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Behavior of Concrete When It Is Mixed With Different Proportions of Basalt Fibers and Tested Under Elevated Temperatures


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Abstract:

The aim of this paper is to study the performance of basalt fibre concrete at levated temperatures, and also compare the compressive and split tensile strengths of M30 (normal concrete) and M60 (high strength concrete) grade concretes mixed with basalt fibres of 0.3%,0.5%,0.7% and 0.9% by volume .To study compressive strength cubes of 100mm x 100mm x 100mm size and for split tensile strength cylinders of 150mm dia x 300mm length were casted. These specimens were exposed to temperatures of 200°C, 400°C, 600°C & 800°C at 7 days and 28 days of curing. The temperature is maintained for 3 hours in the bogie hearth furnace for sustained temperature condition. These heated specimens were cooled to room temperature to determine the mechanical properties. The weight loss, spalling, bonding and colour change is determined for both medium & high strength concrete. The specimens were tested for its compressive and split tensile strength and found that the use of basalt fibres in High Strength Concrete is a good advantage than Normal Strength Concrete.

I. INTRODUCTION

Concrete is known as the construction material most used around the world. It is strong in compression as the aggregates can effectively carry the compression load. However, concrete is weak in tension, as the cement holding the aggregate can crack, causing concrete to break. An effective way to improve the tensile strength of concrete and reduce the number of defects is by adding different fractions of fibres, Youjiang Wang [1]. Fibres can enhance the concrete strength, which enables the construction to withstand external forces. When plain concrete is compressed, it shatters and fails at the first crack. However, fibres are manufactured specially to prevent the effect of shattering forces by tightly holding concrete together, NRMCA [2].

The rapid increase in the use of fibres in concrete is attributed to its positive effect on the mechanical properties of the cementations composites. It is proven that the addition of fibres to concrete has a significant impact on improving the mechanical properties of fresh and hardened concrete, such as compressive strength, tensile strength, flexural strength, and workability.

The use of fibres has undergone major development in the last 30 years, and this composite material has been used successfully in various applications of civil engineering. The current new generation of fibre applications in concrete include Slurry Infiltrated Fibrous Reinforced Concrete (SIFCON), Engineered Cementations Composite (ECC), and Reactive Powder Concrete (RPC), P.K. Mehta [3].

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Many types of fibre have been used to reinforce concrete, such as steel, glass, and polyethylene fibre. Of the different fibres available, steel fibres are probably the most investigated and most commonly used. According to S.M Chikhalikar and Tande [4], steel fibres are most commonly used (50%), followed by polypropylene fibres (20%) and glass fibres (5%), with other types of fibres making up 25% see (Fig.1).

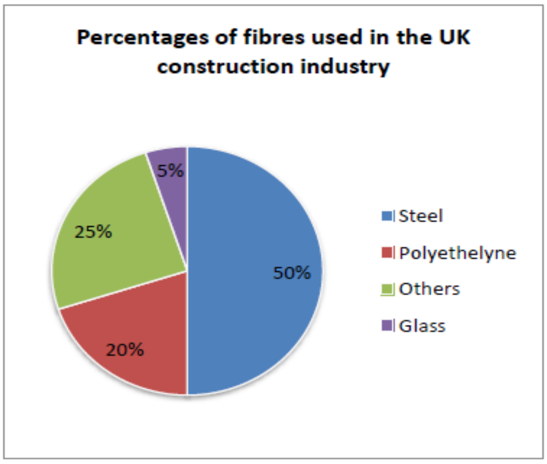

Fig.1Percentage of fibres used in the UK construction industry

II. BASALT FIBER

Basalt rock is a volcanic rock and can be divided into small particles then formed into continues or chopped fibers. Basalt fiber has a higher working temperature and has a good resistance to chemical attack, impact load, and fire with less poisonous fumes. Some of the potential applications of these basalt composites are: plastic polymer reinforcement, soil strengthening, bridges and highways, industrial floors, heat and sound insulation for residential and industrial buildings, bullet proof vests and retrofitting and rehabilitation of structures.

Basalt is fine-grained, extrusive, igneous rock composed of plagioclase, feldspar, pyroxene and magnetite, with or without olivine and containing not more than 53 wt% SiO_2 and less than 5 wt% total alkalis. Many types of basalt contain phenocrysts of olivine, clinopyroxene (augite) and plagioclase feldspar. Basalt is divided into two main types, alkali basalt and toleiites. They have a similar concentration of SiO_2, but alkali basalts have higher content of NA_2O and K_2O than tholeiites. The production of basalt fibers is similar to the production of glass fibers. Basalt is quarried, crushed and washed and then melted at 1500° C. The molten rock is then extruded through small nozzles to produce continuous filaments of basalt fiber.

The fibers used were chopped basalt fibers which are uniformly and randomly distributed in the concrete matrix. Three different fiber contents were choosing 1kg/m3, 2kg/m3, 4kg/m3 for each mix. Chopped basalt fibers are shown in figure 2.

Fig: 2 Basalt fiber

Table-1: Physical Properties Basalt

PROPERTIES	VALUES
Density, g/cm3	2.77
Filament diameter, microns	10-24
Tensile strength, MPa	4840
Compression, psi	550,000
Elastic modulus, G Pa	90
Linear expansion coefficient,x10/K	5.4
Elongation at break, %	3.2
Absorption of humidity, 65% RAH%	<0.1
Stability at tension, 20 C°%	100
Stability at tension, 200 C° %	95
Stability at tension , 400 C° %	82

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III. PRILIMINARY EXPERIMENTAL PROGRAMS

3.1 CEMENT:

Cement is a binder, a substance that sets and hardens and can bind other materials together. The volcanic ash and pulverized brick supplements that were added to the burnt lime, to obtain a hydraulic binder, were later referred as cement. Ordinary Portland cement of 53 grades available in local market is used in the investigation.

Fig3. Cement of 53 grade used in the experiment.

The major phases of Portland cement are tricalcium silicate ($3CaO.Sio_2$), tricalcium silicate ($2CaO.SiO_2$), tricalcium aluminates ($3CaO.AlO_3$), and calcium laluminoferrite ($4CaO.Al_2O_3.FeO_3$). the abbreviations used in concrete technology to represent the major compounds re:CaO=C,SiO_2=S,AlO_3=A,FeO_3=F and H_2O=H. In a commercial clinker they do not exist in a pure form.

The $3CaO.SiO_2$ phase is a solid solution containing Mg and A1 and is called elite. The2CaO. SiO_2 phase occurs in β the form, termed elite, and contains K_2O, in addition to A1 and Mg.The calculation of potential composition of Portland cement is based on the work of R.H Bougue and others and is often referred to as bouge's composition. Bougue's equations for the percentages of main compounds in cement are given below. The terms within bracket represent the percentage of the given oxide the total mass of cement.

Portland cement concrete is considered to be a relatively brittle material. Apart from its excellent properties, concrete shows a rather low performance when subjected to tensile stress. When subjected to tensile stress, unreinforced concrete will crack and fail.

The traditional solution to this problem is reinforced concrete, where reinforcing bars or pre-stressed steel bar inside the concrete elements are capable of absorbing the appearing tensile stresses. Another recent development is steel fiber reinforced concrete. Ordinary Portland cement is the most common cement in use. OPC is suitable for use in general concrete construction when there is no exposure to sulphates in the soil or ground water.

Indian standard classified Portland cement according to their compressive strength. The ASTM uses a 1:2.75 mortar with standard graded sand at water cement ratio 0.485, 50mm cubes are tested. As per Indian standard, cement mortar of proportion cement and standard ennore sand use1:3 by mass with water content P/4+3% is tested by preparing 502cm cubes.

3.2 SPECIFIC GRAVITY OF CEMENT

Specific gravity is the ratio of the density of a substance of the density of a reference substance. Apparent specific gravity is the ratio of the weight of a volume of the substance to the weight of an equal volume of the reference substance.

This experiment is carried out as follows:

1. Weigh a clean and dry Le chartlier flask or specific gravity bottle with its stopper as W1.
2. Place the sample of cement upto the half of the ask of about 50 gms and weight with its stopper as W2.
3. Add kerosene which is polar liquid to the cement in the flask till it is about half full.
4. Mix thoroughly with glass rod to remove entrapped air. Continue stirring and add more kerosene till it is flush with the graduated mark.
5. Dry the outside and weigh (W3).
6. Entrapped air may be removed by vacuum pump, if available.

7. Empty the flask, clean it refills with the kerosene flush upto the graduated mark wipe dry outside and weigh(W4).

The specific gravity of cement can be determined by the following formula:

$$specific\ gravity = \frac{(W2 - W1)}{(W2 - W1) - (W3 - W4)X0.79}$$

Where W1= weight of empty flask

W2= weight of flask +cement

W3 = weight of flask +cement + kerosene

W4 = weight of flask + kerosene

0.79 = specific gravity of kerosene

Specific gravity of cement is limited to 3.15gms/cc

Table-2: Particulars of Test

S. No	Particulars of test	Test results	Requirements as per IS code	IS code number
1	Normal consistency	33%	26-33%	IS 4031(part 4)
2	Specific gravity	3.15	3-3.2	IS 2720 (Part 3)
3	Fineness	8.53	Minimum 3.7	IS 4031 (part 2)
4	Initial setting time	55	30-60 minutes	IS 4031 (part 5)
	Final setting time	185	Max. 600 mins	
5	Compressive strength			
	3- days	26 N/mm^2	27	IS 4031 (part 7)
	7- days	38 N/mm^2	37.5	
	28- days	54 N/mm^2	53	

3.3 INITIAL SETTING TIME AND FINAL SETTING TIME

For convenience, initial setting time is regarded as the time elapsed between the moments that the water is added to the cement, to the time that the paste starts losing its plasticity. The final setting time is the time elapsed between the moment the water is added to the cement, and the time when the paste has completely lost its plasticity and has attained sufficient firmness to resist certain definite pressure.

1. Prepare a neat 300 gm cement paste by gauging the cement with 0.85 times the water required to give a paste of standard consistency. Potable or distilled water shall be used in preparing the paste.

2. Start a stop-watch at the instant when water is added to the cement. Fill the Vicat mould with a cement paste gauged as above, the mould resting on a nonporous plate. Fill the mould completely and smooth off the surface of the paste making it level with the top of the mould.

3. Immediately after moulding, place the test block in the moist closet or moist room and allow it to remain there except when determinations of time of setting are being made.

4. Determination of Initial Setting Time: Place the test block confined in the mould and resting on the non-porous plate, under the rod bearing the needle lower the needle gently until it comes in contact with the surface of the test block and quickly release, allowing it to penetrate into the test block

5. Repeat this procedure until the needle, when brought in contact with the test block and released as described above, fails to pierce the block beyond 5.0 mm ± 0.5 mm measured from the bottom of the mould shall be the initial setting time.

6. Determination of Final Setting Time: Replace the needle of the Vicat apparatus by the needle with an annular attachment.

7. The cement shall be considered as finally set when, upon applying the needle gently to the surface of the test block, the needle makes an impression thereon, while the attachment fails to do so.

8. The period elapsing between the time when water is added to the cement and the time at which the needle makes an impression on the surface of test block while the attachment fails to do so shall be the final setting time.

The following basic data is required to be specified for the design of a concrete mix:

- Characteristic compressive strength (That is, below which only a specified proportion of test results are allowed to fall) of concrete at 28 days fck (Grade designation).
- Type of cement.

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- Minimum cement content. Limitations on the W/C ratio and the minimum cement content to ensure adequate durability as per IS 456-200.
- Standard deviation of compressive strength of concrete.
- Degree of quality control
- Exposure conditions as per IS 456-200
- Specific gravity of cement, fine and coarse aggregate.
- Fineness modulus of fine aggregate.

4.1 PREPARATION OF TESTING SPECIMEN

MIXING:

Mixing of ingredients is done in pan mixer of capacity 50L. The Cementitious materials are thoroughly blended and then the aggregate is added and mixed followed by gradual addition of water and mixing. Wet mixing is done until a mixture of uniform colour and consistency are achieved which is then ready for casting. Before casting the specimens, workability of the mixes was found by slump cone test.

Fig 3. Mixing of cement concrete during experiment

CASTING & CURING:

Fig 4.Casting & Curing of Specimens

The cast iron moulds are cleaned of dust particles and applied with mineral oil on all sides before concrete is poured in to the moulds. The moulds are placed on a level platform. The well mixed concrete is filled in to the moulds and kept on vibration table. Excess concrete was removed with trowel and top surface is finished level and smooth as per IS 516-1969.

The specimens were removed from the moulds after 24hr from the time of adding the water to the ingredients. The specimens then marked for identification. These specimens were then stored in clean water for the required period of curing.

COMPRESSIVE STRENGTH TEST:

The compressive strength is the capacity of a material or structure to withstand loads tending to reduce size. It can be measured by plotting applied force against deformation in a testing machine. Compressive strength were measured at 3, 7,28 day of testing. The test results are shown in the following Table 3.

Table 3.Compressive Strength of Basalt Fiber Specimens

BASALT FIBER (kg/m3)	Compressive Strength (N/mm2)		
	3 days	7days	28 days
0	19.3	25.1	35.4
1	20.37	25.67	36.5
2	21.6	27.75	38.4
4	22.2	28.89	40.2

The figure 5 indicates the comparison of result of compressive strength using cube specimen of M30 grade concrete. It is observed that for addition of 4kg/m3 fiber gives more compressive strength than other volume fraction. Figure 6 shows the test setup for compressive strength.

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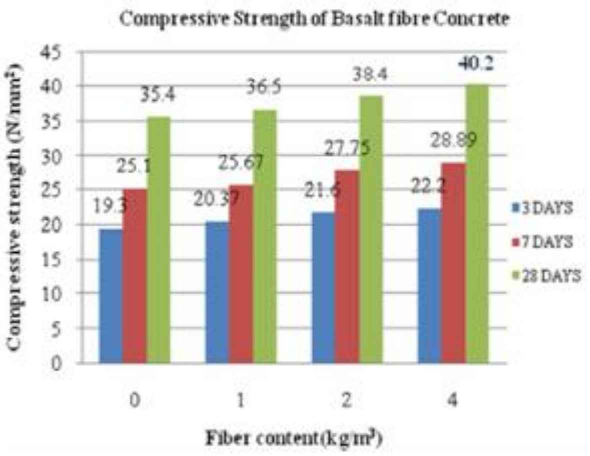

Fig: 5 Compressive strength of basalt fiber specimens

Fig: 6 Test for Compressive Strength

SPLITTING TENSILE STRENGTH TEST:

The split tensile strength values of ordinary concrete and basalt fiber concrete mixes are observed at 7 and 28 day of testing. The test results are presented in the table 4 below.

Table 4.Split Tensile Strength Of Basalt Fiber Specimens

BASALT FIBER (kg/m3)	Split tensile strength (N/mm2)	
	7days	28 days
0	1.65	2.25
1	2.3	3.02
2	2.64	3.33
4	2.87	3.64

The figure 7 indicates the result of split tensile strength for M30 grade basalt fiber reinforced concrete. It is observed that for the addition of 4kg/m3 gives maximum tensile strength at 28 days. Figure 8 shows the test setup for splitting tensile strength.

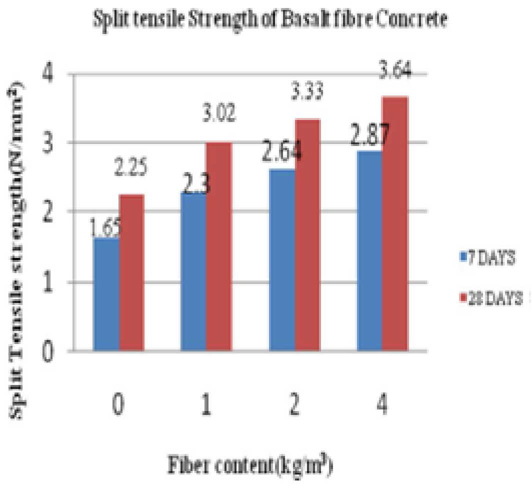

Fig: 7 Split Tensile strength of basalt fiber specimens

Fig: 8 Test for Splitting Tensile Strength

V. RESULTS AND DISCUSSIONS

The compressive strength and split tensile strength of M30 and M60 grade concretes were discussed in this chapter. One set of normal concrete and one set of basalt fibre concrete were casted for each grade. Both the normal and basalt fibre concrete were exposed to temperature between 200°C to 800°C at an interval of 200°C for the duration of 3 hours.

5.1COMPRESSIVE STRENGTH TEST RESULTS:

The casted cubes of M30 grade concretes are cured, exposed to temperatures and tested for its compressive strength at 7 and 28 days after cooling to room temperature. The temperatures ranges between 27°C, 200°C, 400°C, 600°C & 800°C.

Table-5 Residual compressive strength of m30 concrete with and without basalt for 7 & 28 days.

Temp. (°C)	7 DAYS, MPa				28 DAYS, MPa			
	Without Basalt		With Basalt		Without Basalt		With Basalt	
	With Out Basalt Fibres	Percentage Residual Comp. Strength	With Basalt Fibres	Percentage Residual Comp. Strength	With Out Basalt Fibres	Percentage Residual Comp. Strength	With Basalt Fibres	Percentage Residual Comp. Stress
27	37.00	100	35.00	100	41.00	100	39.33	100
200	45.00	121	41.00	117	47.00	114	44.67	113
400	42.00	113	39.60	113	43.67	106	41.33	105
600	32.00	86	30.67	87	38.00	92	36.00	91
800	15.0	40	11.0	31	19.6	47	17.0	43

Mix concrete of for 7 & 28 days. Comparing to normal and basalt the residual compressive strength varies at different temperatures i.e., at 200°C it increases upto 21% & 17%, at 400°C increases upto 13% for both and then getting decreased, 600°C it got decreased to 14% & 15% and for 800°C it decreases to 60% & 69% for 7 days. Were as for 28 days at 200°C increases upto 14% & 13%, at 400°C increases upto 6% & 5% and then getting decreased , 600°C it got decreased to 8% & 9% and for 800°C it decreases to 53% & 57%. It has been clearly represented in graphs.

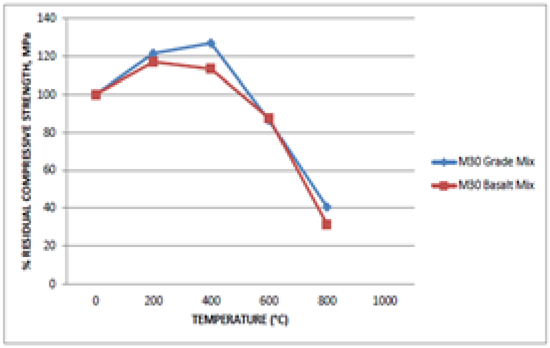

Fig.9 Temperature versus percentage residual strength of normal and basalt mix concrete of M30 at 7 days.

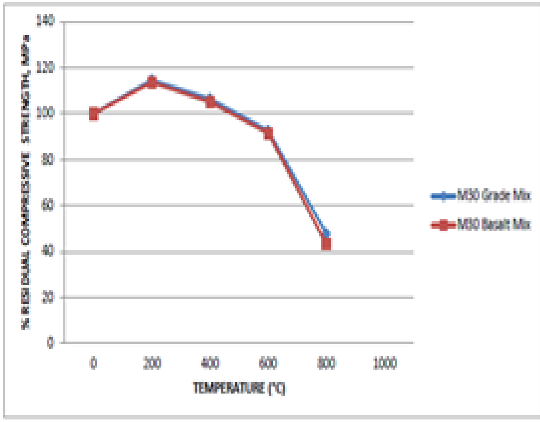

Fig.10 Temperature versus percentage residual strength of normal and basalt mix concrete of M30 at 28 days.

5.2 TESTING OF M60 GRADE CONCRETE CUBES:

The casted cubes of M60 grade concretes are cured, exposed to temperatures and tested for its compressive strength at 7 and 28 days after cooling to room temperature. The temperatures ranges between 27°C, 200°C, 400°C, 600°C & 800°C. Super plasticizer is added to the concrete in order to increase the workability. The quantity of super plasticizer used is 11ml per kg of cement in the mix.

The below table represents the obtained results of high strength concrete in which the residual compressive strength got increased upto 200°C and then got decreased i.e, at 200°C the strength increases upto 4% and 2% for Basalt, for 400°C the strength got decreased to 16% in normal and 13% in basalt mix, for 600°C 24% & 30% and for 800°C 62% & 66&% for 7 days. Were as for 28 days strength the residual compressive strength got increased upto 200°C and then got decreased i.e., at 200°C the strength increases upto 7% and 9% for Basalt, for 400°C the strength got decreased to 3% in normal and 2% in basalt mix, for 600°C 16% & 30% and for 800°C 62% & 65&% The obtained results were represented in graphs.

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Table.6. Residual compressive strength of M60 concrete with and without Basalt mix at 7 & 28 days

Temp	7 DAYS, MPa				28 DAYS, MPa			
	Without Basalt		With Basalt		Without Basalt		With Basalt	
(°C)	Without Basalt Fibres	Percentage Residual Comp. Strength	With Basalt Fibres	Percentage Residual Comp. Strength	Without Basalt Fibres	Percentage Residual Comp. Strength	With Basalt Fibres	Percentage Residual Comp. Stress
27	54.30	100	50.33	100	58.00	100	54.00	100
200	56.40	104	51.32	102	62.30	107	59.30	109
400	45.67	84	43.67	87	56.30	97	53.30	98
600	41.00	76	35.33	70	48.67	84	38.00	70
800	21.00	38	17.00	34	22.00	38	19.00	35

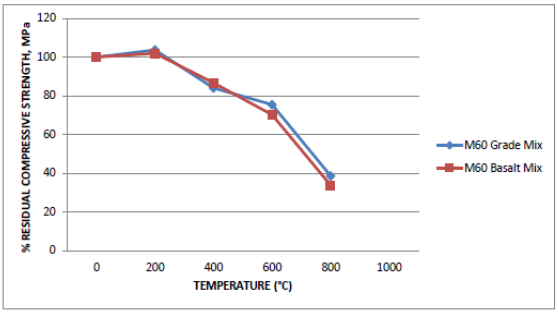

Fig.11 Temperature versus Percentage residual strength of normal and basalt mix concrete of M60 at 7 days

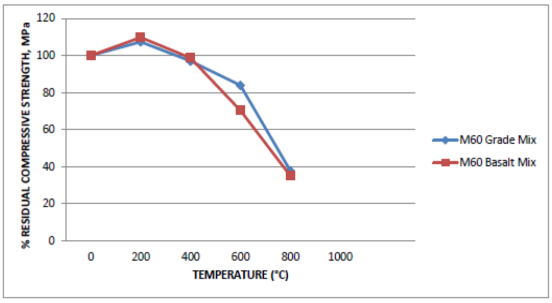

Fig.12 Temperature versus Percentage residual strength of normal and basalt mix concrete of M60 at 28 days

5.3SPLIT TENSILE STRENGTH TEST RESULTS

The casted cubes of M30 grade concretes are cured, exposed to temperatures and tested for its split tensile strength at 7 and 28 days after cooling to room temperature. The temperatures ranges between 27°C, 200°C, 400°C, 600°C & 800°C.

The below table represents residual split tensile strengths of OPC and Basalt mix concrete of for 7 & 28 days. Comparing residual split tensile strengths to normal OPC initially it got increased upto 200°C and then got decreased when temperature increased i.e, at 200°C the strength increases upto 10% and 6% for Basalt, for 400°C the strength got decreased to 3% for both, for 600°C 55% & 59% and for 800°C it is 77% &75&% for 7 days. Were as for 28 days strength the residual compressive strength got increased upto 200°C and then got decreased i.e., at 200°C the strength increases upto 11% and 7% for Basalt, for 400°C the strength got decreased to 3% in normal and 3% in basalt mix, for 600°C 45% & 42% and for 800°C 70% & 72&%. The obtained results were represented in graphs.

Table.7 Residual Split Tensile Strength of M30 Concrete with and Without Basalt Mix of 7 & 28 Days

	7 DAYS, MPa				28 DAYS, MPa			
	Without Basalt		With Basalt		Without Basalt		With Basalt	
Temp. (°C)	Without Basalt Fibres	Percentage Residual Split Tensile Strength	With Basalt Fibres	Percentage Residual Split Tensile Strength	Without Basalt Fibres	Percentage Residual Split Tensile Strength	With Basalt Fibres	Percentage Residual Split Tensile Strength
27	3.12	100	3.40	100	3.33	100	3.63	100
200	3.42	109	3.64	107	3.67	110	3.86	106
400	2.98	97	3.25	96	3.26	97	3.45	95
600	1.39	44	1.40	41	1.87	56	2.15	59
800	0.71	23	0.85	25	0.99	30	1.00	28

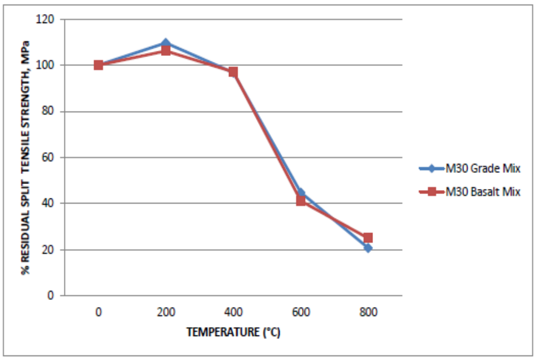

Fig.13.Temperature versus Percentage split tensile strength of normal and basalt mix concrete of M30 at 7 days

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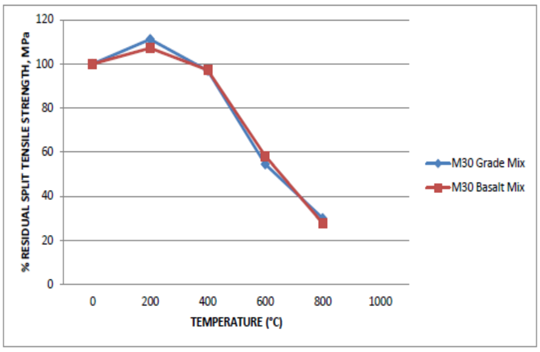

Fig.14Temperature versus Percentage split tensile strength of normal and basalt mix concrete of M30 at 28 days

5.4. COLOUR CHANGE & CRACKS:

After heating at various temperatures, the samples were assessed visually to determine the colour change. Three colour change zones were observed for both normal and basalt mix concrete of M30 & M60 mix. No colour change upto 200°C. At 400 to 600°C it's about grey. At 800°C it's about yellowish grey.

Fig.15.Colour change of M30 Grade Concrete of Basalt and Normal when exposed to 200°C, 600°C & at 800°C temperatures.

Fig.16.Colour change of M60 Grade Concrete of Basalt and Normal when exposed to 200°C, 600°C & at 800°C temperatures.

Cracks occurred at elevated temperature due to the internal pressure of evaporable moisture. Hair line cracks are observed on the surface at low to medium temperature and extending deep into the specimen at higher temperatures. Most of the cracks occurred at 800°C of all the mixes of cylinders.

M30 Normal at 800°C M30 Basalt at 800°C
Fig 17: Crack Pattern of M30 Grade Concrete at 800°C.

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M60 Normal at 800°C   M60 Basalt at 800°C
Fig 18: Crack Pattern of M60 Grade Concrete at 800°C.

VI.CONCLUSION

Basalt fibres when used in concrete, reduces spalling, increases tensile strength, resist crack. As basalt volume increases the strength reduces gradually. Compressive strength & split tensile strength for both the concretes of M30 & M60 grade increases up to 200°C due to evaporation of free moisture inside the concrete. Split tensile strength got increased for basalt mix when compared to normal mix for both M30 & M60 concretes whereas compressive strength for basalt mix reduced when compared to normal. Weight loss is more as temperature increases, maximum weight loss observed at 800°C of high strength concrete. Spalling, cracks, colour change and bond failure observed more in M60 than in M30 concretes at high temperatures. The use of basalt fibres in high strength concrete is a good advantage than in medium strength concrete.

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