STUDY ON FIBER REINFORCED CONCRETE ON THE EFFECT OF TEMPERATURE VARIATION

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***Abstract*------** Fire resistant of the concrete structure is an important factor to be considered for the design of building. Fire may cause different degree of damage to the structure depending up on the temperature and duration of its exposure. Adding of fiber in the concrete improves the residual strength and the fracture energy. In this research an experimental investigation has been carried out to study the impact strength of fiber in concrete at elevated temperature. Specimens will be heated from 250ºC to 1000ºC and cooled by natural air. Steel, Polypropylene, Basalt, Glass and Carbon fibers are added to enhance the fracture energy of concrete at elevated temperature. An attempt has been made to study the effect of temperature on impact strength on concrete at different elevated temperature. These specimens will be heated using Muffle furnace. After heating, the specimens will be allowed to cool naturally in the furnace for about 24 hours. Impact strength of specimens are compared with reference specimen (no fiber).

I. INTRODUCTION

A. *General*

Concrete is weak in tension and has a brittle character. The concept of using fibers to improve the characteristics of construction materials is very old. Early applications include addition of straw to mud bricks, horse hair to reinforce plaster and asbestos to reinforce pottery. Use of continuous reinforcement in concrete (reinforced concrete) increases strength and ductility, but requires careful placement and labour skill. Alternatively, introduction of fibers in discrete form in plain or reinforced concrete may provide a better solution. The modern development of fiber reinforced concrete (FRC) started in the early sixties. Addition of fibers to concrete makes it a homogeneous and isotropic material. When concrete cracks, the randomly oriented fibers start functioning, arrest crack formation and propagation, and thus improve strength and ductility. The failure modes of FRC are either bond failure between fiber and matrix or material failure.

The addition of fibers significantly improves many of the engineering properties of mortar and concrete, notably impact strength and toughness. Flexural strength, fatigue strength, tensile strength and the ability to resist cracking and spalling are also enhanced. Fiber reinforced concrete (FRC) is a composite material consisting of cement, sand, coarse aggregate, water and fibers. In this composite material, short discrete fibers are randomly distributed throughout the concrete mass. The behavioral efficiency of this composite material is far superior to that of plain concrete and many other construction materials of equal cost. Due to this benefit, the use of FRC has steadily increased during the last two decades and its current field of application includes: airport and highway pavements, earthquake-resistant and explosive-resistant structures, mine and tunnel linings, bridge deck overlays, hydraulic structures, rock- slope stabilization, etc.

II. METHADOLOGY & MATERIAL STUDY

A. *General*

Fiber reinforced concrete made by different fibers like steel fiber ,polypropylene fiber, glass fiber, carbon fiber, basalt fiber. These fiber reinforced concrete specimens were casted and curing done by 28 days. This specimens were placed in a furnace up to 1000°c and cooled by air and water.

B. *Material Specification*

1. Cement

The cement used in this experimental investigation is done by 43 grade OPC. The basic properties are evaluated as per Indian specifications IS 8112-1989 and results are given in table II.

Fineness Test

This test is used for checking the proper grading of cement. For testing fineness of cement take 100gm of cement and this continuously passed through standard sieve No. 9 for 15 minutes. According to IS:269-1976 this weight should not be more than 10% of its original weight.

Table I. Fineness Test of Cement

Sl.No.	Weight of cement (g)	Weight retained on sieve (g)	% weight of residue (W_2/W_1) * 100
1	100	4.8	4.8
2	100	4.3	4.3

Percentage weight of residue = (4.9 + 4.3) x 100
= 4.55

This result satisfies the IS specification.

Specific Gravity

Weight of cement = 65g
Initial reading = 0.8ml
Final reading = 21.6ml
Volume of cement =final reading – initial reading
=21.6 – 0.8

=20.8ml

Specific gravity = weight / volume

$= \frac{65}{20.8}$

=3.13

Table II. Test Results of Cement

S.No	Description	Result Obtained
1	Grade	OPC 53
2	Specific Gravity	3.13
3	Initial Setting Time	70 min
4	Final Setting Time	105 min
5	Standard Consistency	33%
6	Fineness	4.55

2. Fine Aggregate

Fine aggregate used in this investigation is clean river sand passing through 4.75mm sieve. The fine aggregate were tested, as per Indian Specifications IS 383-1970 and results are given in table III.

Sieve Analysis

The particle size distribution of fine aggregate was determined from sieve analysis and the experiments are carried out to find the properties of fine aggregates. IS sieve ranging from 10mm to 150micron were used to conduct the sieve analysis and fineness modulus was also found. The properties of fine aggregate satisfy the allowable limits of IS 383: 1970.

Table III. Sieve Analysis of Fine Aggregate

IS sieve Designation	Mass retained	Percentage retained	Percentage passing	Cumulative percentage Retained
4.75mm	4	0.2	99.8	0.2
2.36mm	98	0.4	99.4	0.6
1.18mm	249	9.8	89.6	10.4
600µm	555	24.9	64.7	35.3
300µm	81	55.5	9.2	90.8
150µm	5	8.1	1.1	98.9
75 µm	5	0.5	0.6	99.4

Fineness modulus = sum of cumulative % weight retained/100
= (0.2+0.6+10.4+35.3+90.8+98.9) / 100
=2.4

Specific Gravity

Pycnometer was used for determining specific gravity. Take mass of empty Pycnometer (M_1). Then put 200 to 400gm of oven dried sample in the Pycnometer and take the mass (M_2). Pycnometer was then filled with water to the top and shaken well to remove entrapped air. Take its mass (M_3). Then empty the Pycnometer and fill with distilled water alone and take mass (M_4).

Table IV. Specific gravity of fine aggregate test

Description	Weight of sample
Weight of Pycnometer (W_1)	616 g
Weight of Pycnometer + sample (W_2)	1379 g
Weight of Pycnometer + sample + water(W_3)	1936 g
Weight of Pycnometer + water (W_4)	1467 g

Specific gravity = $(W_2-W_1) / ((W_2-W_1) – (W_3-W_4))$
= (1379 - 616) / ((1379 - 616) - (1936 – 1467))
= 2.61

Table V. Properties of Fine Aggregates

SI No	Description	Result Obtained
1	Specific Gravity	2.61
2	Fineness Modulus	2.4

3. Coarse Aggregate

Coarse aggregate used in this investigation is locally available crushed aggregates having maximum size of 20mm. The coarse aggregate were tested, as per Indian Specifications IS 383-1970 and results are given in table VI.

Particle Size Distribution: 2kg of coarse aggregate was taken. The sieves were in the order of 80mm, 40mm, 20mm, 10 mm and 4.75 mm with 80mm size at the top. Carry out sieving for 15 minutes and the weight of aggregate retained on each sieve was obtained.

Table VI. Sieve Analysis of Coarse Aggregate

IS sieve designation	Mass Retained	Percentage Retained	Percentage passing	Cumulative percentage retained
80mm	0	0	100	0
40mm	870	43.5	43.5	56.5
20mm	466	23.3	66.8	33.2
10mm	534	53.4	0	100
4.75mm	0	0	0	100
Pan	0	0	0	100

Fineness modulus= sum of cumulative % weight retained / 100
= (56.5+33.2+100+100+100+100+100+100) / 100
= 6.9

Specific Gravity

The container was filled with the given aggregate in three layers and then overfills with water. The weight of container with aggregate and water was noted. Empty the container and allow the aggregate to drain. Refill the container with water and take its weight. Place the aggregate on a dry cloth and gently surface dry with the cloth keeping it away from sun light. Take the weight of the surface dried aggregate. Place the aggregate in the oven in a shallow tray at a temperature of 100 to 110° C for 24± ½ hours. Cool the aggregates and note down the weight of oven dried aggregate

Table VII. Specific gravity of Coarse aggregate test

Description	Weight of sample
Weight of empty pycnometer (W_1)	625 g
Weight of Pycnometer + sample (W_2)	825 g
Weight of Pycnometer + C.A + water(W_3)	1620 g
Weight of Pycnometer + water (W_4)	1492 g

Specific gravity = $(W_2 - W_1) / (W_4 - W_1) - (W_3 - W_2)$
= (825-625) / (1492-625)-(1620-825)
= 200 / 72
= 2.77

Table VIII. Properties of Coarse Aggregates

Sl.No	Description	Result Obtained
1	Specific Gravity	2.77
2	Fineness Modulus	6.9

4. Water

Water is a key ingredient in the manufacture of concrete. Water used in concrete mixes has two functions: the first is to react chemically with the cement, which will finally set and harden, and the second function is to lubricate all other materials and make the concrete workable. Although it is an important ingredient of concrete, it has little to do with the quality of concrete. One of the most common causes of poor-quality concrete is the use of too much mixing water.

5. Fiber in Concrete

An unrestrained concrete member will shorten in all directions when it dries or cools. But because most concrete structural members are at least partially restrained, tensile stresses build up when the concrete dries or cools. The stresses are about the same as those that would occur if the concrete had been allowed to contract freely and had then been pulled back to its original length. When these stresses exceed the tensile strength of the concrete, the member cracks. Measures that can be taken to control this cracking include reducing the potential shrinkage of the concrete, providing joints to control crack location and adding nonstructural reinforcement. Even if joints are used to control crack location, cracks may still occur between joints. And in structural reinforced concrete, added measures may be needed to control shrinkage and temperature cracking. Goals for the engineer and contractor are to reduce the number of cracks and to keep ones that do form from opening up too wide. Adding polypropylene fibers to the concrete has been suggested as one way of achieving these goals.

Table IX. DETAILS OF FIBERS

Types of Fiber	Length (mm)	Aspect ratio	Elastic modulus (GPa)	Melting point (°C)	Tensile strength (MPa)	Density (g/cm³)
Steel fiber	30	60	210	1425-1710	90-1250	0.9-1.6
Polypropylene fiber	12	334	38	234-288	270-650	0.91
Glass fiber	10	208	69	849-930	550-930	2.46
Basalt fiber	12	1333	100-110	650	480-630	2.65
Carbon fiber	12	1200	297	1000	330-750	1.80

C. *Role of Fibers*

Cracks play an important role as they change concrete structures into permeable elements and consequently with a high risk of corrosion. Cracks not only reduce the quality of concrete and make it aesthetically unacceptable but also make structures out of service. If these cracks do not exceed a certain width, they are neither harmful to a structure nor to its serviceability. Therefore, it is important to reduce the crack width and this can be achieved by adding polypropylene fibers to concrete .the bridging of the cracks by the addition of PP fibers. Thus addition of fibers in cement concrete matrix bridges these cracks and restrains them from further opening. In order to achieve more deflection in the beam, additional forces and energies are required to pull out or fracture the fibers. This process, apart from preserving the integrity of concrete, improves the load-carrying capacity of structural member beyond cracking. This improvement creates a long post-peak descending portion in the load deflection curve. Reinforcing steel bars in concrete have the same beneficial effect because they act as long continuous fibres. Short discontinuous fibers have the advantage, however, of being uniformly mixed and dispersed throughout the concrete.

III. MIX DESIGN

The mix design is done for M50 concrete as per IS 456- 2000 and IS 10262-2009.Mix design for M50 concrete is given below.

Mix Design for M50 Concrete

1) Target Mean Strength

$F_{ck1} = f_{ck} + 1.65 \times s$ (clause 3.2 of IS 10262-2009)
F_{ck1} = Target average compressive strength at 28days
f_{ck} = Characteristic compressive strength at 28days
s = Standard deviation (table1 / IS10262-2009)
$F_{ck1} = 50 + (1.65 \times 5) = 58.25$ N/mm^2

2) Determination of Free Water-Cement Ratio

In (Fig.1 of IS 10262-1982) using a curve the water-cement ratio corresponding to the target mean strength is determined.

The free water cement ratio for the required target mean compressive strength of 58.25 = 0.35 (Reference by clause 4.1 of IS 10262-2009).

3) Determination of Water Content

Maximum water content = 186 kg (for 25-50 mm slump value from table 2 of IS 10262-2009)

Estimated w/c for 100 mm slump value = 186 + (6/100*186)
= 197 kg/m^3

4) Determination of Cement Content

The approximate free water cement content required for uncrushed coarse aggregate with maximum size of 20mm = 197 kg/m^3

Cement content = water content / water-cement ratio
= 197 / 0.35 = 562.82 kg/m^3 > 400 kg/m^3
(Hence ok)

5) Proportion of volume of coarse aggregate & fine aggregate content

From table 3, volume of coarse aggregate corresponding to 20mm size aggregate and fine aggregate of (zone I) for w/c ratio of 0.5 = 0.60.
In the present case w/c ratio is 0.35 Therefore the corresponding volume of coarse aggregate is increased to decrease the fine aggregate content. Therefore the corrected volume of coarse aggregate for w/c ratio 0.35 = 0.63.
Volume of fine aggregate content = 1-0.63 = 0.37

Mix calculation
Volume of concrete = 1 m^3
Volume of cement = (562.85x1)/(3.15x1000)
= 0.178 m^3
Volume of water = (197x1)/(1x1000)
= 0.197 m^3
Volume of all aggregate = 1- (0.178 + 0.197)
= 0.625 m^3
Mass of coarse aggregate = 0.625x0.63x2.7x1000
= 1063.12 kg/m^3
Mass of fine aggregate = 0.625x0.37x2.7x1000
= 624.375 kg/m^3

Hence we have found out the required mix proportions:

Table X. Mix Proportion for M50 Grade of Concrete

	Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Water(l)
Quantity	562.85	624.375	1063.12	197
Proportion	1	1.11	1.89	0.35

Table XI. Amount of Fiber Required

Amount of fiber required		
Percentage of fiber	For M50 grade of concrete (kg/m^3)	1 mould of impact cylinder (gram)
0.5%	2.814	3.65
1%	5.628	7.31
1.5%	8.442	10.97
2%	11.256	14.63

IV. EXPERIMENTAL INSVESTIGATION

A. Introduction

In order to understand the effects of elevated temperature on the properties of concrete, an extensive laboratory investigation was carried out. Tests were carried out on impact cylinder. The specimens were heated and cooled by air and water to reach the room temperature. This type of test is known as unstressed residual strength test. Unstressed residual strength test was carried out to determine the different grades of concrete specimens subjected to elevated temperatures. Reference and heated specimens were cast these specimens were heated from 250°c to 1000°c using muffle furnace. After the heating the specimens were cooled by air and water.

B. Testing of specimens under elevated temperature

An electric furnace was used to heat the specimens. The inner dimensions of the furnace are 500mmx500mmx500mm. The sides and top are lined with electrical heating coils embedded in refractory bricks. The control panel has a temperature controller to prevent damage to the furnace by tripping off, if the temperature inside the furnace exceeds the specified temperature. The maximum operating temperature of the furnace is 1200°C. The concrete specimens were exposed to fire inside the furnace and the furnace was heated from 250°C to 1000°C. After exposing the specimens to desired temperature and duration, the furnace was switched off and the specimens were taken out of the furnace. The specimens were naturally allowed to reach the room temperature by air cooling and water cooling. Ultimate loads of the specimens were found at 28th day for the reference and other specimens that were subjected to elevated to temperature.After 28 days of curing the specimens taken out from the curing tank and kept out for one day to avoid moisture. Then the specimens were placed in the furnace. The specimens were heated up to a temperature of 1000°C. The specimens were naturally allowed to reach the room temperature by air cooling and water cooling.

C. Impact strength behavior of concrete

Impact strength is the capability of the material to withstand a suddenly applied load and is expressed in terms of energy. The studies were extended to present the ductile characteristics of M50 grade concrete with different types of fibers under impact. For the studies on impact resistance of concrete,one hundred sixty eight specimens were casted. The drop weight impact testing apparatus was fabricated in the laboratory as per ACI 544 committee's recommendations. Equations were developed to determine the first crack strength of concrete with elevated temperature.

D. Experimental set up and testing procedure

The size of the specimen recommended by the ACI committee is 150mm in diameter and 64mm in height. The equipment consists of a standard manually operated 4.4Kg compaction hammer with an 18 inch drop (457mm) a 44mm diameter hardened steel ball and a flat base plate with positioning bracket. In addition to the above equipment, a mould to cast 150mm diameter and 64mm thick concrete

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specimens is needed. Thickness of the specimens is recorded to the nearest millimeter at its center and at the ends of a diameter prior to the test. The specimen is placed on the base plate with the finished face up and positioned with in two legs of the impact testing equipment. The bracket with the cylindrical sleeve is fixed in place and the hardened steel ball is placed on the top of the specimen within the bracket. The drop hammer is then placed with its base upon the steel ball and held vertically. The hammer is dropped repeatedly, and the number of blows required for the first visible crack to form at the top surface of the specimen and for ultimate failure is to be recorded. The first crack was based on visual observation. White washing the surface of the test specimen facilitated the identification of this crack. Ultimate failure is defined in terms of the number of blows required to open the cracks in the specimen sufficiently to enable fractured pieces to touch three of the two positioning legs on the base plate. The stages of ultimate failure are clearly recognized by the fractured specimen butting against the legs of the base plate.

V. EXPERIMENTAL INVESTIGATION ON BEHAVIOR OF FIBER REINFORCED CONCRETE AT ELEVATED TEMPERATURE

A. *Introduction*

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B. *Impact Strength Behavior of Concrete*

Impact strength is the capability of the material to withstand a suddenly applied load and is expressed in terms of energy. The studies were extended to present the ductile characteristics of M50 grade concrete with different types of fibers under impact. For the studies on impact resistance of concrete,one hundred sixty eight specimens were casted. The drop weight impact testing apparatus was fabricated in the laboratory as per ACI 544 committee's recommendations. Equations were developed to determine the first crack strength of concrete with elevated temperature.

C. *Impact energy*

The amount of energy required to fracture a material called impact strength.

The impact energy is calculated by the formula;

E = W x h x n (N-m)

Where;

W = weight of hammer (N),

h = height of fall (m)

n = no. of blows required for complete failure.

D. *Impact Test Results*

I.Effect of Temperature on Different Types of Fiber

Table XII. Impact Energy for Different Types of Fiber (0.5% and Air Cooling)

Temperature	Types of Fiber				
	Steel	Carbon	Basalt	Polypropylene	Glass
250°C	2189.627	2066.844	1739.423	1186.9004	572.9864
500°C	245.5656	245.5656	204.638	225.1018	143.2466
750°C	102.319	81.8552	61.3914	81.8552	61.3914
1000°C	61.3914	40.9276	40.9276	40.9276	20.4638

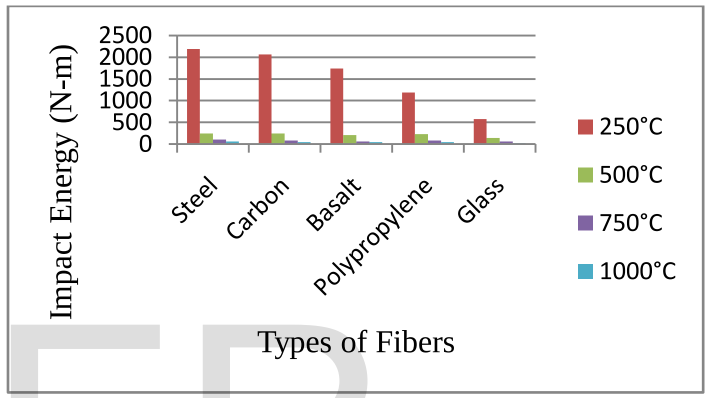

Fig I. Impact Energy for Different Types of Fiber (0.5% and Air Cooling)

Table XIII. Impact Energy for Different Types of Fiber (1% and Air Cooling)

Temperature	Types of Fiber				
	Steel	Carbon	Basalt	Polypropylene	Glass
250°C	2476.12	2517.047	1923.597	1452.9298	736.6968
500°C	286.4932	266.0294	245.5656	266.0294	163.7104
750°C	122.7828	102.319	81.8552	102.319	61.3914
1000°C	61.3914	61.3914	40.9276	40.9276	20.4638

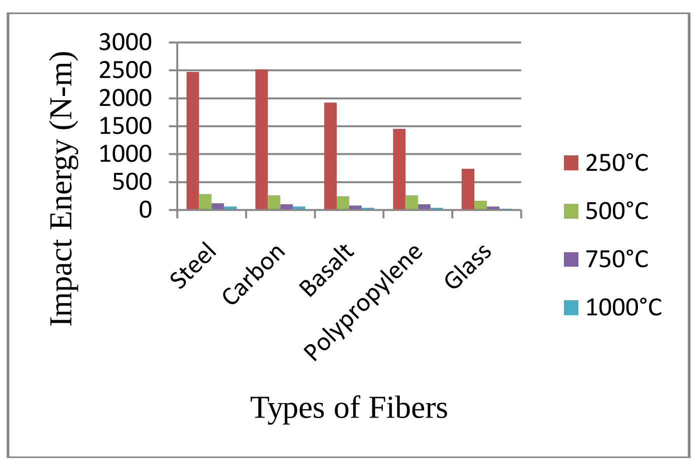

Fig II. Impact Energy for Different Types of Fiber (1% and Air Cooling)

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Table XIV. Impact Energy for Different Types of Fiber (1% and Water Cooling)

Temperature	Types of Fiber				
	Steel	Carbon	Basalt	Polypropylene	Glass
250°C	2230.554	2251.018	1780.351	1166.4366	593.4502
500°C	225.1018	245.5656	225.1018	245.5656	163.7104
750°C	102.319	81.8552	81.8552	81.8552	40.9276
1000°C	40.9276	40.9276	61.3914	20.4638	20.4638

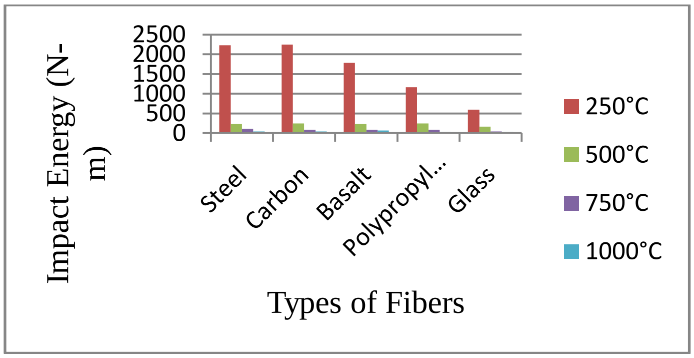

Fig III. Impact Energy for Different Types of Fiber (1% and Water)

Table XV. Impact Energy for Different Types of Fiber (1.5% and Water Cooling)

Temperature	Types of Fiber				
	Steel	Carbon	Basalt	Polypropylene	Glass
250°C	2373.801	2496.584	1964.525	1330.147	859.4796
500°C	266.0294	266.0294	245.5656	266.0294	184.1742
750°C	102.319	102.319	81.8552	81.8552	61.3914
1000°C	40.9276	61.3914	61.3914	40.9276	20.4638

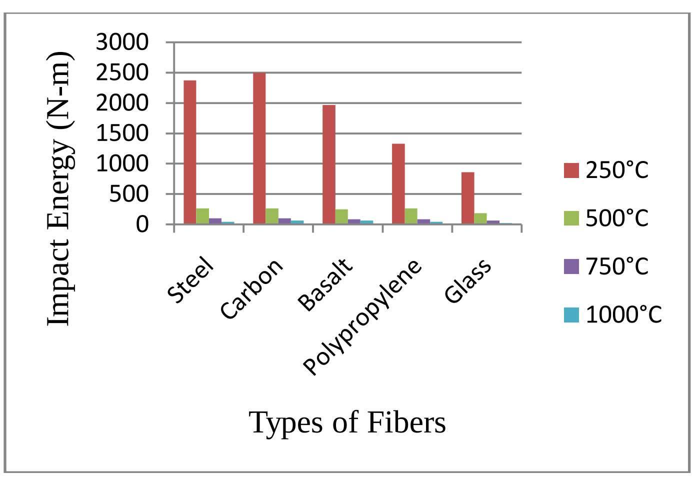

Fig IV. Impact Energy for Different Types of Fiber (1.5% and Water Cooling)

Table XVI. Impact Energy for Different Types of Fiber (2% and Water Cooling)

Temperature	Types of Fiber				
	Steel	Carbon	Basalt	Polypropylene	Glass
27°C	3478.846	3274.208	3274.208	2373.8008	1780.351
250°C	2905.86	2762.613	2414.728	1821.2782	1227.828
500°C	286.4932	286.4932	306.957	306.957	225.1018
1000°C	40.9276	61.3914	61.3914	40.9276	20.4638

It is observed from the figures that when the temperature increases impact strength decreases for all the types of specimens with different types of fibers. It was recorded from the results that all the types of specimens with different types of fiber failed to take impact strength at 1000°C. Steel fiber gives the better performance on impact strength compared to other types of fiber. Carbon and basalt fiber also takes more impact strength next to steel fiber. Polypropylene and glass fiber posses the least impact strength as compared to other fibers.

II. Effect of percentage of different types of fiber on impact energy

Table XVII. Impact Energy for Different Percentage Fiber (750°C and Air Cooling)

Types of Fiber	Percentage of Fiber				
	No fiber	0.5	1	1.5	2
Steel		245.5656	286.4932	327.4208	347.8846
Carbon	184.1742	240.5656	266.0294	306.957	327.4208
Basalt		204.638	245.5656	286.4932	306.957
Poly propylene		195.1018	206.0294	266.957	287.8846
Glass		143.2466	163.7104	184.1742	184.1742

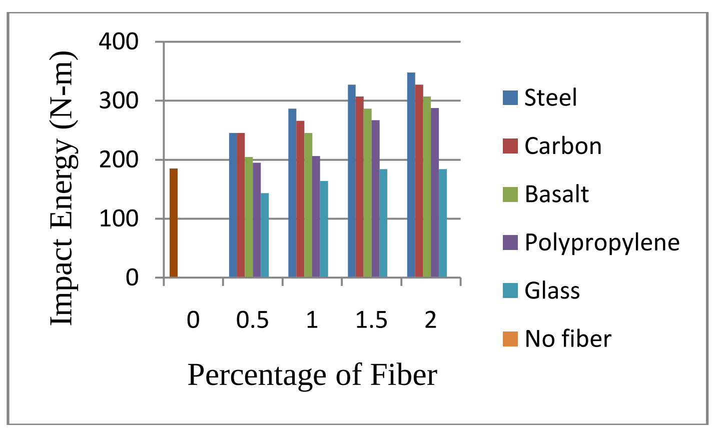

Fig V. Impact Energy for Different Percentage Fiber (750°C and Air Cooling)

Table XVIII. Impact Energy for Different Percentage Fiber (1000°C and Water Cooling)

Types of Fiber	Percentage of Fiber				
	No fiber	0.5	1	1.5	2
Steel	134.2466	204.638	225.1018	266.0294	286.4932
Carbon		184.1742	195.5656	258.0294	275.4932
Basalt		184.1742	189.1018	245.5656	246.957
polypropylene		156.638	178.5656	226.0294	239.957
Glass		122.7828	163.7104	184.1742	225.1018

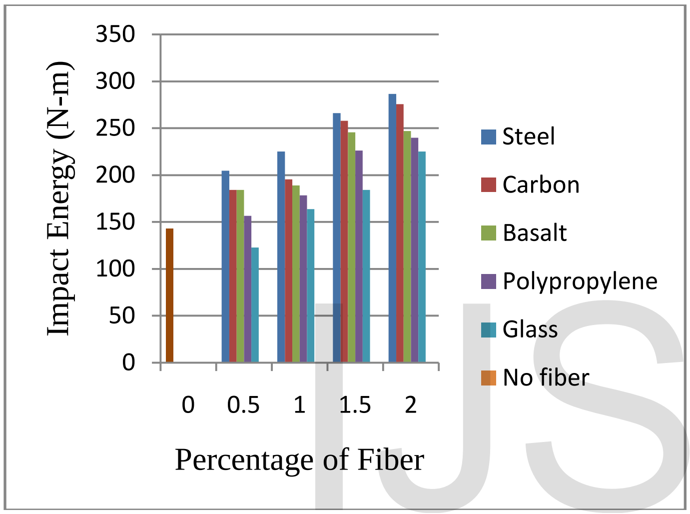

Fig VI. Impact Energy for Different Percentage Fiber (1000°C and Water Cooling)

It can be seen from the above graphs that when the percentage of fiber increases impact strength also increases for all the specimens with different types of fiber. At 750°C carbon and steel fiber has same impact energy where as at 1000°C steel, carbon and basalt fiber has same impact energy for higher percentage of fibers.

VI. CONCLUSION

Based on the experimental investigation the impact strength of heated specimens at 250°C increases in case of air and water cooling about 55%, 52%, 43%, 22% and 54%, 51%, 43%, 19% respectively for the specimens with steel fiber, carbon fiber, basalt fiber and polypropylene fiber. The impact strength of heated specimens at 500°C increases in case of air and water cooling about 38%, 35%, 27%, 20% and 40%, 35%, 32%, 26% respectively for the specimens with steel fiber, carbon fiber, basalt fiber and polypropylene fiber.The impact strength of heated specimens at 750°C increases in case of air and water cooling about 47%, 38%, 26%, 22% and 38%, 28%, 22%, 20% respectively for the specimens with steel fiber, carbon fiber, basalt fiber and polypropylene fiber.When the percentage of fiber increases, the impact strength of the concrete also increases in both air and water cooling when compared to the normal specimens.It suggested that use of steel fiber, carbon fiber and basalt fiber in concrete can be very effective in reducing the thermal stress and improving composite effects on post cracking behavior during heating process at high temperature.During the high temperature polypropylene fiber and glass fiber can mitigate or prevent the explosive spalling, but does not increase the fracture energy of the specimens.

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