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Behaviour of Metakaoline Based Hybrid Fiber Reinforced Concrete when Subjected to Sulphate Attack

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Abstract:

The addition of small closely spaced and uniformly dispersed fibers to concrete would act as crack resistor and would substantially improve its properties. This type of concrete is known as Fiber Reinforced Concrete. The addition more than one type of fiber in concrete is known as Hybrid Fibre Reinforced Concrete. Combining fibres with different geometry and mechanical properties can improve the mechanical properties of fibre reinforced concrete. These composites take advantage of different and synergistic effects on mechanical properties of each fibre type. Macrofibers of steel, due to their high modulus and improved bonding characteristics are known to improve toughness of concrete at relatively small crack openings; on the other hand, micro-fibres of polypropylene are expected to mitigate shrinkage cracking, improve the tensile strength of the matrix, improve the crack growth resistance and enhance strain capability.

In this experimental work an attempt is made to study the strength characteristics of metakaoline based hybrid fiber reinforced concrete when subjected to sulphate attack. Different fibers used in the work are steel fibers (SF), galvanized iron fibers (GIF), waste coiled steel fibers (WCSF), high density polyethylene fibers (HDPEF), waste plastic fibers (WPF) and polypropylene fibers (PPF). Different combinations of hybrid fibers used for the study are (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF).

Keywords: Hybrid fibres, mono fibres, steel fibers (SF), galvanized iron fibers (GIF), waste coiled steel fibers (WCSF), high density polyethylene fibers (HDPEF), waste plastic fibers (WPF), polypropylene fibers (PPF), sulphate attack.

1. Introduction

To overcome the deficiencies in FRC, hybrid fibre reinforced concrete (HFRC) is gaining importance. A composite can be termed as hybrid, if two or more types of fibres are rationally combined in a common matrix to produce a composite that derives benefits from each of the individual's fibres and exhibits a synergetic response. Addition of short discontinuous fibres plays an important role in the improvement of mechanical properties of concrete. It increases elastic modulus; decreases brittleness, controls cracks initiation and its subsequent growth and propagation. Deboning and pull out of the fibre require more energy absorption, resulting in a substantial increase in the toughness and fracture resistance of the materials to the cyclic and dynamic loads [1].

In HFRC two or more different types of fibres are rationally combined in the matrix. Each individual fibre exhibits a synergistic response. The main purpose of use of HFRC is to arrest the cracks at different sizes and levels at different zones of concrete for different curing ages and loading stages [2]. Mobasher et al. [3] have concluded that fracture toughness may be increased by the use of hybrid fibres. Hybrid composites are shown to have superior strength and toughness properties due to the interaction of reinforcing fibers.

Sulphate attack on concrete is a chemical breakdown mechanism where sulphate ions attack components of the cement paste. The compounds responsible for sulphate attack on concrete are water-soluble sulphate-containing salts, such as alkali-earth (calcium, magnesium) and alkali (sodium, potassium) sulphates that are capable of chemically reacting with components of concrete. Sulphate attack is mainly caused by reaction of sulphates with C_3A. This reaction leads to the formation of calcium sulpho-aluminate, which is double salt, known as ettringite. The formation of this voluminous double salt absorbing much water in its formation causes the cracking and destruction of the concrete. The end result of sulphate attack can be excessive expansion, delamination, cracking, and loss of strength. The degree to which this attack can occur depends on water penetration, the sulphate salt and its concentration and type (eg sodium or magnesium), the means by which the salt develops in the concrete (eg is it rising and drying causing crystallization), and the chemistry of the binder present in the concrete[4].

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Experiments conducted by various research workers have shown that the sulphate resistance of ordinary Portland cement was greatly increased when certain pozzolonic materials were used as replacement of cement. Finely divided diatomic and other pozzolanas high in opal are preventing disintegration of concrete due to sulphate action. The obvious reason is that the addition of pozzolonic material converts calcium hydroxide formed in the process of hydration, into insolvable cementitious compound. The improvement in the permeability characteristics of concrete is the important factor responsible for the improved resistant to sulphate attack[5].

The concrete with high replacement level of metakaolin have higher resistance to magnesium solution. Due to the reduction of calcium hydroxide and the increase of secondary C–S–H in the cement matrix, metakaolin provide a good resistive agent to aggressive chloride solution by consuming liberated lime and so prevent the formation of Friedel's salt[6].

II. Materials used

Materials used in this study include ordinary portland cement (OPC 43), metakaoline, fine aggregate, coarse aggregate, steel fibre (SF), galvanised iron fibre (GIF), high density polyethylene fibre (HDPEF), waste plastic fibre (WPF), waste coiled steel fibre (WCSF), poly propylene fibre (PPF) and magnesium sulphate

- Cementicious material

In this experimental work, 43 grade ordinary Portland cement (OPC) with specific gravity 3.15, conforming to IS: 8112 – 1989 was used[7]. Metakaolin supplied by 20 Microns Company Vadodhara, was used in the present experimental investigation.

- Aggregate

Locally available river sand belonging to zone II of IS: 383–1970 and specific gravity 2.26, bulk density 1752 kg/m^3 and water absorption 1.0 % was used. Locally available crushed aggregates confirming to IS: 383–1970 and specific gravity 2.65, bulk density 1782 kg/m^3 and water absorption 0.6 % was used[8].

- Fibres

Crimped steel fibres (SF) of 1mm thickness and 50mm length giving an aspect ratio of 50, with density 7850 kg/m^3 and ultimate tensile strength 395 MPa were used. Steel fibres were obtained from Stewools India (P) Ltd. Nagpur. Galvanized iron fibres (GIF) are made

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up of round galvanized iron wire of 1mm diameter, cut to the required length of 50 mm keeping an aspect ratio of 50. The ultimate strength and density of GI fibres was found to be 395 MPa and 7850 kg/m^3 respectively. Waste coiled steel fibres(WCSF) were obtained from lathe machine shops. The coiled steel wires were cut in lengths of 50mm. Average thickness was found to be 1mm so that the aspect ratio is 50. High density polyethylene fibres (HDPEF) were procured from cutting HDPE oil cans. Fibres were cut to a length of 50 mm and width of 2mm. Thickness was found to be 1 mm, so that the aspect ratio is 50. Density of HDPE fibre was found to be 900 kg/m^3. Waste plastic fibres (WPF) were procured from cutting waste plastic buckets. Fibres were cut to a length of 50 mm and width of 2mm.Thickness was found to be 1mm, so that aspect ratio is 50. Density of waste plastic fibre was found to be 230 kg/m^3. Polypropylene fibers (PPF) were obtained from Conmat India, Bangalore. Length of the polypropylene fibre is found to be 12mm. The specific gravity is found to be 0.92.

- Magnesium sulphate

In this experimental work Magnesium sulphate of 15% concentration was used to study the effect of sulphate attack.

III. Methodology

In order to find out the resistance to sulphate attack, the specimens after 28 days and 90 days of curing, were immersed in 15% of $MgSO_4$ (Magnesium Sulphate) solution for 90 days. After removing the specimens from Magnesium Sulphate solution they were washed, weighed and tested for their respective strengths. Specimens are also tested after 118 days (28+90 days) and 180 days (90+90 days) without subjecting to sulphate attack.

The mix proportion for M 30 grade concrete as per mix design was found to be 1:1.38:2.75 with w/c ratio 0.45. Required quantity of cement, fine aggregates, coarse aggregates were dry mixed. Before dry mixing, 20% of cement was replaced with metakolin. Monofibers were added 1% by volume fraction while hybrid fibers were added (0.5% + 0.5%) by volume fraction. To this dry mix, required quantity of water was added and thoroughly mixed. This green concrete was placed in three different layers in the moulds which were thoroughly oiled. The moulds were vibrated by keeping them on table vibrator. Hand compaction was also adopted simultaneously. After compaction the specimens were covered by wet gunny bags. After 15 hours, the specimens were demoulded and transferred to curing tank. They were allowed to cure in water for 28 days or 90 days as the case may be. For compressive strength tests 150X150X150 mm specimens were cast. For tensile strength test 150mm diameter and 300mm height cylinders were cast. For flexural strength test 100 X 100 X500mm beams were cast. For shear strength 150mm X 90mm X 60mm ‘L’ shaped specimens were cast. For impact 150mm diameter and 60mm height cylinders were cast. All the specimens were tested as per the relevant IS codes.

IV. Experimental results

- **Compressive strength test results when subjected to sulphate attack-[9].**

Table 1 gives the results of compressive strength of metakaoline based hybrid fiber reinforced concrete. Table also gives the percentage increase of compressive strength of hybrid fiber reinforced concrete with respect to respective monofibre reinforced concrete. Table also indicates the percentage increase of compressive strength of hybrid fiber reinforced concrete and monofibre reinforced concrete with respect to reference mix. Residual compressive strengths are also shown in table. The variation of compressive strength is shown graphically in the Figure 1.0 and residual compressive strength in Figure 2.0

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Table 1 Compressive strength test results when subjected to sulphate attack

Description of concrete	118 days compressive strength without subjecting to sulphate attack (MPa)	Compressive strength when subjected to sulphate attack for 90 days after 28 days water curing (MPa)	Percentage increase of 118 days compressive strength (when subjected to sulphate attack) for HFRC with respect to corresponding mono fibre reinforced concrete	Percentage increase of 118 days compressive strength (when subjected to sulphate attack) with respect to reference concrete	118 days residual compressive strength (%)	180 days compressive strength without subjecting to sulphate attack (MPa)	Compressive strength when subjected to sulphate attack for 90 days after 90 days water curing (MPa)	Percentage increase of 180 days compressive strength (when subjected to sulphate attack) for HFRC with respect to corresponding mono fibre reinforced concrete	Percentage increase of 180 days compressive strength (when subjected to sulphate attack) with respect to reference concrete	180 days residual compressive strength (%)
REF	34.30	20.89	-------		61	36.81	23.56			63.98
(SF+GIF)	47.26	44.00	10	111	93	51.26	46.00	7	95	89.74
(SF+WCSF)	46.59	36.00	9	72	77	50.52	38.00	6	61	75.22
(SF+HDPEF)	44.59	31.04	11	49	70	46.30	34.00	10	44	73.44
(SF+WPF)	42.59	28.00	17	34	66	44.59	30.00	11	27	67.28
(SF+PPF)	39.63	24.00	14	15	61	41.48	27.04	13	15	65.18
SF	46.81	41.04	--------	96	88	49.04	44.00	--------	87	89.73
GIF	44.59	40.00	--------	91	90	47.63	43.04	--------	83	90.36
WCSF	43.26	33.04	--------	58	76	45.19	36.00	--------	53	79.67
HDPEF	41.70	28.00	--------	34	67	44.15	31.04	--------	32	70.30

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WPF	39.19	24.00	--------	15	61	41.48	27.04	--------	15	65.18
PPF	36.96	21.04	--------	1	57	38.81	24.00	--------	2	61.83

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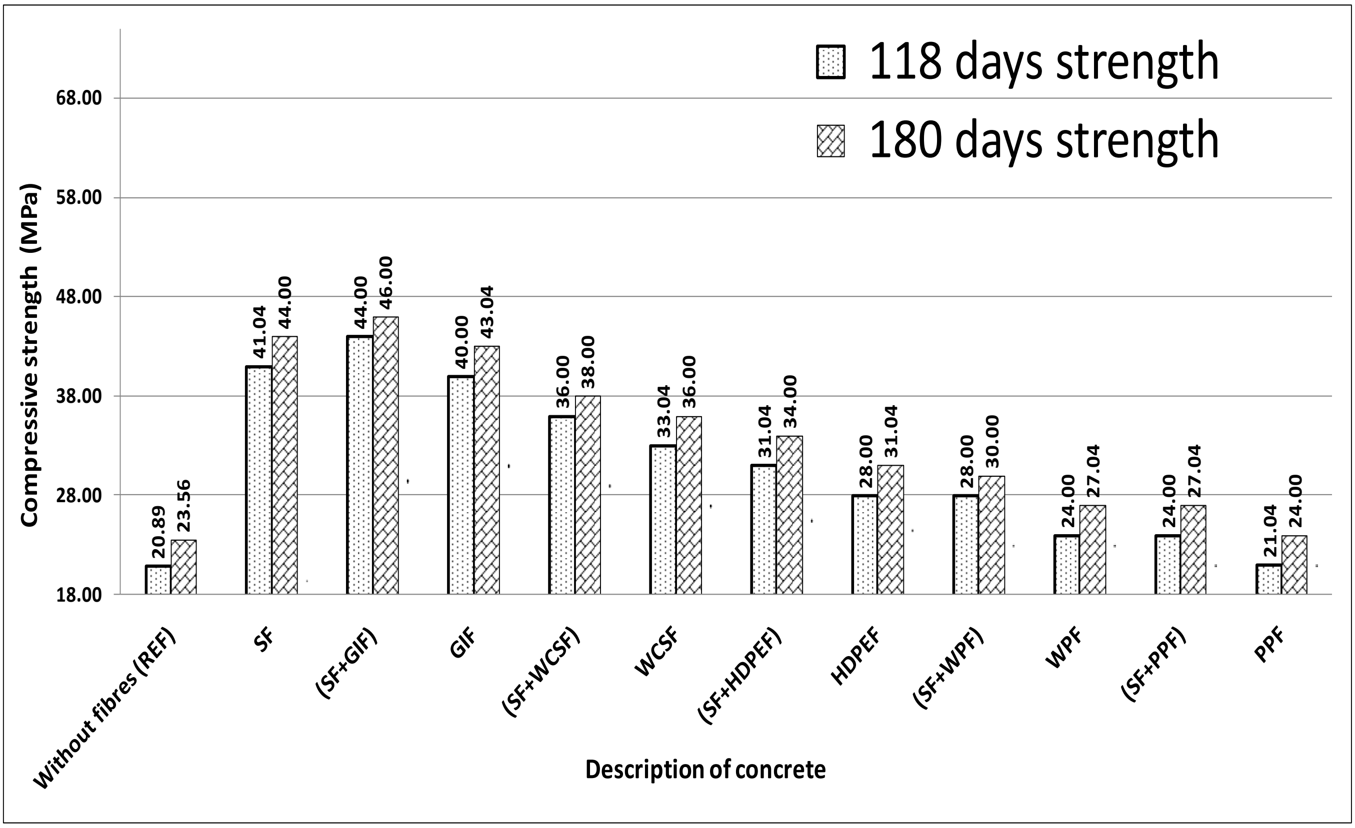

Fig. 1.0 Variation of compressive strength when subjected to sulphate attack

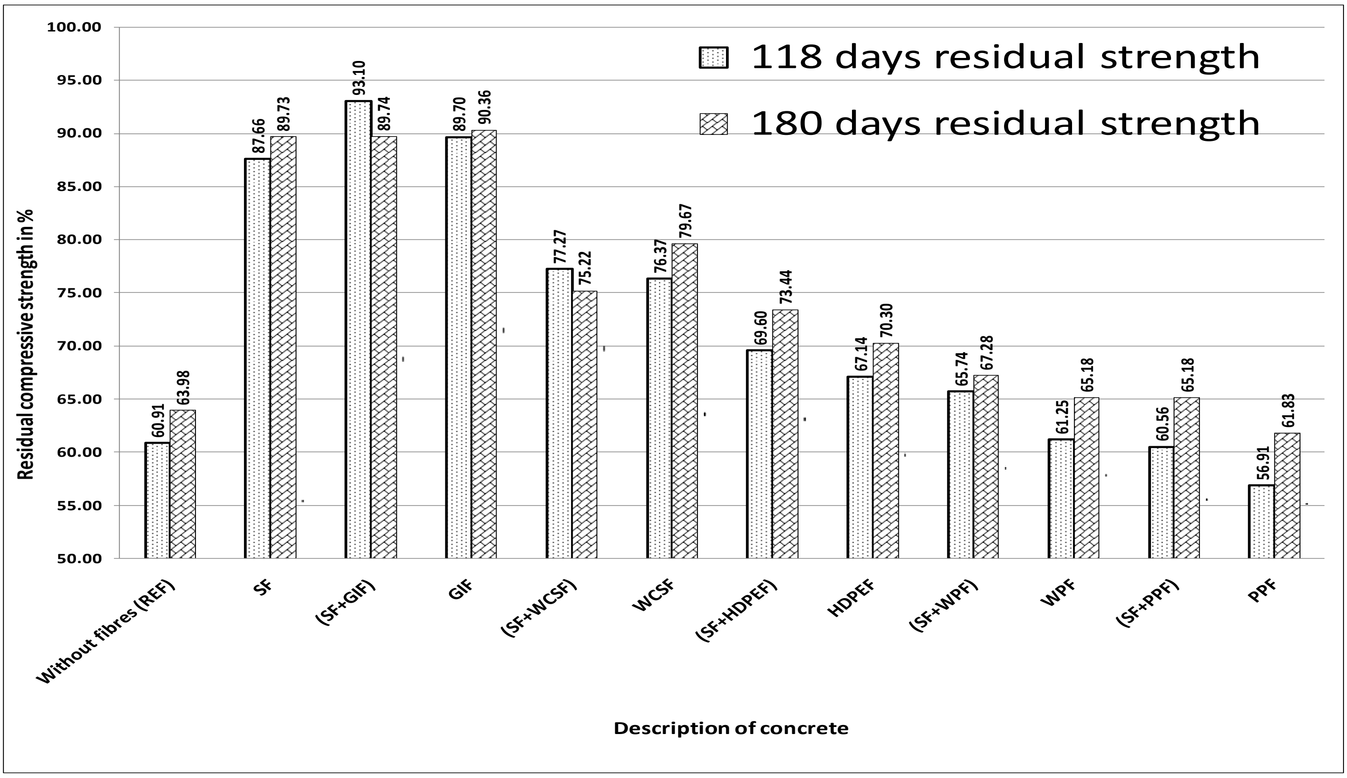

Fig.2.0 Variation of residual compressive strength when subjected to sulphate attack

- **Tensile strength test[10] results when subjected to sulphate attack -** Table 2 gives the results of tensile strength of metakaoline based hybrid fiber reinforced concrete. Table also gives the percentage increase of tensile strength of hybrid fiber reinforced concrete with respect to respective monofibre reinforced concrete. Table also indicates the percentage increase of tensile strength of hybrid fiber reinforced concrete and monofibre reinforced concrete with respect to reference mix. Residual tensile strengths are also shown in table. The variation of tensile strength is shown graphically in the Figure 3.0 and residual tensile strength in Figure 4.0.

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Table 2 Tensile strength test results when subjected to sulphate attack

Description of concrete	118 days tensile strength without subjecting to sulphate attack (MPa)	Tensile strength when subjected to sulphate attack for 90 days after 28 days water curing (MPa)	Percentage increase of 118 days tensile strength (when subjected to sulphate attack) for HFRC with respect to corresponding mono fibre reinforced concrete	Percentage increase of 118 days tensile strength (when subjected to sulphate attack) with respect to reference concrete	118 days residual tensile strength (%)	180 days tensile strength without subjecting to sulphate attack (MPa)	Tensile strength when subjected to sulphate attack for 90 days after 90 days water curing (MPa)	Percentage increase of 180 days tensile strength (when subjected to sulphate attack) for HFRC with respect to corresponding mono fibre reinforced concrete	Percentage increase of 180 days tensile strength (when subjected to sulphate attack) with respect to reference concrete	180 days residual tensile strength (%)
REF	2.43	2.12			87	2.52	2.26			90
(SF+GIF)	4.34	3.70	4	74	85	4.72	4.01	4	77	85
(SF+WCSF)	3.87	3.65	7	72	95	4.43	3.80	5	68	86
(SF+HDPEF)	3.58	3.25	12	53	91	4.15	3.42	8	51	82
(SF+WPF)	3.25	2.81	11	32	86	3.72	3.02	11	33	81
(SF+PPF)	3.11	2.43	10	14	78	3.58	2.62	9	16	73
SF	4.27	3.68	--------	73	86	4.57	3.91	--------	73	86
GIF	4.29	3.56	--------	68	83	4.50	3.84	--------	70	85

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WCSF	3.70	3.42	--------	61	92	4.29	3.61	--------	59	84
HDPEF	3.35	2.90	--------	37	87	4.01	3.16	--------	40	79
WPF	2.99	2.52	--------	19	84	3.58	2.71	--------	20	76
PPF	2.83	2.22	--------	4	78	2.88	2.40	--------	6	84

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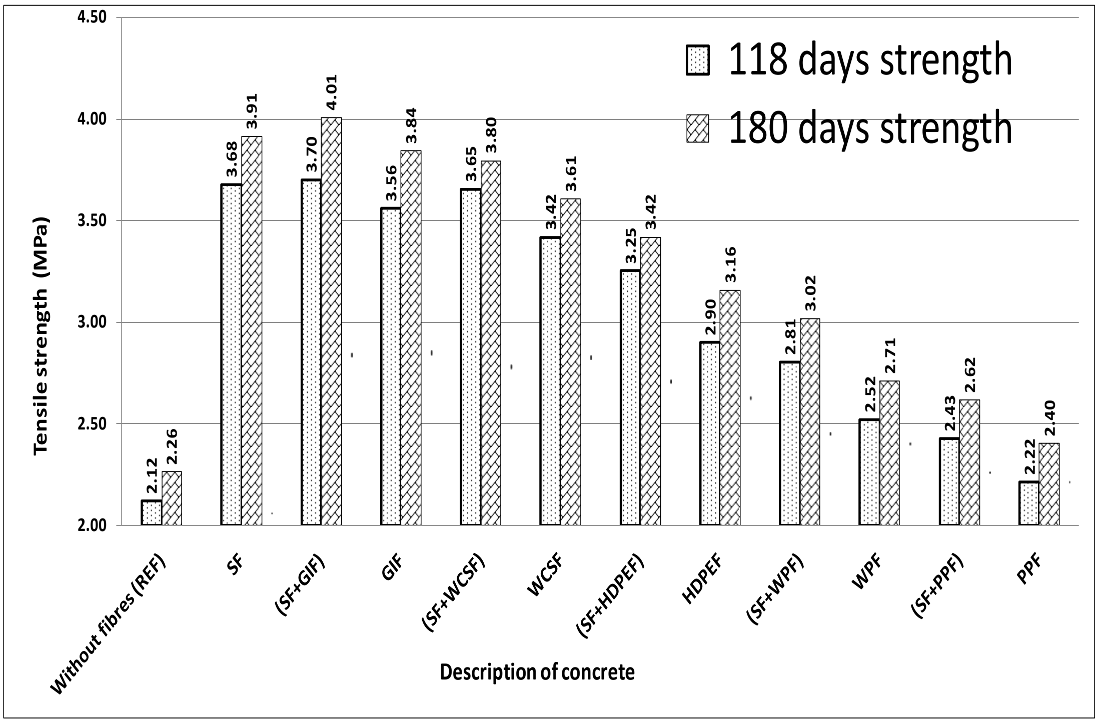

Fig. 3.0 Variation of tensile strength when subjected to sulphate attack

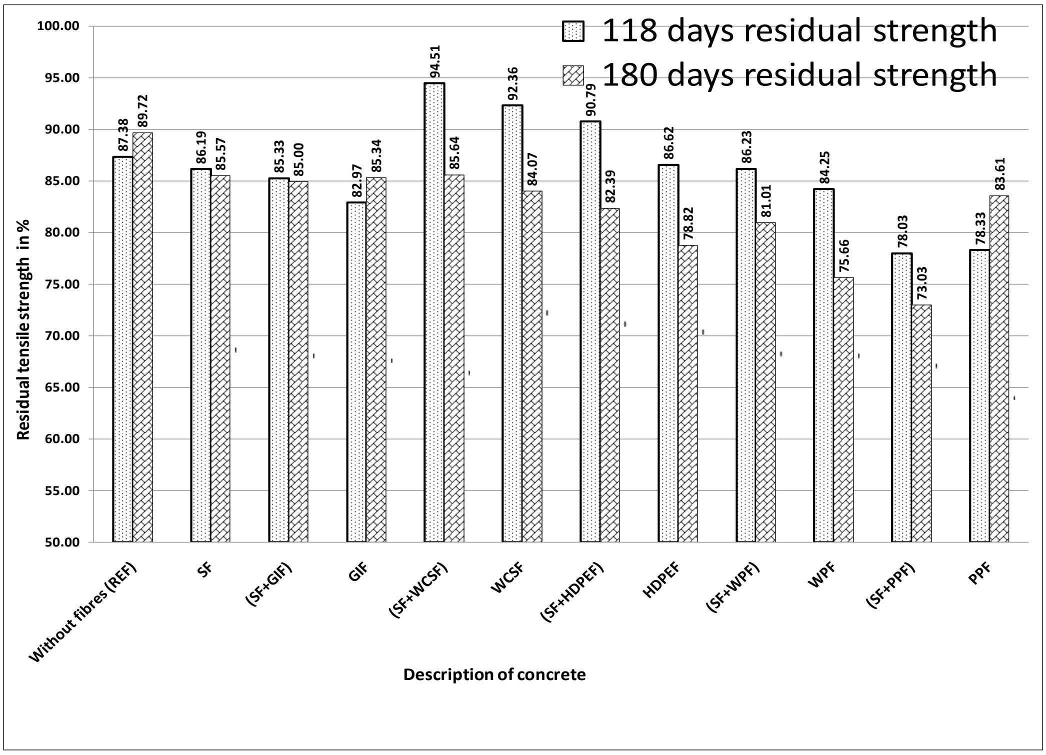

Fig. 4.0 Variation of residual tensile strength when subjected to sulphate attack

- **Flexural strength test[9] results when subjected to sulphate attack -** Table 3 gives the results of flexural strength of metakaoline based hybrid fiber reinforced concrete. Table also gives the percentage increase of flexural strength of hybrid fiber reinforced concrete with respect to respective monofibre reinforced concrete. Table also indicates the percentage increase of flexural strength of hybrid fiber reinforced concrete and monofibre reinforced concrete with respect to reference mix. Residual flexural strengths are also shown in table. The variation of flexural strength is shown graphically in the Figure 5.0 and residual flexural strength in Figure 6.0.

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Table 3 Flexural strength test results when subjected to sulphate attack

Description of concrete	118 days flexural strength without subjecting to sulphate attack (MPa)	Flexural strength when subjected to sulphate attack for 90 days after 28 days water curing (MPa)	Percentage increase of 118 days flexural strength (when subjected to sulphate attack) for HFRC with respect to corresponding mono fibre reinforced concrete	Percentage increase of 118 days flexural strength (when subjected to sulphate attack) with respect to reference concrete	118 days residual flexural strength (%)	180 days flexural strength without subjecting to sulphate attack (MPa)	Flexural strength when subjected to sulphate attack for 90 days after 90 days water curing (MPa)	Percentage increase of 180 days flexural strength (when subjected to sulphate attack) for HFRC with respect to corresponding mono fibre reinforced concrete	Percentage increase of 180 days flexural strength (when subjected to sulphate attack) with respect to reference concrete	180 days residual flexural strength (%)
REF	4.53	3.07			68	5.07	3.47			68
(SF+GIF)	9.07	8.67	20	183	96	11.47	9.60	4	177	84
(SF+WCSF)	8.53	8.00	25	161	94	10.80	8.67	30	150	80
(SF+HDPEF)	7.47	7.07	33	130	95	8.80	7.60	36	119	86
(SF+WPF)	7.07	6.00	29	96	85	8.27	6.67	35	92	81
(SF+PPF)	6.40	5.33	33	74	83	7.60	6.27	34	81	82
SF	8.27	7.73	--------	152	94	11.07	9.33	--------	169	84

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GIF	7.47	7.20	--------	135	96	10.80	9.20	--------	165	85
WCSF	7.47	6.40	--------	109	86	10.27	6.67	--------	92	65
HDPEF	7.07	5.33	--------	74	75	8.27	5.60	--------	62	68
WPF	6.27	4.67	--------	52	74	7.47	4.93	--------	42	66
PPF	5.47	4.00	--------	30	73	6.80	4.67	--------	35	69

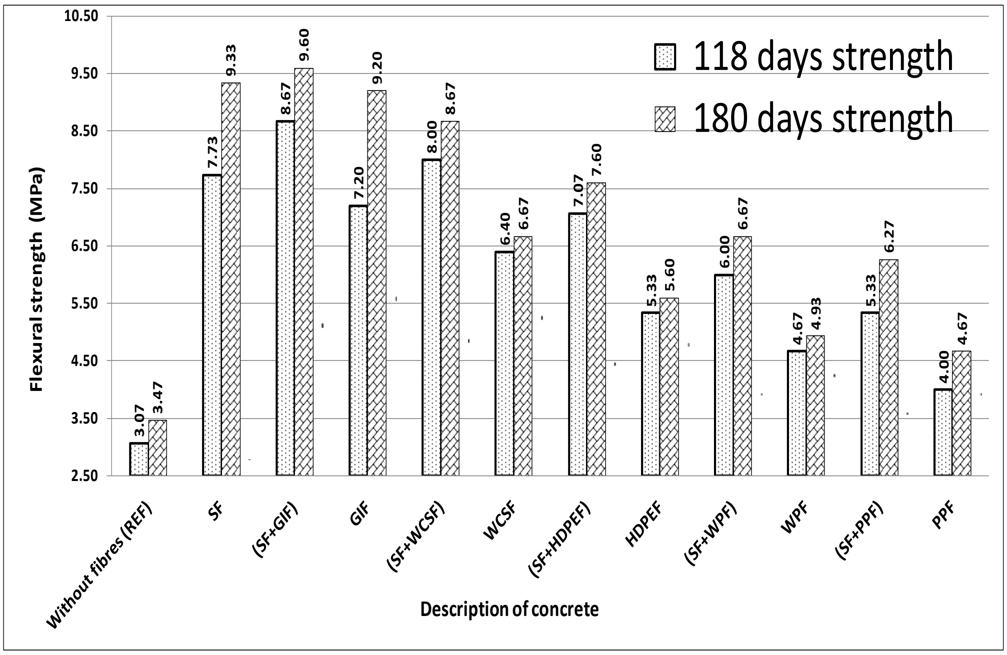

Fig. 5.0 Variation of flexural strength when subjected to sulphate attack

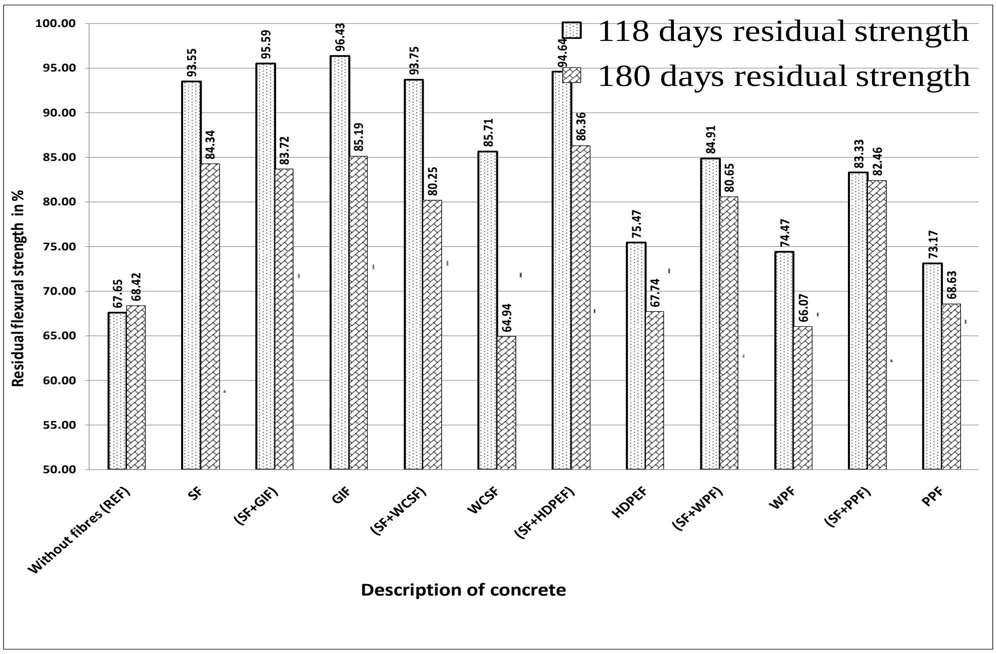

Fig. 6.0 Variation of residual flexural strength when subjected to sulphate attack

- **Shear strength test[11] results when subjected to sulphate attack -** Table 4 gives the results of shear strength of metakaoline based hybrid fiber reinforced concrete. Table also gives the percentage increase of shear strength of hybrid fiber reinforced concrete with respect to respective monofibre reinforced concrete. Table also indicates the percentage increase of shear strength of hybrid fiber reinforced concrete and monofibre reinforced

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concrete with respect to reference mix. Residual shear strengths are also shown in table. The variation of shear strength is shown graphically in the Figure 7.0 and residual shear strength in Figure 8.0

Table 4 Shear strength test results when subjected to sulphate attack

Description of concrete	118 days shear strength without subjecting to sulphate attack (MPa)	Shear strength when subjected to sulphate attack for 90 days after 28 days water curing (MPa)	Percentage increase of 118 days shear strength (when subjected to sulphate attack) for HFRC with respect to corresponding mono fibre reinforced concrete	Percentage increase of 118 days shear strength (when subjected to sulphate attack) with respect to reference concrete	118 days residual shear strength (%)	180 days shear strength without subjecting to sulphate attack (MPa)	Shear strength when subjected to sulphate attack for 90 days after 90 days water curing (MPa)	Percentage increase of 180 days shear strength (when subjected to sulphate attack) for HFRC with respect to corresponding mono fibre reinforced concrete	Percentage increase of 180 days shear strength (when subjected to sulphate attack) with respect to reference concrete	180 days residual shear strength (%)
REF	3.98	3.80			95	4.72	4.17			88
(SF+GIF)	6.39	6.20	18	63.41	97	7.41	6.85	6	64	93
(SF+WCSF)	6.30	6.02	20	58.54	96	7.22	6.67	14	60	92
(SF+HDPEF)	5.83	5.65	20	48.78	97	6.76	6.11	18	47	90
(SF+WPF)	5.28	5.09	17	34.15	96	6.02	5.65	17	36	94
(SF+PPF)	4.91	4.72	19	24.39	96	5.74	5.19	17	24	90
SF	5.65	5.37	--------	41.46	95	7.41	6.57	--------	58	89
GIF	5.56	5.28	--------	39.02	95	6.85	6.48	--------	56	95
WCSF	5.19	5.00	--------	31.71	96	6.67	5.83	--------	40	88

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HDPEF	5.00	4.72	--------	24.39	94	6.48	5.19	--------	24	80
WPF	4.63	4.35	--------	14.63	94	6.02	4.81	--------	16	80
PPF	4.44	3.98	--------	4.88	90	5.74	4.44	--------	7	77

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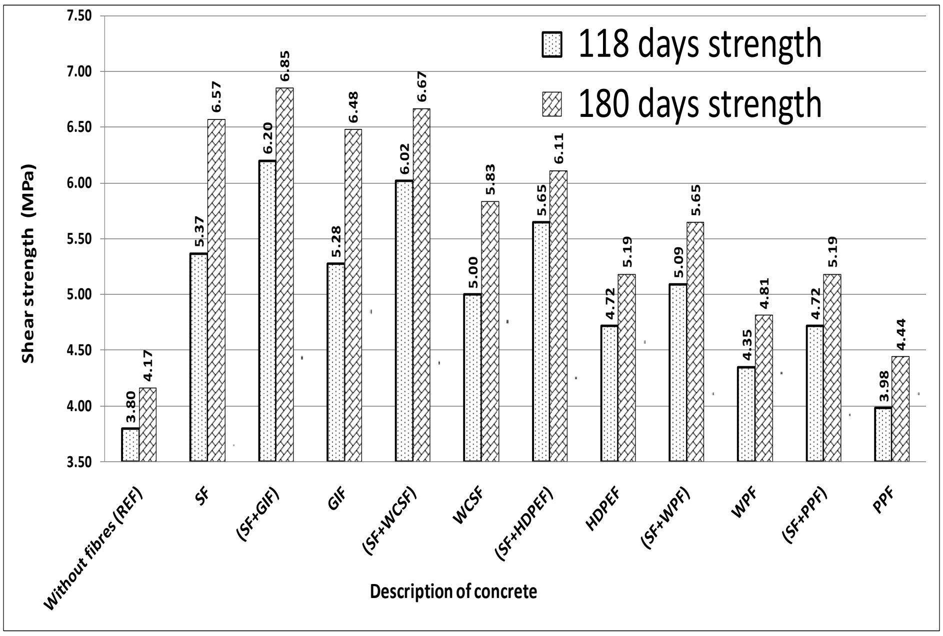

Fig. 7.0 Variation of shear strength when subjected to sulphate attack

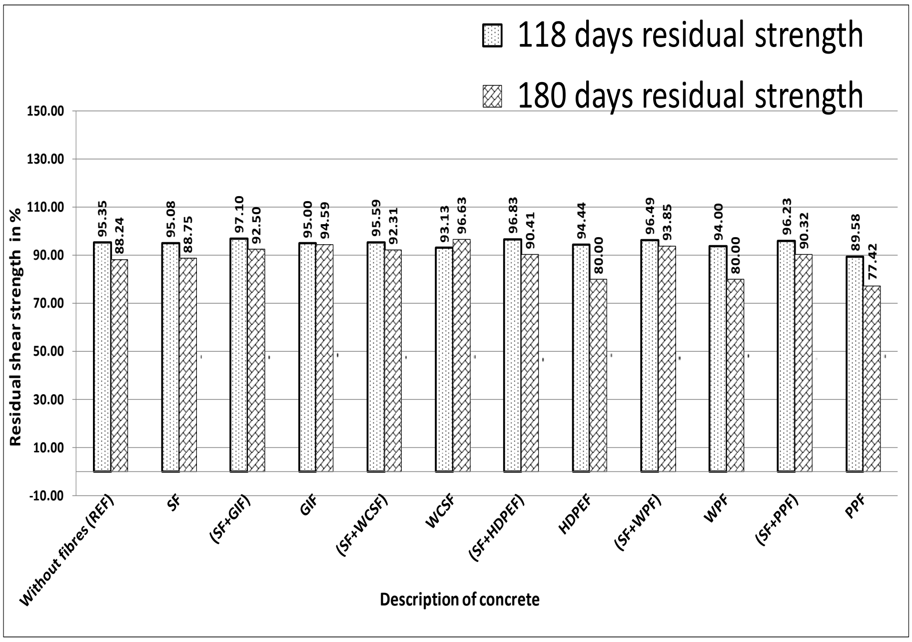

Fig. 8.0 Variation of residual shear strength when subjected to sulphate attack

- **Impact strength test[12] results when subjected to sulphate attack -** Table 5 gives the results of impact strength of metakaoline based hybrid fiber reinforced concrete. Table also gives the percentage increase of impact strength of hybrid fiber reinforced concrete with respect to respective monofibre reinforced concrete. Table also indicates the percentage increase of impact strength of hybrid fiber reinforced concrete and monofibre reinforced

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concrete with respect to reference mix. Residual impact strengths are also shown in table. The variation of impact strength is shown graphically in the Figure 9.0 and residual impact strength in Figure 10.0.

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Table 5 Impact strength test results when subjected to sulphate attack

Description of concrete	118 days impact strength without subjecting to sulphate attack (MPa)	Impact strength when subjected to sulphate attack for 90 days after 28 days water curing (MPa)	Percentage increase of 118 days impact strength (when subjected to sulphate attack) for HFRC with respect to corresponding mono fibre reinforced concrete	Percentage increase of 118 days impact strength (when subjected to sulphate attack) with respect to reference concrete	118 days residual impact strength (%)	180 days impact strength without subjecting to sulphate attack (MPa)	Impact strength when subjected to sulphate attack for 90 days after 90 days water curing (MPa)	Percentage increase of 180 days impact strength (when subjected to sulphate attack) for HFRC with respect to corresponding mono fibre reinforced concrete	Percentage increase of 180 days impact strength (when subjected to sulphate attack) with respect to reference concrete	180 days residual impact strength (%)
REF	380.38	172.90	0	0	45	463.37	200.56	0	0	43
(SF+GIF)	14558.04	13278.59	11	7580	91	16632.82	13693.55	4	6728	82
(SF+WCSF)	13928.69	13071.11	13	7460	94	16031.13	13278.59	5	6521	83
(SF+HDPEF)	6666.96	5947.70	5	3340	89	7227.15	7054.25	15	3417	98
(SF+WPF)	6300.42	5740.22	23	3220	91	6909.02	6570.14	29	3176	95
(SF+PPF)	9391.84	7642.11	6	4320	81	10131.84	8817.82	3	4297	87
SF	13963.27	11999.14	--------	6840	86	14523.46	13313.17	--------	6538	92

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GIF	13686.63	11929.99	--------	6800	87	14336.73	13105.69	--------	6434	91
WCSF	12476.34	11618.77	--------	6620	93	13133.36	12690.74	--------	6228	97
HDPEF	5843.96	5671.07	--------	3180	97	6411.07	6127.52	--------	2955	96
WPF	4841.15	4668.26	--------	2600	96	5394.43	5083.21	--------	2434	94
PPF	8541.18	7227.15	--------	4080	85	9142.86	8541.18	--------	4159	93

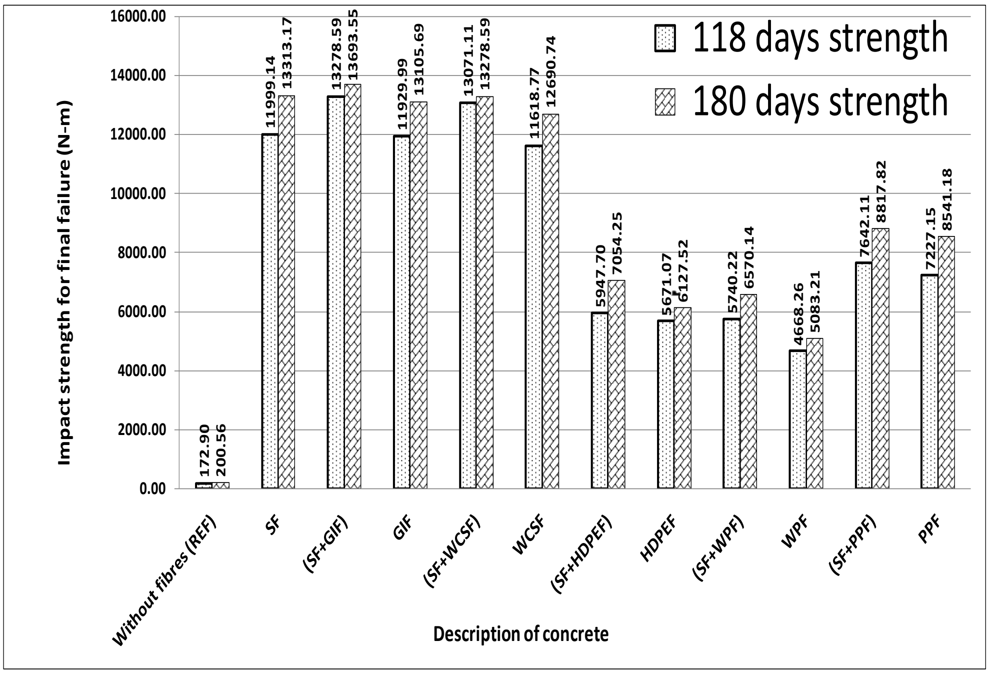

Fig. 9.0 Variation of impact strength (final failure) when subjected to sulphate attack

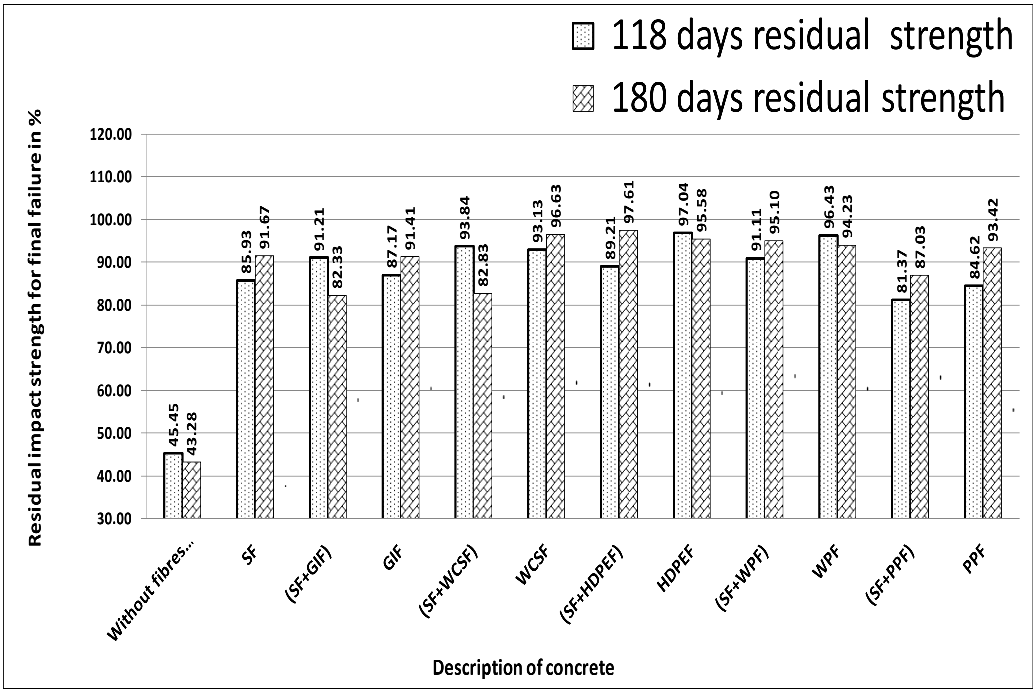

Fig. 10.0 Variation of residual impact strength (final failure) when subjected to sulphate attack

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V. Observations and discussions

Following observations are made based on the experimentations conducted on the behavior of metakaoline based hybrid fibre reinforced concrete under sulphate attack.

The compressive strength test results for metakaoline based hybrid fibre reinforced concrete when subjected to sulphate attack are presented in table 1.0. As is evident from the table that metakaoline based hybrid fibre reinforced concrete and mono fibre reinforced concrete suffer a heavy loss of compressive strength when subjected to 90 days of sulphate attack. Also it is seen that the performance of metakaoline based hybrid fibre reinforced concrete is much superior as compared to that of mono fibre reinforced concrete under sulphate attack. Metakaoline based hybrid fibre reinforced concrete with combination of fibres (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF) show 10%, 9%, 11%, 17% and 14% increase in the compressive strength after 90 days of sulphate attack. This is further supported by the observation of residual compressive strength of 93%, 77%, 70%, 66% and 61% respectively for the above mentioned metakaoline based hybrid fibre reinforced concretes. A similar observation was made when metakaoline based hybrid fibre reinforced concrete was subjected to sulphate attack after 90 days of curing.

Tensile strength test results for metakaoline based hybrid fibre reinforced concrete when subjected to sulphate attack are presented in table 2.0. As is evident from the table that metakaoline based hybrid fibre reinforced concrete and mono fibre reinforced concrete suffer a heavy loss of tensile strength when subjected to 90 days of sulphate attack. Also it is seen that the performance of metakaoline based hybrid fibre reinforced concrete is much superior as compared to that of mono fibre reinforced concrete under sulphate attack. Metakaoline based hybrid fibre reinforced concrete with combination of fibres (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF) show 4%, 7%, 12%, 11% and 10% increase in the tensile strength after 90 days of sulphate attack. This is further supported by the observation of residual tensile strength of 85%, 95%, 91%, 86% and 78% respectively for the above mentioned metakaoline based hybrid fibre reinforced concretes. A similar observation was made when metakaoline based hybrid fibre reinforced concrete was subjected to sulphate attack after 90 days of curing.

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Flexural strength test results for metakaoline based hybrid fibre reinforced concrete when subjected to sulphate attack are presented in table 3.0. As is evident from the table that metakaoline based hybrid fibre reinforced concrete and mono fibre reinforced concrete suffer a heavy loss of flexural strength when subjected to 90 days of sulphate attack. Also it is seen that the performance of metakaoline based hybrid fibre reinforced concrete is much superior as compared to that of mono fibre reinforced concrete under sulphate attack. Metakaoline based hybrid fibre reinforced concrete with combination of fibres (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF) show 20%, 25%, 33%, 29% and 33% increase in the flexural strength after 90 days of sulphate attack. This is further supported by the observation of residual flexural strength of 96%, 94%, 95%, 85% and 83% respectively for the above mentioned metakaoline based hybrid fibre reinforced concretes. A similar observation was made when metakaoline based hybrid fibre reinforced concrete was subjected to sulphate attack after 90 days of curing.

Shear strength test results for metakaoline based hybrid fibre reinforced concrete when subjected to sulphate attack are presented in table 4.0. As is evident from the table that metakaoline based hybrid fibre reinforced concrete and mono fibre reinforced concrete suffer a heavy loss of shear strength when subjected to 90 days of sulphate attack. Also it is seen that the performance of metakaoline based hybrid fibre reinforced concrete is much superior as compared to that of mono fibre reinforced concrete under sulphate attack. Metakaoline based hybrid fibre reinforced concrete with combination of fibre (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF) show 18%, 20%, 20%, 17% and 19% increase in the shear strength after 90 days of sulphate attack. This is further supported by the observation of residual shear strength of 97%, 96%, 97%, 96% and 96% respectively for the above mentioned metakaoline based hybrid fibre reinforced concretes. A similar observation was made when metakaoline based hybrid fibre reinforced concrete was subjected to sulphate attack after 90 days of curing.

Impact strength test results for metakaoline based hybrid fibre reinforced concrete when subjected to sulphate attack are presented in table 5.0. As is evident from the table that metakaoline based hybrid fibre reinforced concrete and mono fibre reinforced concrete suffer a heavy loss of impact strength when subjected to 90 days of sulphate attack. Also it is seen that the performance of metakaoline based hybrid fibre reinforced concrete is much superior as compared to that of mono fibre reinforced concrete under sulphate attack. Metakaoline

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based hybrid fibre reinforced concrete with combination of fibre (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF) show 11%, 13%, 5%, 23% and 6% increase in the impact strength after 90 days of sulphate attack. This is further supported by the observation of residual impact strength of 91%, 94%, 89%, 91% and 81% respectively for the above mentioned metakaoline based hybrid fibre reinforced concretes. A similar observation was made when metakaoline based hybrid fibre reinforced concrete was subjected to sulphate attack after 90 days of curing.

The sulfates react with the hydration products of tri-calcium aluminate (C_3A) phase of Portland cement and with calcium hydroxide ($Ca(OH_2)$) to form an expansive crystalline product called ettringite. Expansion due to ettringite formation causes tensile stresses to develop in the concrete. When these stresses become greater than the concrete tensile capacity, the concrete begins to crack. These cracks allow easy ingress of more sulfates into the concrete and the deterioration accelerates. Magnesium sulphate attack on concrete is more aggressive than any other sulphate attack. The pH of magnesium sulphate solution is acidic. Solubility of this salt is relatively high. The impact of magnesium sulphate on concrete is a double chemical attack because each of the ions SO^{2-} and Mg^{2+} forms its usual products. Therefore magnesium sulphate attack is dangerous for cement composites. The mechanism of magnesium sulphate attack with cement hydrates is as follows.

$$MgSO_4 + Ca(OH)_2 \longrightarrow CaSO_4.2H_2O + Mg(OH)_2$$

$$MgSO_4 + C\text{-}S\text{-}H \longrightarrow CaSO_4.2H_2O + M\text{-}S\text{-}H$$

Where M-S-H is Magnesium Silicate Hydrate

The added hybrid fibres may act as small aggregates or they may form a net in the concrete mass which will prevent the ingress of sulphate into the concrete mass. Also the synergetic effect of hybrid fibres will prevent the cracks, thereby reducing the ingress of sulphate. In addition to this the pozzolonic reaction and filler effect of metakaoline will reduce the pore structure of concrete, thereby reducing the ingress of sulphate into the concrete mass.

Thus, it can be concluded that the metakaoline based hybrid fibre reinforced concrete exhibit better performance in sulphate attack as compared to their corresponding mono fibre reinforced concrete by exhibiting higher strength characteristics.

It is observed that metakaoline based hybrid fibre reinforced concrete with combination of (SF+GIF) show better performance in sulphate attack as compared to

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metakaoline based hybrid fibre reinforced concrete with (SF+WCSF), (SF+HDPEF), (SF+WPF) & (SF+PPF). This may be due to the fact of similar modulii of elasticity for both SF & GI fibres and their synergestic interaction which will prevent the infiltration of sulphate into the concrete mass.

Thus it can be concluded that metakaoline based hybrid fibre reinforced concrete with (SF+GIF) has greater resistance to sulphate attack as compared to metakaoline based hybrid fibre reinforced concretes with (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF).

VI. Conclusions

Following conclusions may be drawn based on the experimentations conducted on the behavior of metakaoline based hybrid fibre reinforced concrete under sulphate attack:

1) Metakaoline based hybrid fibre reinforced concrete exhibit better performance in sulphate attack as compared to their corresponding mono fibre reinforced concrete by exhibiting higher strength characteristics.
2) Metakaoline based hybrid fibre reinforced concrete with (SF+GIF) has greater resistance to sulphate attack as compared to metakaoline based hybrid fibre reinforced concrete with (SF+WCSF), (SF+HDPEF), (SF+WPF) & (SF+PPF).

References

1) Mohankar R.H, Pidurkar M.D, Thakre P.V, Pakhare S.S, *Hybrid Fibre Reinforced Concrete*, International Journal of Science, Engineering and Technology Research (IJSETR), Volume 5, Issue 1, January 2016
2) Ravi Kottur, *An experimental investigation on the characteristic properties of hybrid fibre reinforced concrete,* A Ph.D. thesis submitted to Visvesvaraya Technological University, Belgaum, August 2009
3) Mobasher. B, Li and Cheng Yu, *Mechanical properties of hybrid cement – based composites,* ACI Materials Journal, Vol. 93, No. 3, May-Jun, 1996, pp. 284-292.
4) QCL Group Technical Note *"Sulphate Attack and Chloride Ion Penetration: Their Role in Concrete Durability", March 99*
5) Shetty M.S, *Concrete technology theory and practice*, S. Chand & Company ltd. Publications, New Delhi, Edition-2012.

6) Deepa A.Sinha "*An experimental investigation on the behaviour of steel fibre reinforced ternary blended concrete subjected to sustained elevated tempreture",* A Ph.D. thesis submitted to Sardar Patel University,Vallabh Vidyanagar, April 2013
7) IS: 8112 – 1989, *43 Grade ordinary Portland cement—Specifications*, (First revision), Bureau of Indian Standards, Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi, May 1990.
8) IS: 383 – 1970, *Specifications for coarse and fine Aggregate from natural sources for concrete* (Second revision), Bureau of Indian Standards, Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi, April 1971.
9) IS: 516 – 1959, *Methods of tests for strength of concrete*, edition 1.2, Bureau of Indian Standards, Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi, reaffirmed 1999.
10) IS 5816 : 1999 (reaffirmed in 2004) *Splitting tensile strength of concrete - method of test*, Bureau of Indian Standards, Manak Bhavan, 9Bahadur Shah Zafar Marg, New Delhi, July 1999.
11) Sadat Ali Khan, Prakash K B, *Behaviour of sifcon produced with hybrid fibres under sulphate attack,* IJOER, 2014, Issue-4, Vol-2, pp 154-164
12) Deepak Namadev Mudgal, *An experimental investigation on the characteristic properties and structural behavior of silica fume concrete produced with hybrid fiber*, A Ph.D. thesis submitted to Shivaji University, Kolhapur, May 2012

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