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Experimental Studies on Influence of Mineral and Chemical admixtures in Ordinary Portland cement on Physical and Mechanical Properties

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Abstract *The supplementary cementious materials (SCMs) or mineral admixtures like fly ash, silica fume, metakaolin and ground granulated blast furnace slag (GGBS) are used in cement composite by partial replacement of cement about 20%. The effect of SCMs in Ordinary Portland cement (OPC) with regard to water requirement for consistency, setting time and cement mortar cubes with and without addition of super-plasticizer (SP) has been studied. It has been observed from the experimental studies that the cement consistency for OPC is 27.5% and addition of different mineral admixtures demands more water than cement consistency. Particularly, the mix with metakaolin demands 39% water for consistency. It is observed that with the addition of SP, the water required for consistency found reduced to 25% in all the mixes. The use of mineral admixtures influence fast setting time and with the addition of SP, the setting time is much faster. For preparation of mortar cubes demand 1 % more water as compared to IS-1489. XRD test has been conducted on cement and other cementitious materials, such as fly ash, silica fume, metakaolin, GGBS, to know the nature of particles present in that, which have more influence in imparting strength property. River sand and standard sand has been used in the present study. The compressive strength has been determined for these mixes at 3, 7, 28, 56 and 90days and the compressive strength determined at 90 days indicates that all the mixes with mineral admixtures give more or less same strength except the mix with fly ash in both conditions i.e. with river and standard sand, which gives 10.20 % less by using River sand and 16.5% less by using standard sand. With the addition of SP, the compressive strength of cubes prepared using river and standard sand is more compared to the strength of cubes prepared without SP. The compressive strength of the mortar cubes using standard sand gave better results on compared to cubes using river sand. The compressive strength of cubes for silica fume using River sand gave higher strength of about 56.38Mpa and by using standard sand cement with silica fume gave higher strength of about 57.52MPa. With the addition of SP, the compressive strength of the mortar cubes using river and standard sand, silica fume gave higher strength of about 60.25 and 61.11MPa respectively.*

Key words: *cement, fly ash, GGBS, silica fume, Metakaolin, super-plasticizer, Consistency, Initial and Final setting time, Compressive strength.*

I. Introduction

Concrete is one of the most widely used construction material in the world. The most expensive ingredient of ordinary concrete is undoubtedly cement both economically and environmentally. It is also noticed that due to production of cement every year several million tonnes of CO_2 is releasing to environment, in order to overcome all these adverse effect supplementary cementitious materials (SCM) such as Fly ash, Silica fume, Metakaolin, Ground granulated blast furnace slag (GGBS) are used as partial replacement of cement. Several studies are being done to understand the hydration reactions in cement as well as cement with admixtures. Cement contains many ingredients like oxides of calcium (CaO), silica (SiO_2), aluminium (Al_2O_3), iron (Fe_2O_3), magnesium (MgO) and alkalise like Na2O and K_2O as shown in Fig 1. The main products of hydration of cement are calcium silicate hydrates (C-S-H), calcium hydroxides (CH), and calcium aluminate hydrates (C-A-H). The changes in the chemistry of binder due to addition of an admixture to cement affects the rate, quantity and quality of hydration products which eventually results in changes in the strength of the cement paste.

Mortar consists of fine aggregates in addition to binder. Natural sand are weathered and worn out particles of rocks and are of various grades or size depending on the accounting of wearing. Natural river sand is the commonly used fine aggregate. But standard sand as specified by Bureau of Indian Standards (BIS) is used to make mortar to find the strength. So the study regarding the variation of strength of mortar using the two types of sand is significant.

The purpose of present study is to find out the Physical, mechanical, and durability properties of mortar cubes with mineral admixtures such as Fly ash, GGBS, Silica fume and Metakaolin, and Chemical admixture such as super plasticizer (Glenium B-233), this study also includes comparison on mechanical properties between mortar cubes with river sand and mortar cubes with standard sand.

II. Literature Review

Every year the production of cement is increasing with increasing demand of construction industries. Therefore the rate generation of co_2 also increases. If one ton of cement is produced then one ton of Co_2 is releasing, it will effects the

environment like global warming. Therefore it is necessary to replace the cement from concrete by other supplementary cementious materials called admixtures (PATANKAR.V et.al, 2007).

"A material other than water, aggregate, cement, used as an ingredient of concrete or mortar added to the batch immediately before or during mixing is called admixture". These are also called as supplementary cementious materials. There are two kinds of admixtures they are chemical admixtures and mineral admixtures.

Mineral admixtures are of different types i.e. pozzolanic (low calcium fly ash), cementious (ground granulated blast furnace slag), both pozzolanic and cementious (high calcium fly ash), natural materials (volcanic ash) and by-product material (M.S SHETTY, 1982).

Pozzolanic materials are siliceous or siliceous and aluminous material, which in themselves possess little or no cementitious value, but in finely divided form and in the presence of moisture, chemically react with calcium hydroxide liberated on hydration to form compounds, possessing cementitious properties (Shetty M S ,Concrete Technology Theory and Practice).

III. Materials and Methodology

A. Raw Materials Used in the Study

The materials used in the present study are Ordinary Portland Cement (OPC) and four mineral admixtures namely Fly Ash (FA), Ground Granulated Blast Furnace Slag (GGBS), Metakaolin (MK) and Silica Fume (SF), Natural River sand, water and superplasticiser (SP).

The percent replacement of cement was fixed at 20% by weight of cement. Separate set of mixes using SP were also casted. The SP dosage was 0.6% by weight of binder. The binder to fine aggregate ratio was 1:3.

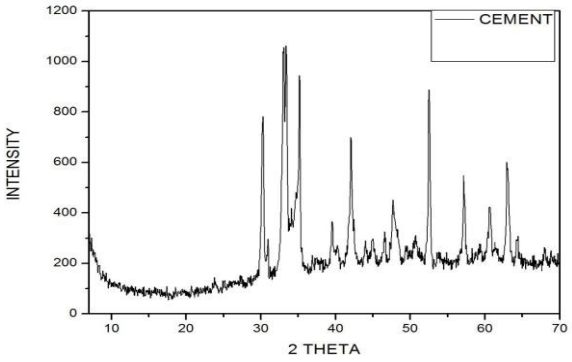


Fig. 1, XRD of OPC

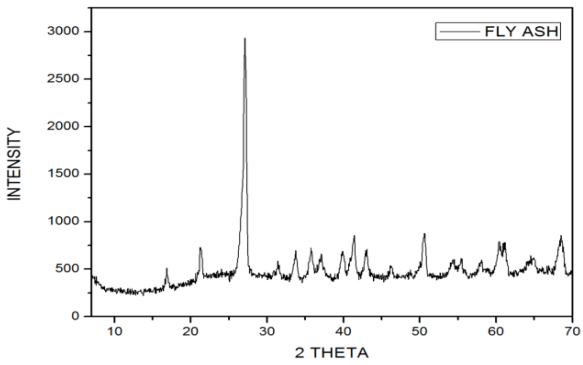
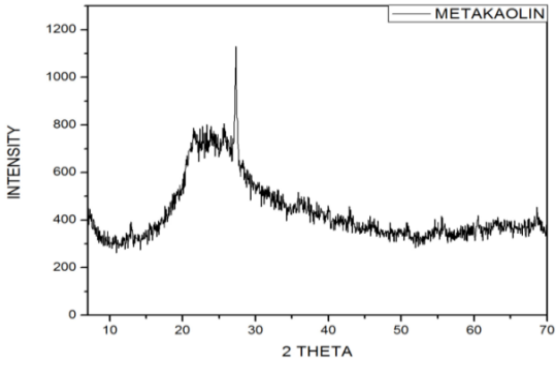
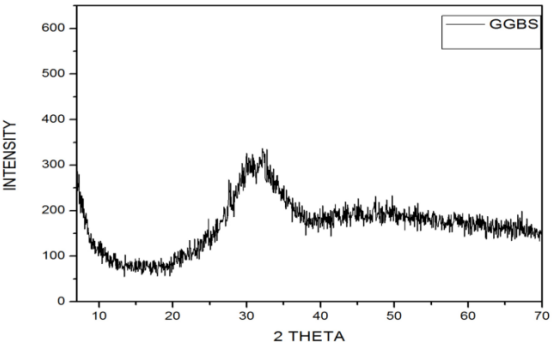


Fig. 2, XRD of Fly Ash



Fig, 3 XRD of Metakaolin



Fig, 4, XRD of GGBS

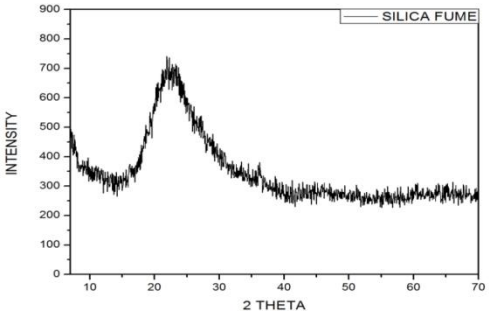


Fig. 5, XRD of Silica Fume

Table 1 Chemical Composition of Cement, fly ash, metakaolin, GGBS, silica fume

Chemical Constituents	Cement(OPC)	Fly ash	Metakaolin	GGBS	Silica fume
CaO	63.1	40	0.09	-	1.6
SiO_2	19.8	35	54	52.52	90
Al_2O3	4.9	12	46	32.56	0.4
Fe_2O_3	2	1	1.2	6.16	0.4
MgO	2	-	0.03	-	-
Na_2O	0.85	0.3	0.03	0.02	0.5
K_2O	-	0.4	0.1	0.11	2.2
SO_3	3.8	9	-	4.95	0.4

River Sand

Natural river sand was collected from Chengalpettu Local River. The sand was sieved through 4.75 micron IS sieve. The fineness modulus of sand was 2.95.

Standard Sand

Standard sand as specified in IS 650:1991 ie; Ennore sand was used. Three varieties i.e. fine (300micron), medium (900micron) and coarse (2.36mm) sand were mixed in equal proportions.

Superplasticiser (SP)

Glenium B233 type superplasticiser was used. (0.5-0.6 litters per 100 kg of cement).

B. Experimental Methodology

1 Consistency Test

Consistency is the general term to indicate the degree of fluidity or the degree of mobility. The standard consistency of cement paste is defined as that consistency which will permit a Vicat plunger having 10mm diameter and 50mm length to penetrate to a depth of 33-35 mm from the top of the mould.

The following procedure is adopted to find out standard consistency as per IS 4031. The paste was prepared in a standard manner and filled into the Vicat mould within 3-5 minutes. A standard plunger, 10 mm diameter, 50 mm long is attached and brought down to touch the surface of the paste in the test block and quickly released allowing it to sink into the paste by its own weight. Reading by noting the depth of penetration of the plunger was done till the plunger penetrates for a depth of 33-35 mm from the top. Similarly, cement with admixtures like FA, SF, MK and GGBS of 20% replacement also done

2 Initial Setting Time of Cement

It is defined as the time elapsed between the moments that water is added to the cement, to the time that the paste starts losing its plasticity. As per laboratory procedure, initial setting time is the time elapsed between the moments that water was added to the cement, to the time when the needle of a Vicat apparatus penetrates 5 mm measured from the bottom of mould.

0.85 times the water required to produce cement paste of standard consistency was used. The period elapsing between the time when water was added to cement and the time at which the needle penetrates the test block to a depth equal to 33-35 mm from top was taken as initial setting time.

3 Final Setting Time

It is defined as the time elapsed between the moment that water is added to the cement and the time when the paste has completely Loses its plasticity and has attained sufficient firmness to resist certain definite pressure. As per laboratory procedure, final setting time is the time elapsed between the moment that water is added to the cement, to the time when only the needle of a Vicat apparatus makes an impression while the collar fails to do so. Needle was replaced in the Vicat apparatus by a circular attachment. The cement was considered as finally set when, upon lowering the attachment gently cover the surface of test block, the centre needle makes an impression, while the circular cutting edge of the attachment fails to do so.

4 Compressive Strength

The cement is always tested for strength at the laboratory before it is used for important works. Strength tests are not made on neat cement paste because of difficulties of excessive shrinkages and subsequent cracking of neat cement. Strength of cement is found on a cube cast using cement mortar, sand in specific proportions. The fine aggregate as river sand is used for cement mortar. A total of 70.6 mm size mortar cubes are cast and are tested at different ages (3, 7, 28, 56 and 90 days) for compressive strength.

Cube moulds of size 70.6 mmx70.6 mm x70.6 mm were used. Table-2 gives the details of mixes used for the study. The cube moulds were cleaned thoroughly using a waste cloth and then properly oiled along its faces. A mixture of cement and river sand in the proportion 1:3 by weight was mixed dry (IS 4031 (part 6) – 1968). Mixing was carried out using a mechanical pan mixer corresponding to IS specifications.

Table.2 Details of Mixes

Mix Designation	Mix Constituents	SP Dosage (% wt of binder)
C1	Cement + Sand	Nil
F1	Cement + FA + Sand	Nil
G1	Cement + GGBS + Sand	Nil
M1	Cement + MK + Sand	Nil
S1	Cement + SF + Sand	Nil
C2	Cement + Sand	0.6
F2	Cement + FA + Sand	0.6
G2	Cement + GGBS + Sand	0.6
M2	Cement + MK + Sand	0.6
S2	Cement + SF + Sand	0.6

The constituents were first poured in to the mixer and mixed in dry condition till uniform colour was obtained. Then the required calculated amount of water was added to it and mixing was continued till a uniform and homogenous paste was obtained. The quantities of cement, river sand and mixing water for each cube are 200gms, 600gms and p/4+3 percent of combined weight of cement and sand, where p is the standard consistency of cement. The mortar cubes were compacted using a table vibrator. Cubes were demoulded exactly 24 hours later and curing was started immediately.
Compressive strength test was done in order to evaluate the strength characteristics of mortar. The compression test was done on standard cube specimens of size 70.6×70.6×70.6 mm for each mix. The compressive load was applied at 1.2 KN/Sec using a compression testing machine of 2000 KN capacity. In each type, 3 cubes were tested at the age of 3 days, 7 days, 28 days, 56 days and 90 days, and the average strength of these cubes were reported for each age.

IV. Results and Discussions

The results obtained from the various tests are given below with a brief discussion about them

A. Standard Consistency Values

The standard consistency test was carried out for each of the different mixes a. The results are shown in Table 3 below and also presented in Fig, 6 and 7.

Table .3 Standard Consistency of Cement with Different Admixtures

Materials	% of Water (without SP)	% of Water (with SP)	% Reduction in water due to usage of SP
C	27.5	20.5	25.45
F	31	23	25.81
M	39	28	25.64
G	28	21	25.00
S	27	20	25.92

Consistency test is conducted on different mixes i.e. with and without addition of mineral and chemical admixtures in order to know the percentage of water required to meet the required consistency for that particular mix.

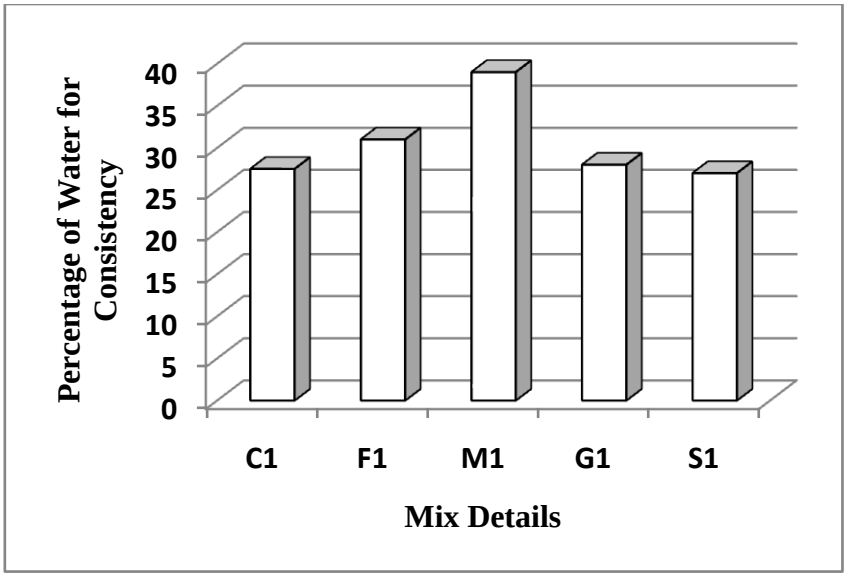


Fig. 6, Standard Consistency (without SP)

From the table 3 and Fig. 6 it clearly indicates that the consistency of cement without any admixtures is 27.5%, and by addition of mineral admixtures except silica fumes other mineral admixtures consumes more water for consistency, particularly Metakaolin consumes about 39%, i.e 41.80 % more than that of consistency of cement.

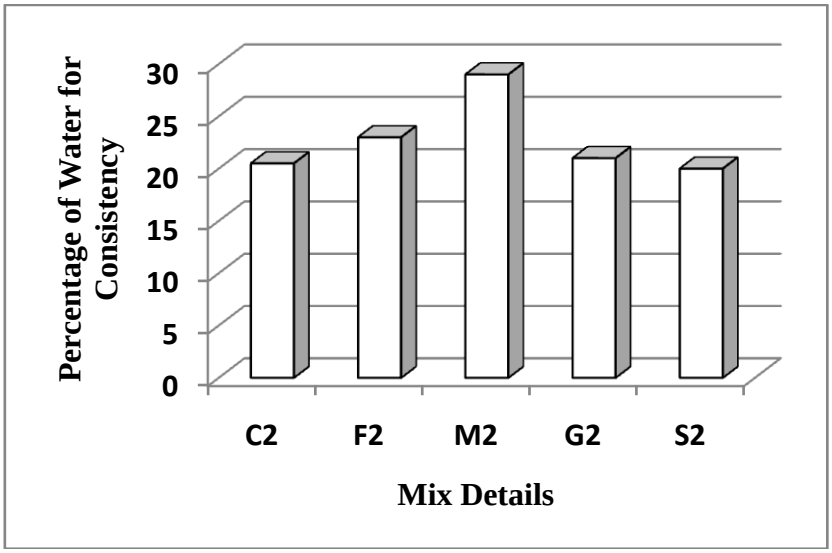


Fig. 7, Standard Consistency (with SP)

Fig. 7 clearly indicates that, by addition of chemical admixture (super plasticizer) there is a reduction of water consumption for consistency. The cement with SP alone consumed 20.5% of water only for consistency and by addition of mineral admixtures the water consumption for consistency is observed more except Silica fume. When compare the mixes without SP to with SP, there is almost 25% reduction in water requirement with SP.

B. Initial and Final Setting Time

The initial and final setting time for mixes with and without admixtures is given in table 4.

Table.4 Initial and Final setting time

Materials	Initial Setting Time ,min		Final Setting Time ,min	
	Without SP	With SP	Without SP	With SP
C	130	120	340	260
F	145	140	370	320
M	85	60	265	195
G	140	125	350	305
S	60	45	250	150

The initial setting and final setting time test conducted with and without mineral and chemical admixtures. It has been observed that addition of different mineral admixtures modifies the setting time. Some mineral admixtures fasters the rate of setting and some delays the rate of setting.

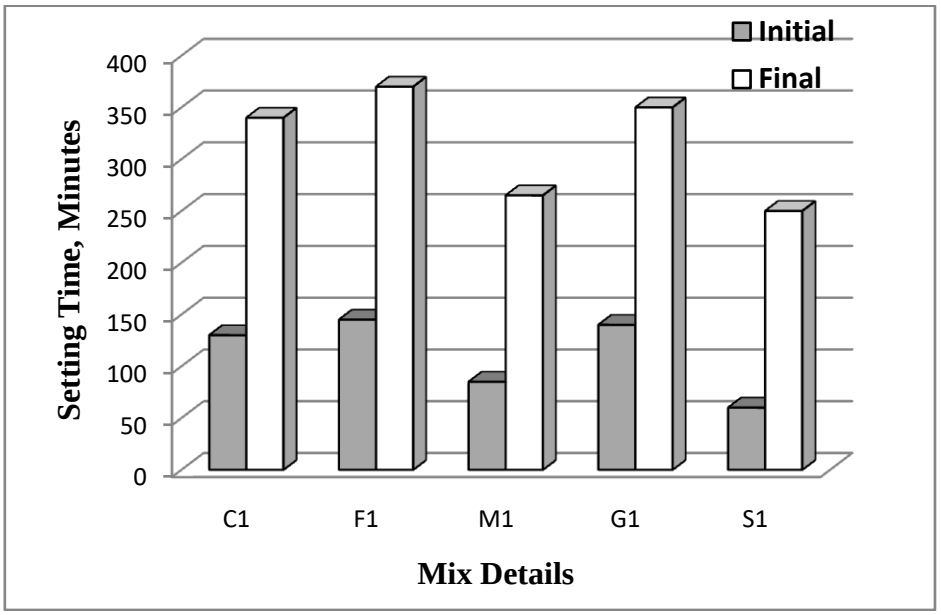


Fig.7, Initial and Final setting Time (without SP)

From the table 4 and Fig, 7 it has been clearly observed that cement alone, without any mineral and chemical admixtures both initial and final setting time is 130 and 340 Min. With the addition of mineral admixture i.e. fly ash the setting time is delayed than setting time of cement alone, it is about 145 and 370 Min, initial and final setting time. With GGBS it is also some more are equal to that of cement. But in the case of metakaolin and silica fume it is observed that both initial and final setting times are in faster rate when compared to cement alone. Silica fume is showing much faster rate of initial and final setting time 60 and 250 Min, when compared to all other mixes. Similar hardening rate was observed for the cubes cast out of the above admixtures and also that Silica fume mortar cubes were found to set very fast. It is also noticed that even though metakaolin having more consistency of water, it showing very faster rate of initial and final setting, i.e. next to silica fume.

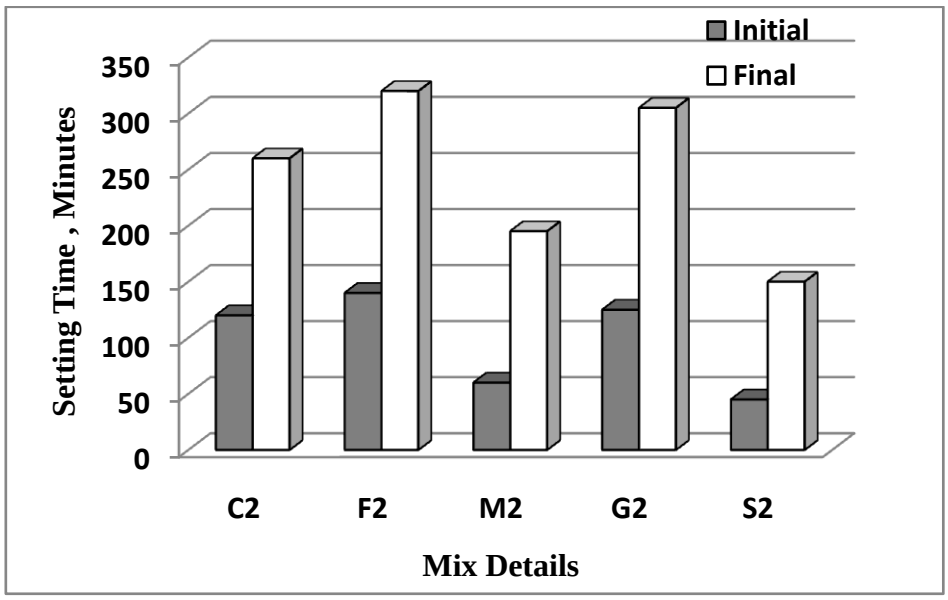


Fig.8, Initial and Final Setting Time (With SP)

From the table 4 and Fig, 8 it has been observed that with addition of chemical admixture i.e. super-plasticizer, the rate of setting time is comparatively faster than the mixes without chemical admixtures. It is observed that cement alone with SP the initial and final setting time is 120 and 260 Min. With the addition of mineral admixture i.e. fly ash the setting time is

delayed than setting time of cement alone, it is about 140 and 320 Min, initial and final setting time. But in the case of metakaolin and silica fume it is observed that both initial and final setting times are in faster rate when compared to cement alone. Silica fume is showing much faster rate of initial and final setting time 45 and 150 Min, when compared to all other mixes. It is also observed that with the addition of SP decreases the water required for consistency, and there by increases the rate of setting.

C. Compressive strength Values of Mortar Cubes

Compressive strength is inherent mechanical property of material by which they resist against deformation. The compression tests were carried out at different ages on mortar cubes of size 70.6×70.6×70.6mm using river and standard sand.

Compression test has been conducted on the mortar cubes with and without mineral and chemical admixtures with river and standard sand. It has been observed that all the mixes are showing different compressive strength, some are giving higher compressive strength and some are giving lower compressive strength than mix with cement mortar cubes alone. The test has been conducted on 3, 7, 28, 56, and 90 days. The results are tabulated below as Table 5, 6, 7 & 8 and also presented in Fig 9, 10, 11 & 12.

Table 5 Compression Strength of Mortar Cubes with River Sand (without SP)

Materials	3Days (MPa)	7Days (MPa)	28Days (MPa)	56Days (MPa)	90Days (MPa)
C1	31.86	38.44	44.77	50.77	54.56
F1	24.85	27.41	37.44	47.08	49.61
M1	24.12	29.61	37.63	42.4	48.24
G1	28.42	36.44	46.50	51.26	56.46
S1	28.91	38.78	44.73	50.43	56.38

Compression test has been conducted on mortar cubes without SP and with river sand at 3, 7, 28, 56, and 90 days and results were tabulated. From the table 4.3 it is observed that cement alone without any admixtures giving 28 days compressive strength of 44.77MPa. It is almost 85% of final strength of OPC 53grade. It is also observed that all the mixes with mineral admixtures except Metakaolin and fly ash are giving compression strength is same range.

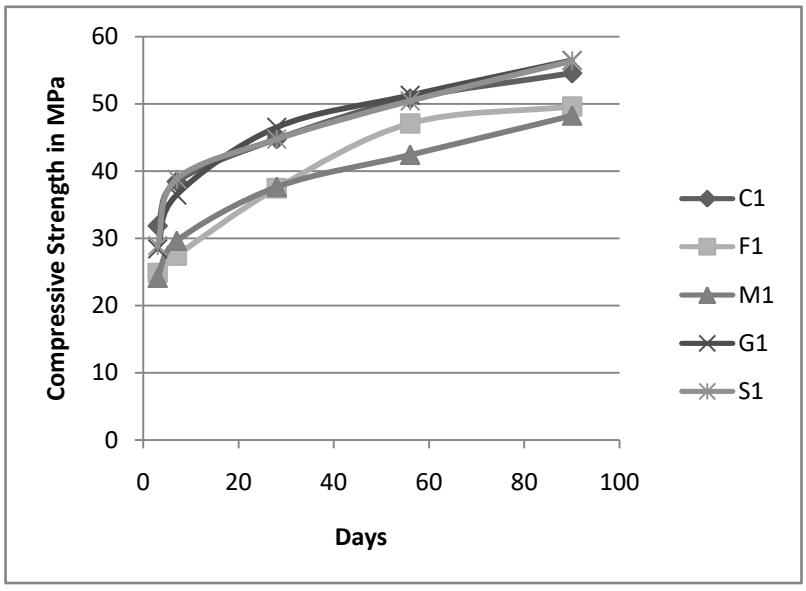


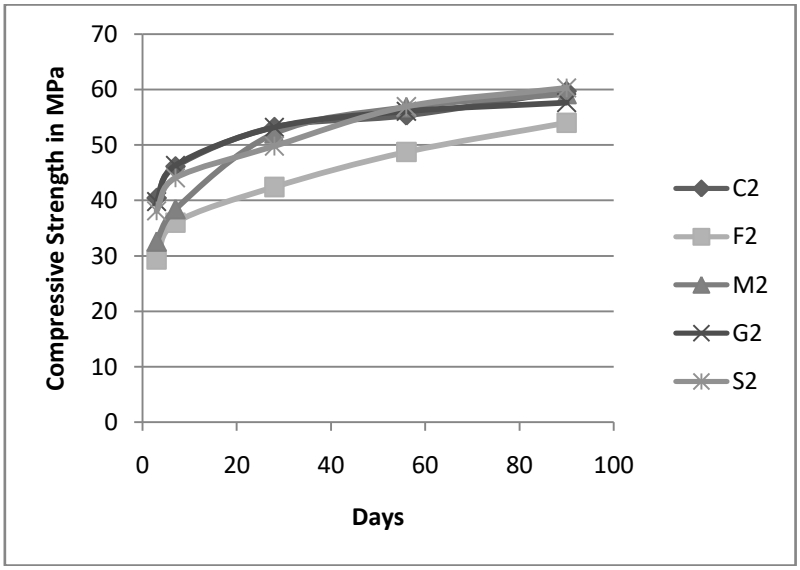
Fig.9, Compression Strength Values of cubes with River Sand (without SP)

From the Fig, 9 it observed that at 3 days metakaolin and Fly ash are giving less strength compare to other mixes i.e. 24.12MPa and 24.85MPa. And cement alone showing higher strength i.e. 31.86MPa. At 7days also we are observing same pattern i.e. Fly ash and Metakaolin are giving lesser strength. But in this case Silica fume is giving higher strength i.e. 38.74, all other mixes except Fly ash and Metakaolin are behaving lesser or equal to Silica fume. At 28 days GGBS giving little higher value than other mixes i.e. 46.50MPa. Same pattern in compression strength is observed at 56 and 90 days i.e. GGBS is giving higher strength. Silica fumes and only cement mortar cubes also behaving in the same range

Table.6 Compression Strength of Mortar Cubes with River Sand (with SP)

Materials	3Days (MPa)	7Days (MPa)	28Days (MPa)	56Days (MPa)	90Days (MPa)
C2	40.41	46.11	53.21	55.31	59.69
F2	29.34	35.98	42.41	48.71	53.96
M2	32.58	38.42	52.07	56.81	59.18
G2	39.79	46.32	53.19	56.08	57.63
S2	38.14	44.08	49.80	56.90	60.25

Compression test has been conducted also for mortar cubes with addition SP and with river sand at 3, 7, 28, 56, and 90 days and results were tabulated. From the table 6 it is observed that cement alone without any mineral admixtures and with SP giving 28 days compressive strength of 53.21MPa. It is also observed that with the addition of SP or due to reduction of water content the compressive strength increases for all the mixes with and without mineral admixtures. And it is also observed that with the addition of SP the compressive strength of all mixes are increased about 10-15%.



Fig, 10 Compression Strength Values of cubes with River Sand (with SP)

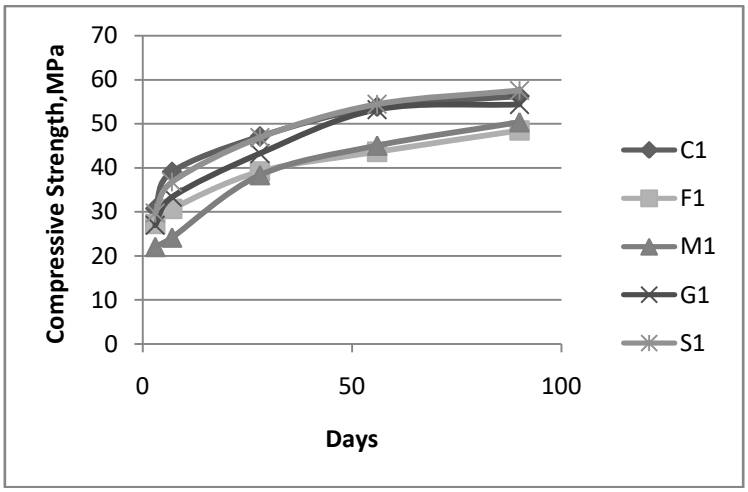
From the Fig, 10 it has observed that in the earlier stage i.e. at 3 days Fly ash is giving lesser compressive strength when compared to other mixes. It is about 28% lesser than mix with cement cubes. At 7 days also fly ash is giving lesser strength i.e. almost 22% lesser strength than the cement cubes. Up to 7days it is observed that Metakaolin is showing lesser strength when compare to other mixes except Fly ash, but at 28 days there is lot of variation in strength, there is almost 27% increment in strength. At 28 days also fly ash is giving lesser strength. At 28 days cement mortar cubes are giving higher strength i.e. 53.21MPa. Other mixes except Fly ash also behaving in the same range. At 56 days also same pattern is continuing, at 56 days also Fly ash giving lesser strength and all other mixes giving almost same compressive strength. At 90 days silica fume is giving higher strength i.e. 60.25MPa, and all other mixes are in less or equal range.

Table.7 Compression Strength of Mortar Cubes with Standard Sand (without SP)

Materials	3Days (MPa)	7Days (MPa)	28Days (MPa)	56Days (MPa)	90Days (MPa)
C1	30.72	39.07	47.12	51.10	56.25
F1	27.25	30.65	39.15	43.61	48.44
M1	22.03	24.17	38.35	45.05	50.36
G1	26.98	33.35	43.25	53.20	54.35
S1	29.74	36.78	46.85	48.91	57.52

Compression test has been conducted also for mortar cubes without SP and with standard sand at 3, 7, 28, 56, and 90 days and results were tabulated. From the table 7 it is observed that cement alone without any mineral and chemical admixtures giving 28 days compressive strength of 47.12MPa, it is about 89% of final strength attained by OPC 53grade. It is observed that initially metakaolin giving lesser strength compared to other mixes, but later stages it showed better strength, it is because of pozzolanic reaction between metakaolin, cement and sand. From 7 days to 28 days it is almost

37% increment in the strength. Finally at 90days it is observed that silica fume is giving higher strength when compared to all other mixes i.e. 57.52MPa. And fly ash is giving lesser strength i.e. 48.44MPa, it is about 16% lesser than silica fume.



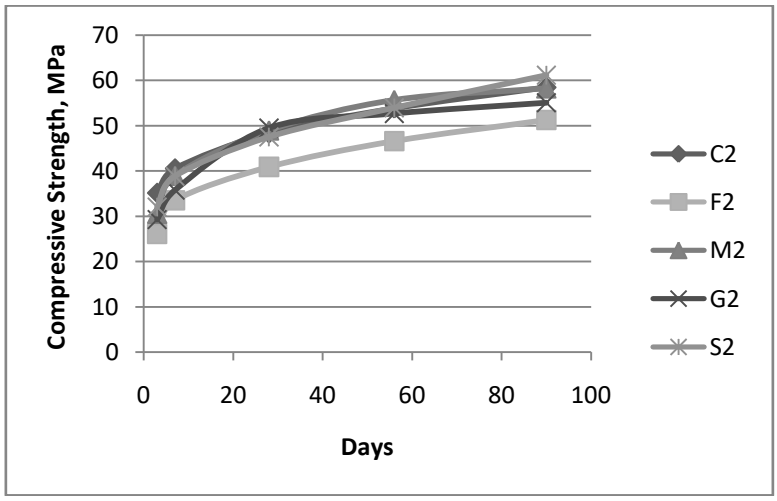
Fig, 11 Compression Strength Values of cubes with Standard Sand (without SP)

From fig, 11 it is clearly observed that initially Metakaolin is giving lesser strength when compare with other mixes. It is about 22.05MPa at 3days test. At 7 days also same pattern is observed i.e. Metakaolin giving lesser strength of about 24.17MPa. And cement mortar cubes alone giving 39.07MPa. At 28 days it is observed that Metakolin and fly ash are in same range, cement mortar cubes are giving higher strength of 47.12MPa. At 56 days GGBS is giving higher strength of 53.20MPa. At 90 days silica fume is giving 57.42MPa.

Table 8 Compression Strength of Mortar Cubes with Standard Sand (with SP)

Materials	3Days (MPa)	7Days (MPa)	28Days (MPa)	56Days (MPa)	90Days (MPa)
C2	35.10	40.50	48.32	53.81	58.45
F2	26.09	33.49	40.89	46.59	51.25
M2	30.52	38.93	48.95	55.67	58.25
G2	29.27	35.78	49.47	52.67	55.04
S2	32.05	38.83	47.49	53.92	61.11

Compression test has been conducted also for mortar cubes with addition SP and with standard sand at 3, 7, 28, 56, and 90 days and results were tabulated. From the table 8 it is observed that mix with Metakaolin and with SP giving 28 days compressive strength of 48.95MPa. It is observed that compressive strength for all other mixes i.e. with mineral admixtures are observed to be in the same range of mortar cubes with cement alone, except fly ash. Fly ash at 28 days gave lesser strength than other mixes. At 56 days also Metakaolin is giving higher strength of 55.67MPa. But at 90 days silica fume is behaving better than other mixes, it is due pozzolanic reactions leads to gain in strength at 90 days.



Fig, 12 Compression Strength Values of cubes with Standard Sand (with SP)

From fig, 12 it is clearly observed that initially fly ash is giving lesser strength when compare with other mixes. It is about 26.09MPa at 3days test. At 7days also same pattern is observed i.e. fly ash giving lesser strength of about 33.95MPa. And cement mortar cubes alone giving 40.50MPa. At 28 days it is observed that Metakaolin mix is giving higher strength of 48.95MPa. And all other mixes are less or equal to strength of Metakaolin except fly ash. At 56days GGBS is giving higher strength of 55.67MPa. At 90 days silica fume is giving 61.11MPa. It is also noticed that with river and standard sand silica fume is attaining higher strength at later ages i.e. at 90 days.

V. Conclusion

From this study, it is observed that the supplementary cementious materials used in the present investigations can be used in cement composite. The strength obtained by addition of these materials is more or less in the same range as compared to the control mix. However, with the addition of SP, maximum increment in strength was noticed with the reduction in water consumption.

The following conclusions may be drawn from this study

- Water requirement for standard consistency was increased by the addition of mineral admixtures.
- Metakaolin was observed to be consuming maximum water for consistency.
- There is almost 25% reduction in water requirement for consistency observed with the addition of super-plasticizer for all the mixes.
- The use of mineral admixtures influence fast setting time and with addition of SP, the setting time is much faster
- As per IS1489, the water required for preparation of mortar cubes by addition of these materials demands 1% more water with both river and standard sand.
- The compressive strength at 90 days using River and Standard sand indicates that all the mixes with mineral admixtures give more or less same strength except the mix with fly ash, which gives 10.20 % less.
- The compressive strength at 90days for mortar cubes with silica fume with SP is giving higher compressive strength in both the cases i.e. is using river and standard sand. And all other mixes are giving lesser equal to the silica fume except Fly ash.
- With the addition of super-plasticizer the compressive strength of mixes increased by 10-15%.

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Reference

1) Abhishek Jain, Nazrul Islam, “Use of Fly ash as Partial Replacement of Sand in Cement Mortar” , International Journal of Innovative Research in Science, Engineering and Technology *Vol. 2, Issue 5, May 2013* ISSN: 2319-8753
2) Md. Moinul Islam and Md. Saiful Islam “Strength Behaviour of Mortar Using Fly Ash as Partial Replacement of Cement “, Concrete Research Letters, www.crl.issres.net Vol. 1 (3) – September 2010 .
3) S.J. Barnett *, M.N. Soutsos, S.G. Millard, J.H. Bungey, “Strength development of mortars containing ground granulated blast-furnace slag: Effect of curing temperature and determination of apparent activation energies”, Cement and Concrete Research 36 (2006) 434– 440. available at www.science direct.com.
4) DP Bentz, A Dura´n-Herrera, CA Jua´rez, “Thermal properties of high-volume fly ash mortars and concretes “ ACI Materials Journal/March-April 2011, Technical paper Title no:108-M17.
5) Amarnath Yerramala, Rama Chandurdu C, Bhaskar Desai V. “Influence Of Fly Ash Replacement On Strength Properties Of Cement Mortar” International Journal of Scientific & Engineering Research Volume 3, Issue 8, August-2012 1 ISSN 2229-5518.
6) Journal of Building Physics 34(3) 263–275 _ The Author(s) 2011 Reprints and permissionssagepub.com.uk/journals Permissions.nav DOI:10.1177/ 1744259110376613 jen.sagepub.com.

