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Characterization of cementitious composite using fiber reinforcement

P.Ruba*, S. Karthikeyan, R. Nandha Kumar, C.Suresh
Dept.of Civil Engineering, Vel Tech Multi Tech Dr Rangarajan Dr Sakunthala Engineering College, Tamil Nadu.
***Corresponding author: E-Mail: rubap@gmail.com**

ABSTRACT

The objective of this study is to find the effect of lime waters with replacement of silica fume (10%, 20%, and 30%) of cement in the pastes and mortar. The physico-chemical reaction of pastes at 3 and 28 days with and without lime waters are monitored by using XRD analysis. The compressive strength of the mortar cubes of the mixes containing cement-sand-silica fume-lime water system is studied. Two types of lime water are used in this study, one type prepared by slaking of lime obtained from calcination of sea shells(labelled, LW) and other one obtained by dissolving(~1gm/litre) commercial $Ca(OH)_2$ in water(labelled, LD). Ordinary potable water is used for control pastes and mortar. The mortar cylinders of similar mixes are cast for split tensile strength studies with and without basalt fibres (1% and 2%) of total volume. The results of the setting times showed that there is a reduction in both the initial and final setting timings for the samples with replacement of silica fume by 10, 20 and 30% and with ordinary potable water compared to control samples. The compressive strength results showed that the saturated lime water with 20% silica fume and natural lime water with 30% silica fume replacements provided 16% higher compressive strength compared to control mortars. Experimental results showed that the split tensile strength was found to be increasing with the increasing fiber volume (2%).

KEY WORDS: Lime water, Basalt fiber, Silica fume, XRD, Mechanical properties.

1. INTRODUCTION

The use of pozzolanic materials as a mineral addition to cement based composites to obtain construction materials of enhanced engineering properties due to the influence on microstructure and durability of the blended cement composites were reported by many researchers. In cement industry, sub-sources of the mineral admixtures are the by-products of many industries. The common types of mineral admixtures are fly ash, ash, silica fume (SF) or condensed silica fume (CSF), blast furnace slag and other slags were used. Moreover, rice husk is also used as amineral admixture.The uses of these mineral admixtures resulted in ecological, economic and energy saving considerations.

In general, Limewater is known as a saturated solution of calcium hydroxide. It is found major in the Free State by burning of sea shells. Limewater is recovered by homogenized dispersion of calcium hydroxide in the presence of water. Basalt is a natural, hard, dense, dark brown to black volcanic igneous rock originating at a depth of hundreds of kilometers beneath the earth and results the surface as molten magma. Basalt fiber is used due to its improved mechanical property particularly high strength, high elastic modulus, high thermal and chemical stability, good sound insulation and electrical characteristics. Basalt fiber used in normal strength concrete was reported in 1998 by Highway Innovations Deserving Exploratory Analysis (IDEA) Project 45 in which performances of 3D Basalt fiber reinforced concrete (using fiber volume as 0.1, 0.25, 0.4, and 0.5%) and Basalt rod reinforced concrete were investigated.

Silica fume (SF) is a by-product of the smelting process in the silicon and Ferro-silicon industry. Silica fume is also known as micro silica, condensed silica fume, volatized silica or silica dust. Silica fume has been recognized as a pozzolanic admixture that is effective in enhancing the mechanical properties to a great extent. With this background, the present study is proposed to investigate the effect of lime water with silica fume (10%, 20%, and 30%) in the presence of basalt fiber (1% and 2%) for replacement of cement and the mechanical properties.

2. MATERIALS AND EXPERIMENTAL PROGRAM

2.1. Materials and mixture Proportion: The cement used for paste / mortar was 53 grade Ordinary Portland Cement (OPC) conforming to IS: 12269 – 1987, and the physical and chemical properties are shown in the Table 1. Silica fume powder (SF), a mineral admixture was used as a replacement of cement by weight (10%, 20% &30%). Specific surface area of silica fume is 150,000 cm^2/g and its physical and chemical properties are shown in Table 1. The grade 2 sand conforming to IS: 383-1970, with a fineness modulus of 2.6, specific gravity of 2.65 and maximum size of 4.74 mm was used. Two types of lime water were used in this study, one type prepared by slaking of lime obtained from calcination of sea shells (labeled, LW) and other one obtained by dissolving (~1gm/liter) commercial $Ca(OH)_2$ in water(labeled, LD). The pH and conductivity of the prepared solutions along with potable water are shown in the Table 2. The increased conductivity value of the slaked lime water may be due to the mobility of more ions in this particular case. The polycarboxylate based high range water reducing admixture (HRWRA) was used as superplasticizer (SP) in the range between 0.5 and 2 % by the weight of cementitious materials to get the uniform flowability in cube mortars / cylinder mortars. The water to binder (cement+SF) ratio for all mixtures was fixed as 0.4.Basalt fiber of 24 mm length and 13µm diameter was used in this study with total volume of1% and 2 %. The experimental program to evaluate the performance of Portland cement based materials containing silica fume mixed with W, LW and LD was designed. The mixture proportions are given in Table 3. CLWSF10, CLWSF20 and CLWSF30 denote the mortars containing 10%, 20% and 30% of weight replacement of cement by silica fume respectively with slaked lime water. CLDSF10, CLDSF20 and CLDSF30 denote the mortars containing 10%, 20% and 30% of weight replacement of cement by silica fume respectively with saturated lime water. Ordinary potable water was used for control pastes and mortar.

Table.1.Physical and chemical properties of cement

Chemicals Properties		
Oxide Constituents (%)	**Cement**	**Silica fume**
SiO_2	20.24	94.73
Al_2O_3	5.64	-
Fe_2O_3	4.07	-
CaO	63.42	-
SO_3	3.48	0.2
Na_2O	0.19	0.51
K_2O	0.56	-
MgO + MnO	0.88	-
LOI	1.52	1.5
Physical Properties		
Color	Dark gray	Gray
Specific gravity	3.162	2.15
Bulk Density gm / cm^3	1.561	0.13-0.6
Fineness passing 40µm sieve, %	85	92-95
Moisture content, %	<1-2	<1

Table.2.The pH and conductivity measurements

Solution	pH Value	Conductivity, mS/cm
Potable water, (W)	7.678	1.431
Slaked lime water, (LW)	9.733	5.142
Saturated calcium hydroxide solution, (LD)	10.719	1.286

Table.3.Mix proportions of specimens

Mix Id	Cement(kg/m^3)	Sand(kg/m^3)	Silica Fume(kg/m^3)	Water(kg/m^3)	Super Plasticizer
Control	455	1364	0	181	0
CLDSF10	410	1364	45	181	1%
CLDSF20	364	1364	91	181	1.5%
CLDSF30	319	1364	136	181	2%
CLWSF10	410	1364	45	181	1%
CLWSF20	364	1364	91	181	1.5%
CLWSF30	319	1364	136	181	2%

2.2. Specimen preparation: To prepare the mortars containing silica fume, first the binders such as cement and silica fume added with river sand and placed in mixer machine resuming dry mix for about 2 minutes. Then the remaining water which was premixed with the superplasticizer was added and mixing has been carried out for 5 minutes. Finally, the freshly prepared mortar was poured into cube moulds of size 70.6 x 70.6 x70.6mm. Similarly, the mortar cylinders of size 50 x 100 mm with and without basalt fibers were cast. After pouring, an external table vibrator was used to facilitate compaction and decrease the amount of air bubbles. The specimens are de-molded after a lapse of 24 hours for moist curing and then cured in standard curing till for the testing periods 3, 7 and 28 days. Concurrently, to study the hydration kinetics by using XRD analysis of the above mixes in the paste form were also prepared.

2.3. Test Procedure: Following tests were conducted in order to determine the physico-chemical properties of composite pastes and mechanical properties of cube mortars and cylinder mortars with and without basalt fiber containing silica fume with respect to control mix.

a. The designed composite pastes were studied by using XRD analysis.

b. Compressive strength test on 10 cubic specimens for each mixture of size 70.6 mm were conducted after 7 and 28 days of curing was determined. .

c. Split tensile strength test on 6 cylindrical specimen of size 50mm x 100mm were conducted after 7 and 28 days of curing was determined.

3. RESULTS AND DISCUSSION

The following sections present the properties of Portland cement based materials mixed with W, LD or LW solution. Physico-chemical properties of composite pastes, setting properties, compressive strength of mortars and split tensile strength of mortar cylinders with and without basalt fibers were evaluated in this study.

i) Initial and final setting times

Cement paste mixes: To investigate the influence of using LW and LD solution with silica fume as a mixing solution, a preliminary study aimed at evaluating the degree of saturation on setting properties was conducted. The recorded initial times of setting were 110, 120, 180 and 210min for saturated lime with different percentages of silica fume (“CLDSF”). Whereas, the final setting times for the same mixes were 220, 250, 330 and 350 min, respectively. These results concluded that the best retardation was achieved by using LW at 100% degree of saturation. The graphical results show both initial and final setting times are presented in Fig. 1for the mixtures of LD and LW with silica fume. Two series were conducted; first one was conducted using LD with silica fume as a mixing solution whereas; second one was conducted using LW with silica fume as a mixing solution. For both series, SF was used as a partial replacement of cement by weight. The conducted replacement ratios were 10%, 20% and 30%. For mixes made up of control mix containing SF caused a delay in initial setting times which was observed compared to the LD containing SF. The initial setting time values are 120, 130, 150, and 180 min for mixes CNT, CSF10, CSF20, and CSF30 respectively.

The values of initial setting times for cement pastes made up of LW with SF were recorded as 120, 130, 145, and 160 min for CNT, CLWSF10, CLWSF20, and CLWSF30respectively. Whereas, the final setting times were recorded as 230, 250, 320 and 350 min for the same mix, respectively. The maximum delay in initial setting time was recorded for mix CLD as 47.6% over the control mix CLDSF30 whereas, the biggest delay in final setting time was recorded for mix CONT as 27.7% over the control mix CSF30. In general, using both SF with LD and LW in a cement paste mix tend to delay both initial and final setting times.

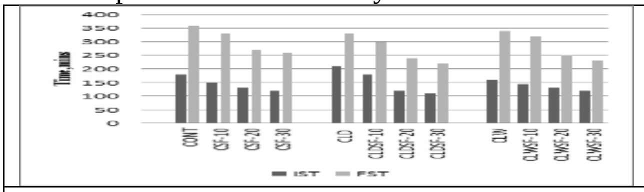

Fig.1.Shows the initial and final setting time of the cement paste

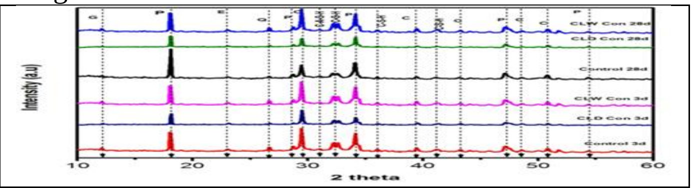

Fig.2.XRD of different mixes CONT, CLD and CLW without SF at 3 and 28days

The results of the setting times showed that there is a reduction in both the initial and final setting timings [IST and FST] for the samples with replacement of silica fume by 10, 20 and 30% and with ordinary potable water compared to control samples. This could be due to the acceleration of hydration process by silica fume. In the case of control with saturated lime water, the initial setting time is slightly higher because of more availability of the calcium hydroxide. This trend has changed with addition of silica fume, that is, both IST and FST are reduced because of consumption of calcium hydroxide by silica fume in both the cases of lime waters. The experimental study conducted on mortar cubes for 3 days, 7 days and 28 days of curing and observed that the increase of compressive strength is in two stages viz. early (3-day) and later day strength (28-day) compared to control mortars.

3.1. XRD analysis: The semi-quantitative (S-Q) analysis of the respective designed cement paste composites was studied by using XRD. The major quantities of calcite (C), ettringite (E), gypsum (G), portlandite (P), quartz (Q), tobermorite like C-S-H forms and other amorphous contents have been identified and quantified. Fig. 2 showed the XRD patterns of the paste samples without silica fume, but with W, LD and LW for 3 and 28 days of curing. The quantitative values of the major crystalline phases along with amorphous contents including C-S-H were provided in Table 3 and observed that the portlandite peaks were identified even after 28 days of curing of paste specimens. In the cases of LD and LW series with SF were shown in Figs. 3 and 4 and the identified and quantified values of similar phases discussed above were given in Table 4 and 5. It can be clearly seen that there were reduction in the portlandite peaks in the early stage (3 days) as well as in the later stage (28 days) because of its consumption by SF. At the same time, it was observed that there was an incremental effect in the peaks of C-S-H and the like structure.

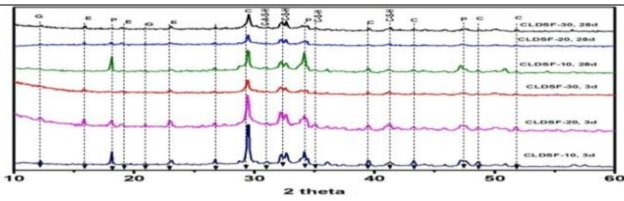

Fig.3.XRD of different mixes LD series with SF at 3 and 28days

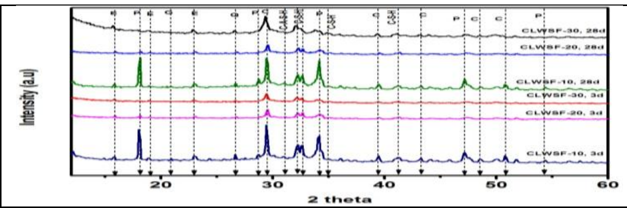

Fig.4.XRD of different mixes LW series with SF at 3 and 28days

Table.3.S-Q analysis for different mixes without SF at 3and 28days

Compounds	3 days			28 days		
	CON	CLD	CLW	CON	CLD	CLW
Calcite (c)	16.69	7.51	11.19	11.91	12.19	15.12
Ettringite (E)	1.11	2.05	1.26	0.92	1.13	0.364
Gypsum (G)	3.69	3.69	3.39	3.61	4.39	4.12
Portlandite (P)	12.57	7.51	12.58	19.09	17.97	15.11
Quartz (Q)	1.37	0.84	1.03	0.65	1.22	1.1
Tobermorite	4.36	4.07	4.18	1.93	1.09	1.26
Others amorphous contents including C-S-H, C-A-S-H	60.21	74.33	66.37	61.89	62.01	62.93

Table.4.S-Q analysis for different mixes LD series with SF at 3and 28days

Compounds	3 days			28 days		
	CLDSF-10	CLDSF-20	CLDSF-30	CLDSF-10	CLDSF-20	CLDSF-30
Calcite (c)	24.95	11.43	9.58	12.27	9.76	12.33
Ettringite (E)	1.02	3.36	2.52	0.64	4.02	2.09
Gypsum (G)	3.43	6.04	0	4.15	4.18	0
Portlandite (P)	5.15	0.86	0	9.15	0	0
Quartz (Q)	1.89	0.47	0	0.52	0.24	0.29
Tobermorite	6.85	29.45	69.53	10.99	18.25	33.78
Others amorphous contents including C-S-H, C-A-S-H	56.71	48.39	18.37	62.28	63.55	51.51

Table.5.S-Q analysis for different mixes LW series with SF at 3 and 28days

Compounds	3 days			28 days		
	CLWSF-10	CLWSF-20	CLWSF-30	CLWSF-10	CLWSF-20	CLWSF-30
Calcite (c)	12.65	6.99	8.54	10.44	9.79	15.37
Ettringite (E)	3.35	8.59	3.15	0.688	8.1	0
Gypsum (G)	5.45	0	0	6.01	0	1.88
Portlandite (P)	9.51	4.51	0	11.27	2.02	0
Quartz (Q)	0.64	0.25	0	0.17	0.95	0
Tobermorite	2.5	36.18	68.61	5.12	25.65	44.71
Others amorphous contents including C-S-H, C-A-S-H	65.9	43.48	19.7	66.302	53.49	38.04

3.2. Compressive Strength: The experimental study conducted on mortar cubes for 3 days, 7 days and 28 days of curing and observed that the increase of compressive strength was in two stages viz. early (3-day) and later day strength (28-day) compared to control mortars. This was due to the early consumption of added calcium hydroxide solution by silica fume to form additional C-S-H. The graphical representations of these results were shown in Fig. 5. This has been confirmed by semi-quantitative analysis of XRD of cement composite pastes of similar mix proportions. Similarly, in the second stage, that is 28 days cured samples, the strength increments observed because of consumption of the by-product of cement hydration, namely the calcium hydroxide (portlandite) by silica fume. It was also noted that the saturated lime water with 20% silica fume and natural lime water with 30% silica fume replacements provided 16% higher compressive strength compared to control mortars.

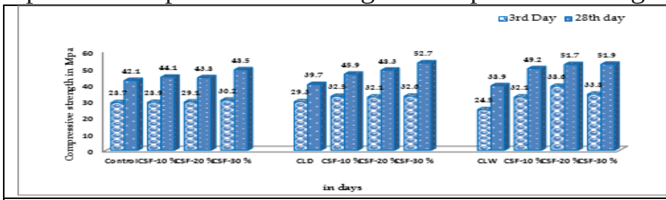

Fig.5.Shows the compressive strength of mortars with silica fume for 3 and 28 day samples

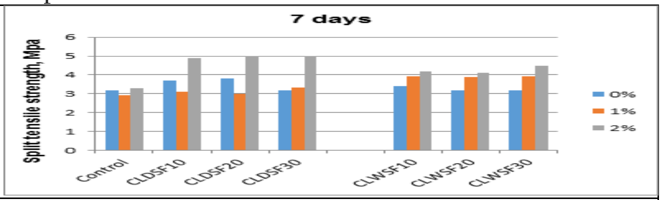

Fig. 6 Split tensile strength of mortars with silica fume/basalt fiber (0, 1 and 2%) for 7 days of curing

3.3. Split Tensile Strength: Split tensile strength results of the mortar cylinders with and without basalt fibers (1% and 2%) of similar mixes as discussed above for 7 days and 28 days of curing were presented in figs. 6 and 7. It has been observed that the addition of 1% and 2% of basalt fibers considerably improved the tensile characteristics of the mortars compared to control mortars with and without fibers. It was observed that the split tensile strength with 1 % basalt fiber for LD series have not shown any strength improvement compared to 7 days cured control specimens. But there was a significant improvement in strength (about 51%) for the LD series samples with 2 % basalt fibres cured for 7 days compared to LW series and control series specimens. But for 28 days cured LD series specimens, it was not found any further strength gain in LD series. It showed that the complete tensile strength was gained in 7 days of curing itself. As for as the LW series concerned, it was observed that the continual improvement of split tensile strength for 1 % and 2 % basal fibers over control mix with fibers for both 7 days and 28 days of curing. To sum up, LD series with 2% basalt fiber achieved the maximum strength in 7 days of curing, whereas LW series achieved the same level with 2% fiber in 28 days of curing that showed the later day strength gain. Hence, LD series gained early strength with fiber than LW series.

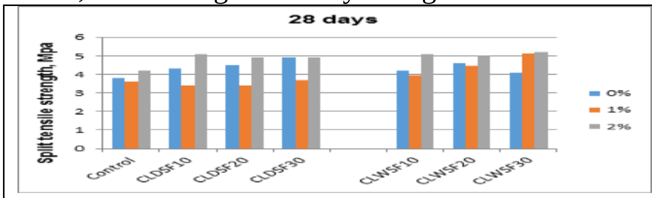

Fig.7.Split tensile strength of mortars with silica fume/basalt fiber (0, 1, 2%) for 28 days of curing

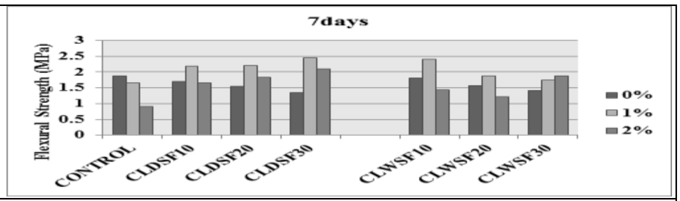

Fig.8.Flexural Strength of mortars with Silica Fume/Basalt Fiber (0, 1 & 2%) For 7 Days of Curing

3.4. Flexural strength: Flexural strength results of the mortar beams with and without basalt fibers (1% and 2%) of similar mixes as discussed above for 7 days and 28 days of curing were presented in figs. 6.7 and 6.8. It has been observed that the addition of 1% and 2% of basalt fibers considerably improved the flexure behavior of the mortars compared to control mortars with and without fibers. It was observed that the flexural strength with control specimens have not shown any strength improvement compared to 7 days cured LD series specimens with 2% basalt fiber. But there was a significant improvement in strength for the LD series samples with 1 % basalt fibres cured for 7 days compared to LW series and control series specimens. But for 28 days cured LD series specimens, it was not found any further strength gain in LD series. As for as the LW series concerned, it was observed that the continual improvement of flexure strength for 1 % and 2 % basal fibers over control mix with fibers for both 7 days and 28 days of curing. To sum up, LD series with 1% basalt fiber achieved the maximum strength in 7 days of curing, whereas LW series achieved the same level with 1% fiber in 28 days of curing that showed the early day strength gain. Thus it was observed with addition of fiber in flexural strength, 2% basalt fiber have not shown any strength improvement compared to the 1% basalt fiber. Hence, LW series gained later strength with fiber than LD series at 1%.

4. CONCLUSION

In this study, the effect of lime waters on the properties of basalt fiber reinforced binary blended (cement and SF) cementitious composite has been observed. The research results include the following:

a. The physico-chemical properties of pastes with cement-SF-lime water composites were studied for their pozzolanic activity by hydration kinetics and setting time properties.

b. In this study, incorporation of SF, a mineral admixtures, as partial replacement of cement mortar cubes / cylinders with is enhanced the mechanical properties of cement composite materials have been observed.

c. It was noted that the saturated lime water with 20% silica fume and natural lime water with 30% silica fume replacements provided 16% higher compressive strength compared to control mortars.

d. The early split tensile strength about 51% has been achieved for LD series (saturated lime water) in 7 days cured samples that is early day strength gain, compared to Control and LW series. At the same time, the continual improvement in split tensile strength for LW series for both percentage of basalt fiber viz 1% and 2 % have been observed.

The basalt fiber reinforced with cementitious composite concrete with lime waters is under study towards future research.

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