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Experimental Investigations on Flexural Strength and Durability Properties of Mortars Containing Cement Replacement Materials

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Abstract

This paper discusses the effects of using different pozzolonic materials as a partial cement replacement material in mortar mixes. An experimental study of mortar made with 43 grade Ordinary Portland Cement (OPC) and 12% of OPC partially replaced by different cement replacement materials (CRMs) such as fly ash, rice husk ash, silica fumes, Calcined Clay (Grog) and Slag (GGBS) in mortar mixes. The mechanical properties of mortar mixes with these (CRMs) were tested to determine the effect of incorporating these mineral admixtures on mortar properties and compared with that of control mix.

Mortar specimens were cured in water for 28 days, through which, flexural strength and compressive strength were tested at ages 3, 7 and 28 days. Then, the rest of specimens were immersed in fresh water with solutions of 10% sodium sulfate (Na_2SO_4) and 10% magnesium sulfate ($MgSO_4$) for period of 3 months. The specimens were also tested for variation in compressive strength at 28, 60 and 90 days to investigate the durability properties.

Key words: Pozzolanic materials, Mortars, Compressive Strength, Flexural Strength, Durability.

Introduction

Supplementary cementitious materials (SCMs) (i.e. pozzolonas) are used to partially replace cement in concrete. They are often added to concrete to make the mixtures more economical, reduce permeability, increase strength, or influence other properties. Typical examples include natural pozzolonas (like volcanic ash), fly ash, ground granulated blast furnace slag, rice husk ash, and silica fume [1]. Pozzolona is a siliceous or alumino-siliceous material that, in finely divided form and in the presence of moisture, chemically reacts with the calcium hydroxide that is released by the hydration of Portland cement to form compounds possessing cementitious properties. Pozzolonas react chemically with calcium hydroxide ($Ca(OH)_2$) from the hydration of Portland cement to form calcium silicate hydrates or CSH. The CSH is the strong binder that hardens in concrete. For simplifying, this reaction can be schematically represented as following

$$Ca(OH)_2 + H_4SiO_4 \rightarrow Ca^{2+} + H_2SiO_4^{2-} + 2\,H_2O \rightarrow CaH_2SiO_4 \cdot 2\,H_2O$$

or

$$CH + SH \rightarrow CSH$$

(Summarized in abbreviated notation of cement chemists)

The product of general formula ($CaH_2SiO_4 \cdot 2\,H_2O$) formed is a calcium silicate hydrate, also abbreviated as CSH in cement chemist notation [2].

Concrete is the most commonly used material for construction. Engineers have been looking for concrete which is ever stronger and more durable against aggressive environment; Concrete structures may be exposed to sulfate and chloride salts and various acids because of the environmental pollution. Sulfates are found as sodium sulfate, magnesium sulfate, calcium sulfate, ammonium sulfate in the solutions. The type of action of these salts on the concrete varies [3].

Concrete exposed to sulfate attack looses compressive strength and this loss increases as function of sulfate concentration and age of exposure. Pozzolonas show different durability properties with the content and type of active silica present in their composition. In relation to the effect of pozzolana on concrete strength, it should be stated that type, amount and fineness of pozzolona and also the type of cement are factors that affect the strength of concrete [4, 5, 6].

Through this work, different cement replacement materials were employed as a partial replacement of cement with percentage of 12% in mortar mixes. The mechanical properties of control cement mortar, Silica Fume (SF) mortar, Fly Ash (FA) mortar and Rice Husk Ash (RHA) mortar, Calcined Clay (Grog) mortar and Slag (GGBS) mortar were tested to determine the effect of these materials on mortar properties.
The aim of this study was to experimentally investigate the effect of replacing 12% of cement by different pozzolanic materials on the flexural strength. Also, in addition, to evaluate the effect of presence of these replacement materials on the durability of specimens exposed to solutions of 10% sodium sulfate (Na_2SO_4) and10% magnesium sulfate ($MgSO_4$). The strengths of these specimens are evaluated by compressive strength.

Experimental Programme

Basic Materials and their Properties

The basic materials used in the investigation are

1) Ordinary Portland Cement 43grade
2) River sand (Srikalahasti, River Sand)
3) Fly Ash
4) Silica Fume
5) Rice Husk Ash
6) Calcined Clay
7) Slag

The pozzolanic materials used were Silica Fume, Fly Ash, Rice Husk Ash, Calcined Clay (Grog) and Slag (GGBS) at a replacement of 12% of cement. The constant water-cement ratio (w/c) of 0.50 was maintained. The mix proportion of mortar was 1: 3.

Cement

Ordinary Portland Cement (Ultra Tech brand) comply with the Indian Standard Specification for 43 Grade conforming to IS: 8112-1989 and tested as per IS: 4031(part I)-1988 was employed. Table 1 and 2 shows chemical and physical properties of the cement respectively.

Table 1 Chemical Properties of OPC (43 Grade)

Sl No.	Particulars	Result Obtained	Requirements confirming to IS
1	Lime saturated factor.	0.87	0.66 – 1.02
2	Ratio of % alumina to that of iron oxide.	1.34	0.66 (min)
3	Insoluble residue (% by mass)	0..96	3.00 (max)
4	Magnesia (% by mass)	0.83	6.00 (max)
5	Sulphuric an hydrate (% by mass)	2.54	3.00 (max)
6	Total loss on ignition (%)	2.64	5.00 (max)
7	Total chloride content (% by mass)	0.003	0.10 (max)
8	C_3A %	11.92	-

Table 2 Physical Properties of OPC (43 Grade)

Sl No.	Tests conducted	Result Obtained	Requirements as per IS
1	Specific Gravity	3.10	-
2	Normal Consistency, percent	30	-
3	Setting Time, minutes	Initial:70 Final:225	Not less than 30 minutes Not more than 600 minutes
4	Fineness,m^2/Kg	325	Not less than 225 m^2/Kg
5	Soundness, mm	3	Expansion should not be more than 10mm
6	Compressive strength,Mpa	3day:36 7day:46 28day:56	23 33 43

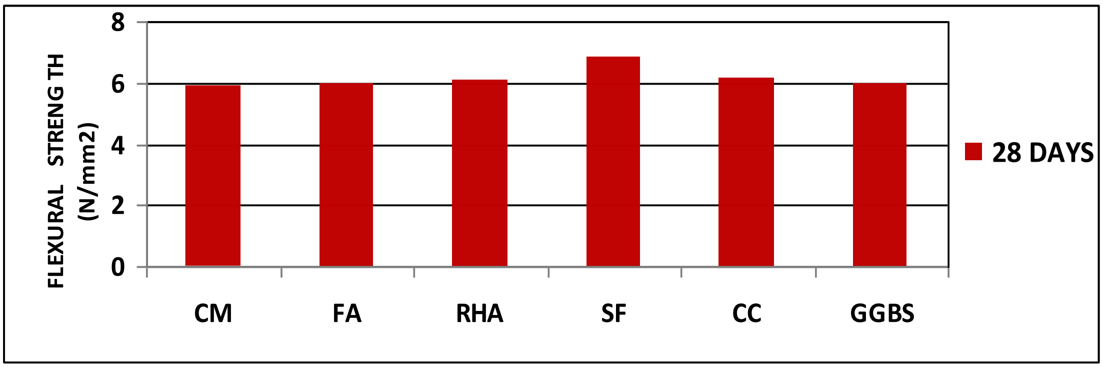
Pozzolanic materials

The following are the various pozzolanic materials used in the experimental investigation.

Table 3 indicates the chemical and physical properties.

Table 3 Chemical & Physical properties of Fly Ash, Rice Husk, Silica Fumes, Calcined Clay and Slag (GGBS)

Sl No	Particulars	Designation	Tested results				
			Fly Ash (%)*	Rice Husk (%)	Silica Fumes (%)**	Calcined Clay (%)	Slag (%)
Chemical properties							
1	Silica	SiO_2	58.95	87.94	97.02	41-46	36
2	Alumina	Al_2O_3	29.24	3.80	0.20	19.3-20	10
3	Ferric oxide	Fe_2O_3	0.98	0.84	0.09	10-12.8	0.5
4	Magnesia	MgO	1.05	1.05	0.04	1.84-2.5	0.44
5	Lime	CaO	1.02	0.80	0.11	2.14-3.09	39
6	Alkalies	Na_2O	0.24	…	0.28	2.24-2.77	…
7	Carbon	C	…	0.80	…	…	…
8	Phosporous Pentoxide	P_2O_5	…	2.15	…	…	…
9	Potassium	K_2O	…	…	0.02	0.38-1.0	…



10	Sulphur dioxide	SO_2	…	…	…	…	…
11	Titanium Oxide	TiO_2	…	…	…	1.32-2.4	…
12	Sulphur		…	…	…	…	1.4
Physical properties							
13	Specific gravity		2.06	2.6	2.629	2.162	…
14	Blaine 's Specific surface		3020m²/kg	…	..	…	…
15	Fineness modulus		380m²/Kg	…	…	…	…
16	Lime reactivity		85.20	…	….	…	…
17	Compressive strength		5.5 N/mm²	…	….	…	…
18	Loss of Ignition		…	2.46	2.46	9.90-10.93	…
19	Bulk Density		…	…	1.116g/cc	0.916 g/cc	…
20	Moisture Content		…	…	…	5-10	…

*Fly ash was obtained from Raichur Thermal Power Plant (RTPC)

**Silica Fumes was obtained from Excel Micro Silica MST Karur Tamil Nadu through Sai Dhurga Enterprises, Bangalore.

Fine Aggregate

Locally available clean Srikalahasti River sand from chittoor District, Andhra Pradesh. confirming to IS 383: 1970, Zone-II requirement was used with specific gravity of 2.62, and Bulk density (compacted) of 1707Kg/m.³

Water

Portable drinking water was used for the preparation and curing of specimens.

Preparation of sample

The cement and pozzolanic materials were first thoroughly mixed to ensure homogeneity. Then, the dry constituents of the mortar, cement and sand in 1:3 proportions by weight were mixed with the trowel, and then mixed with water thoroughly until uniformity is gained.

The moulds were made ready for use, by covering the joints between the halves of the mould with a thin film of petroleum jelly and by applying coating of petroleum jelly between the contact surfaces of the bottom of the mould and its base plate in order to ensure that no water leaks during vibration, and placed the assembled mould on the table of the vibration machine and clamped. Immediately after mixing the mortar, it was placed in the cube mould in two layers and rodded 20 times for each layer to ensure elimination of entrapped air and honey-comb, then compacted the mortar by vibration for two minutes in vibrator. At the end of vibration, the mould together with the base plate, removed from the machine and the top surface of the cube in the mould finished by smoothing the surface with trowel. After 24 hours, the specimens were demoulded and cured in water until the age of testing.

Testing Methodology

Six types of mixes were cast to explore the validity of replacing 12% of Silica fume, Fly ash, Rice husk ash, Calcined Clay and Slag (GGBS) to cement mortar mixes. The specimen moulds were prepared and tested to evaluate compressive strength and flexural strength. For each of them the compressive strength test was performed on standard mortar cubes 70.6 mm x70.6mm x70.6 mm size and accessories conforming to IS: 10086-1982 at different ages i.e. 3, 7 and 28 days.

Flexural strength was determined for all the investigated mixes using prisms of dimensions 40mmx40mmx160mm tested after 28 days of curing. The flexural specimens were prepared according to I S 1727-1967. The results of three companion specimens were averaged for one test result to investigate the effect of the cement-replacement materials used on the strength of the mortars. The rest of specimens cast for compressive strength test were exposed to water and solutions of 10% sodium sulfate(Na_2SO_4) and10% magnesium sulfate ($MgSO_4$) and tested at ages 1,2 and 3 months after 28 days preliminary of curing in water. Details of test conditions have been indicated in Table 4 & 5.

Table 4 Summary of test conditions for the different mixes before exposure to sulfate solutions.

Mix No.	Type of the mix	Type of replacement material	Media of curing	Curing period	Test
1	Control mix(CM)	-----	Fresh Water	*3 days *7 days *28 days	*Compressive Strength *Flexural Strength
2	Fly ash Mix(FA)	12% FA			
3	Rice husk ash (RHA) mix	12% RHA			
4	Silica fume (SF) mix	12% SF			
5	Calcined Clay (CC) mix	12% CC			
6	Slag (GGBS) mix	12%GGBS			

Table 5 Summary of test conditions for the different mixes when exposed to sulfate solutions of 10% sodium sulfate (Na_2SO_4) and magnesium sulfate ($MgSO_4$) along with fresh water.

Mix No.	Type of the mix	Type of replacement material	Media of curing	Curing Period*	Test
1	Control mix (CM)	-----	Fresh Water *10% (Na_2SO_4) *10%($MgSO_4$)	*1month *2months *3months	*Compressive Strength
2	Fly ash Mix (FA)	12% FA			
3	Rice husk ash (RHA) mix	12% RHA			
4	Silica fume (SF) mix	12% SF			
5	Calcined Clay (CC) mix	12% CC			
6	Slag (GGBS) mix	12% GGBS			

** After preliminary 28 days curing in fresh water

Test Results and Discussion

Flexural Strength

Figure 1 shows the flexural strength of control mix (CM), Fly Ash (FA), Rice Husk Ash (RHA), and Silica fumes (SF) and Calcined Clay (CC) and Slag (GGBS) mortars at the age of 28 days. It indicates that using 12% of FA, RHA, SF, Calcined Clay and Slag in the mortar causes an increase in the flexural strength. This increase was obtained 0.68%, 3.72 %, 15.55%, 4.05% and 1.18% respectively than the control mortar.

Fig 1 Flexural strength of investigated mixes for the age of 28 days

Durability

The compressive strength versus period of immersion in water after the preliminary 28 days of curing is as shown in fig 2. The compressive strength was obtained for ages 1, 2 and 3 months for all remaining mortar mixes after 28 days of curing in water. The presence of 12% , Fly Ash, Rice Husk Ash , and Silica fumes, Calcined Clay and Slag in the mortar as a partial replacement for cement shows an increase in the compressive strength of 1.66 %, 4.96 % and 7.44 %,3.29 % and 1.66 % respectively than the control mortar

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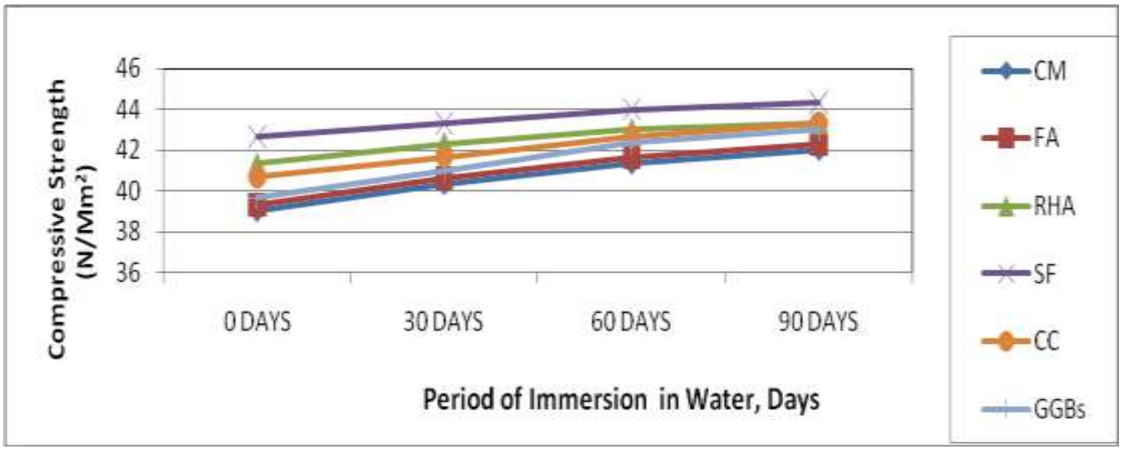

Fig 2 Compressive Strength versus Period of Immersion of the Investigated Mortar Mixes in Water the Preliminary after 28 Days of curing in Water

For the age of 2 months, the increase in the compressive strength was, 0.82 %, 4.04 %, 6.46 %, 3.21 % and 2.41 % respectively. After the age of 3 months, the increase in the compressive strength was 0.78 %, 3.17 %, 5.54 %, 3.16% and 2.38 % respectively than the control mortar.

Fig. 3 shows the compressive strength versus period of immersion in sodium sulfate (Na_2SO_4) solution after the preliminary 28 days curing.

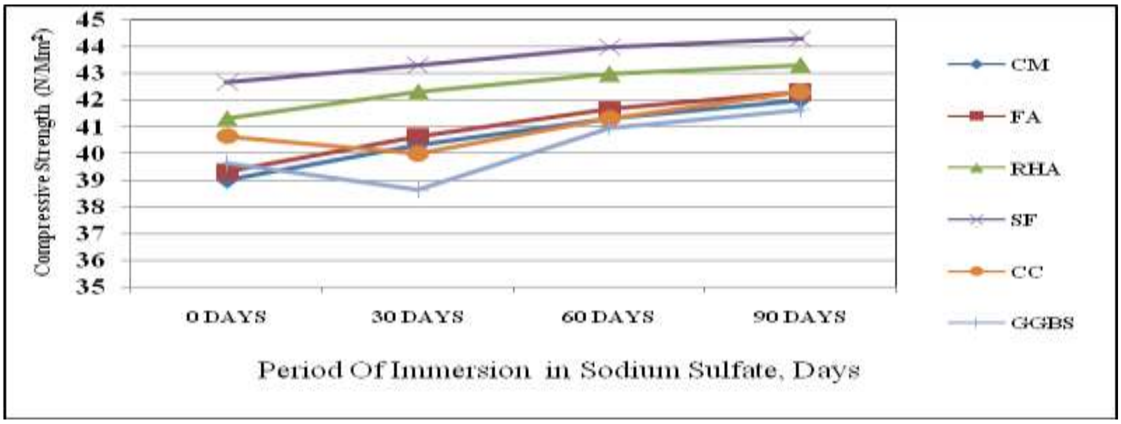

Fig 3 Compressive Strength versus Period of Immersion of the Investigated Mortar Mixes in Sodium Sulphate Solution after the Preliminary28 Days of Curing In Water.

The compressive strength was determined for ages 1, 2 and 3 months for all mixes. Using 12% of, Fly Ash, Rice Husk Ash, and Silica fume, Calcined Clay and Slag in the mortar as replacement causes an increase in the compressive strength 1.70%, 4.24 %, 7.62 %, 1.73% and 1.70 % respectively than the control mortar for curing age of 1 month in the solution. For the age of 2 months, the increase in the compressive strength was 0.82%, 4.04 %, 6.46 % 1.622 % and 0.84% respectively. After age of 3 months, the increase in the compressive strength was 0.79 %, 3.17 %, 5.54 %, 3.24% and 1.60% respectively than the control mortar. The tested results demonstrate that the replacement of 12% of the Portland Cement by the different pozzolanic materials used in the experimental investigation improved the resistance of the mortar to the sulfate solution attack. This may be due to its finer pore structure and the reduced content of calcium hydroxide in the cement paste.

The compressive strength versus period of immersion in magnesium sulfate ($MgSO_4$) solution after the preliminary 28 days curing in water is shown in fig. 4.

The compressive strength was obtained for ages 1, 2 and 3 months for all mixes. The presence of 12% of Fly Ash, Rice Husk Ash and Silica fumes, Calcined Clay and Slag in the mortar causes an increase in the compressive strength 0.85 %, 5.17 %, 8.61 %, 1.76 % and 2.56% respectively than the control mortar for curing age of 1 month in the solution. For the age of 2 months, the increase in the compressive strength was 0.83 %, 5.04 % and 7.56%, 3.35% and 1.66% respectively. After age of 3 months, the increase in the compressive strength was 1.67 %, 5 %, 6.54 %, 3.325 % and 2.5 % respectively than the control mortar.

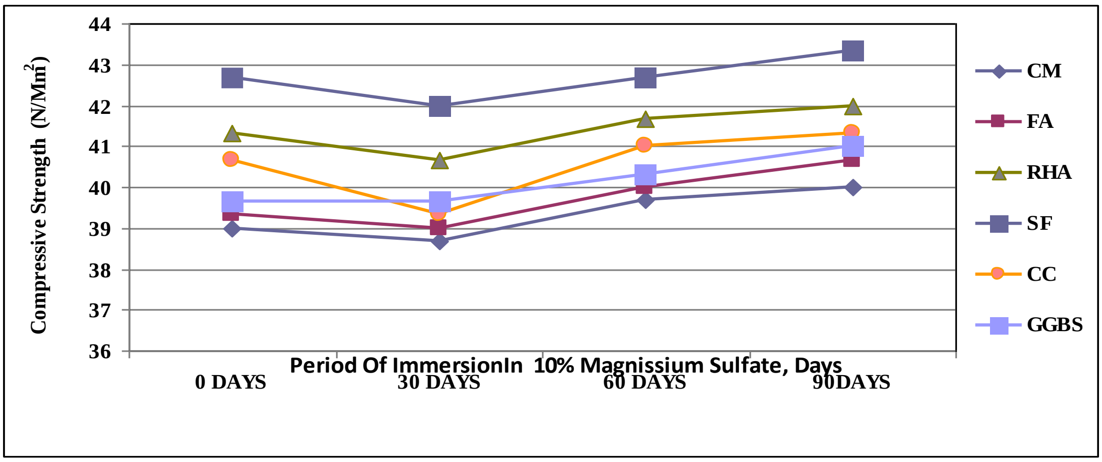

Fig 4 Compressive strength versus period of immersion of the mortar mixes in magnesium sulfate solution after 28 days of water curing

It is observed that the effect of magnesium sulfate solution was found to be most severe. This may be due to the reaction of the magnesium sulfate solution with C_3A as well as C_3S which is the principal cementatious constituent and may also be due to the lower value of pH of the saturated solution in the case of magnesium sulfate attack and thereby the instability of CSH.

Conclusions

The experimental work has been devoted to evaluate the flexural strength, and durability of cement mortar, when different cement replacement materials were employed as a partial replacement of cement with percentage of 12% in the mortar mixes. The following are the conclusions drawn from the investigation.

1. The increase in flexural strength of mortar specimens containing 12% of cement replacement materials and cured for 28 days in water ranged from 0.68% to 15.55% than the control mortar.
2. The presence of 12% cement replacement materials in the mortar mixes decrease the deterioration of the compressive strength

of the mortar due to immersion in 10% sulfate solutions.

3. In the case of sodium sulfate solution, the compressive strength of the mortar containing 12% cement replacement materials was higher with a range of 1.70% to 7.62% for 1 month immersion in solution. For 2 months of immersion, the range of increase was 0.82% to 6.46% and for 3 months of immersion, the increase was 0.79 % to 5.54 % than the control mortar.
4. In the case of magnesium sulfate solution, the compressive strength of the mortar containing 12% cement replacement materials was higher with a range of 0.85% to 8.61% for 1 month of immersion. For 2 months of immersion, the range of increase was 0.83% to 7.56% and for 3 months of immersion the increase was 1.67% to 6.54% than the control mortar.
5. It was found that the silica fume was the best pozzolanic material used in this research with 12% cement replacement material to the cement mortar mixes, as it improves the properties of the mortar such as compressive strength, flexural strength, and hence the durability when exposed to sulfate solutions.
6. It was noticed that magnesium sulfate ($MgSO_4$) solution has a more severe effect on the compressive strength when compared with that of sodium sulfate (Na_2SO_4) solution.

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