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Influence of Temperature on the Fracture Parameters of Basalt Fiber Concrete

N. Shiva kumar[1] and Dr. T. Muralidhara Rao[2]
[1]PG Scholar, CVR College of Engineering/Civil Engg. Department, Hyderabad, India
Email: nshivakumarneela@gmail.com
[2]Professor, CVR College of Engineering/Civil Engg. Department, Hyderabad, India
Email: tmuralidhararao@gmail.com

Abstract: **In the present study, the effect of elevated temperatures on the strength parameters and fracture parameters of plain and basalt fiber high strength concrete was studied at the end of 28 days of conventional curing. The study was done for 100^{0}C, 300^{0}C, 500^{0}C, 700^{0}C and 900^{0}C temperatures for 02 hours in a high temperature furnace of 1000^{0}C capacity. The percentage decrease in strength parameters and fracture parameters was increased for plain and basalt fiber concrete specimens with the increase in the temperature.**

Index Terms: **Elevated temperatures, compressive strength, modulus of elasticity, fracture energy, fracture toughness, basalt fiber**

I. Introduction

Basalt is a type of igneous rock formed by the rapid cooling of lava at the surface of earth. Crushed basalt rock is the only raw material required for manufacturing the fiber. Characteristics of Basalt rock vary from the source of lava, cooling rate, and historical exposure to the elements. Though basalt rocks are available in different compositions, only certain compositions and characteristics can be used for making the continuous filaments with a diameter range of 9 to 24 microns. Basalt rocks with SiO2 content about 46% (acid basalt) are suitable for fiber production. Basalt fiber is composed of minerals plagioclase, pyroxene, and olivine. Basalt fibers are available in different lengths of 3,6,9,12,18 and 24mm having diameters 13-20 microns.

II. Literature Review

Aathithya Raja M, Saravanan G, Satheesh.V. S [3] used basalt chopped fibre of length 6mm and 12mm to study the compressive strength, flexural strength and split tensile strength. The addition of basalt chopped fibres to concrete improved the tensile strength and flexural strength significantly compared to plain concrete due to the ability to hold on crack surfaces of concrete.

N. Gopi, P. Baskar, B. Dharani and P. Abinaya[4] investigated the Mechanical properties of fiber reinforced concrete cubes, cylinders and prisms (M20 Grade) by varying the percentage of fibers (0.20%, 0.25%, and 0.30%). It was found that the addition of basalt fibre in concrete changes the mode of failure from brittle to ductile failure when subjected to compression, bending and impact. The experimental results showed that the compressive strength of Basalt fibre concrete was 38.34 N/mm^2 which is 22% higher than control concrete of 31.34 N/mm^2. The Basalt fibre concrete exhibited higher tensile strength than the normal concrete. The tensile strength of basalt fibre concrete was 7.66 N/mm^2 which is 45% higher than the tensile strength of normal concrete (5.26 N/mm^2).

Mohammed Ishtiyaque and M.G. Ghaikh[5] studied the effect of addition of basalt fibers at 0.25%, 0.5%, 0.75%, 1% (of volume of concrete) on fracture properties of concrete was studied. The test results showed an improvement in tensile strength and fracture properties of basalt fiber reinforced concrete mixes when compared with the normal mix. Tensile strength increased by 11% with addition of 0.25% basalt fibers. Fracture toughness also increased by 402% and 269% with addition of 0.25% and 0.75% of basalt fibers. But workability and compressive strengths reduced with the increased basalt fiber percentage.

M.P.Sureshkumar, S.Ramesh, P.Easwaran, P.Pruthviraj [7] discussed about the properties, advantages and application of basalt fiber in various concrete works. Basalt fiber has high oxidation resistance, high softening and melting temperatures, higher young’s modulus and tensile strength properties than that of glass fiber and it has better fire resisting property compared to the glass fiber. The basalt fiber rebar having full resistance against corrosion may be good alternative for the reinforcement of concrete structures, like RC bridge girders subjected to an environmental attack. Finally, it was concluded that the basalt fiber can be used as a good alternative strengthening material instead of glass fiber, carbon fiber, steel fiber, etc.

Suchita Hirde and Sagar Shelar[8] studied the variation of compressive strength, flexural strength and split tensile strength of M40 grade concrete with various percentages (0% to 5 % by weight of cement at interval of 1%) of basalt fiber. The length of fiber used was 18 mm length. The compressive strength increased by 7.31% for 3 % basalt fiber content. Flexural strength increased by 57.14 % for 5 % basalt fiber. Split tensile strength increased by 33.6% for 4 % basalt fiber content.

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III. Experimental Study

A. Cement

Ordinary Portland Cement of 53 grade conforming to IS:8112-1989 was used in the present study.

B. Aggregates

The physical properties of Fine aggregate and coarse aggregate used in the present study are presented in Table I.

TABLE I.
PHYSICAL PROPERTIES OF AGGREGATES

Physical property	Fine aggregates	Coarse aggregates
Specific Gravity	2.65	2.70
Fineness Modulus	2.87	7.10
Water Absorption	1.5 %	0.8 %

Fine aggregate in the concrete mix was taken in the following proportions. 2.36 mm=10% ;1.18 mm=30% ; 600 microns=25% ; 300 microns=25%; 150 microns=10%. Coarse aggregate in the concrete mix was taken in the following proportions. 20mm passing and 10 mm retained= 60%; 10mm passing and 4.75 mm retained=40%.

C. Water

Potable water was used in the preparation of concrete. Water used conforms to IS:456-2000.

D. Mineral Admixture

Ultrafine material 'Alccofine1203' conforming to IS:12089-1987 and IS:456-2000 (Clause No:5.2.2) was used as a supplementary cementitious material. Its particle size is much finer than the cement particle size. Ten percent of cement is replaced by alccofine1203. 10% replacement of cement is found to be the optimum percentage of replacement to produce the desired high strength concrete. The physical properties and chemical properties of Alccofine 1203 are given in Table II and Table III respectively.

TABLE II.
PHYSICAL PROPERTIES OF ALCCOFINE 1203

Specifi gravity	Bulk density (kg/m^3)	Fineness (cm^2/gm)	Particle size distribution (μ)		
2.9	680	12000	D10	D50	D90
			1-2	4-5	8-9

TABLE III.
CHEMICAL PROPERTIES OF ALCCOFINE 1203

CaO	Al_2O_3	SiO_2	Fe_2O_3	SO_3	MgO	Glass
34%	24%	35%	1.2%	0.13%	8.2%	>90%

E. Chemical Admixture

Superplasticizer used in the present study was MasterEASE3709(BASF Product). It is based on the modified polycarboxylic ether used for workability of concrete at fresh state. 1.5% by weight of binder was used in the concrete mix for workability.

F. Basalt fiber

In the present study 18mm length basalt fibers were used. The chemical composition of basalt fiber is shown in the below Table IV.

TABLE IV.
CHEMICAL COMPOSITION OF BASALT FIBER

S.No	Chemical Name	Percentage
1	Sio_2	51.6%-59.3%
2	Al_2o_3	14.6%-18.3%
3	Cao	5.9%-9.44%
4	Mgo	3.0%-5.33%
5	Na_2o+k_2o	3.6%-5.2%
6	Tio_2	0.8%-2.25%
7	Fe_2o_3+Feo	9.0%-14%
8	Others	0.09%-0.13%

Physical Properties of Basalt fibers:

Sustained operating temperature	-	+680° C
Minimum operating temperature	-	(-)260°C
Melting Temperature	-	1450°C
Density	-	2.6 g/cm^3
Elastic Modulus	-	93 Gpa
Elongation at break	-	3.15%
Tensile Strength	-	3200- 3850Mpa
Filament Diameter	-	13- 20 microns

G. Mix Proportion

Mix proportion used was 1:0.556:1.629:0.25. Using Absolute Volume Method, materials required are calculated as Cement = 721.643 kg/m^3; Fine Aggregate = 401.233 kg/m^3; Coarse Aggregate = 1175.556 kg/m^3; Water = 180.410 kg/m^3.

IV. Test Results

A. Compressive strength

Eighteen, 100mm plain concrete cubes and eighteen 100mm basalt fiber concrete cubes were cast and tested for studying the effect of elevated temperatures on the compressive strength. Each cube was tested for residual compressive strength under 3000kN Compression Testing Machine.

At the end of 28 days of conventional curing, cubes cast were taken out and air dried and tested for 100^0C, 300^0C, 500^0c, 700^0C and 900^0C temperatures for 02 hours in a high temperature furnace of 1000^0C capacity. After 02 hours, cubes were taken out of the furnace and allowed to cool.

TABLE V.
COMPRESSIVE STRENGTH OF PLAIN AND BASALT FIBER CONCRETE CUBES

Plain concrete cubes		
Temperature (^{0}C)	Avg residual compressive strength (Mpa)	Percentage decrease in avg. residual strength
20	79.2	--
100	75..5	4.7
300	72.5	8.5
500	71.5	9.7
700	42	46.9
900	14.5	81.7
Basalt fiber concrete cubes		
Temperature (^{0}C)	Avg residual compressive strength (Mpa)	Percentage decrease in avg. residual strength
20	81.5	---
100	80	1.84
300	77.5	4.9
500	77	5.5
700	58	28.8
900	33	59.5

TABLE VI.
FLEXURAL STRENGTH OF PLAIN AND BASALT FIBER CONCRETE PRISMS

Plain concrete prisms		
Temperature (^{0}C)	Avg residual flexural strength (Mpa)	Percentage decrease in avg. residual flexure
20	18.45	--
100	16.91	8.4
300	16.38	11.2
500	13.81	25.2
700	7.5	59.35
900	5.4	70.7
Basalt fiber concrete prisms		
Temperature (^{0}C)	Avg residual flexural strength (Mpa)	Percentage decrease in avg. residual flexure
20	22.35	--
100	21.25	4.9
300	20.5	8.27
500	19.14	14.36
700	13.98	37.5
900	12.75	42.9

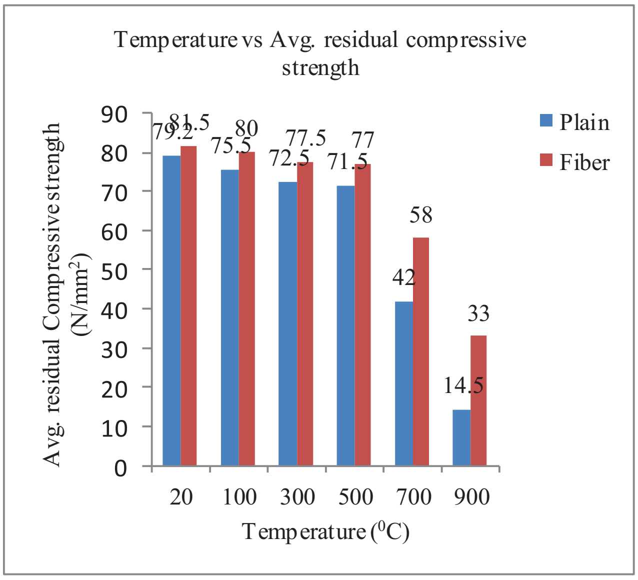

Figure 1. Average residual Compressive strength of Plain and Basalt fiber concrete cubes at different temperatures

room temperature before testing for their compressive strength.

The average residual compressive strength and percentage decrease in average residual compressive strength of 100mm plain and basalt fiber concrete cubes are presented in Table V and Fig. 1.

B. Flexural strength

Eighteen,100mmX100mmX420mm plain concrete prisms and eighteen 100mmX100X420mm basalt fiber concrete prisms were cast and tested for studying the effect of elevated temperatures on the Flexural strength. Each prism

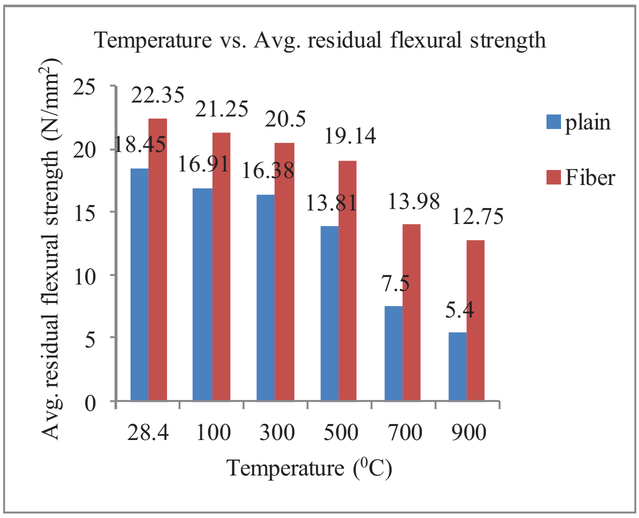

Figure 2. Residual Flexural strength of plain concrete prisms and fiber concrete prisms at different temperatures

was tested for residual flexural strength under Universal Testing Machine.

At the end of 28 days of conventional curing, prisms were taken out from water and air dried and tested for 100^{0}C, 300^{0}C, 500^{0}c, 700^{0}C and 900^{0}C temperatures for 02 hours in a high temperature furnace of 1000^{0}C capacity. After 02 hours, prisms were taken out of the furnace and allowed to cool at room temperature before testing for their flexural strength.

The average residual flexural strength and percentage decrease in average residual flexural strength of 100mmX100mmX420mm plain and basalt fiber concrete prisms are presented in Table VI and Fig. 2.

Between 100^{0}C to 900^{0}C, the percentage decrease in residual flexural strength was increased for both plain concrete prisms and basalt fiber concrete prisms.

C. Split tensile strength

Eighteen,300mm length and 150mm diameter plain concrete cylinders and eighteen 300mm length and 150mm diameter basalt fiber concrete cylinders were cast and tested for studying the effect of elevated temperatures on the split tensile strength. Each cylinder was tested for residual split tensile strength under compression Testing Machine.

At the end of 28 days of conventional curing, cylinders cast were taken out and air dried and tested for 100^{0}C, 300^{0}C, 500^{0}c, 700^{0}C and 900^{0}C temperatures for 02 hours in a high temperature furnace of 1000^{0}C capacity. After 02 hours, cylinders were taken out of the furnace and allowed to cool at room temperature before testing for their split tensile strength. The average residual split tensile strength and percentage decrease in average residual split strength of 300mm length and 150mm diameter plain and basalt fiber concrete cylinders are presented in Table VII and Fig. 3.

Between 100^{0}C to 900^{0}C, the percentage decrease in residual split tensile strength was increased for both plain concrete cylinders and basalt fiber concrete cylinders.

TABLE VII.
SPLIT TENSILE STRENGTH OF PLAIN AND BASALT FIBER CONCRETE CYLINDERS

Plain concrete cylinders		
Temperature (^{0}C)	Avg residual split tensile strength (Mpa)	Percentage decrease in avg. residual split tensile strength
20	5.16	--
100	4.95	4
300	4.13	19.9
500	3.25	37
700	2.26	56.2
900	1.82	64.7
Basalt fiber concrete cylinders		
Temperature (^{0}C)	Avg residual split tensile strength (Mpa)	Percentage decrease in avg. residual split tensile strength
20	6.1	--
100	5.94	2.62
300	5.58	8.52
500	5.21	14.59
700	4.83	20.81
900	3.35	45.08

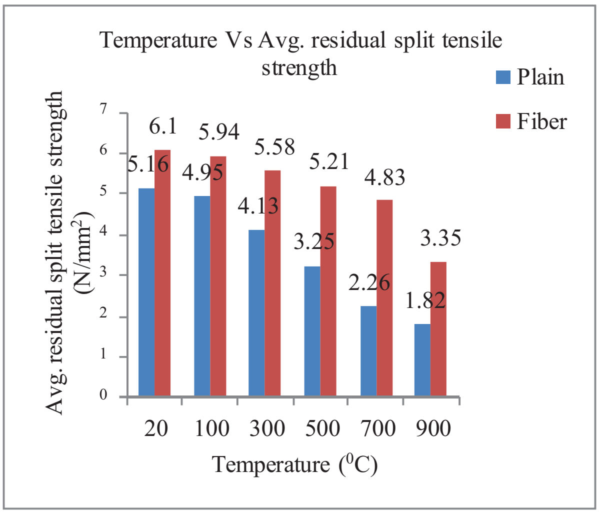

Figure 3. Average residual split tensile strengths of plain concrete cylinders and fiber concrete cylinders at different temperatures.

D. Modulus of Elasticity

Eighteen,300mm length and 150mm diameter plain concrete cylinderss and eighteen 300mm length and 150mm diameter basalt fiber concrete cylinders were cast and tested or studying the effect of elevated temperatures on the Modulus of Elasticity. Each cylinder was tested for residual Modulus of Elasticiry under compression Testing Machine.

At the end of 28 days of conventional curing, cylinders cast were taken out and air dried and tested for 100^{0}C, 300^{0}C, 500^{0}c, 700^{0}C and 900^{0}C temperatures for 02 hours in a high temperature furnace of 1000^{0}C capacity. After 02 hours, cylinders were taken out of the furnace and allowed to cool at room temperature before testing for their Modulus of Elasticity.

The average Modulus of Elasticity and percentage decrease in average Modulus of Elasticity of 300mm length and 150mm diameter plain and basalt fiber concrete cylinders are presented in Table VIII and Fig. 4.

TABLE VIII.
MODULUS OF ELASTICITY OF PLAIN AND BASALT FIBER CONCRETE CYLINDERS

Plain concrete cylinders		
Temperature (^{0}C)	Modulus of Elasticity (Mpa)	Percentage decrease in Modulus of Elasticity
20	41668	--
100	39130	6.1
300	35986	13.6
500	31425	24.6
700	23568	43.3
900	15580	62.61
Basalt fiber concrete cylinders		
Temperature (^{0}C)	Modulus of Elasticity (Mpa)	Percentage decrease in Modulus of Elasticity
20	43500	--
100	41392	4.8
300	39000	10.3
500	37700	13.3
700	32040	26.3
900	25415	41.6

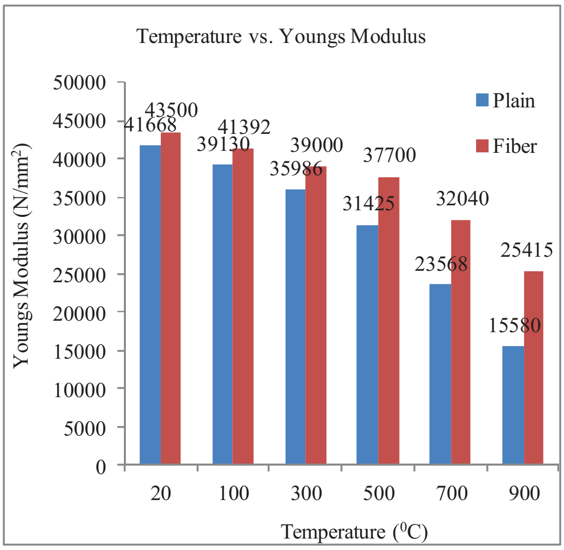

Figure 4. Average Youngs Modulus of plain concrete cylinders and fiber concrete cylinders at different temperatures.

E. Fracture Energy and Fracture Toughness

Eighteen,100mmX100mmX420mm plain concrete prisms and eighteen 100mmX100X420mm basalt fiber concrete prisms were cast and tested under Universal Testing Machine for studying the effect of elevated temperatures on the Fracture energy and Fracture toughness.

At the end of 28 days of conventional curing, prisms cast were taken out and air dried and tested for 100^{0}C, 300^{0}C, 500^{0}c, 700^{0}C and 900^{0}C temperatures for 02 hours in a high temperature furnace of 1000^{0}C capacity. After 02 hours, prisms were taken out of the furnace and allowed to cool at room temperature before testing for their Fracture energy and Fracture toughness.

The average Fracture energy, Fracture toughness and percentage decrease in average fracture energy and Fracture toughness of 100mmX100mmX420mm plain and basalt fiber concrete prisms are presented in Table IX, Table X, Fig.5 and Fig.6. Load-Deflection of Plain concrete prisms and basalt fiber concrete prisms at different temperatures is shown in fig.7 and fig. 8 respectively.

TABLE IX.
FRACTURE ENERGY OF PLAIN AND BASALT FIBER CONCRETE PRISMS

Plain concrete prisms		
Temperature (^{0}C)	Avg Fracture Energy (J/m^2)	Percentage decrease in Fracture Energy
20	692.5	-
100	585	15.52
300	426	38.48
500	194	71.9
700	85	87.7
900	61.25	91.1
Basalt fiber concrete concrete prisms		
Temperature (^{0}C)	Avg Fracture Energy (J/m^2)	Percentage decrease in Fracture Energy
20	1067.5	-
100	966.25	9.48
300	850	20.37
500	612	42.66
700	408.25	61.75
900	340.5	68.10

TABLE X.
FRACTURE TOUGHNESS OF PLAIN AND BASALT FIBER CONCRETE PRISMS

Plain concrete prisms		
Temperature (^{0}C)	Fracture Toughness(K_{ic})	Percentage decrease in fracture toughness
20	169.86	-
100	153.98	9.34
300	131.39	22.64
500	78.08	54.03
700	44.75	73.6
900	34.97	79.4
Basalt fiber concrete concrete prisms		
Temperature (^{0}C)	Fracture Toughness(K_{ic})	Percentage decrease in fracture toughness
20	215.49	-
100	199.98	7.2
300	182.07	15.5
500	151.89	29.51
700	114.36	46.93

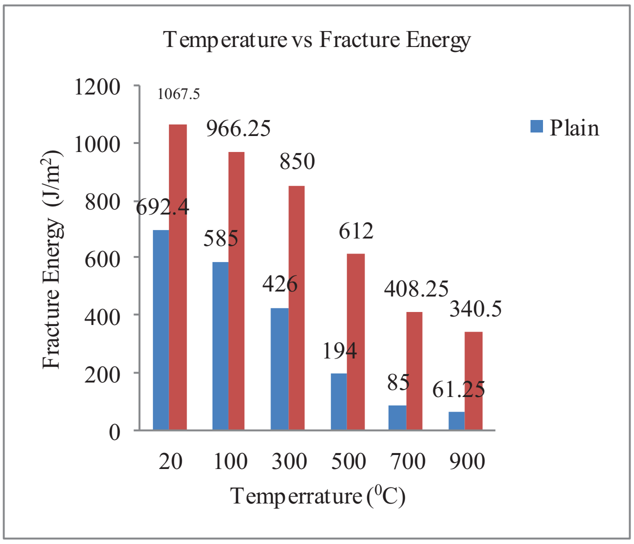

Figure 5. Fracture Energy of Plain and basalt Fiber concrete prisms at different temperatures.

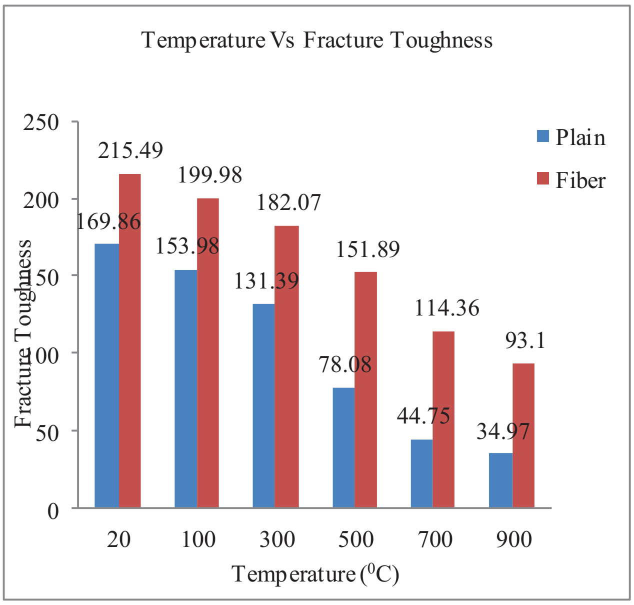

Figure 6. Fracture Toughness of Plain and basalt Fiber concrete prisms at different temperatures.

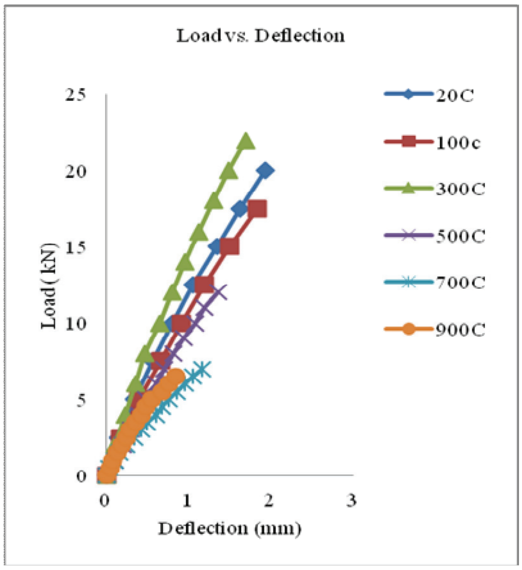

Figure 7. Load-Deflection of Plain concrete prisms at different temperatures

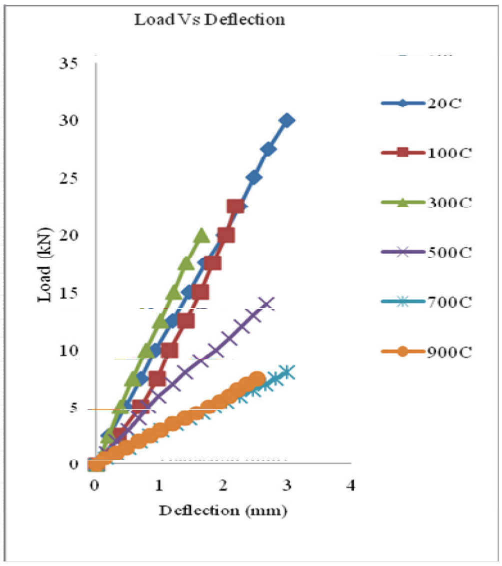

Figure 8. Load-Deflection of Fiber concrete prisms at different temperatures

V. CONCLUSIONS

The sustaining temperature and melting temperature of Basalt fiber is 680^0C and 1450^0C respectively. Since the sustaining temperature of Basalt fiber is 680^0C, the decrease in residual compressive strength, flexural strength, split tensile strength and modulus of elasticity is less than 15% up to 500^0C. The percentage decrease in average Fracture energy (single point loading) and fracture toughness at 500^0C for basalt fiber concrete prisms was 42.66% and 29.51% respectively. Even at 900^0C, the average percentage decrease in fracture energy and fracture toughness was 68.1% and 56.79% respectively. Due to the strong flexural resistance of basalt fiber, there was less decrease in the strength parameters and fracture parameters. Hence, use of Basalt fiber in high strength concrete is recommended.

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