International Journal of Engineering Research-Online
A Peer Reviewed International Journal
Email:editorijoer@gmail.com http://www.ijoer.in

Vol.4., Issue.1., 2016
(Jan-Feb)

RESEARCH ARTICLE

ISSN: 2321-7758

AN INVESTIGATION ON THE WORKABILITY AND STRENGTH CHARACTERISTICS OF METAKAOLINE BASED HYBRID FIBER REINFORCED CONCRETE

SHREEPAD DESAI[1], Dr. PRAKASH K B[2]

[1]Assistant Professor, [2]Principal,
Civil Engineering Department, Government Engineering College, Haveri, Visvesvaraya Technological University, Belgaum, Karnataka, India

SHREEPAD DESAI

Dr. PRAKASH K B

ABSTRACT

Combining fibres with different geometry and mechanical properties can improve the mechanical properties of fibre reinforced concrete. Often called hybrid fibre reinforced concrete (HFRC), 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 and workability characteristics of metakaoline based hybrid fiber reinforced concrete, in which 20 % of cement is replaced by metakaoline. Different fibers used in this experimentation 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 in this experimentation are (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF).

Key words: 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), workability and strength characteristics

I. INTRODUCTION

The concept of fibre reinforcement dates backs to the history where the fibres made of straw or horse hair were used as reinforcing material. In the early 1960's straight steel fibres were used to improve fracture, toughness and ductility properties. But it was found that the workability was affected by adding these fibres. This is due to lump formation, segregation of the constituents of the mix. The formation of lump and forming voids is called as balling. This phenomenon can be reduced by using deformed fibres and super plasticizer. The performance ultimately depends upon properties of the fibres and bond strength.[1]

To overcome the deficiencies in FRC, hybrid fibre reinforced concrete (HFRC) is gaining importance. In HFRC two or more different types of fibres are rationally combined in the matrix. Each individual fibres exhibit a synergestic 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]

The use of pozzolonic materials is as old as that of art of concrete construction. It was recognized long time ago, that the suitable pozzolanas used in appropriate amount, modify certain properties of fresh and hardened mortars and concretes.

Pozzolonic materials or supplementary cementitious materials can be defined as materials of siliceous or combination of siliceous and aluminous with little or no cementitious property. In the presence of moisture, it reacts with calcium hydroxide forming tri-calcium silicate, di-calcium silicate as product of hydration. The siliceous or aluminous compound in a finely divided state react with calcium hydroxide to form highly stable cementitious substance of complex composition. This reaction is called pozzolanic reaction. [3]

The reaction can be shown as *Pozzolana + Calcium Hydroxide + Water*

$$\Longrightarrow C\text{–}S\text{–}H(Gel) + Ca(OH)_2$$

In the beginning the reaction is slow, with the result that heat of hydration and strength development will be accordingly slow. The reduction of Ca (OH)2 improves the durability of cement paste and makes it dense and impervious. [4]

II. MATERIALS USED

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

- Cement

In this experimental work,43 grade ordinary Portland cement (OPC) with specific gravity 3.15, conforming to IS: 8112 – 1989 was used.. [5]

- Metakaoline

Metakaolin supplied by 20 Microns Company Vadodhara, was used in the present experimental investigation. Metakaolin is obtained from the calcination of kaolinitic clays at temperatures in the range of 700 to 800ºC, having specific gravity 2.1 was used.

- Fine aggregate

Locally available river sand belonging to zone II of IS: 383–1970 and specific gravity 2.26, bulk density 1752 kg/m3 and water absorption 1.0 % was used. [6]

- Coarse aggregate

Locally available crushed aggregates confirming to IS: 383–1970 and specific gravity 2.65, bulk density 1782 kg/m3 and water absorption 0.6 % was used. [6]

- Water

Water which is free from acids, oils, alkalies or other organic impurities was used.

- Steel fibres (SF)

Crimped steel fibres of 1mm thickness and 50mm length giving an aspect ratio of 50, with density 7850 kg/m3 and ultimate tensile strength 395 MPa were used. Steel fibres were obtained from Stewools India (P) Ltd. Nagpur

- Galvanized iron fibres (GIF)

Round galvanized iron wire of 1mm diameter was cut to the required length of 50 mm giving an aspect ratio of 50.The ultimate strength and density of fibres was found to be 395 MPa and 7850 kg/m3 respectively.

- Waste coiled steel fiber (WCSF)

Waste coiled steel fibres 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 fibers(HDPEF)

High density polyethylene fibres 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/m3.

- Waste plastic fibre(WPF)

Waste plastic fibres 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/m3.

- Polypropylene fibre (PPF)

Length of the polypropylene fibre is found to be 12mm. The specific gravity is found to be 0.92. Polypropylene fibers were obtained from Conmat India, Bangalore.

III. PROCEDURE

Main aim of this experimentation is to find out the strength and workability characteristics of metakaoline based hybrid fiber reinforced concrete, in which 20 % of cement is replaced by metakaoline. Different fibers used in this experimentation 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 in this experimentation are (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF).

The mix proportion for M 30 grade concrete as per mix design is 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. While the concrete wet workability tests were conducted though slump test, compaction factor test, veebee degree test, flow test. 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. For compressive strength tests 150 X 150 X 150mm specimens were cast. For tensile strength test 150mm diameter and 300mm height cylinders were cast. For flexural strength test 100 X 100 X 500mm beams were cast. For shear strength test 150mm X 90mm X 60mm ‘L’ sections specimens were cast. For impact strength test 150mm diameter and 60mm height cylinders were cast. All the specimens were tested as per the relevant IS codes.

IV. EXPERIMENTAL RESULTS

- Workability test results

Table 1 gives the workability test results of metakaoline based hybrid fibre reinforced concrete. The variation of slump, compaction factor, V. B. degree and flow of metakaoline based hybrid fibre reinforced concrete are shown in fig 1, fig 2, fig 3 and fig 4 respectively.

Table 1 Workability test results

Description of concrete	Slump in mm	Compaction factor	Veebee degree in Sec	Flow in %
Without fibres (REF)	60.00	0.89	6.00	5.60
(SF+GIF)	2.00	0.79	14.00	1.33
(SF+WCSF)	0.00	0.81	10.00	1.47
(SF+HDPEF)	0.00	0.81	7.67	1.87
(SF+WPF)	0.00	0.81	7.00	2.00
(SF+PPF)	0.00	0.80	30.00	1.33
SF	3.33	0.84	10.33	2.67
GIF	3.00	0.79	12.00	2.00
WCSF	15.00	0.82	7.72	1.47
HDPEF	11.67	0.83	7.10	1.47
WPF	10.00	0.83	6.78	2.00
PPF	6.67	0.88	37.00	2.27

International Journal of Engineering Research-Online
A Peer Reviewed International Journal
Email:editorijoer@gmail.com http://www.ijoer.in
Vol.4., Issue.1., 2016 (Jan-Feb)

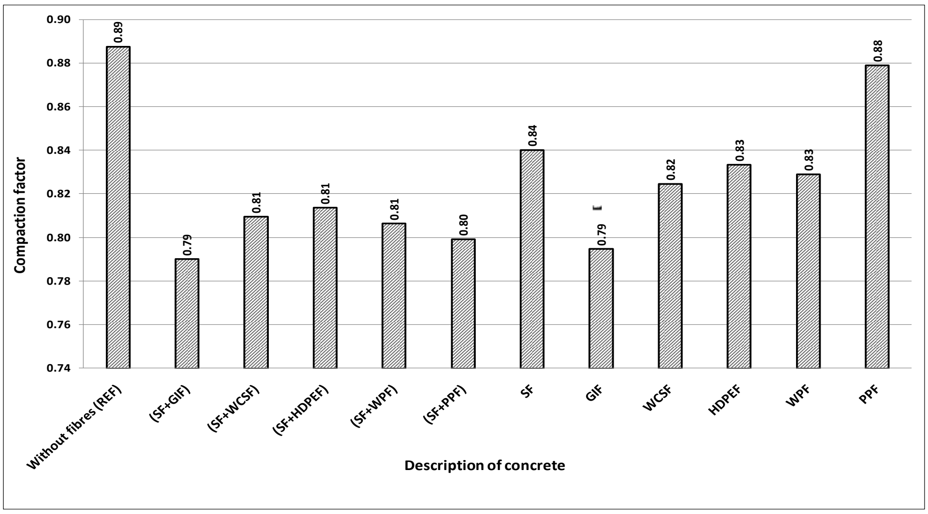

Fig 2 Variation of compaction factor

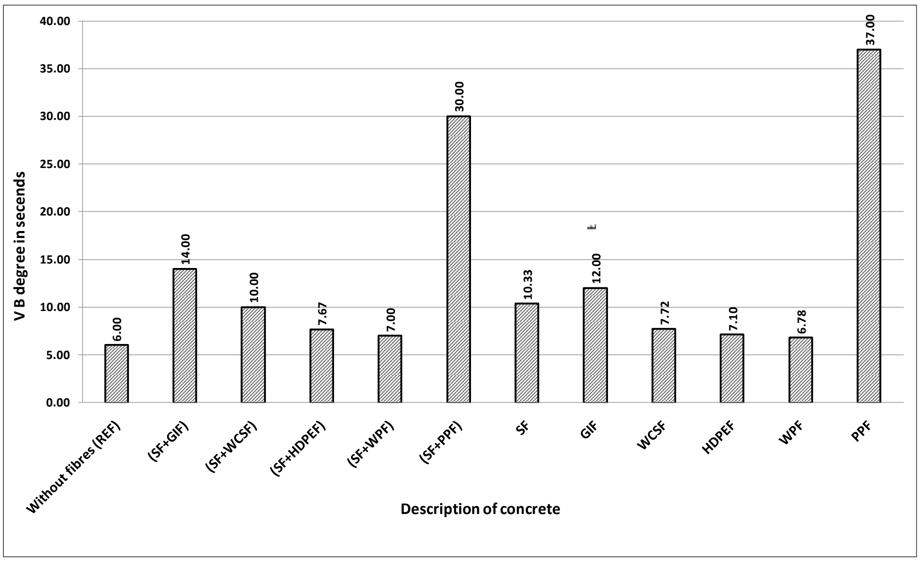

Fig. 3 Variation of V B degree

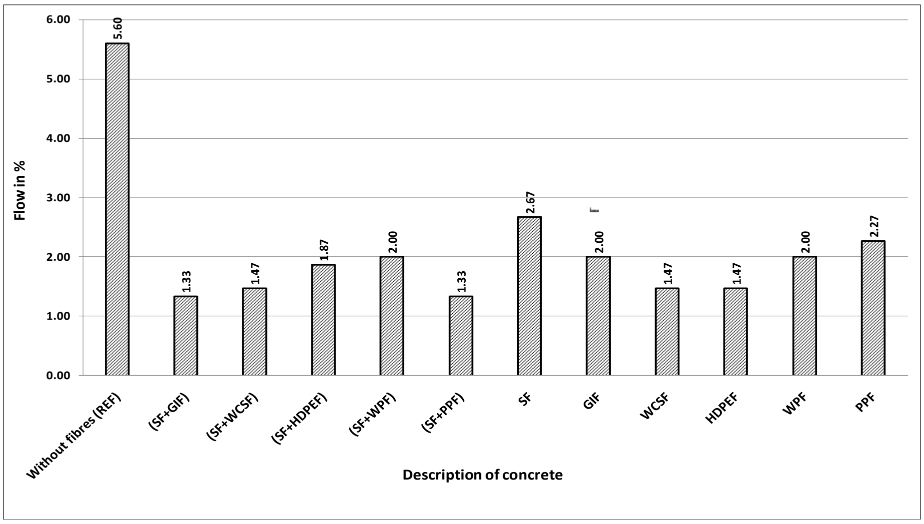

Fig. 4 Variation of flow

- Compressive strength test[7] results – Table 2 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 corresponding 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. The variation of compressive strength is shown graphically in the figure 5.0.

Table 2 Compressive strength test results

Description of concrete	28 days compressive strength (MPa)	Percentage increase of 28 days compressive strength for HFRC with respect to corresponding mono fibre reinforced concrete	Percentage increase of 28 days compressive strength with respect to reference concrete
Without fibres (REF)	34.22		
(SF+GIF)	47.11	6	38
(SF+WCSF)	46.44	8	36
(SF+HDPEF)	44.44	7	30
(SF+WPF)	42.44	9	24
(SF+PPF)	39.56	7	16
SF	46.67	--------	36
GIF	44.44	--------	30
WCSF	43.11	--------	26
HDPEF	41.56	--------	21
WPF	39.11	--------	14
PPF	36.89	--------	8

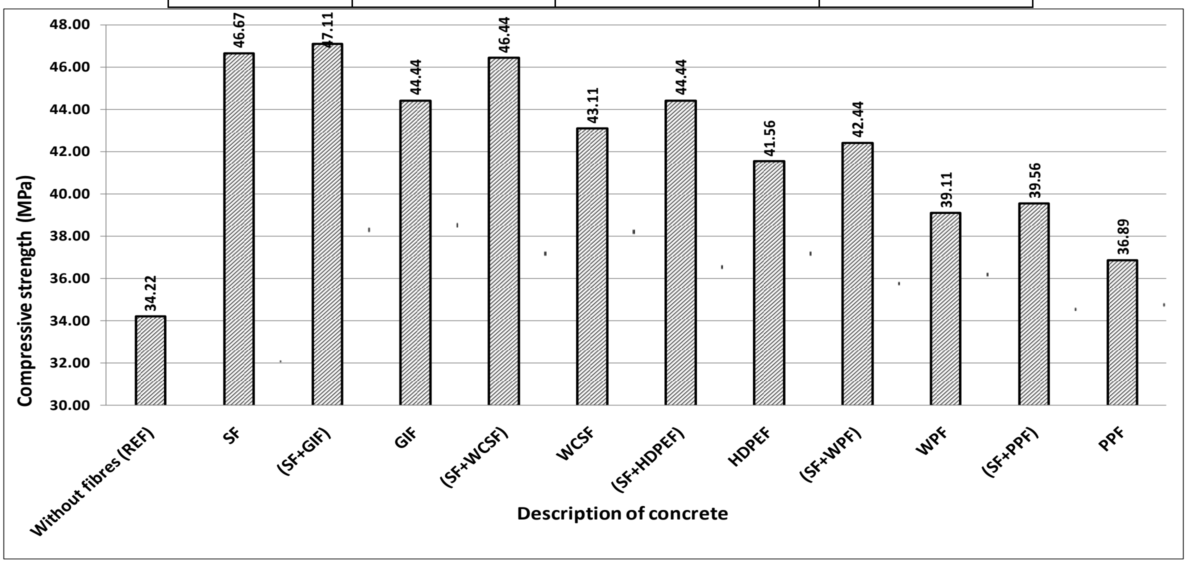

Fig. 5.0 Variation of compressive strength

- **Tensile strength test[8] results** – Table 3 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 corresponding 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. The variation of tensile strength is shown graphically in the figure 6.0.

Table 3 Tensile strength test results

Description of concrete	28 days tensile strength (MPa)	Percentage increase of 28 days tensile strength for HFRC with respect to corresponding mono fibre reinforced concrete	Percentage increase of 28 days tensile strength with respect to reference concrete
Without fibres (REF)	2.4		
(SF+GIF)	4.31	2	79
(SF+WCSF)	3.82	4	59
(SF+HDPEF)	3.54	6	47
(SF+WPF)	3.23	9	34
(SF+PPF)	3.09	10	28
SF	4.24	--------	76
GIF	4.24	--------	76
WCSF	3.68	--------	53
HDPEF	3.32	--------	38
WPF	2.97	--------	24
PPF	2.81	--------	17

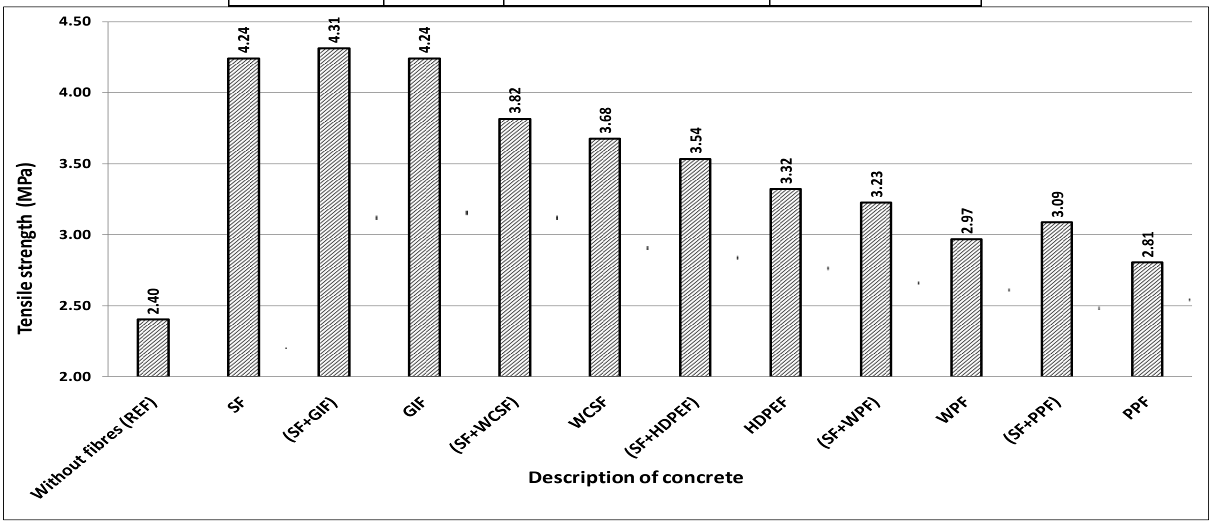

Fig. 6.0 Variation of tensile strength

- **Flexural strength test[7] results** – Table 4 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 corresponding 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. The variation of flexural strength is shown graphically in the figure 7.0.

Table 4 Flexural strength test results

Description of fibre	28 days flexural strength (MPa)	Percentage increase of 28 days flexural strength for HFRC with respect to corresponding mono fibre reinforced concrete	Percentage increase of 28 days flexural strength with respect to reference concrete
(SF+GIF)	8.8	20	120
(SF+WCSF)	8.13	13	103
(SF+HDPEF)	7.2	6	80
(SF+WPF)	6.8	16	70
(SF+PPF)	5.87	16	47
SF	8	--------	100
GIF	7.33	--------	83
WCSF	7.2	--------	80
HDPEF	6.8	--------	70
WPF	5.87	--------	47
PPF	5.07	--------	27

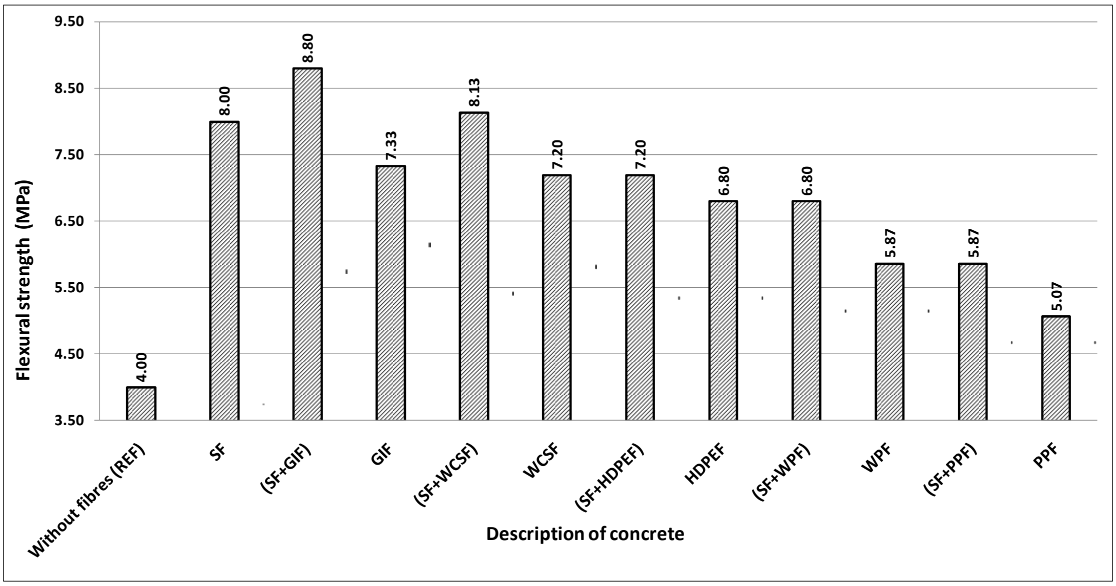

Fig. 7.0 Variation of flexural strength

- **Shear strength test[9] results** – Table 5 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 corresponding monofibre reinforced concrete. Table also indicates the percentage increase of shear strength of hybrid fiber reinforced concrete and monofibre reinforced concrete with respect to reference mix. The variation of shear strength is shown graphically in the figure 8.0.

Table 5 Shear strength test results

Description of fibre	28 days shear strength (MPa)	Percentage increase of 28 days shear strength for HFRC with respect to corresponding mono fibre reinforced concrete	Percentage increase of 28 days shear strength with respect to reference concrete
Without fibres (REF)	3.89		
(SF+GIF)	6.30	15	62
(SF+WCSF)	6.11	20	57
(SF+HDPEF)	5.74	17	48
(SF+WPF)	5.19	14	33
(SF+PPF)	4.81	11	24
SF	5.56	--------	43
GIF	5.46	--------	40
WCSF	5.09	--------	31
HDPEF	4.91	--------	26
WPF	4.54	--------	17
PPF	4.35	--------	12

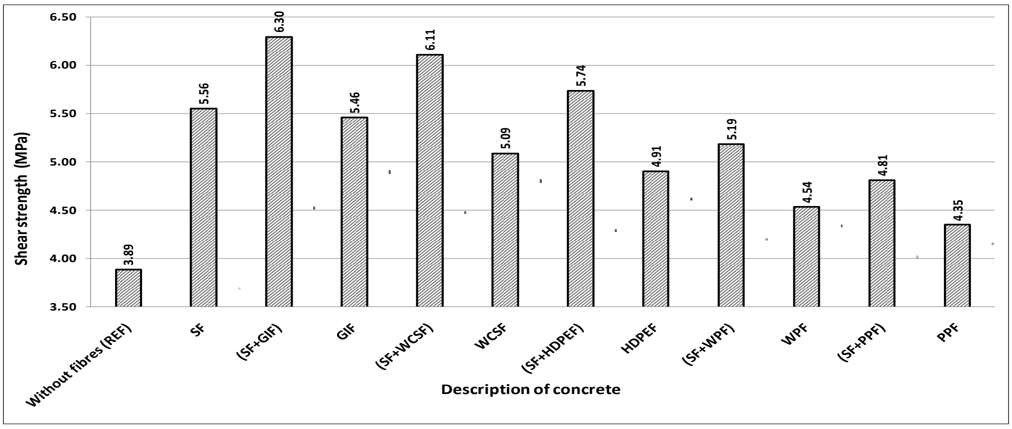

Fig. 8.0 Variation of shear strength

- **Impact strength test[10] results** – Table 6 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 corresponding monofibre reinforced concrete. Table also indicates the percentage increase of impact strength of hybrid fiber reinforced concrete and monofibre reinforced concrete with respect to reference mix. The variation of impact strength is shown graphically in the figure 9.0 and 10.0

Table 6 Impact strength test results

Description of concrete	28 days impact strength for first crack (N-m)	28 days impact strength for final failure (N-m)	Percentage increase of 28 days impact strength (first crack) for HFRC with respect to corresponding mono fibre reinforced concrete	Percentage increase of 28 days impact strength (first crack) with respect to reference concrete	Percentage increase of 28 days impact strength (final failure) for HFRC with respect to corresponding mono fibre reinforced concrete	Percentage increase of 28 days impact strength (final failure) with respect to reference concrete
Without fibres (REF)	228.23	373.46	0	0	0	0
(SF+GIF)	13513.73	14537.29	5	5821	6	3793
(SF+WCSF)	12981.21	13894.11	11	5588	12	3620
(SF+HDPEF)	6016.86	6632.38	24	2536	14	1676
(SF+WPF)	5719.48	6272.75	34	2406	31	1580
(SF+PPF)	8617.25	9364.17	12	3676	10	2407
SF	13098.78	13928.69	--------	5639	--------	3630
GIF	12912.05	13658.97	--------	5558	--------	3557
WCSF	11743.25	12441.76	--------	5045	--------	3231
HDPEF	4854.99	5816.30	--------	2027	--------	1457
WPF	4260.21	4806.57	--------	1767	--------	1187
PPF	7697.43	8513.51	--------	3273	--------	2180

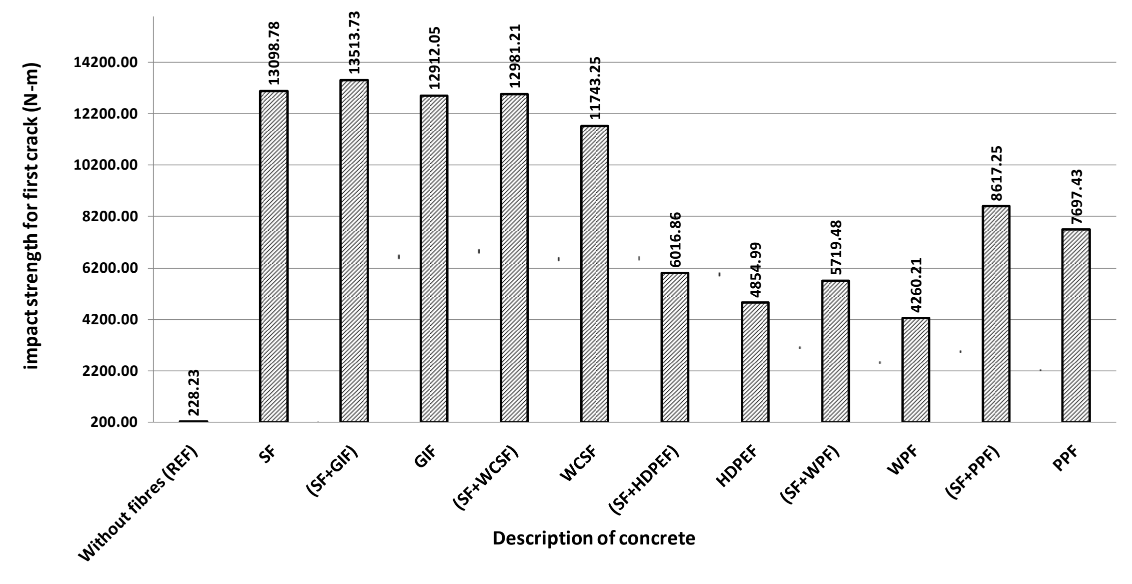

Fig. 9.0 Variation of impact strength for first crack

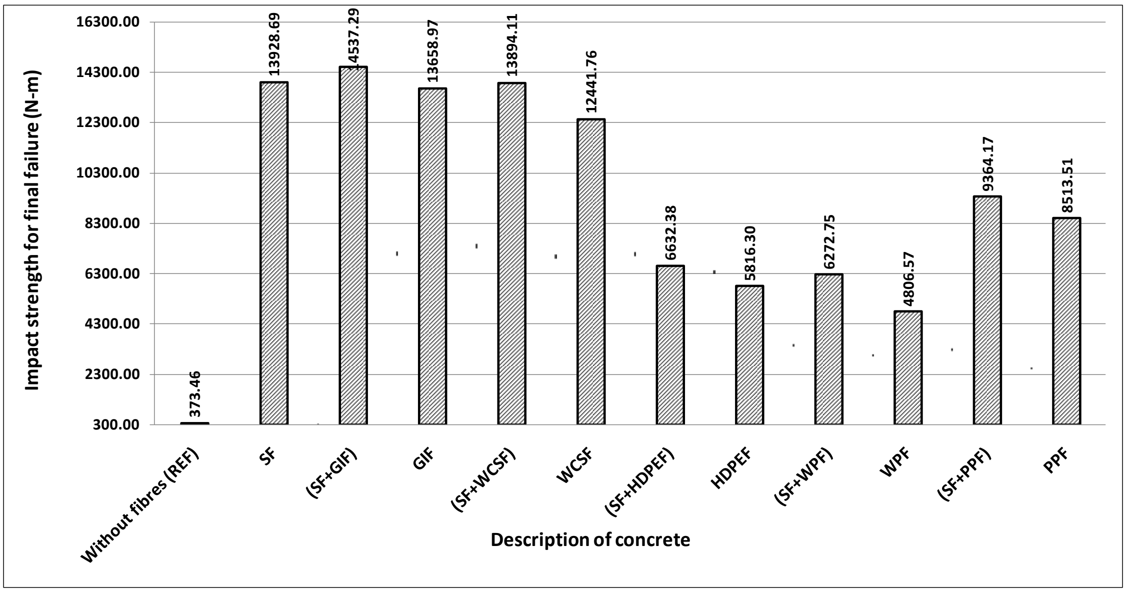

Fig. 10.0 Variation of impact strength for final failure

V. OBSERVATIONS AND DISCUSSIONS

Following observations are made based on the experimentations conducted on workability and strength characteristics of metakaoline based hybrid fibre reinforced concrete.

Workability test results of metakaoline based hybrid fibre reinforced concrete are presented in table 1. It is evident from the results that the hybrid fibre reinforced concrete produced with the combination of fibres (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF) exhibit lower slump values as compared to the corresponding mono fibre reinforced concrete produced by different fibres like SF, GIF, WCSF, HDPEF, WPF and PPF. A similar observation was made in case of compaction factor, V.B. degree and percentage flow. Also it is observed that the workability of hybrid fibre reinforced concrete or mono fibre reinforced concrete drastically reduces as compared to the reference concrete without fibres. The probable reason of lower workability is that adding the hybrid fibres can form a network structure in concrete which can restrain the mixture from segregation and flow. Also the added fibres will absorb more cement paste content to wrap around which will minimize the matrix content in the mixture, there by affecting the flow characteristics.

Compared to all other combinations of hybrid fibres, (SF+HDPEF) & (SF+WPF) relatively show better workability properties.

Therefore, it can be concluded that the hybrid fibre reinforced concrete produced with the combination of fibres (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF) exhibit lower workability values as compared to the corresponding mono fibre reinforced concrete as well as reference concrete without fibre.

Compressive strength test results of metakaoline based hybrid fibre reinforced concrete are presented in table 2. It is observed from table that the performance of hybrid fibre reinforced concrete is superior to that of corresponding mono fibre reinforced concrete. Metakaoline based hybrid fibre reinforced concrete with the combination of fibres (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF) show 6%, 8%, 7%, 9% and 7% increase in the 28 days compressive strength as compared to the corresponding mono fibre reinforced concrete. The metakaoline based hybrid fibre reinforced concrete with the combination of fibres (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF) show 38%, 36%, 30%, 24% and 16% increase in 28 days compressive strength respectively as compared to the reference concrete without fibres. Thus there is a remarkable improvement in the compressive strength of hybrid fibre reinforced concrete.

The reason for increase in the compressive strength of hybrid fibre reinforced concrete is that, under the axial loads cracks that occur in micro structure of concrete and fibres limit the formation and growth of cracks by providing pinching forces at crack tips. The hybrid fibres bare some stresses that occur in the cement matrix and transfer the other portion of stresses at stable cement matrix portions. This reduces the crack tip stress concentration there by blocking the forward propagation of the crack and even diverting the path of the crack. This blocking and diverting of the crack allows the hybrid fibre reinforced concrete to withstand additional compressive loads thereby upgrading its compressive strength over the reference concrete without fibres. This is also due to the reason that the added hybrid fibres can form a network structure thereby lowering the concrete stress concentration and thus help in increasing the compressive strength.

Thus it can be concluded that the performance of hybrid fibre reinforced concrete is better as compared to mono fibre reinforced concrete and reference concrete without fibre. The metakaoline based hybrid fibre reinforced concrete with the combination of fibres (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF) show 6%, 8%, 7%, 9% and 7% increase in the 28 days compressive strength as compared to the corresponding mono fibre reinforced concrete and show 38%, 36%, 30%, 24% and 16% increase in 28 days compressive strength respectively as compared to the reference concrete without fibres.

Tensile strength test results of metakaoline based hybrid fibre reinforced concrete are presented in table 3. It is observed from table that the performance of hybrid fibre reinforced concrete is superior to that of corresponding mono fibre reinforced concrete. Metakaoline based hybrid fibre reinforced concrete with the combination of fibres (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF) show 2%, 4%, 6%, 9% and 10% increase in the 28 days tensile strength as compared to the corresponding mono fibre reinforced concrete. The metakaoline based hybrid fibre reinforced concrete with the combination of fibres (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF) show 79%, 59%, 47%, 34% and 28% increase in 28 days tensile strength respectively as compared to the reference concrete without fibres. Thus there is a remarkable improvement in the tensile strength of hybrid fibre reinforced concrete.

The enhancement of split tensile strength of hybrid fibre reinforced concrete is more as compared to mono fibre reinforced concrete because of the availability of more fibres in case of

(SF+HDPEF), (SF+WPF) & (SF+PPF) because of low densities of HDPEF, WPF & PPF. In case of (SF+GIF) and (SF+WCSF), the available fibres are more stiff which can resist the cracks effectively, because fibre availability is not the only parameter governing the strength. The stiffness of the fibre is also major parameter which affects the strength.

Thus it can be concluded that the performance of hybrid fibre reinforced concrete is better as compared to mono fibre reinforced concrete and reference concrete without fibre. The metakaoline based hybrid fibre reinforced concrete with the combination of fibres (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF) show 2%, 4%, 6%, 9% and 10% increase in the 28 days tensile strength as compared to the corresponding mono fibre reinforced concrete and show 79%, 59%, 47%, 34% and 28% increase in 28 days tensile strength respectively as compared to the reference concrete without fibres.

Flexural strength test results of metakaoline based hybrid fibre reinforced concrete are presented in table 4. It is observed from table that the performance of hybrid fibre reinforced concrete is superior to that of mono fibre reinforced concrete. Metakaoline based hybrid fibre reinforced concrete with the combination of fibres (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF) show 20%, 13%, 6%, 16% and 16% increase in the 28 days flexural strength as compared to the corresponding mono fibre reinforced concrete. The metakaoline based hybrid fibre reinforced concrete with the combination of fibres (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF) show 120%, 103%, 80%, 70% and 47% increase in 28 days flexural strength respectively as compared to the reference concrete without fibres. Thus there is a remarkable improvement in the flexural strength of hybrid fibre reinforced concrete.

The increase in the flexural strength of hybrid fibre reinforced concrete is more compared to mono fibre reinforced concrete because of the availability of more fibres in case of (SF+HDPEF), (SF+WPF) & (SF+PPF) or availability of more stiff fibers as incase of (SF+GIF) and (SF+WCSF). The hybrid fibre shows synergistic effect in which one fibre is efficient in micro cracking level and other fibre is at macro cracking level, thereby improving the flexural response of metakaoline based hybrid fibre reinforced concrete.

Thus it can be concluded that the performance of hybrid fibre reinforced concrete is better as compared to mono fibre reinforced concrete and reference concrete without fibre. The metakaoline based hybrid fibre reinforced concrete with the combination of fibres (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF) show 20%, 13%, 6%, 16% and 16% increase in the 28 days flexural strength as compared to the corresponding mono fibre reinforced concrete and show 120%, 103%, 80%, 70% and 47% increase in 28 days flexural strength respectively as compared to the reference concrete without fibres.

Shear strength test results of metakaoline based hybrid fibre reinforced concrete are presented in table 5. It is observed from table that the performance of hybrid fibre reinforced concrete is superior to that of mono fibre reinforced concrete. Metakaoline based hybrid fibre reinforced concrete with the combination of fibres (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF) show 15%, 20%, 17%, 14% and 11% increase in the 28 days shear strength as compared to the corresponding mono fibre reinforced concrete. The metakaoline based hybrid fibre reinforced concrete with the combination of fibres (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF) show 62%, 57%, 48%, 33% and 24% increase in 28 days shear strength respectively as compared to the reference concrete without fibres. Thus there is a remarkable improvement in the shear strength of hybrid fibre reinforced concrete. The increase in the shear strength of hybrid fibre reinforced concrete is more compared to mono fibre reinforced concrete because of the availability of more fibres in case of (SF+HDPEF), (SF+WPF) & (SF+PPF) or availability of more stiff fibers as incase of (SF+GIF) and (SF+WCSF). Also it is due to the fact that the hybrid fibres show synergistic response where in different fibres come into play at different stages of loading.

Thus it can be concluded that the performance of hybrid fibre reinforced concrete is better as compared to mono fibre reinforced concrete and reference concrete without fibre. The metakaoline based hybrid fibre reinforced concrete with the combination of fibres (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF) show 15%, 20%, 17%, 14% and 11% increase in the 28 days shear strength as compared to the corresponding mono fibre reinforced concrete and show 62%, 57%, 48%, 33% and 24% increase in 28 days shear strength respectively as compared to the reference concrete without fibres.

Impact strength test results of metakaoline based hybrid fibre reinforced concrete are presented in table 6. It is observed from table that the performance of hybrid fibre reinforced concrete is superior to that of mono fibre reinforced concrete. Metakaoline based hybrid fibre reinforced concrete with the combination of fibres (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF) show 6%, 12%, 14%, 31% and 10% increase in the 28 days impact strength (final failure) as compared to the corresponding mono fibre reinforced concrete. The metakaoline based hybrid fibre reinforced concrete with the combination of fibres (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF) show 3793%, 3620%, 1676%, 1580% and 2407% increase in 28 days impact strength (final failure) respectively as compared to the reference concrete without fibres. Thus there is a remarkable improvement in the impact strength for hybrid fibre reinforced concrete.

The increase in the impact strength of hybrid fibre reinforced concrete is more as compared to the mono fibre reinforced concrete because of the redistribution of the stresses during the period of each impact. The impact blows were efficiently absorbed by the hybrid fibres as compared to mono fibres.

Thus it can be concluded that the performance of hybrid fibre reinforced concrete is better as compared to mono fibre reinforced concrete and reference concrete without fibre. The metakaoline based hybrid fibre reinforced concrete with the combination of fibres (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF) show 6%, 12%, 14%, 31% and 10% increase in the 28 days impact strength as compared to the corresponding mono fibre reinforced concrete and show 3793%, 3620%, 1676%, 1580% and 2407% increase in 28 days impact strength respectively as compared to the reference concrete without fibres.

In general it is observed that the best composite mechanical properties are obtained from metakaoline based hybrid fibre reinforced concrete with the combination (SF+GIF) which showed higher compressive strength, tensile strength, flexural strength, shear strength and impact strength. This is because of the similar modulus and the synergistic interaction between two reinforcing fibres.

Thus it can be concluded that the best composite among all the hybrid fibre combination is metakaoline based hybrid fibre reinforced concrete with the combination (SF+GIF).

VI. CONCLUSIONS

Following conclusions may be drawn based on experimentations conducted on workability and strength characteristics of metakaoline based hybrid fibre reinforced concrete:

1) Hybrid fibre reinforced concrete produced with the combination of fibres (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF) exhibit lower workability as compared to the corresponding mono fibre reinforced concrete as well as reference concrete without fibre.
2) Performance of hybrid fibre reinforced concrete in compression is better as compared to mono fibre reinforced concrete and reference concrete without fibre. The metakaoline based hybrid fibre reinforced concrete with the combination of fibres (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF) show 6%, 8%, 7%, 9% and 7% increase in 28 days compressive strength as compared to the corresponding mono fibre reinforced concrete and show 38%, 36%, 30%, 24% and 16% increase in 28 days compressive strength respectively

as compared to the reference concrete without fibres.

3) Performance of hybrid fibre reinforced concrete in tension is better as compared to mono fibre reinforced concrete and reference concrete without fibre. The metakaoline based hybrid fibre reinforced concrete with the combination of fibres (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF) show 2%, 4%, 6%, 9% and 10% increase in 28 days tensile strength as compared to the corresponding mono fibre reinforced concrete and show 79%, 59%, 47%, 34% and 28% increase in 28 days tensile strength respectively as compared to the reference concrete without fibres.

4) Performance of hybrid fibre reinforced concrete in flexure is better as compared to mono fibre reinforced concrete and reference concrete without fibre. The metakaoline based hybrid fibre reinforced concrete with the combination of fibres (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF) show 20%, 13%, 6%, 16% and 16% increase in 28 days flexural strength as compared to the corresponding mono fibre reinforced concrete and show 120%, 103%, 80%, 70% and 47% increase in 28 days flexural strength respectively as compared to the reference concrete without fibres.

5) Performance of hybrid fibre reinforced concrete in shear is better as compared to mono fibre reinforced concrete and reference concrete without fibre. The metakaoline based hybrid fibre reinforced concrete with the combination of fibres (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF) show 15%, 20%, 17%, 14% and 11% increase in 28 days shear strength as compared to the corresponding mono fibre reinforced concrete and show 62%, 57%, 48%, 33% and 24% increase in 28 days shear strength respectively as compared to the reference concrete without fibres.

6) Performance of hybrid fibre reinforced concrete in impact is better as compared to mono fibre reinforced concrete and reference concrete without fibre. The metakaoline based hybrid fibre reinforced concrete with the combination of fibres (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF) show 6%, 12%, 14%, 31% and 10% increase in 28 days impact strength as compared to the corresponding mono fibre reinforced concrete and show 3793%, 3620%, 1676%, 1580% and 2407% increase in 28 days impact strength respectively as compared to the reference concrete without fibres.

7) The best composite among all the hybrid fibre combination is metakaoline based hybrid fibre reinforced concrete with (SF+GIF).

VII. ACKNOWLEDGEMENTS

The authors would like to thank Prof. H U Talawar, Director, Department of Technical Education, Bangalore, Dr. Jagadish G Kori, Head of the Civil Engineering Department, teaching and non-teaching staff of Government Engineering College, Devagiri, Haveri for giving all the encouragement needed which kept the enthusiasm alive.

REFERENCES

[1]. Jagadish K.S, Venkatararama Reddy B.V, Nanjunda Rao K.S, *"Alternate building materials and technology"*, New Age International (P) Limited, Publisher, New Delhi.

[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]. Shetty M.S, *"Concrete technology theory and practice"*, S. Chand & Company ltd. Publications, New Delhi, Edition-2012.

[4]. 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

[5]. 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.

[6]. 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.

[7]. 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.

[8]. 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.

[9]. Sadat Ali Khan, Prakash K B, "*Behaviour of sifcon produced with hybrid fibres under sulfate attack*" , IJOER , 2014,Issue4, Vol2,pp154-164

[10]. Deepak Namadev Mudgal, " *An experimental investigation on the characteristic properties and structural behavior of silica fume concrete produced with hybrid fibers*", A Ph.D thesis submitted to Shivaji University,Kolhapur, May 2012