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Effect Of Sulphate Attack On Strength Characteristic Of Fiber Reinforced High Volume Fly Ash Concrete

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ABSTRACT

The production of fly ash increases with the coal utilisation and contributes to environmental degradation. The dumping problem of fly ash raised the alarming situation in the world which initiated towards consumption of fly ash in industry. The road construction industry is one which consumes the cement for its pavement and other structures. The pavement will fail mostly due to excessive tensile stress. The use of plain high volume fly ash concrete suffers from low tensile strength and limited ductility. These problems can be eliminated by introducing the reinforcement. When the fibers are mixed with concrete the tensile property of concrete increases.

There were numerous studies on the strength characteristic of concrete containing fly ash. However, there is little study in the literature regarding the strength of HVFA concrete with fibers subjected to sulphate media. Thus the aim of this work is to study the effect of variation of fiber content from 0.2% to 1.8% in high volume fly ash concrete exposed to sulphate media. It is also aimed to study the effect of fibers on HVFAC subjected to sulphate attack for different periods. The studies cited in this paper, regarding sulphate attack on fiber reinforced high volume fly ash concrete, are presented the strength characteristics up to 90 days of exposer condition. In this research work locally available materials are used. The fly ash is obtained from Raichur thermal power plant. Crimped steel fibers are used. The design of HVFAC mix was carried out as per the guidelines of CANMET hand book [1].

The study reveals the fact that the strength characteristics of fiber reinforced high volume fly ash concrete (FRHVFAC) attain higher value at 1.4% additions of steel fibers, when subjected to sulphate attack.

Keywords - Fly ash, HVFAC, FRHVFAC, Pavement, Compressive strength, Tensile strength. Flexural strength, Impact strength, sulphate attack.

I. INTRODUCTION

The main challenge before the construction industry is to serve the two important need of the society, namely, the protection of the environment and meeting the requirement of developing construction industry. The development of human activity results in environmental degradation. The main challenge is to minimise this degradation to a level consistent with sustainable development [2]. For civil engineers, the concept of sustainable development involves the use of high performance materials with reasonable cost with lowest possible environmental impact. The means of achieving it is to consume the waste products in construction industry.

The production of fly ash is increasing with the coal utilisation and contributing to environmental degradation. This problem has raised the alarming situation in the world which initiated towards utilization of fly ash in construction industry.

The large size of the concrete and cement industry is unquestionably the ideal place for economic and safe disposal of million tons of industrial byproduct fly ash due to its highly pozolonic and cementitious properties. Fly ash can be used in much larger amounts as cement replacement material in concrete than that being practiced today. The concrete containing 40 to 60 percentage of cement replacement by fly ash have shown the high strength and durability even at early ages. The study on suitability of superplasticized high volume fly ash concrete for pavements showed that high volume fly ash concrete with 50% - 60% fly ash can be designed to meet the strength and workability requirement of concrete pavements[3]. This has removed the strong objection of usages of high volume fly ash in concrete. The high volume fly ash utilization in concrete is highly advantageous in view of energy efficiency, durability, economy and overall ecological and environmental benefits [4].

The use of high volume fly ash (HVFA) concrete fits in very well with sustainable development. High volume fly ash concrete mixtures contain lower quantities of cement and higher volume of fly ash (up to 60%)[5]. The use of fly ash in concrete at proportions ranging from 35% to 60% of total cementitious binder has been studied extensively over the last twenty five years and the properties of blended concrete are well documented. The replacement of fly ash as a cementitious component in concrete depends upon several factors. From the literature it is generally found that fly ash content in the cementitious material varies from 30-80% for low strength (20 MPa) to high strength (100MPa) of concrete [5].

In India, fly ash mission has initiated projects on use of higher volume fly ash concrete construction. Gujrat Ambuja cements had laid down a high volume fly ash (50%) concrete road at their Ropar Plant, Punjab. The grade of the concrete was M-40 [6].

The road construction industry is one which consumes the cement for its pavement and other structures. The pavement will fail mostly due to excessive tensile stress, which is the guiding factor of design [7]. Flexural strength of concrete is also an important property for concrete pavements. The rigid pavements are assumed to rest on a flexible soil subgrade and undergo mainly flexural stresses during service loads. The use of plain high volume fly ash concrete suffers from low tensile strength and limited ductility. These problems can be eliminated by introducing the reinforcement in tensile zone of concrete. When the fibers are mixed with concrete, the post cracking behavior improves.

The fibers are added to the HVFAC to improve the tensile, flexural and impact strength of concrete required for pavement. The pavement is laid on various types of soil environment, which may contain sulphates and other chemicals. The sulphate present in the soil will cause the deterioration of concrete and results in lowering the strength. The consequences of this are to reduce the life span of the FRHVFAC or reinforced concrete structure.

This paper reports effect of sulphate attack on FRHVFAC with varying exposer condition to sulphate media. The percentage replacement of cement by fly ash and fiber aspect ratio are kept constant. The fibers percentage is varied from 0.2% to 1.8% and the strength properties are studied.

II. OBJECTIVE OF THE STUDY

There are numerous studies on the strength characteristic of concrete containing fly ash. However, there is little study in the literature regarding the strength of high volume fly ash concrete with fibers subjected to sulphate attack. Thus the main aim of this work is to study the effect of variation of fiber content from 0% to 1.8% in high volume fly ash concrete under sulphate attack. It is also aimed to study the effect of fibers on HVFAC with different sulphate exposer condition. The studies are made to evaluate the compressive strength, tensile strength, flexural strength and impact strength subjected to sulphate media.

III. MATERIALS USED

3.1 Cement

In the present research work ordinary Portland cement of 43 grade is used. The tests on cement were conducted in accordance with Indian standards confirming to IS: 8112 – 1989[8]. The specific gravity of cement is 3.15

3.2 Fly ash

The fly ash used in the present study is taken from Raichur Thermal Power Station, Shakthinagar, Raichur, Karnataka. The physical and chemical properties of fly ash used are reported in the table 1 and table 2.

Table: 1 Physical properties of fly ash

Test conducted	**Results**	**Requirement as per IS:3812:2003[9]**	
Specific gravity	2.5	Part 1	Part 2
Fineness–Specific surface in m^2/kg by Blaine's Air-permeability method, (Minimum)	469	320	200
Lime reactivity –Average compressive strength in N/mm^2, (Minimum).	4.6	4.5	--
Comparative compressive strength at 28 days, percent, (minimum)	90	Not less than 80% of the strength to plain cement mortar cubes.	
Soundness by autoclave test, expansion of specimens in percentage, (maximum)	0.0025	34	50
Residue on 45 micron sieve, percent,(Maximum)	28.5	34	50

Table: 2 Chemical composition of fly ash

Test conducted	Results	Requirement as per IS:3812:2003[9]			
		Part 1		Part 2	
		Siliceous pulverized fuel ash %	Calcareous pulverized fuel ash %	Siliceous pulverized fuel ash %	Calcareous pulverized fuel ash %
Silicon dioxide (SiO) plus aluminium oxide (Al2O2) plus iron oxide (Fe), percent by mass,(Minimum)	94.68	70%	50%	70%	50%
Silicon dioxide (SiO),Percent by mass,(Minimum)	61.90	35%	25%	35%	25%
Magnesium oxide (MgO) percent by mass,(Maximum)	0.79	5%	5%	5%	5%
Total sulphur as sulphurtrioxide (SO3),percent bymass,(Maximum)	0.13	3%	3%	5%	5%
Loss on ignition, percent bymass, (Maximum)	0.47	5%	5%	5%	5%

3.3 Fine aggregate

The fine aggregates used in this experimental program is procured locally from Tungabhadra river bed near Harihar. The test on sand is conducted according to IS:2386 – 1963 and IS:383-1970. The test results of sieve analysis confirmed the sand to zone II and fineness modulus 2.65. Properties of the fine aggregate used in the experimental work are tabulated in table 3.

Table: 3 Physical properties of fine aggregate[10][11][12]

Property	Result in %	Reference code
Specific gravity	2.66	As per ,IS:2386-(PART-III) -
Fineness modulus	2.65	As per ,IS:2386-(PART-I) -
Water absorption	0.91	As per ,IS:2386-(PART-III) -

3.4 Coarse aggregate

Locally available crushed granite coarse aggregates having maximum size of 20 mm are used in the present work. The aggregates are tested as per IS: 2386-1963. The specific gravity was found to be 2.72 and fineness modulus 6.53.

3.5 Superplasticizer

Conplast- SP430, a concrete superplasticizer based on Sulphonated Naphthalene Polymer is used as a water-reducing admixture and to improve the workability of fly ash concrete.

3.6 Steel fibers

Crimped steel fibers manufactured by M/s Stewols India (P) Ltd., Nagapur, are used in the present study. The average equivalent diameter is 0.75 and average aspect ratio 50.

3.7 Proportioning

The design of HVFAC mix was carried out as per the guidelines of CANMET hand book[1]. The guidelines of CANMET have used the absolute volume method, which is the most common procedure of mix design. The trail batch mixes with 50% replacement of cement by fly ash are tested and mix proportion of 1:1.17:2.54 was arrived with water to binder ratio of 0.3 for M40 concrete.

IV. EXPERIMENTAL PROCEDURE

The design mix of M40 concrete is designed in accordance with the guidelines of CANMET hand book with 50% replacement of cement by fly ash. The mix proportion arrived is 1:1.17:2.54 (BC: FA: CA) with water binder ratio of 0.3% and superplasticizer dosage of 1.1% (by weight of cement). Fibers are added at varying percentages of 0, 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6 and 1.8 % by volume fraction.

The specimens are cast for compressive strength, split tensile strength, flexural strength and impact strength test. The specimens are cured in water for 7, 28 and 90 days and then the specimens are subjected to sulphate attack for 90 days. They are immersed in magnesium sulphate solution of 15% concentration for 90 days. After 90 days of sulphate attack, the specimens are removed from the sulphate media, washed in running water and weighed accurately. Then they are tested for their respective strengths.

V. EXPERIMENTAL RESULTS

5.1 Overall results of compressive strength

Following table 4 gives the overall results of compressive strength of FRHVFAC when subjected to sulphate attack for 90 days with magnesium sulphate solution of 15% concentration. Also it gives the percentage increase or decrease of compressive strength with respect to reference mix. Variation in the compressive strength can be depicted in the form of graph as shown in fig 1.

Table 4 Overall results of compressive strength for FRHVFAC when subjected to sulphate attack.

Percentage of fiber	7 days compressive strength (MPa)	Percentage increase or decrease of 7 days compressive strength with respect to reference mix.	28 days compressive strength (MPa)	Percentage increase or decrease of 28 days compressive strength with respect to reference mix.	90 days compressive strength (MPa)	Percentage increase or decrease of 90 days compressive strength with respect to reference mix.
0.00 (Reference mix)	16.22	.-	36.00	.-	42.44	.-
0.20	16.59	2	37.04	3	43.85	3
0.40	17.22	6	38.21	6	45.04	6
0.60	17.74	9	39.33	9	46.52	10
0.80	18.44	14	40.89	14	48.30	14
1.00	18.81	16	41.70	16	48.74	15
1.20	19.00	17	41.85	16	49.04	16
1.40	19.04	17	42.15	17	49.19	16
1.60	18.89	16	41.78	16	48.89	15
1.80	18.74	16	41.70	16	48.89	15

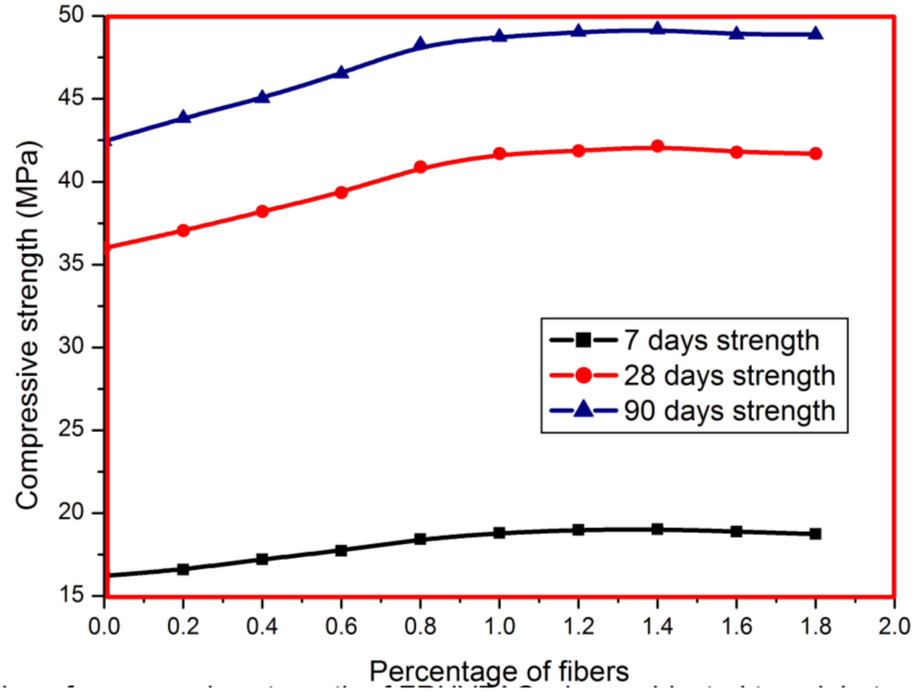

Fig. 1 - Variation of compressive strength in FRHVFAC subjected to sulphate attack.

5.2 Overall results of tensile strength

Following table 5 gives the overall results of compressive strength of FRHVFAC when subjected to sulphate attack for 90 days with magnesium sulphate solution of 15% concentration. Also it gives the percentage increase or decrease of tensile strength with respect to reference mix. Variation in the tensile strength can be depicted in the form of graph as shown in fig. 2.

Table 5 Overall results of tensile strength for FRHVFAC when subjected to sulphate attack.

Percentage of fiber	7 days tensile strength (MPa)	Percentage increase or decrease of 7 days tensile strength with respect to reference mix.	28 days tensile strength (MPa)	Percentage increase or decrease of 28 days tensile strength with respect to reference mix.	90 days tensile strength (MPa)	Percentage increase or decrease of 90 days tensile strength with respect to reference mix.
0.00 (Reference mix)	1.41	.-	1.92	.-	2.75	.-
0.20	1.53	8	2.16	12	2.76	0
0.40	1.59	13	2.23	16	2.81	2
0.60	1.67	18	2.26	18	2.94	7
0.80	1.73	23	2.36	23	2.97	8
1.00	1.84	30	2.45	28	3.01	9
1.20	1.87	33	2.51	31	3.22	17
1.40	1.99	41	2.55	33	3.28	19
1.60	1.96	39	2.49	30	3.25	18
1.80	1.94	37	2.45	27	3.17	15

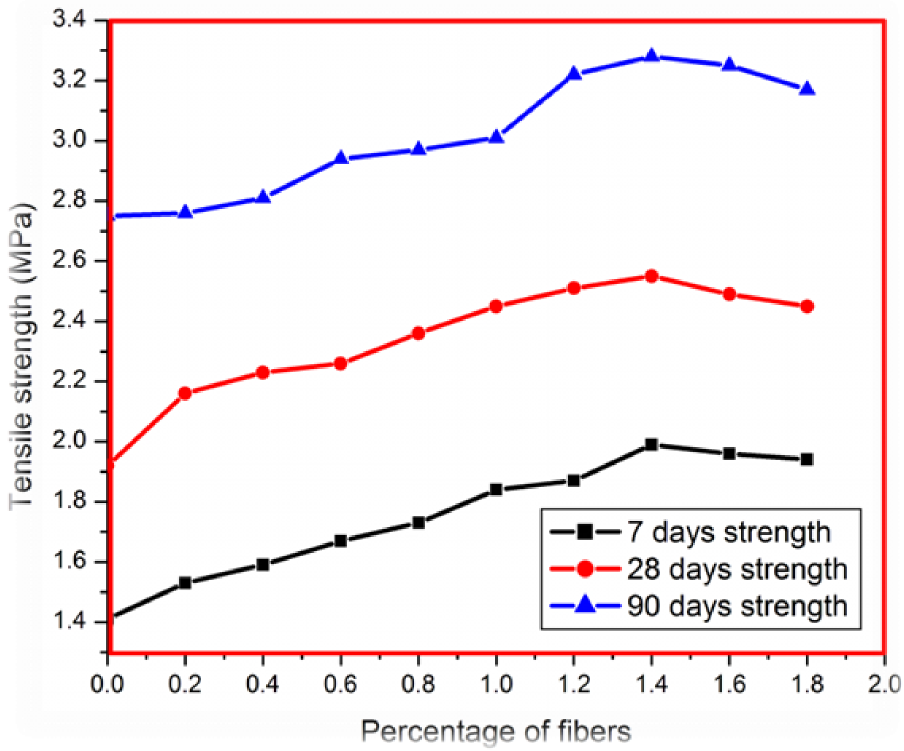

Fig. 2 Variation of tensile strength in FRHVFAC subjected to sulphate attack.

5.3 Overall results of flexural strength

Following table 6 gives the overall results of flexural strength of FRHVFAC when subjected to sulphate attack for 90 days with magnesium sulphate solution of 15% concentration. Also it gives the percentage increase or decrease of flexural strength with respect to reference mix. Variation in the flexural strength can be depicted in the form of graph as shown in fig. 3.

Table 6 Overall results of flexural strength for FRHVFAC when subjected to sulphate attack.

Percentage of fiber	7 days flexural strength (MPa)	Percentage increase or decrease of 7 days flexural strength with respect to reference mix.	28 days flexural strength (MPa)	Percentage increase or decrease of 28 days flexural strength with respect to reference mix.	90 days flexural strength (MPa)	Percentage increase or decrease of 90 days flexural strength with respect to reference mix.
0.00 (Reference mix)	1.84	.-	2.79	.-	4.79	.-
0.20	2.29	25	3.48	25	5.23	9
0.40	2.53	38	3.85	38	5.51	15
0.60	2.61	42	4.09	47	5.85	22
0.80	2.84	54	4.29	54	5.91	23
1.00	3.17	72	4.79	72	5.92	24
1.20	3.23	75	4.88	75	6.08	27
1.40	3.32	80	4.91	76	6.20	30
1.60	3.27	78	4.87	75	6.16	29
1.80	3.23	76	4.84	74	6.12	28

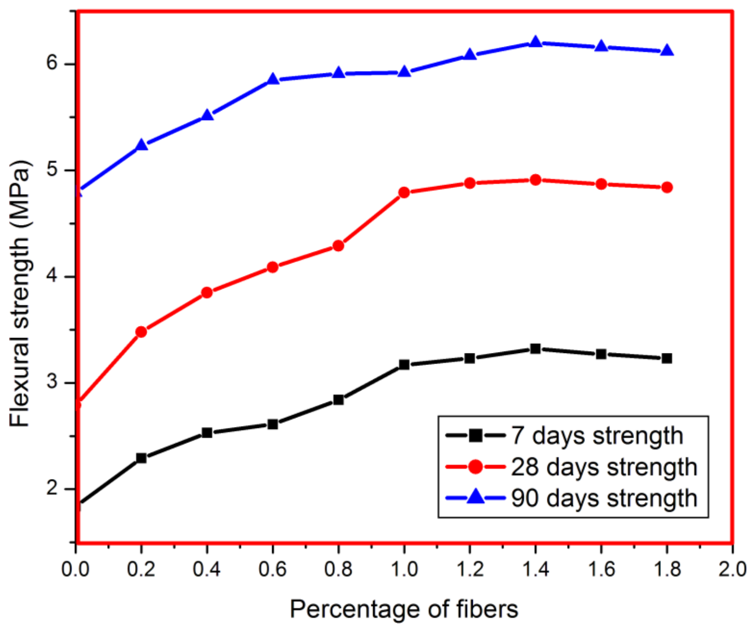

Fig. 3 – Variation of flexural strength in FRHVFAC subjected to sulphate attack.

5.4 Overall results impact strength

Following table 7 gives the overall results of impact strength of FRHVFAC when subjected to sulphate attack for 90 days with magnesium sulphate solution of 15% concentration. Also it gives the percentage increase or decrease of impact strength with respect to reference mix. Variation in the impact strength can be depicted in the form of graph as shown in fig. 4.

Table 7 Overall results of impact strength for FRHVFAC when subjected to sulphate attack.

Percentage of fiber	7 days impact energy (N-m)	Percentage increase or decrease of 7 days impact energy with respect to reference mix.	28 days impact energy (N-m)	Percentage increase or decrease of 28 days impact energy with respect to reference mix.	90 days impact energy (N-m)	Percentage increase or decrease of 90 days impact energy with respect to reference mix.
(Reference mix)	1120.38		1708.24		2040.20	
0.20	1811.97	62	2752.54	61	3291.98	61
0.40	2123.19	90	3229.74	89	3852.17	89
0.60	2558.90	128	3886.75	128	4640.59	127
0.80	2953.10	164	4488.44	163	5352.93	162
1.00	2966.94	165	4509.19	164	5373.68	163
1.20	3298.90	194	5000.22	193	5968.45	193
1.40	3451.05	208	5221.53	206	6231.26	205
1.60	3215.91	187	4882.65	186	5823.22	185
1.80	2738.71	144	4156.48	143	4965.64	143

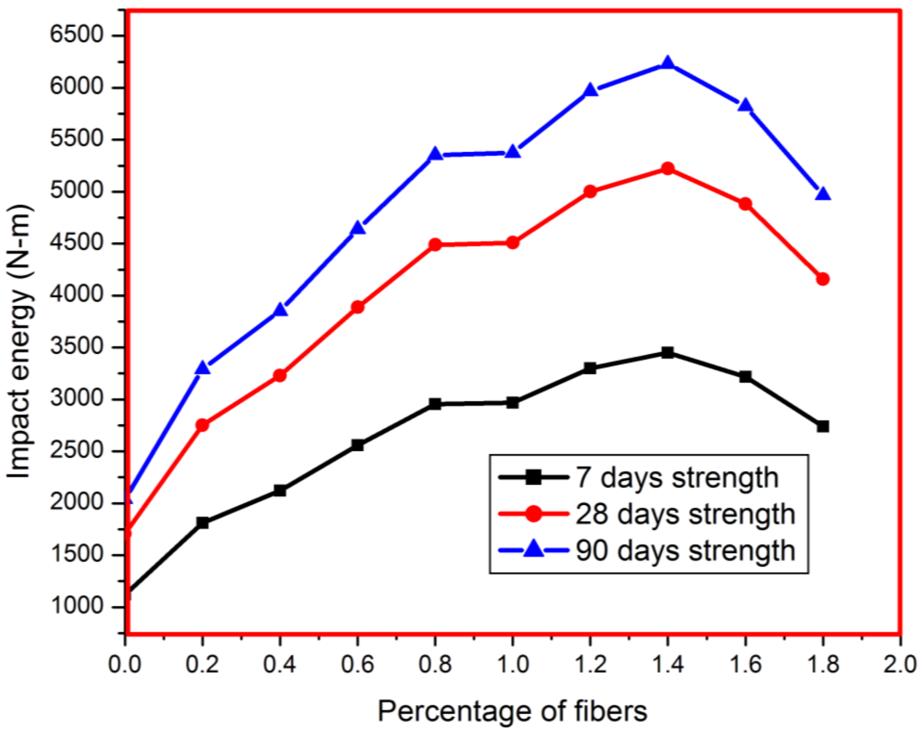

Fig. 4 –Variation of impact strength in FRHVFAC subjected to sulphate attack.

VI. OBSERVATIONS AND DISCUSSIONS

Following observations were made based on the studies conducted on FRHVFAC.

It is observed that the compressive strength of FRHVFAC subjected to sulphate attack increases as the percentage of steel fibers in it increases up to 1.4%. Thereafter the compressive strength shows a decreasing trend. Thus the higher value of compressive strength may be obtained by using 1.4% steel fibers when subjected to sulphate attack. This is true for 7 days, 28 days and 90 days compressive strength. At 1.4% addition of steel fibers the percentage increase of 7 days, 28 days and 90 days compressive strength are found to be 17%, 17% and 16% respectively. It is also observed that a small percentage addition of fibers have improved the compressive strength of high volume fly ash concrete. (Table 4 and fig 1)

It is observed that the tensile strength of FRHVFAC subjected to sulphate attack increases as the percentage of steel fibers in it increases up to 1.4%. Thereafter the tensile strength shows a decreasing trend. Thus the higher value of tensile strength may be obtained by using 1.4% steel fibers when subjected to sulphate attack. This is true for 7 days, 28 days and 90 days tensile strength. At 1.4% addition of steel fibers the percentage increase of 7 days, 28 days and 90 days tensile strength are found to be 40%, 33% and 18% respectively. Also it is observed that a small percentage addition of fibers have improved the tensile strength of high volume fly ash concrete. (Table 5, and fig 2)

It is observed that the flexural strength of FRHVFAC subjected to sulphate attack increases as the percentage of steel fibers in it increases up to 1.4%. Thereafter the flexural strength shows a decreasing trend. Thus the higher value of flexural strength may be obtained by using 1.4% steel fibers when subjected to sulphate attack. This is true for 7 days, 28 days and 90 days flexural strength. At 1.4% addition of steel fibers the percentage increase of 7 days, 28 days and 90 days flexural strength are found to be 78%, 76% and 29% respectively. Also it is observed that a small percentage addition of fibers have improved the flexural strength of high volume fly ash concrete. (Table 6 and fig 3)

It is observed that the impact strength of FRHVFAC subjected to sulphate attack increases as the percentage of steel fibers in it increases up to 1.4%. Thereafter the impact strength shows a decreasing trend. Thus the higher value of impact strength may be obtained by using1.4% steel fibers when subjected to sulphate attack. This is true for 7 days, 28 days and 90 days impact strength. At 1.4% addition of steel fibers the percentage increase of 7 days, 28 days and 90 days impact strength are found to be 208%, 206% and 205% respectively. Also it is observed that a small percentage addition of fibers have improved the impact strength of high volume fly ash concrete substantially. (Table 7 and fig 4)

The improvement in the properties of HVFAC subjected to sulphate attack may be due to the fact that additions of fibers improve the stiffness of concrete. Also, addition of 1.4% fibers will fill all the major voids resulting in dense mass. Addition of more than 1.4% steel fiber result in lowering the strength characteristics, since it affect the workability of concrete seriously. Mixing and compaction operations become difficult when more than 1.4% steel fibers are added in high volume fly ash concrete. Substantial improvements are found in tensile strength, flexural strength and impact strength when 1.4% steel fibers are added to high volume fly ash concrete, and marginal increase is found for compressive strength when subjected to sulphate attack.

Thus, there is a clear indication that the use of steel fibers in high volume fly ash concrete can modify the properties even in sulphate environment to suit it for rigid pavement construction.

VII. CONCLUSIONS

Following conclusions can be drawn based on the study conducted

a. Compressive strength of FRHVFAC subjected to sulphate attack shows an increasing trend up to 1.4% addition of steel fibers. Thereafter compressive strength shows a decreasing trend. The percentage increase of 7 days, 28 days and 90 days compressive strength for 1.4% addition of steel fibers are found to be 17%, 17% and 16% respectively.
b. Tensile strength of FRHVFAC subjected to sulphate attack shows an increasing trend up to 1.4% addition of steel fibers. Thereafter tensile strength shows a decreasing trend. The percentage increase of 7 days, 28 days and 90 days tensile strength for 1.4% addition of steel fibers are found to be 40%, 33% and 18% respectively.
c. Flexural strength of FRHVFAC subjected to sulphate attack shows an increasing trend up to 1.4% addition of steel fibers. Thereafter flexural strength shows a decreasing trend. The percentage increase of 7 days, 28 days and 90 days flexural strength for 1.4% addition of steel fibers are found to be 78%, 76% and 29% respectively.
d. Impact strength of FRHVFAC subjected to sulphate attack shows an increasing trend up to 1.4% addition of steel fibers. Thereafter impact strength shows a decreasing trend. The percentage increase of 7 days, 28 days and 90 days impact strength for 1.4% addition of steel fibers are found to be 208%, 206% and 205% respectively.
e. FRHVFAC shows better resistance to sulphate attack. Therefore FRHVFAC can be recommended in the construction of rigid pavements in soil affected by sulphates.

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