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Strength Properties of Hybrid Fiber Reinforced High Performance Concrete with Mineral Admixtures

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***Abstract**: In recent days, High Performance Concrete (HPC) is rapid accomplishment for wide range of applications in the construction of concrete structures. When two fibers are added to concrete in a suitable combination to make the composite structures and it produce overall improve properties of concrete gives and also result in performance concrete that type of concrete is Hybrid Fiber Reinforced High Performance Concrete (HFRHPC). The use of mineral admixtures in concrete enhances its properties regarding strength parameters,, workability and durability of concrete. In this experimental work using mineral admixture like fly ash, silica fume and metakaolin towards the performance of HPC. The partial replacement of cement by different percentages of mineral admixtures are 0,10, 20 & 30% was used in the concrete mix containing composite fibers (Steel and Polypropylene) of different percentages viz 0,0.75,1.0 and 1.25% for all concrete mixes on the properties of High Performance Concrete. An Aggregate Binder (A/B) ratio of 1.75 with different water binder (W/B) ratio viz, 0.275, 0.30, 0.325, 0.350 and 0.375 was used in this investigation. In order to evaluate and compare the strength properties of different concrete mixes are conducted and results are tabulated. From the present investigation results showed that as the percentage of fibers increases the strength of concrete increases. Hybrid fiber ratio is 1.25% with 10% of metakaolin admixture and Aggregate binder ratio 1.75 gives maximum results in all strength parameters compare to other different mixes.*

***Keywords** : Fly Ash, High Performance Concrete (HPC), Hybrid Fiber, Metakaolin, Polypropylene fiber, Silica fume Steel fiber.*

I. INTRODUCTION

Concrete is the most extensively used construction material developed by man. Because of its superior specialty of being cast in any desirable shape, it has replaced stone and brick masonry. In spite of all this it has some serious deficiencies which, but for its remarkable qualities of flexibility, resilience and ability to redistribute stress, would have prevented its use as a building material. In HPC, a substantial reduction in water-to-cement ratio is achieved through the use of super plasticizers. Further enhancements of some properties have been obtained through the addition of mineral admixtures such as Fly Ash, Metakaolin (MK) and Silica Fume (SF).

The early deterioration of structures constructed in previous years well before their expected life span evoked a new thought process in the field of concrete technology shifting the emphasis from pure compressive strength to durability. It is to be realized that durability of concrete cannot be enhanced without a holistic approach considering the strength-cracking-durability relation. A change-over to a holistic approach to control cracking in concrete structures is necessary to create a much closer working relationship between the structural designer, materials engineer and construction personnel. To overcome various problems encountered in the field and to achieve better and better performance even in aggressive environments, use of high-performance-concrete is becoming a more popular solution.

HPC is usually more brittle when compared with Normal Strength Concrete (NSC), especially when high strength is the main focus of the performance.

It is well know that the ductility of concrete can be improved by applying a confining pressure on HPC. Besides confinement the ductility of HPC can be improved by altering its composition through the addition of fibers in the design mix. High-Performance-concrete made with steel and polypropylene fibers contained by Hybrid Fiber Reinforced High Performance Concrete (HFRHPC).

II. LITERATURE SURVEY

Forster.S.W et al.[1] defined HPC as "A concrete made with appropriate materials combined according to a selected mix design and properly mixed, placed, transported, consolidated and cured so that the resulting concrete will give excellent performance in the structure in which it will be exposed and with the loads to which it will be subjected for its design life".

Naaman A.E et al.[2] showed that application of steel fibers in lower strength concrete it increases their compressive strength significantly compared to plain unreinforced concrete and it's directly related to volume fraction of steel fibre used. Strength increase is more for hooked end fibers in comparison with polypropylene fiber and glass fiber.

Sivakumar.R et al.[3] showed that Metakaolin is a alternate material for high performance concrete. A concrete property with metakaolin is most common preferred additives in HPC.

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The various proportion of metakaolin used was 0 %, 5.00 %, 10.00 %, 15.00 %, by the weight of cement, prepared cubes and cylinders to determine performance of concrete and Conclude that increases strength properties with metakaolin.

Duval, R et al.[4], presented the influence of silica fume on the workability and the compressive strength of high-performance concrete and conclude that the partial cement replacement up to 10% by silica fume does not reduce the concrete workability and also silica fume replacements up to 20% produced higher compressive strengths than control concrete.

Priyanka Dilip et al. [5] reported that crimped steel fibers and polypropylene fibers (PP) content at 0, 0.50, 1.0, 1.50 and 2.0% for the given ratio they combined steel fibers 80% and PP is 20% for each composite fiber of mix M25 concrete and conclude that strength parameters increases for hybrid fiber ratio 1.0% and above 1.0% of composite ratio of all parameter of strength decreases.

Akila.R et al.[6] reported study on strength and durability characteristics of hybrid fiber reinforced concrete", steel fibers added with different percentage of 0.5,0.6,0.7 and 0.8% by volume of concrete and polypropylene fibers added with percentage of 0.5,0.4,0.3 and 0.2% by weight of cement and conclude that compressive strength S0.8P0.2 percentage give high strength as compare to other combination.

Sudarshan.H et al.[7] investigate on "Mix design of high performance concrete using silica fume and superplasticizers", states that mix design is formulate by ACI method mix design and as the silica fume content increases the compressive strength increases up to 15%, then decreases. Hence the optimum replacement is 15%.

Murahari. K et al.[8] presented on the effect of polypropylene fiber fraction in fly ash mix concrete with different volume fraction of fibers are 0.15% to 0.30% was used in fly ash concrete. Fly ash content was varied from 30% to 50% .The results are conclude that the compressive strength gained at early age and strength increased gradually from 0.15 to 0.30% fiber content.

III. MATERIALS

Materials used in the present work and the various tests conducted on them and also along with methodology of mix proportion with various mix proportions of addition of steel fibers in the concrete. Properties of materials which are used for the project are discussed and also along with their permissible limits according to the standards. The following are the materials used in the experimental work.

Cement(C):- Ordinary Portland cement (OPC) of 43 grades are used for the throughout experimental work.

Table-1: Physical properties of Cement.

Sl.No	Properties	Result
1	Specific Gravity	3.08
2	Normal Consistency	33%
3	Initial Setting Time	45 minutes
4	Final Setting Time	300 minutes

Fine Aggregate (F.A):- Locally available river sand is used in the current study as fine aggregate.

Table-2: Physical properties of Fine Aggregate.

Sl.No	Properties	Result
1	Specific Gravity	2.5
2	Zone	II
3	Fineness modules	2.0

Coarse Aggregate (C.A):- Crushed granite stones were used as a Coarse Aggregate. The nominal size of the coarse aggregate used in the investigation was 12.5-20 mm sieve is 60% and 4.75-12.5 mm sieve is 40% were used.

Table-3: Physical properties of Coarse Aggregate.

Sl.No	Properties	Result
1	Specific Gravity	2.7
2	Water Absorption	16%
3	Shape of Aggregate	Angular
3	Fineness modules	7.13

Water (W): - Water is a very important ingredient of the concrete as it actually involved in the chemical reaction with cement. In general, portable water free from any harmful amount of alkalis, oils, sugars, salts and organic material was suitable for mixing and curing of concrete.

Super Plasticizer (SP):- To improve the workability of concrete mixes, to reduce the water content, con plast-SP 430 is used.

Silica Fume (SF):- Condensed silica fume is a material which is used as artificial mineral admixture and it is obtained from By-product of the manufacture of silicon metal, ferrosilicon or the like from quartz and carbon in electric arc furnace was used in the present investigation. It is commercially available from the Elkem India Pvt. Ltd, Mumbai in Maharastra. The Sp. gravity of 2.10 is used and specific surface area was 20,000 cm2 /gm.

Fly ash (FA):- It is obtained from combustion of coal by using flue gases, results the collection of Electrostatic precipitator .The most widely used as mineral admixture is fly ash over the world. The fly ash collects from thermal power station at kudithini, Ballari (dist). The Sp. gravity of fly ash was 1.90 is used in these investigation.

Metakaolin (MK):- High Reactivity Metakaolin (HRM), which is manufactured by the high temperature treatment of specially selected kaolin under controlled conditions. It is a white mineral admixture, having very good pozzolanic properties. The specific gravity of metakaolin is 2.60.

Polypropylene Fiber (PP):- Polypropylene fiber is composed of crystalline and non crystalline regions.

Recron 3s with objective of improving the quality of concrete. It is lighter than water and all other fiber.

The fiber ranges in size from micrometer to centimetre in diameter. In present work the polypropylene fiber with 12 mm cut length and density of fiber is 900 g/m3 is used.

Steel Fibers (S_f):- Steel fibers are short and discrete length of steel fibers with different aspect ratio from 30-150 with different cross section. The different types of steel fibers are crimped end, hooked end and glue hooked end etc., in this present research work we have used crimped steel fibers.

Table-4: Steel Fiber properties

Sl.No	Properties	Result
1	Types of fiber	Crimped
2	Material	Low carbon draw flat wire
3	Length of fiber	30 mm
4	Diameter	0.6 mm
5	Aspect Ratio	50 mm
6	Tensile strength	500-750 Mpa

IV. RESEARCH METHODOLOGY

As there is no standard method for mix proportioning of Hybrid Fiber Reinforced High Performance Concrete (HFRHPC) mixes. In this investigation, absolute volume method has been used for arriving at the mix proportions. The various parameters studied are given below.

- Aggregate – Binder Ratio (A/B ratio): 1.75
- Water-Binder ratio (W/B ratio): 0.275, 0.300, 0.325, 0.350 & 0.375
- Mineral admixtures used:
  Fly ash, Metakaolin and Silica fume
- Percentage replacement of cement by mineral admixture: 0, 10, 20 & 30 (for Each Mineral Admixture)
- Steel Fiber Volume percentage (SF); 0, 0.50, 0.75 & 1.0
- Polypropylene fiber (PP): 0.25% (constant for all mixes)
- Mix Proportions: 1:0.75:1.0 (C:F.A:C.A)

Table -5: Percentage variation of fibers in mix.

Total volume fraction of fiber (%)	Steel fiber (%)	Polypropylene fiber (%)
0	0	0
0.75	0.5	0.25
1	0.75	0.25
1.25	1	0.25

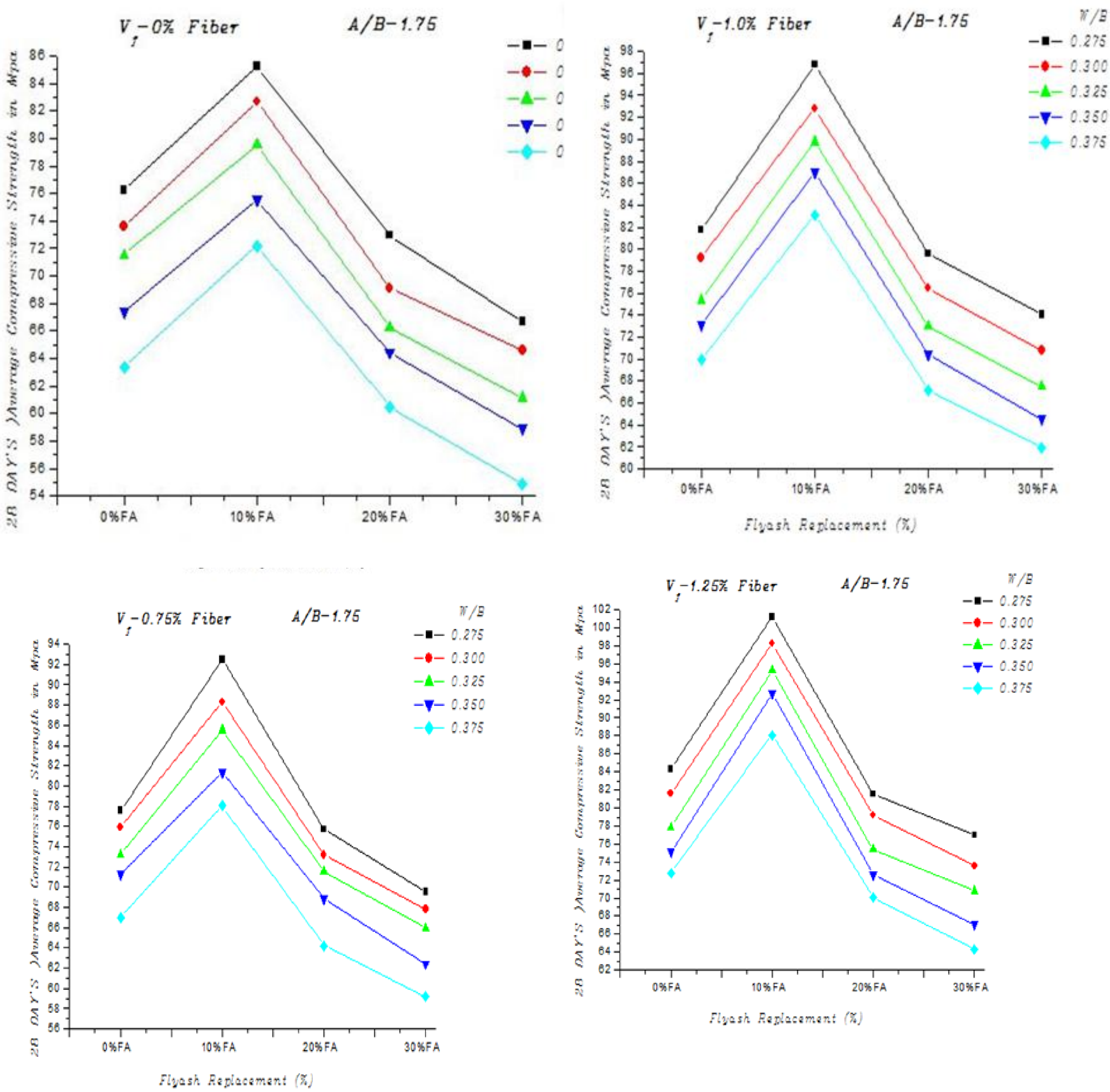
V. RESULT AND DISCUSSION

Compressive strength test: It is taken as an important property as it is majorly used to test hard state concrete.0.10m3 test specimens which are cured at room temperature are tested in Compressive Testing Machine of 3000KN capacity and this test is done as per Indian Standard 516:1959. The cubes are tested at 28days.

Table-6: 28 Days Compressive Strength Test of Flyash.

Sl. no	Mineral Admixture(%) by wt. of cement	Total fiber Volume Fraction (%)	28 DAY'S Average Cube Compressive Strength in N/mm2				
			A/B = 1.75				
			W/B Ratio				
			0.275	0.3	0.325	0.35	0.375
1	0%	0	76.22	73.61	71.53	67.4	63.35
		0.75	77.56	75.93	73.21	71.29	66.98
		1	81.77	79.19	75.37	73.08	70
		1.25	84.33	81.6	77.86	75.11	72.82
2	10% FA	0	85.23	82.7	79.56	75.55	72.21
		0.75	92.49	88.3	85.49	81.34	78.03
		1	96.8	92.77	89.79	87	83.1
		1.25	101.21	98.27	95.26	92.68	88.09
3	20% FA	0	72.95	69.12	66.26	64.42	60.51
		0.75	75.7	73.17	71.54	68.84	64.24
		1	79.6	76.43	73	70.44	67.17
		1.25	81.53	79.19	75.4	72.6	70.07
4	30% FA	0	66.7	64.6	61.13	58.9	54.86
		0.75	69.51	67.8	65.96	62.4	59.19
		1	74.03	70.81	67.52	64.52	61.93

		1.25	76.96	73.59	70.76	67.03	64.32



Graph -1: 28 Days Compressive Strength Test of Fly ash.

Observations:-

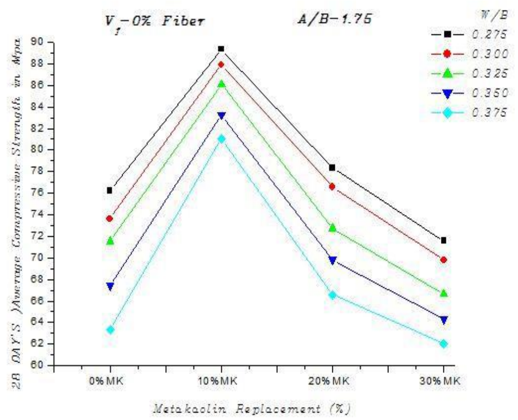
- The 28-Day's cube strength with different percentage of Fly ash is obtained in Graph-1. It can be observe that the addition of enhances the load carrying capacity of the mix.The maximum cube compressive strength is obtained cement replaced by 10% of Fly ash and further increase in replacement of cement by Fly ash of cube compressive strength was decreases.

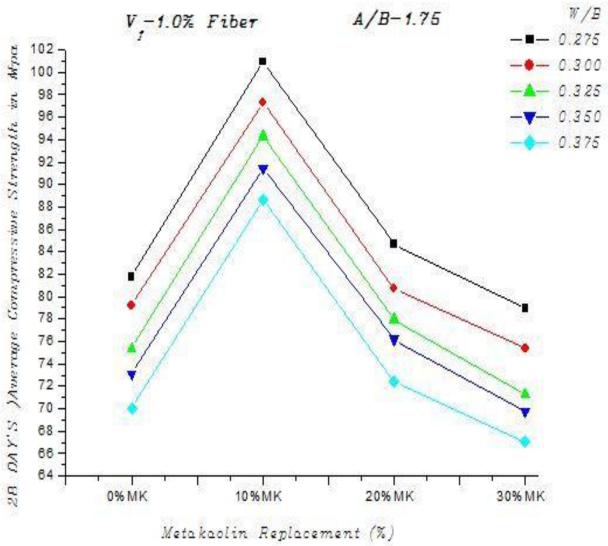
- The percentage increase in cube strength of 10% Fly ash is 10.57% for 10% FA mix over 0% mix of W/B=0.275 mix. Hence, it can be conclude that the maximum replacement of cement by Fly ash as a mineral admixture is 10%.

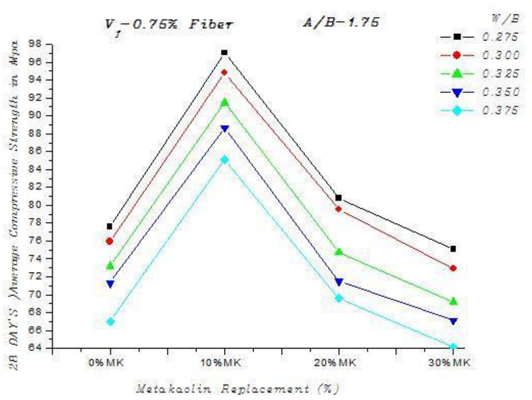
- It can be asserted that the 28-Day's cube strength increases with increase percentage of Hybrid Fibers 0, 0.75, 1 and 1.25%. The addition of steel fiber amplifies the load carrying capacity of the mix. The maximum compressive strength of HFRHPC at 1.25% Volume Fraction of fiber is 24.69% for 10% FA mix over 0% mix of W/B=0.275 mix.

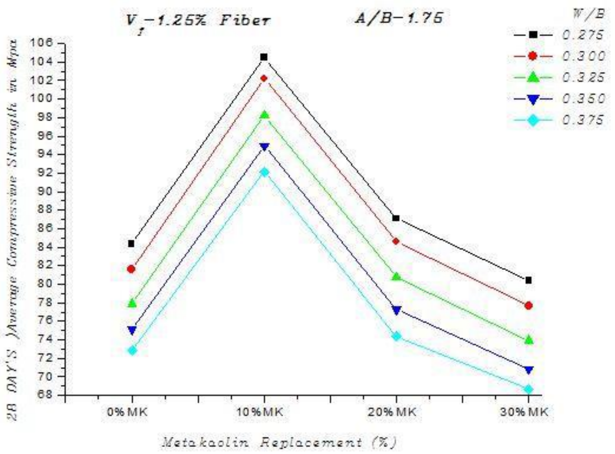
Table-7: 28 Days Compressive Strength Test of Metakaolin.

Sl. no	Mineral Admixture(%) by wt. of cement	Total fiber Volume Fraction (%)	28 DAY'S Average Cube Compressive Strength in N/mm2				
			A/B = 1.75				
			W/B Ratio				
			0.275	0.3	0.325	0.35	0.375
1	0%	0	76.22	73.61	71.53	67.4	63.35
		0.75	77.56	75.93	73.21	71.29	66.98
		1	81.77	79.19	75.37	73.08	70
		1.25	84.33	81.6	77.86	75.11	72.82
2	10% MK	0	89.34	87.92	86.1	83.27	81.06
		0.75	97.03	94.82	91.43	88.67	85.1
		1	100.93	97.31	94.29	91.45	88.64
		1.25	104.46	102.22	98.2	94.94	92.16
3	20% MK	0	78.33	76.57	72.73	69.81	66.58
		0.75	80.81	79.54	74.71	71.5	69.58
		1	84.67	80.71	77.97	76.18	72.4
		1.25	87.1	84.6	80.79	77.26	74.33
4	30% MK	0	71.56	69.8	66.66	64.32	62.01
		0.75	75.05	72.9	69.17	67.11	64.19
		1	78.91	75.39	71.26	69.78	67.04
		1.25	80.36	77.65	73.92	70.83	68.7









Graph-2: 28 Days Compressive Strength Test of Metakaolin.

Observations:-

- The 28-Day's cube strength with different percentage of Metakaolin is obtained in Graph-2. It can be observe that the addition of enhances the load carrying capacity of the mix.The maximum cube compressive strength is obtained cement replaced by 10% of Metakaolin and further increase in replacement of cement by Metakaolin of cube compressive strength was decreases.
- The percentage increase in cube strength of 10% Metakaolin is 14.68% for 10% MK mix over 0% mix of W/B=0.275 mix. Hence, it can be conclude that the maximum replacement of cement by Metakaolin as a mineral admixture is 10%.
- It can be asserted that the 28-Day's cube strength increases with increase percentage of Hybrid Fibers 0, 0.75, 1 and 1.25%. The addition of steel fiber amplifies the load carrying capacity of the mix. The maximum compressive strength of HFRHPC at 1.25% Volume Fraction of fiber is 28.24% for 10% MK mix over 0% mix of W/B=0.275 mix.

Table-8: 28 Days Compressive Strength Test of Silica Fume.

Sl. no	**Mineral Admixture(%) by wt. of cement**	**Total fiber Volume Fraction (%)**	**28 DAY'S Average Cube Compressive Strength in N/mm2**				
			A/B = 1.75				
			W/B Ratio				
			0.275	**0.3**	**0.325**	**0.35**	**0.375**
		0	76.22	73.61	71.53	67.4	63.35
		0.75	77.56	75.93	73.21	71.29	66.98
		1	81.77	79.19	75.37	73.08	70
1	0%	1.25	84.33	81.6	77.86	75.11	72.82
		0	88.02	85.95	83.37	80.96	77.81
		0.75	93.39	90.79	88.25	86.52	83.22
		1	98.51	95.33	92.5	90.46	87.23
2	10% SF	1.25	103.04	99.58	96.94	95.27	91.9
		0	77.56	75.26	72.96	68.74	65.62
		0.75	78.79	77.75	74.8	72.73	70.57
		1	84.29	80.76	77.97	75.27	71.6
3	20%SF	1.25	87.42	83.34	79.66	77.9	74.45
		0	72.54	70.37	67.93	63.69	60.47
		0.75	74.2	73.31	70.21	69.4	65.98
		1	79.24	77.43	73.52	70.89	67.02
4	30% SF	1.25	81.73	79.26	75.65	73.67	70.42

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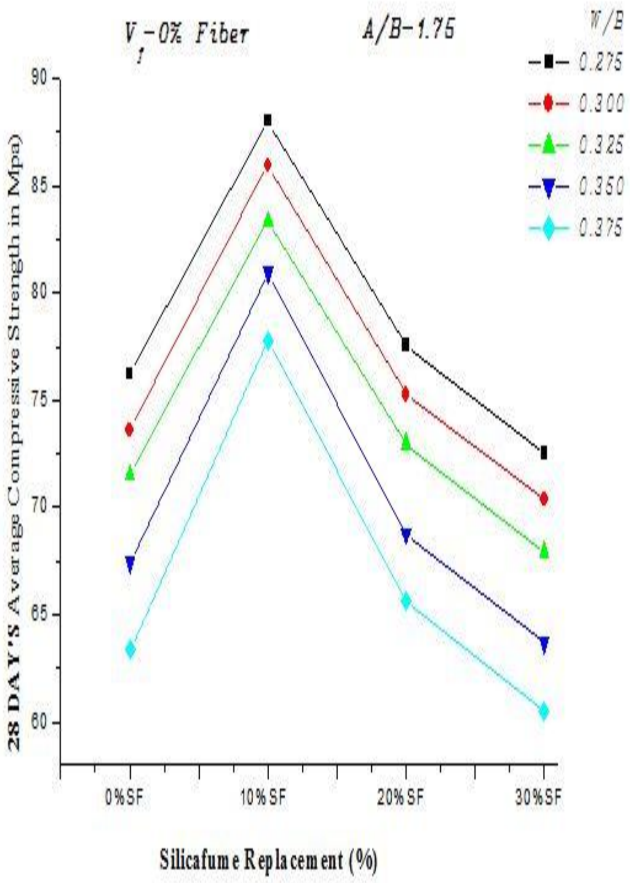
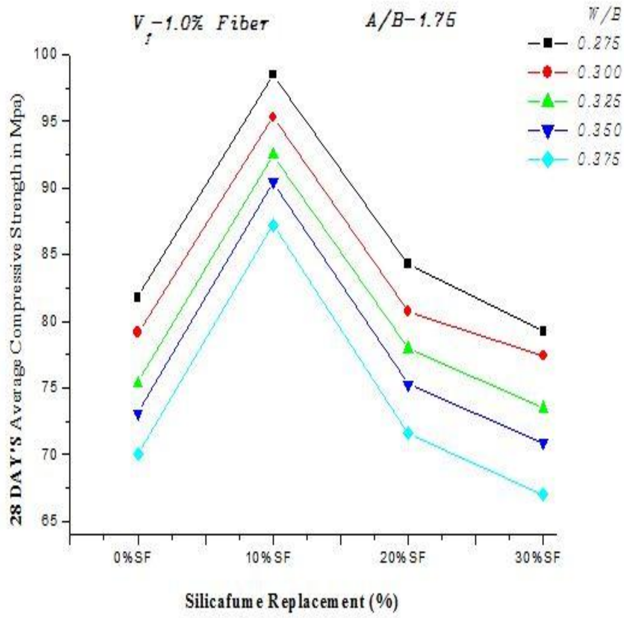
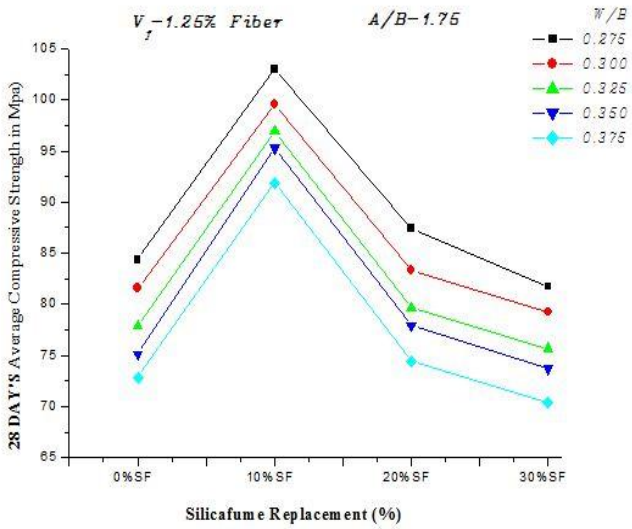
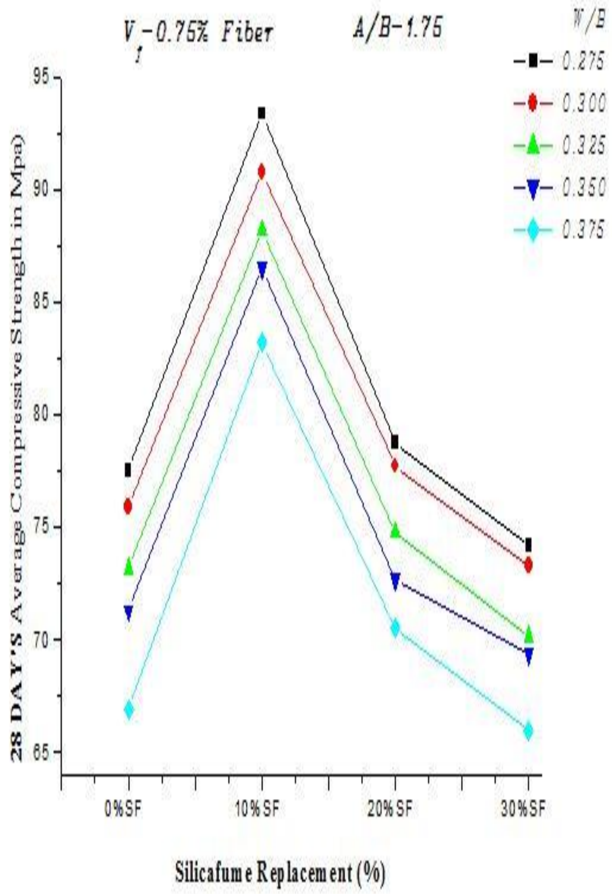








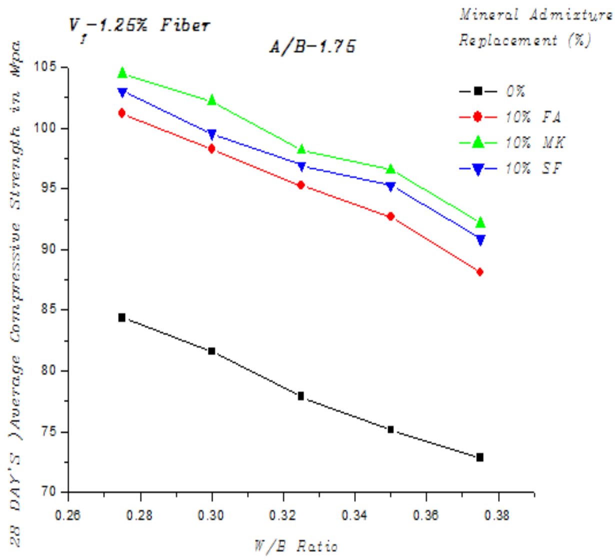
Graph-3: 28 Days Compressive Strength Test of Silica fume.

Observations:-

- The 28-Day's cube strength with different percentage of Silica fume is obtained in Graph-3. It can be observe that the addition of silica fume enhances the load carrying capacity of the mix.The maximum cube compressive strength is obtained cement replaced by 10% of silica fume and further increase in replacement of cement by silica fume of cube compressive strength was decreases.
- The percentage increase in cube strength of 10% silica fume is 13.40% for 10% SF mix over 0% mix of W/B=0.275 mix. Hence, it can be conclude that the maximum replacement of cement by silica fume as a mineral admixture is 10%.
- It can be asserted that the 28-Day's cube strength increases with increase percentage of Hybrid Fibers 0, 0.75, 1 and 1.25%. The addition of steel fiber amplifies the load carrying capacity of the mix. The percentage increase compressive strength of HFRHPC at 1.25% Volume Fraction of fiber is 26.02% for 10% SF mix over 0% mix of W/B=0.275 mix.

Table -9: Comparison of mineral admixture with respect to Compressive strength of V_f= 1.25%.

Total fiber Volume Fraction	W/B Ratio	28 DAY'S Average Cube Compressive Strength in N/mm2			
		A/B = 1.75			
		Mineral Admixture(%) by wt. of cement			
		0%	10% FA	10% MK	10% SF
Vf 0.0125	0.275	84.33	101.21	104.46	103.04
	0.3	81.6	98.27	102.22	99.58
	0.325	77.86	95.26	98.2	96.94
	0.35	75.11	92.68	96.54	95.27
	0.375	72.82	88.09	92.16	90.9



Graph-4: Comparison of mineral admixture with respect to compressive strength.

Observations:-

- From Graph-4, Observed that the higher cube compressive strength is achieved with metakaolin. This is mainly due to its higher pozzolanic activity compared to the silica fume and Fly ash admixtures. Further metakaolin is a manufactured admixture under controlled conditions, hence it has performed better. Through the graph is presented for 10% replacement and 1.25% Hybrid fiber, similar results are observed at other replacement levels and Hybrid fiber contents. The percentage increase in compressive strength of 10% Metakaolin is 19.27% to 20.98% for 10% MK mix over 0% admixture mix for over 3.12% to 4.42% of 10% FA mix for over 1.36% of 10% SF. Hence it is concluded that from compressive strength aspect, metakaolin is a better admixture than fly ash and silica fume.

VI. CONCLUSION

Based on experimental work and the analysis of the results the following conclusions seem to be valid.

1. Concrete with 10% of Metakaolin gives better results compared to fly ash and silica fume admixture.
2. The 28-days cube compressive strength also increases in percentage of Hybrid fibers i.e., 0, 0.75, 1.0 and 1.25% compressive strength of Hybrid fiber reinforced HPC for 1.25% (1% of Steel Fiber and 0.25% of Polypropylene fiber) hybridization ratio is maximum in the present investigation. It is increased by 9.47% to 13% with respect to plain HPC (i.e. hybridization ratio is 0%).
3. For all the three mineral admixtures, the maximum compressive strength of HFRHPC is obtained at 10% replacement of cement. In the present work, HFRHPC mixes with maximum compressive strengths of 104.46 Mpa, 10.04 Mpa and 101.21 Mpa have been produced at 10% replacement levels of metakaolin, silica fume and fly ash respectively using normal curing methods.
4. From the results it was found that the optimum replacements of fly ash, metakaolin and silica fume are 10%.
5. High performance concrete could be more economical considering the long term benefits through its enhanced strength and properties.

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