positioning bracket. The test specimen is then placed on the base plate with the finished face up and positioned inside the brackets. During this testing the hammer was dropped repeatedly and the number of drops required to produce the first visible crack (N1) in the specimen and for the ultimate failure (N2) were recorded.

The impact energy of the specimens was claculated by [20]

E= Nmgh (1)

Where

E - impact energy,

N - the number of drops,

m - the mass of dropped ball(4.45 kg),

g - the gravity based acceleration (9.8m/s^2)

h - the height of drop (457mm).

Figure 2: Impact Test Setup

III. RESULTS AND DISCUSSION

A. Impact resistance of specimens without heat exposure

It is observed that for the plain concrete specimens (without heat exposure) after the testing the pieces are fractured into separate pieces, whereas the specimens with fiber the pieces damage level was less. This phenomenon may be because of the addition of fiber leads to slow down the crack formation and final failure of the specimen [20]. From table 2 and table 3 it is understood that the impact energy of every FRC specimen increased 4-7 times with respect to the fiber properties than that of the plain concrete. This can be explained by assumption that the fiber enhanced the ductility behaviour of the concrete [20].Concrete with AF in all grades of concrete shows 5 times increase in impact energy than plain concrete. Concrete with BF and CF shows 6 times increase in impact energy. GF shows least (3 times) increment compared to other FRC's. PPF and PVA fibers shows 4 times increment in the impact energy as compared to that of plain concrete. M50 grade concrete (D series) containing CF possess highest impact energy of 2034N-m and 2733N-m for first crack and ultimate failure respectively. Similarly it was observed for the specimen with BF the impact energy was2014N-m and 2693N-m. The similar was observed for other grades (A, B and C series) of concrete. The crack bridging property of the fibers is assumed to absorb additional energy and inhibits the sudden failure of specimens. The present investigation findings support the research findings of Mohammad hosseini et al [21] and Mastali et al [22]

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Table 2: Impact Resistance of Plain and FRC specimens (First Crack)

Mix	Characteristic compressive strength (MPa)	Type of fiber	No of blows to develop first crack				Impact Energy (N-m)			
			Duration of heating				Duration of heating			
			Reference	30 min.	60 min.	90 min.	Reference	30 min.	60 min.	90 min.
A1	20	--	9	4	2	1	179.55	79.8	39.9	19.95
A2	20	AF	40	2	1	1	798	39.9	19.95	19.95
A3	20	BF	61	5	2	1	1216.96	99.75	39.9	19.95
A4	20	CF	60	5	2	1	1197.01	99.75	39.9	19.95
A5	20	GF	26	4	1	1	518.7	79.8	19.95	19.95
A6	20	PPF	39	4	1	1	778.05	79.8	19.95	19.95
A7	20	PVA	40	4	1	1	798	79.8	19.95	19.95
B1	30	--	11	5	2	1	219.45	99.75	39.9	19.95
B2	30	AF	52	2	1	1	1037.41	39.9	19.95	19.95
B3	30	BF	73	7	2	1	1456.36	139.65	39.9	19.95
B4	30	CF	74	7	2	1	1476.31	139.65	39.9	19.95
B5	30	GF	38	6	3	1	758.1	119.7	59.85	19.95
B6	30	PPF	48	6	3	1	957.61	119.7	59.85	19.95
B7	30	PVA	47	5	3	1	937.66	99.75	59.85	19.95
C1	40	--	13	6	2	1	259.35	119.7	39.9	19.95
C2	40	AF	68	2	1	1	1356.61	39.9	19.95	19.95
C3	40	BF	89	8	3	1	1775.56	159.6	59.85	19.95
C4	40	CF	90	7	3	1	1795.51	139.65	59.85	19.95
C5	40	GF	47	6	2	1	937.66	119.7	39.9	19.95
C6	40	PPF	62	5	2	1	1236.91	99.75	39.9	19.95
C7	40	PVA	61	5	2	1	1216.96	99.75	39.9	19.95
D1	50	--	17	8	3	1	339.15	159.6	59.85	19.95
D2	50	AF	86	3	1	1	1715.71	59.85	19.95	19.95
D3	50	BF	101	10	3	1	2014.96	199.5	59.85	19.95
D4	50	CF	102	11	3	1	2034.91	219.45	59.85	19.95
D5	50	GF	61	8	3	1	1216.96	159.6	59.85	19.95
D6	50	PPF	79	7	3	1	1576.06	139.65	59.85	19.95
D7	50	PVA	80	7	3	1	1596.01	139.65	59.85	19.95

B. Impact resistance of specimens with heat exposure

For all concrete mixes, reduction in impact resistance after exposure to elevated temperature was observed. The degradation of impact strength on concrete may be due to the thermal gradient as well as different physical and chemical changes occurred in the concrete [23-26]. Table 2 and Table 3 illustrate the loss in impact strength of concrete with different mixes with reference mix. In the case of 90 minutes (986°C) of heat exposure, all the specimens broken into pieces with 1-3 number of drops and first crack was formed in the first drop itself. It may be due to the formation of voids and thermal stress formed inside the specimens during the heating process. For the temperature with higher range there were little impact energy exists for the all FRC's. Because at these temperatures bond between the fibers and matrix decreased as the mechanical properties of the fibers reduced [27-28].

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Table 3: Impact Resistance of Plain and FRC specimens (ultimate failure)

Mix	Characteristic compressive strength (MPa)	Type of fiber	No of blows to develop ultimate failure				Impact Energy (N-m)			
			Duration of heating				Duration of heating			
			Reference	30 min.	60 min.	90 min.	Reference	30 min.	60 min.	90min.
A1	20	--	12	7	3	1	239.4	139.65	59.85	19.95
A2	20	AF	58	4	2	1	1157.11	79.8	39.9	19.95
A3	20	BF	70	7	3	2	1396.51	139.65	59.85	39.9
A4	20	CF	71	9	4	2	1416.46	179.55	79.8	39.9
A5	20	GF	37	7	3	2	738.15	139.65	59.85	39.9
A6	20	PPF	45	8	4	2	897.75	159.6	79.8	39.9
A7	20	PVA	43	7	4	2	857.85	139.65	79.8	39.9
B1	30	--	14	8	3	1	279.3	159.6	59.85	19.95
B2	30	AF	71	5	2	1	1416.46	99.75	39.9	19.95
B3	30	BF	86	9	4	2	1715.71	179.55	79.8	39.9
B4	30	CF	87	11	4	2	1735.66	219.45	79.8	39.9
B5	30	GF	45	9	4	2	897.75	179.55	79.8	39.9
B6	30	PPF	55	10	4	2	1097.26	199.5	79.8	39.9
B7	30	PVA	56	11	4	2	1117.21	219.45	79.8	39.9
C1	40	--	18	9	4	2	359.1	179.55	79.8	39.9
C2	40	AF	90	6	3	1	1795.51	119.7	59.85	19.95
C3	40	BF	108	11	4	3	2154.61	219.45	79.8	59.85
C4	40	CF	110	13	5	3	2194.51	259.35	99.75	59.85
C5	40	GF	56	11	4	2	1117.21	219.45	79.8	39.9
C6	40	PPF	69	12	5	3	1376.56	239.4	99.75	59.85
C7	40	PVA	70	11	6	2	1396.51	219.45	119.7	39.9
D1	50	--	22	10	4	2	438.9	199.5	79.8	39.9
D2	50	AF	112	7	3	1	2234.41	139.65	59.85	19.95
D3	50	BF	135	13	5	3	2693.26	259.35	99.75	59.85
D4	50	CF	137	16	6	3	2733.16	319.2	119.7	59.85
D5	50	GF	70	13	5	2	1396.51	259.35	99.75	39.9
D6	50	PPF	86	15	6	2	1715.71	299.25	119.7	39.9
D7	50	PVA	84	16	6	2	1675.81	319.2	119.7	39.9

Specimens heated up to 60 minutes (925^{0}C), the first crack developed with 1-3 hammer drops. But the ultimate failures of specimens were according to the type of fiber added in to it. Concrete with AF specimens suffered with severe degradation at its 3rd drop. When heated up to 30 minutes (821^{0}C) a sudden decrement in impact resistance observed for all the specimens with respect to that of plain concrete. The drastic decrease in impact strength is observed for concrete with AF and it was 64% - 67%. The least reduction (21%-27%) in impact resistance was observed for concrete with CF.

C. Impact resistance of specimens based on type of fiber

Figure 3 depicts the impact resistance of various FRC specimens exposed to heat exposure. It is clearly visible that the addition of fiber has a direct contribution on impact resistance. For unheated FRC specimens it can be seen that the impact resistance are 3 to 6 times more than that of reference specimen. A drastic drop (5.2 – 14.5 times) in impact resistance can be seen when all FRC specimens exposed to 30 minutes of heat exposure. Concrete with CF has more impact resistance (1.1 – 2.3 times) compared to other specimens in 30 minutes of heat exposure. For 60 minutes of heat exposure CF, PPF and PVA shows similar impact resistance. For 90 minutes of heat exposure, plain concrete and concrete with AF shows least impact resistance (19.95 N-m) whereas concrete with all other fibers exhibit better impact resistance (39.90 N-m).

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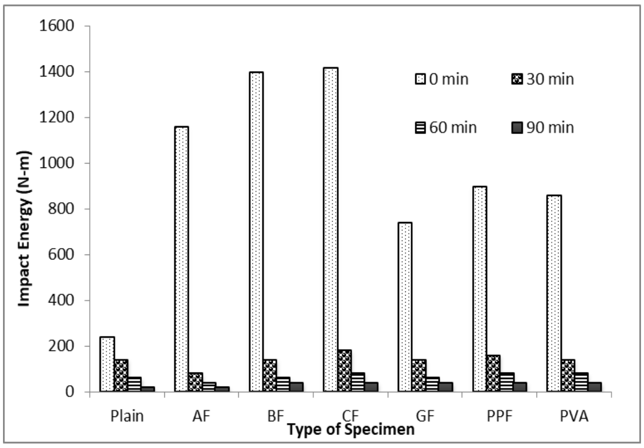

Figure 3: Impact Energy of different types of specimen

IV. CONCLUSIONS

The impact resistance of plain concrete and various fiber reinforced concretes of different grades with and without heat exposure are investigated. Based on the observations made from the investigation, the following results concluded.

- The addition of fiber enhanced the impact strength of concrete.
- The physical properties of fibers affect the impact resistance. The highest impact resistance is observed for concrete with CF.
- At elevated temperature all the specimens showed negligible variations in impact resistance due to the loss in bond with concrete, i.e. Specimen subjected to 90 minutes duration of heating.
- All the grades of concrete exhibited a similar trend in impact resistance for all the duration of heating.
- AF showed a drastic reduction in impact resistance with increase in temperature.

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