Influence of Temperature on the Fracture Parameters of Basalt Fiber Concrete

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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°C, 300°C, 500°C, 700°C and 900°C temperatures for 2 hours in a high temperature furnace of 1000°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/mm² which is 22% higher than control concrete of 31.34 N/mm². The Basalt fibre concrete exhibited higher tensile strength than the normal concrete. The tensile strength of basalt fibre concrete was 7.66 N/mm² which is 45% higher than the tensile strength of normal concrete (5.26 N/mm²).

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. Suresh kumar, 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.
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 aggregate | Coarse aggregate |
|-------------------|----------------|------------------|
| 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 |
|-----------------------------------------------|
| S.No  | Property        | Value |
|-------|-----------------|-------|
| 1     | Specifi gravity | 2.9   |
| 2     | Bulk density    | 680   |
| 3     | Fineness (cm²/gm)| 12000|
| 4     | Particle size distribution (μ) | 0-10 |

| TABLE III. CHEMICAL PROPERTIES OF ALCCOFINE 1203 |
|-----------------------------------------------|
| S.No  | Chemical Name | Percentage |
|-------|---------------|------------|
| 1     | SiO₂          | 51.6%-59.3%|
| 2     | Al₂O₃         | 14.6%-18.3%|
| 3     | CaO           | 5.9%-9.44% |
| 4     | MgO           | 3.0%-5.33% |
| 5     | Na₂S+K₂O     | 3.6%-5.2%  |
| 6     | TiO₂          | 0.8%-2.25% |
| 7     | Fe₂O₃+Fe₂O   | 9.0%-14%   |
| 8     | Others        | 0.09%-0.13%|

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     | SiO₂          | 51.6%-59.3%|
| 2     | Al₂O₃         | 14.6%-18.3%|
| 3     | CaO           | 5.9%-9.44% |
| 4     | MgO           | 3.0%-5.33% |
| 5     | Na₂S+K₂O     | 3.6%-5.2%  |
| 6     | TiO₂          | 0.8%-2.25% |
| 7     | Fe₂O₃+Fe₂O   | 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/cm³
- 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/m³; Fine Aggregate = 401.233 kg/m³; Coarse Aggregate = 1175.556 kg/m³; Water = 180.410 kg/m³.

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°C, 300°C, 500°C, 700°C and 900°C temperatures for 2 hours in a high temperature furnace of 1000°C capacity. After 2 hours, cubes were taken out of the furnace and allowed to cool.
TABLE V.
COMPRESSIVE STRENGTH OF PLAIN AND BASALT FIBER
CONCRETE CUBES

| Temperature (°C) | Plain concrete cubes | Basalt fiber concrete cubes |
|------------------|----------------------|----------------------------|
|                  | Avg residual compressive strength (Mpa) | Percentage decrease in avg. residual strength |
| 20               | 79.2 | 75.5 | 72.5 | 71.5 | 42 | 14.5 |
| 100              | 75.5 | 73.5 | 72.5 | 71.5 | 42 | 14.5 |
| 300              | 72.5 | 72.5 | 72.5 | 71.5 | 42 | 14.5 |
| 500              | 71.5 | 71.5 | 71.5 | 71.5 | 42 | 14.5 |
| 700              | 42   | 42   | 42   | 42   | 42 | 42   |
| 900              | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 |

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

| Temperature (°C) | Plain concrete prisms | Basalt fiber concrete prisms |
|------------------|-----------------------|------------------------------|
|                  | Avg residual flexural strength (Mpa) | Percentage decrease in avg. residual flexure |
| 20               | 18.45 | 22.35 | 21.25 | 20.5 |
| 100              | 16.91 | 21.25 | 20.5 | 19.14 |
| 300              | 16.38 | 20.5 | 19.14 | 18.75 |
| 500              | 13.81 | 19.14 | 18.75 | 17.31 |
| 700              | 7.5   | 13.81 | 12.75 | 11.39 |
| 900              | 5.4   | 12.75 | 11.39 | 10.01 |

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 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°C, 300°C, 500°C, 700°C and 900°C temperatures for 02 hours in a high temperature furnace of 1000°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°C to 900°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 aired and tested for 100°C, 300°C, 500°C, 700°C and 900°C temperatures for 02 hours in a high temperature furnace of 1000°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°C to 900°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**

| Temperature (°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                                                          |

| Temperature (°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                                                         |

### D. Modulus of Elasticity

Eighteen, 300mm length and 150mm diameter plain concrete cylinders 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 Elasticity under compression Testing Machine. At the end of 28 days of conventional curing, cylinders cast were taken out and aired and tested for 100°C, 300°C, 500°C, 700°C and 900°C temperatures for 02 hours in a high temperature furnace of 1000°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**

| Temperature (°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                                       |

| Temperature (°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 3. Average residual split tensile strengths of plain concrete cylinders and fiber concrete cylinders at different temperatures.

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 100mmX100mmX420mm 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°C, 300°C, 500°C, 700°C and 900°C temperatures for 02 hours in a high temperature furnace of 1000°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 |
|----------------------|--------------------------|--------------------------|
| Temperature (°C)     | Avg Fracture Energy (J/m²) | 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 prisms |
|-----------------------------|--------------------------|--------------------------|
| Temperature (°C)     | Avg Fracture Energy (J/m²) | 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 |
|----------------------|--------------------------|--------------------------|
| Temperature (°C)     | Fracture Toughness (Kic) | 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 prisms |
|-----------------------------|--------------------------|--------------------------|
| Temperature (°C)     | Fracture Toughness (Kic) | 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 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°C and 1450°C respectively. Since the sustaining temperature of Basalt fiber is 680°C, the decrease in residual compressive strength, flexural strength, split tensile strength and modulus of elasticity is less than 15% up to 500°C. The percentage decrease in average Fracture energy (single point loading) and fracture toughness at 500°C for basalt fiber concrete prisms was 42.66% and 29.51% respectively. Even at 900°C, 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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