Effect of Addition of Basalt Fibers and Temperature on the Strength of High Volume Fly Ash Self-Compacting Concrete

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Abstract- **Concrete is the most widely used man-made construction material in the world. Various required performance attributes of concrete includes strength, workability and durability.To attain these characteristics, it is imperative to emphasize the mix design, which generates the above characteristics with the conservation of energy and materials. Self-Compacting Concrete (SCC) growth has become a revolutionary milestone in the history of the construction industry. SCC is a flowing concrete mixture that is able to consolidate under its own weight. The highly fluid nature of SSC makes it suitable for placing in difficult conditions and in section with congested reinforcement. Fine aggregate content is increased higher than coarse aggregates to make concrete highly flowable. It is desirable to replace river sand by M-Sand due to high fine aggregate content. In this paper, High Volume Fly ash Self-Compacting Concrete (HVFASCC) of M30 grade was designed based on Nan-Su trial and error mix design procedure. HVFASCC differs from normal SCC since the fly ash content varies from 50 to 80%. The fresh properties of SCC were characterised by EFNARC guidelines. Here Ordinary Portland Cement is replaced with 50% of fly ash. Basalt fibers were added in the mix by 0%, 0.25%, 0.5%, 0.75%, 1% of its total volume of concrete and optimum fiber content was found out. Compressive and flexural strengths were determined for all percentages of basalt fibers. The experimental test results showed marginal increase in compression and considerable increase in flexural strength. To understand basalt fiber influence on durability characteristics Rapid Chloride Permeability Test (RCPT) was carried out for 28 days cured specimens. The present work also deals with the effect of elevated temperature on Rebound Number (RN) and Ultrasonic Pulse Velocity (UPV).The exposure temperatures were 200^{0}C and 400^{0}C for two hours duration. The results revealed the reduction in rebound number and ultrasonic pulse velocity.**

***Keywords*-EFNARC, Fly Ash, M-sand, SCC, Basalt fibers, Compressive strength, Rapid Chloride Penetration Test (RCPT), Elevated temperature.**

I. INTRODUCTION

Self-Compacting Concrete (SCC), a new kind of high performance concrete (HPC) was first developed in Japan in the year 1986. It has outstanding deformability and segregation resistance. During the placing process there is no need of any external vibration since it can flow through and fill gaps of reinforcement under its own weight [1].Using high cement content in the production of SCC leads to shrinkage of concrete and also increases the cost. Reduction of cement content in SCC is possible by partial replacement of cement with fly ash. The utilization of fly ash enhances filling ability and passing ability of SCC while maintaining segregation. Also SCC with higher fly ash content as cement replacement tends to reduce both drying and autogenous shrinkage. HVFASCC comprises fly ash ranging from 50 to 80% of total powdered content [2].

SCC requires a high slump that can easily be achieved by addition of superplasticizer to a concrete mixture. Fine aggregate content is increased compared to coarse aggregates to avoid segregation on superplasticizer addition which results in using high volume of cement. More amount of cement leads to higher temperature rise and an increased cost. Use of fly ash and blast furnace slag in SCC reduces the superplasticizer dosage needed to obtain similar slump flow compared to concrete made with Portland cement only. Use of fly ash also improves rheological properties and reduces cracking of concrete due to the heat of hydration of the cement. An economical SCC that achieved a 28-day compressive strength of approximately 35 MPa was that made with 50% replacement of cement by fly ash [3].

Now a days, major problem in the construction industry is the scarcity of natural sand. Due to this it gave rise to new generation sand named as M-sand or manufacture sand as an alternative to natural sand. Up to 30% of replacement by M-sand for natural sand was found to be optimum replacement. Decreased workability and incraeased compressive strength of SCC was observed by partial replacement of river sand by M-sand [4].

Rapid Chloride Penetration Test (RCPT) is conducted to test the durability of SCC. Chlorides penetrate crack-free concrete by a variety of mechanisms such as capillary absorption, hydrostatic pressure, diffusion and evaporation transport. Of these, diffusion is predominant. Diffusion occurs when the concentration of chloride on the outside of the concrete member is greater than on the inside. This results in chloride ions moving through the concrete to the level of rebar. RCPT was conducted on glass fiber reinforced concrete and concluded that chloride permeability of glass fiber reinforced concrete showed less permeability of chlorides in concrete compared with 0% of GFRC [5].

The effect of high temperature on HVFA basalt fibers reinforced SCC was determined for all the specimens subjected to 200^{0}C and 400^{0}C for duration of 2 hours. Specimens were placed in box type electric furnace in which rate of heating was kept constant for all specimens. The effect of elevated temperature on strength properties of fiber reinforced concrete. It was concluded that addition of steel fibers and polypropylene fibers reduced spalling at high temperatures but did not affect the compressive strength [6]. Generally speaking, the impact of presenting SCC examples to higher temperatures brought about reduction in strength. The strength diminishment on heating is because of numerous complex physical and chemical changes inside concrete. An increase in temperature causes loss of dampness from concrete [7].

II. MATERIALS AND METHODS

A. Materials

1. Cement: Ordinary Portland cement of grade 43with specific gravity 3.15 conforming to IS: 8112 (2013) was used in this experimental work.
2. Fine aggregates: Natural sand: River sand obtained from a local source was used as fine aggregates in this experimental work. It was conforming to zone II and specific gravity was determined to be 2.65.
3. Manufactured sand: It was procured from a local source. It was confirming to zone II and specific gravity was determined to be 2.74.
4. Coarse aggregates: In the present work locally available 12.5mm down sized aggregates were used. The specific gravity of coarse aggregates was found to be 278.
5. Mineral admixture: Fly ash was used as the filler material and cement is replaced with 50% of fly ash in this experimental work. Specific gravity of fly ash was found to be 2.1.
6. Water: Potable tap water was used for casting specimens as well as for curing purpose.
7. Superplasticizer: Conplast SP 430 admixture was used in this experimental work to impart high degree of workability and retention time required. Specific gravity was found to be 1.20.
8. Basalt fibers: Chopped basalt fibers were used. The thickness and length were 24µ and 12mm respectively.

B. Mix Design

Nan-Su method of mix proportioning for SCC was used in this study to design M30 grade concrete satisfying EFNARC guidelines in fresh state [1].

TABLE I

MIX PROPORTION

CA	FA	Cement	Fly Ash	Water	Super plasticizer
830	1000	230	230	172.6	3.68
Note: CA = Coarse aggregates content; FA = Fine aggregates content.					

III. RESULTS AND DISCUSSION

A. Compressive Strength of HVFA Basalt Fiber Reinforced SCC

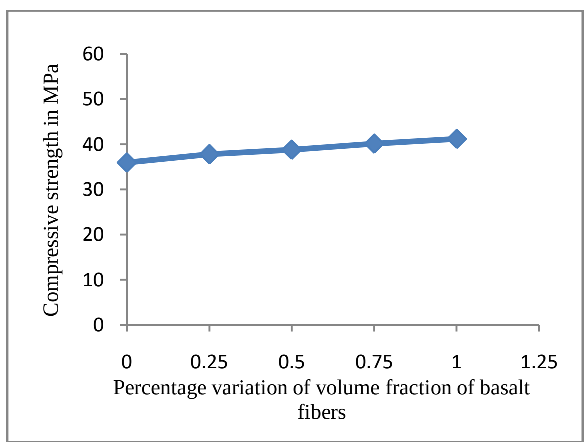
TABLE II

COMPRESSIVE STRENGTH FOR VARIOUS VOLUME FRACTIONS OF BASALT FIBERS FOR HVFASCC

Sl. No.	Percentage Variation of volume fraction of basalt fibers	Compressive strength in MPa
1.	0	35.96
2.	0.25	37.77
3.	0.5	38.81
4.	0.75	40.14
5.	1	41.2

FIGURE I

VARIATION OF COMPRESSIVE STRENGTH FOR PERCENTAGE VARIATION OF VOLUME FRACTION OF BASALT FIBERS



Marginal increase in compressive strength of HVFA SCC was observed due to addition of basalt fibres in the mix as shown in Table II. Basalt fibres were added at an interval of 0.25% to 1% volume fraction. The maximum compressive strength at 28 days was found to be 41.2 N/mm^2 for 1% volume fraction of basalt fibres. But since workability properties were not satisfied as per EFNARC guidelines, 1% volume fraction of basalt fibres is not considered to be optimum dosage. 0.75% volume fraction of basalt fibres is considered to be optimum dosage. Upsurge in strength may be due to increase in density of concrete after adding basalt fibres. Figure Ishowsvariation in compressivestrength with percentage variation of volume fraction basalt fibres.

B. Ultrasonic Pulse Velocity of HVFA Basalt Fiber Reinforced SCC

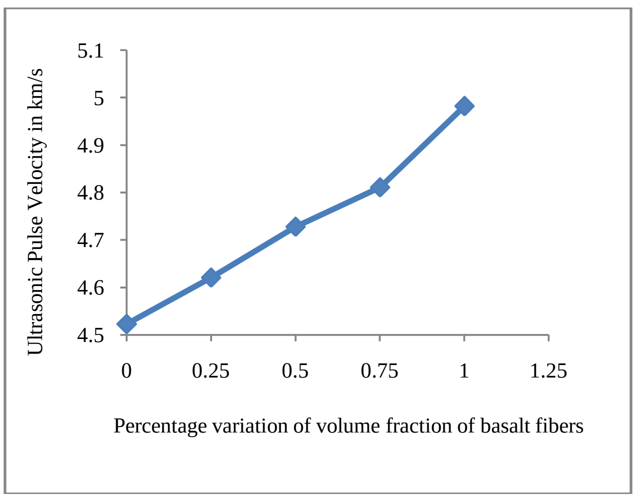
TABLE III

ULTRASONIC PULSE VELOCITY FOR VARIOUS VOLUME FRACTIONS OF BASALT FIBERS FOR HVFASCC

Sl. No	Percentage variation of basalt fibers	UPV (km/s)
1	0	4.523
2	0.25	4.621
3	0.5	4.728
4	0.75	4.811
5	1	4.982

FIGURE II

VARIATION OF ULTRASONIC PULSE VELOCITY FOR PERCENTAGE VARIATION OF VOLUME FRACTION OF BASALT FIBERS



Direct method of testing was adopted in the present work. Table III shows marginal increase in Ultrasonic pulse velocity as the percentage of basalt fibers increased. It can be concluded that the quality of concrete was excellent since velocities of all the specimens were more than 4km/s. An upsurge in pulse velocity is due to fibers which increase the density of concrete. As a result the pulse travels in lessertime which increases its velocity. Figure II indicates the variation of ultrasonic pulse velocity for different volume fraction of basalt fibers

C. Rebound Number of HVFA Basalt Fiber Reinforced SCC

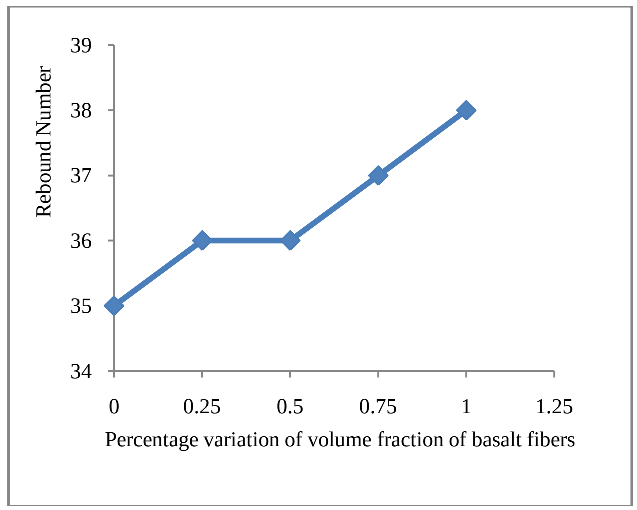
TABLE IV

REBOUND NUMBER FOR VARIOUS VOLUME FRACTIONS OF BASALT FIBERS FOR HVFASCC

Percentage of Basalt fibers	Rebound Number	Compressive strength MPa
0	35	32
0.25	36	34
0.5	36	34
0.75	37	35
1	38	37

FIGURE III

VARIATION OF REBOUND NUMBER FOR PERCENTAGE VARIATION OF VOLUME FRACTION OF BASALT FIBERS



The concrete cube specimens were kept at room temperature for 24 hours after 28 days curing before testing it with the rebound hammer. From Table IV it can be depicted that Rebound Number increased as the percentage of basalt fibresincreased. Increment in density of concrete was observed after addition of basalt fibres hence resistance offered by the specimens increased. Maximum Rebound number was observed for 1% volume fraction of basalt fibres. Figure III indicates the variation of compressive strength from Rebound number for different volume fraction of basalt fibres.

D. Chloride Permeability of HVFA Basalt Fiber Reinforced SCC

The electrical conductance of concrete specimen is determined by this test which can be related to the resistance offered by the specimen to the chloride ions. The specimens chosen for this test are standard cylindrical specimens of 50mm thick and 100mm diameter. The apparatus consists of DC supply which maintains constant voltage 60volts. Digital current meter precisely measures the passage of current through the specimen. At every 30 min interval, current readings were recorded in this test. Total charge passed in Coulombs was calculated based on the current readings at every 30 min interval.

Total charge $Q = 900 \times (I_0+2I_{30}+2I_{60}\ldots\ldots\ldots+I_{360})$

Q = Current flowing in Coulombs;

$I_{cumulative}$= Current reading in amperes at time interval (t) [9]

TABLE V

CHLORIDE PENETRATION IN COULOMBS FOR VARIOUS VOLUME FRACTIONS OF BASALT FIBERS FOR HVFASCC

Sl. No.	Percentage variation of volume fraction of basalt fibers	Total charge (Coulombs)
1	0	1562
2	0.25	1448
3	0.5	1320
4	0.75	1208
5	1	1082

FIGURE IV

VARIATION OF CHLORIDE PENETRATION VALUES FOR PERCENTAGE VARIATION OF VOLUME FRACTION OF BASALT FIBERS

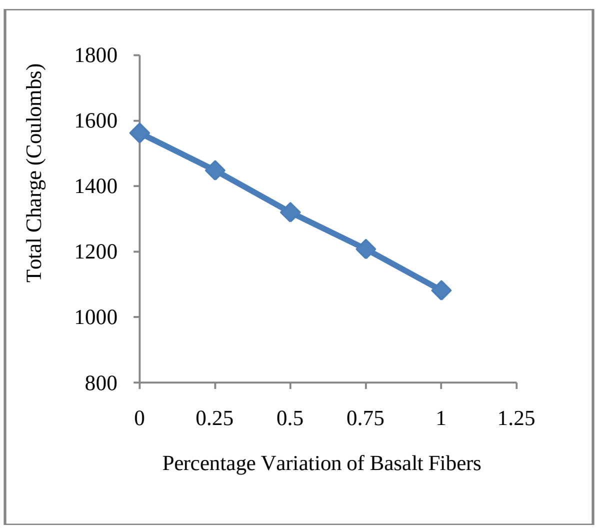


Table V indicates that chloride penetration is low for all specimens as per ASTM C1202-94 (1994) which indicates that the specimens are dense and possess low volume of voids. Fly ash and basalt fibers increase the resistance of SCC to chloride penetration. There was decrease in chloride penetration as the percentage of basalt fibers increased. Addition of basalt fibers may lead to reduction in the permeability of concrete. Resistance of SCC to chloride penetration increased as the percentage of basalt fibers was increased. Least amount of charge in Coulombs value was seen for 0.75% volume fraction of basalt fibers. Figure IV shows variation of coulombs value for different volume fractions of basalt fibers.

E. Ultrasonic Pulse Velocity of HVFA Basalt Fiber Reinforced SCC Exposed to Elevated Temperatures

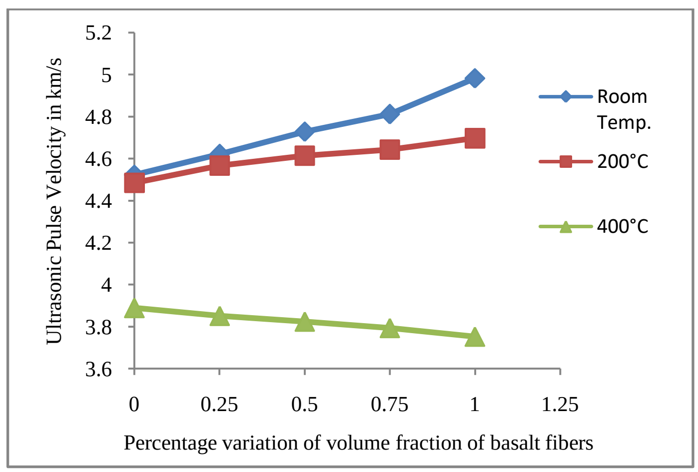
TABLE VI

ULTRASONIC PULSE VELOCITY OF HVFA BASALT FIBER REINFORCED SCC EXPOSED TO ELEVATED TEMPERATURES

Sl. No	Percentage variation of basalt fibers	UPV (km/s)	
		200^0C	400^0C
1	0	4.485	3.889
2	0.25	4.567	3.852
3	0.5	4.614	3.824
4	0.75	4.643	3.794
5	1	4.697	3.753

FIGURE V

VARIATION OF ULTRASONIC PULSE VELOCITY OF HVFA BASALT FIBER REINFORCED SCC SUBJECTED TO ELEVATEDTEMPERATURE



The effect of high temperature on HVFA basalt fibers reinforced SCC was determined for all the specimens subjected to 200^0C and 400^0C for duration of 2 hours. All specimens were placed in box type electric furnace in which rate of heating was kept constant for all specimens. Less reduction in UPV was observed in HVFA SCC without basalt fibers compared to basalt fiber reinforced HVFA SCC. From Table VI it is observed that, at 200^0C maximum decrease in UPV was observed for 1% volume fraction of basalt fibers i.e. 5.72% and at 400^0C maximum decrease in UPV was observed for 1% volume fraction of basalt fibers i.e. 24.66%. The decrease in UPV of SCC may be due to formation of cracks when subjected to elevated temperature. Figure V depicts variation of Ultrasonic Pulse Velocity of HVFA basalt fiber reinforced SCC subjected to elevatedtemperature.

F. Rebound Number of HVFA Basalt Fiber Reinforced SCC Exposed to Elevated Temperatures

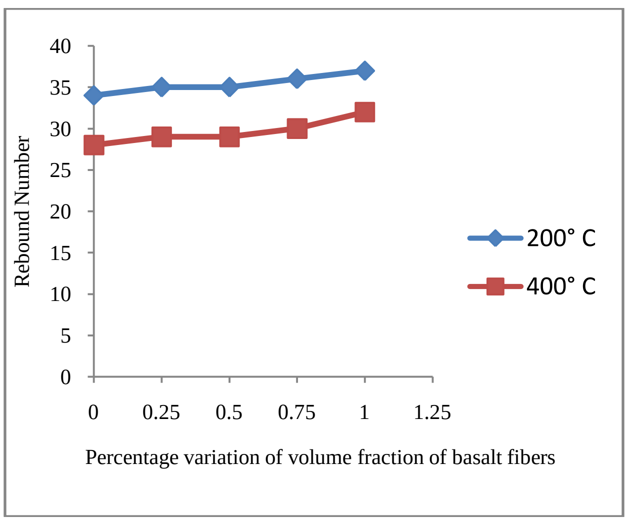
TABLE VII

REBOUND NUMBER OF HVFA BASALT FIBER REINFORCED SCC EXPOSED TO ELEVATED TEMPERATURES

Percentage of Basalt fibers	Rebound Number		Compressive strength MPa	
	200^0C	400^0C	200^0C	400^0C
0	34	28	30	20
0.25	35	29	32	22
0.5	35	29	32	22
0.75	36	30	34	24
1	37	32	35	26

FIGURE VI

VARIATION OF REBOUND NUMBER OF HVFA BASALT FIBER REINFORCED SCC SUBJECTED TO ELEVATED TEMPERATURES



From Table VII it is observed that for 200^0C rebound number reduced marginally, whereas for 400^0C rebound number reduced significantly. It was observed that rate of reduction in Rebound number was less as the percentage of basalt fibres increased. Maximum reduction in rebound number was for the mix without basalt fibres for both 200^0C and 400^0C. At 400^0C, surface hardness reduced and there was formation of micro-cracks. Hence resistance offered by specimens at 400^0C reduced significantly. Figure VI indicates the variation of compressive strength from Rebound number for different volume fraction of basalt fibres after exposing to elevated temperature.

G. Compressive Strength of HVFA Basalt Fiber Reinforced SCC Exposed To Elevated Temperatures

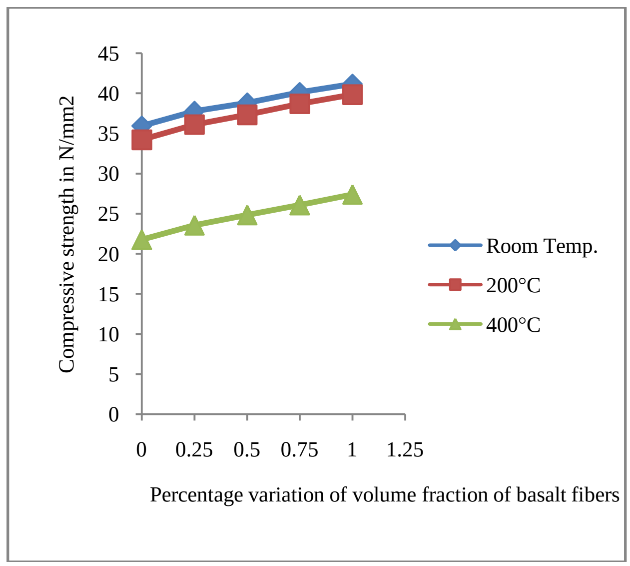
TABLE VIII

COMPRESSIVE STRENGTH OF HVFA BASALT FIBER REINFORCED SCC EXPOSED TO ELEVATED TEMPERATURES

Percentage of basalt fibers	Normal temperature strength (N/mm^2)	Compressive strength at high temperature for 2 hours duration (N/mm2)	
		200^0C	400^0C
0	35.96	34.22 (95.17%)	21.76 (60.6%)
0.25	37.77	36.13 (95.66%)	23.55 (62.35%)
0.5	38.81	37.33 (96.18%)	24.83 (63.98%)
0.75	40.14	38.7 (96.42%)	26.07 (64.95%)
1	41.2	39.85 (96.75%)	27.40 (66.52%)

FIGURE VII

VARIATION OF COMPRESSIVE STRENGTH OF HVFA BASALT FIBER REINFORCED SCC SUBJECTED TO ELEVATED TEMPERATURES



It was observed that the strength was reduced with an increase in temperature. The percentage loss of compressive strength was very less for all percentage of basalt fibers at 200^0C for 2 hours duration. For 200^0C maximum reduction in strength is observed for reference mix (0% volume fraction of basalt fibers). It has been observed as the concentration of basalt fibers increased in the specimens the percentage reduction in strength reduced. For 1% volume fraction of basalt fibers the reduction in strength was least as shown in Table 9. The percentage loss of compressive strength was high in all percentage of basalt fibers (0%, 0.25%, 0.5%, 0.75% and 1%) at 400^0C for 2 hours duration. For 400^0C maximum reduction in strength is observed for reference mix (0% volume fraction of basalt fibers). For 0.75% volume fraction of basalt fibers the reduction in strength was less.

H. Regression and Correlation

TABLE IX

COMPRESSIVE STRENGTH OBTAINED FROM EXPERIMENTAL AND ANALYTICAL METHODS

Percentage of basalt fibers	Compressive strength in MPa		
	Experimental Results	Predicted from Equations	% Error in prediction
0	35.96	36.03	0.20
0.25	37.77	37.57	0.52
0.5	38.81	38.94	0.33
0.75	40.14	40.14	0
1	41.2	41.17	0.07

TABLE X

COMPRESSIVE STRENGTH OBTAINED FROM EXPERIMENTAL AND ANALYTICAL METHODS SUBJECTED TO ELEVATED TEMPERATURE AT 200^{O}C

Percentage of basalt fibers	Compressive strength in MPa		
	Experimental Results	Predicted from Equations	% Error in prediction
0	34.22	31.56	7.77
0.25	36.13	33.22	8.05
0.5	37.33	34.64	7.20
0.75	38.7	35.82	7.44
1	39.85	36.76	7.75

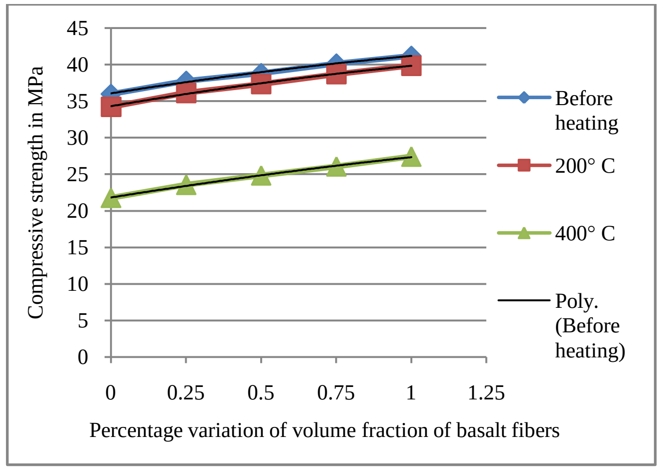
TABLE XI

COMPRESSIVE STRENGTH OBTAINED FROM EXPERIMENTAL AND ANALYTICAL METHODS SUBJECTED TO ELEVATED TEMPERATURE AT 400^{O}C

Percentage of basalt fibers	Compressive strength in MPa		
	Experimental Results	Predicted from Equations	% Error in prediction
0	21.76	18.47	15.11
0.25	23.55	20.29	13.84
0.5	24.83	21.92	11.71
0.75	26.07	23.36	10.39
1	27.40	24.61	10.18

FIGURE VIII

BEST FIT CURVES FOR COMPRESSION STRENGTH BEFORE AND AFTER HEATING FOR BASALT FIBERS



From Table IX, X, XI it is witnessed that, various best fit polynomial equations satisfies the experimental values for compressive strength at 28 days for different volume fraction of basalt fibers with different temperatures.

Regression equations for compressive strength are as given below:

1. Regression equation and Coefficient of correlation for mix tested before heating is given below,

$$y = -1.3829x^2 + 6.5229x + 36.033$$

$$r^2 = 0.9963$$

2. Regression equation and Coefficient of correlation for mix tested before heating is given below,

$$y = -1.5429x^2 + 7.0749x + 34.287$$

$$r^2 = 0.9976$$

3. Regression equation and Coefficient of correlation for mix tested before heating is given below,

$$y = -1.0971x^2 + 6.6171x + 21.825$$

$$r^2 = 0.998$$

Where, x= Percentage variation of volume fraction of basalt fibers

y=Compressive strength

Figure VIII shows the best fit curves for Compression strength before and after heating for basalt fibers reinforced HVFASCC.

IV. CONCLUSIONS

Based on the study, following conclusions are made:

1. No significant change in compressive strength with addition of basalt fibers was observed. Marginal increase in compressive strength with increase in percentage of basalt fibers up to 1% volume fraction was found.
2. Ultrasonic Pulse velocity increased continuously for all percentage of basalt fibers. Maximum ultrasonic pulse velocity was obtained for 1% volume fraction of basalt fibers. Reduction in UPV was observed for all volume fractions of basalt fibers for both 200^0C and 400^0C temperatures. At 200^0C maximum decrease in UPV was observed for 0.75% volume fraction of basalt fibers i.e. 3.5% and at 400^0C maximum decrease in UPV was observed for 0.75% volume fraction of basalt fibers i.e. 21.13%. The decrease in UPV of SCC may be due to formation of cracks when subjected to elevated temperature.
3. Rebound Number increased as the percentage of basalt fibers increased. Rebound number reduced marginally at 200^0C, whereas for 400^0C rebound number reduced significantly.
4. It is observed that chloride penetration is low for all specimens. Resistance of HVFA SCC to chloride penetration increases as the percentage of basalt fibers increased. For 0.75% volume fraction of basalt fibers, least value of total charge (Coulombs) was observed. The lessening in charge is ascribed to decrease in permeability of concrete with the expansion in basalt fiber fixation.
5. It was observed that there was reduction in compressive strength with increase in temperature. Maximum reduction in strength was observed for reference mix for both 200^0C and 400^0C. For 0.75% volume fraction of basalt fibers the reduction in strength was less.
6. It can be concluded from regression and correlation analysis that best fit polynomial curves were found to be satisfied for combined compressive strength v/s basalt fibers before heating and at different temperatures with positive correlation value near to unity.

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