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Studies on high-performance blended/multiblended cements and their durability characteristics

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Abstract

Number of blends were prepared by intergrinding clinker, gypsum, fly ash, calcined clay, microsilica and limestone in laboratory ball mill in varying percentages, and their physical properties such as fineness, consistency, setting time and compressive strength have been determined. The durability tests on selected compositions were also conducted by exposing the mortar cubes separately in 5% Na_2SO_4 and 5% NaCl solutions till the age of 90 and 180 days. The performance was observed by compressive strength development criteria after various length of exposure. Results have been discussed and found that the durability of blended cement is higher than the ordinary Portland cement.

Keywords: Properties, Compressive strength; Durability; Composition, Blended cement; Fly ash; Pozzolana

1. Introduction

Blended/multiblended cements based on industrial by-products/pozzolanic materials like fly ash, calcined clay, microsilica, granulated blast furnace slag, etc., are the best examples of alternate cementitious materials. This class of cements is better known for their improved long-term strength and durability [1,2]. The combination of two or three kinds of mineral admixtures has emerged as a superior choice over single admixture to improve concrete properties [3–9]. The combination of silica fume and fly ash in a ternary cement system results in a number of synergistic effects such as increase in early strength, sulphate and chloride resistance [10–13]. Low CaO fly ashes generally provided good resistance to sulphate and chloride attack as compared to high CaO fly ash; however, the strength development at early age is typically slower than that of OPC especially at a higher level of replacement [14,15].

In the present study, attempts have been made to understand the effect of mineral admixtures on the performance and durability of resulting cement after intergrinding in laboratory ball mill in variable amount with clinker and gypsum.

2. Material and experiments

Ordinary Portland cement clinker as base material for the study was collected from one of the cement plant of Grasim Industries. Limestone, gypsum and calcined clay were obtained from nearby sources. Fly ash "A", a good quality fly ash having low carbon content and high Blaine fineness, was collected from the last hopper of a power plant of Grasim Industries; microsilica or silica fume was received from a ferrosilicon industry. The materials were characterised for various chemical and physical properties (Table 1). After finding suitable, they were mixed on weight replacement basis with clinker and gypsum in different percentages and ground in the laboratory ball mill for a fixed time. The physical properties such as fineness, consistency, specific gravity, compressive strength and setting time were tested as per IS 4031, 1989. For examining the resistance to aggressive medium, the mortar cubes of selected blends after 28 days of curing in ordinary water were placed in 5% NaCl and 5% Na_2SO_4 solutions separately. After 90 and 180 days of exposing in aggressive medium, the cubes were tested for compressive strength.

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3. Results and discussion

The chemical compositions of the blending components are given in Table 1. The experimental results of the blends prepared with 5–35% weight replacement of fly ash "A" are given in Table 2 and Fig. 1. With increasing addition of fly ash, an increase in Blaine fineness of all the samples has been observed when ground in the laboratory ball mill for a specific time. The reason for the increased fineness may be due to the increase in grindability of clinker as well as the crushing and disagglomeration of fly ash particles itself. Water requirement increases up to 20% fly ash addition but decreases with further addition up to 35%. There is no regular sequence for the variation of setting time with the additions of fly ash.

Fig. 1 shows that up to 20% addition of fly ash, there is little change in strength at 3 days except a major gain (8%) with 5% fly ash addition, which may be due to the combined effect of fineness of clinker particles as well as pozzolanic reactivity of fly ash. At 25% and 35% fly ash addition, a decreasing effect in strength is observed due to the corresponding decrease in primary cementitious material, which cannot be compensated by the pozzolanic activity of fly ash. The strength at 28 days is more or less the same up to 35% addition of fly ash, which indicate a better pozzolanic reaction. With the increasing addition of fly ash, there is an increase in fineness of the samples. The strength at 90 days and afterwards goes on increasing and exceeds the control sample at 1 year of hydration.

The results of the mortar cubes cured in 5% sodium sulphate solution after 28 days of curing in plain water are given in Fig. 2. The experimental results indicate a decrease in compressive strength of control OPC sample without fly ash at 90 days of curing in sodium sulphate. The similar trend has been observed in sample with 5% fly ash addition. But above 10% fly ash addition, the strength goes on increasing till 180 days. The maximum gain in strength (14.7%) is obtained at 25% addition of fly ash. The reason for the decrease in strength of samples may be due to the ingress of sulphate ions into the cementitious system with subsequent formation of gypsum and ettringite that cause expansion. As the amount of fly ash is increased, the cementitious mass becomes more impermeable due to the formation of more C-S-H gel and refinement of pores.

There is no significant change in the strength of the control sample without fly ash addition at the age of 90 days curing in 5% NaCl solution but improves considerably at 180 days (Fig. 2). With 10–25% fly ash addition, the compressive strength improves at 90 days, which is not observed at 35% addition. At 180 days curing, there is a further gain in strength at all level of addition of fly ash. The maximum gain is at 25% and the minimum is at 5% and 35% addition of fly ash. Sodium chloride acts as accelerator to both cement hydration and pozzolanic reaction. The glassy particles of fly ash are easily attacked by Na^+ to convert into soluble silicates, which further combine with $Ca(OH)_2$ and produce more CSH gel. With increasing amount of CSH gel, the mass becomes more impermeable to foreign ions.

Table 2
Physical properties of blended cements

With fly ash "A"				
Composition	Blaine	Water (%)	Setting time (minutes)	
			Initial	Final
5% F, 5% G	3000	27	165	210
10% F, 5% G	3200	27	165	215
15% F, 4% G	3355	27	150	200
20% F, 3.5% G	3350	28	160	245
25% F, 3% G	3540	23	170	225
35% F, 3% G	4000	25	155	185

F = fly ash, G = gypsum.

Table 1
Chemical composition of blending components

Constituents	Clinker	Gypsum	Fly ash "A"	Calcined clay	Limestone	Microsilica
LOI	0.20	20.00	2.15	0.22	36.95	6.38
SiO_2	22.80	10.00	56.80	70.65	13.29	85.25
CaO	64.90	26.00	1.70	1.34	45.49	0.62
MgO	1.36	1.50	1.40	0.88	0.99	0.65
Fe_2O_3	4.43	1.60	6.43	7.18	0.79	1.16
Al_2O_3	4.64	6.00	25.80	15.03	1.63	4.45
SO_3	0.74	32.67	0.60	0.20	0.10	–
IR	0.80	15.80	84.90	85.00	14.50	–
Na_2O	0.22	0.20	0.36	0.30	0.08	–
K_2O	0.50	0.50	0.79	0.70	0.20	
Specific gravity (gm/cc)	3.15	2.45	2.25	2.54	2.60	–
Soluble silica			32.0	21.05		–
LR (MPa)			6.7	4.1		–
Blaine (cm^2/gm)	–	–	6660	–	–	–

LOI = loss on ignition, IR = insoluble residue, LR = lime reactivity.

4. Multiblended cements

Multiblended cements were prepared by intergrinding clinker and gypsum with fly ash "A," calcined clay and

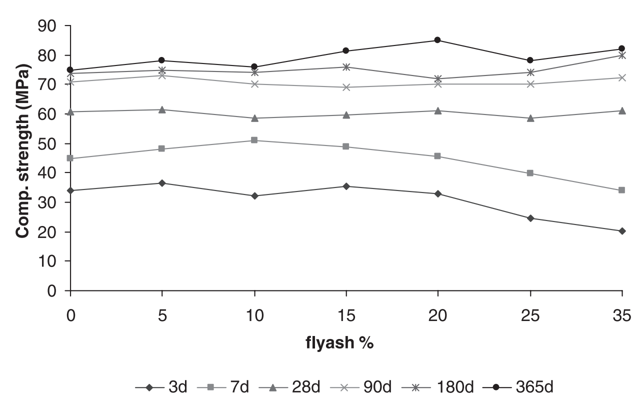

Fig. 1. Strength development in fly ash "A"-based cement.

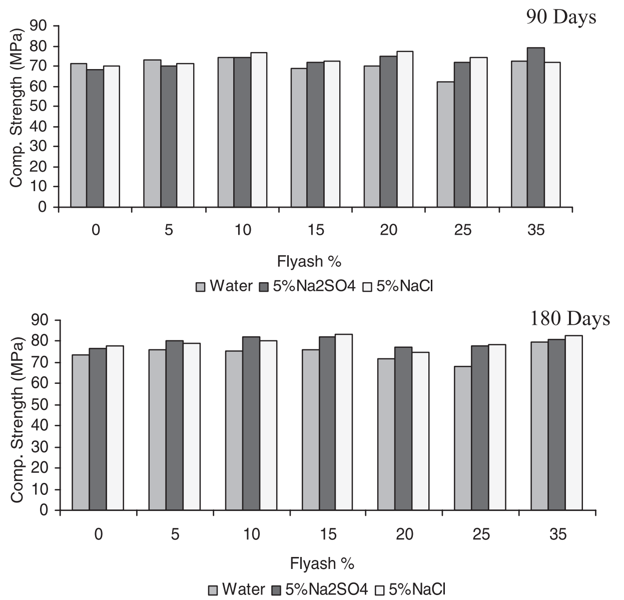

Fig. 2. Performance of fly ash "A"-based cement in aggressive environment.

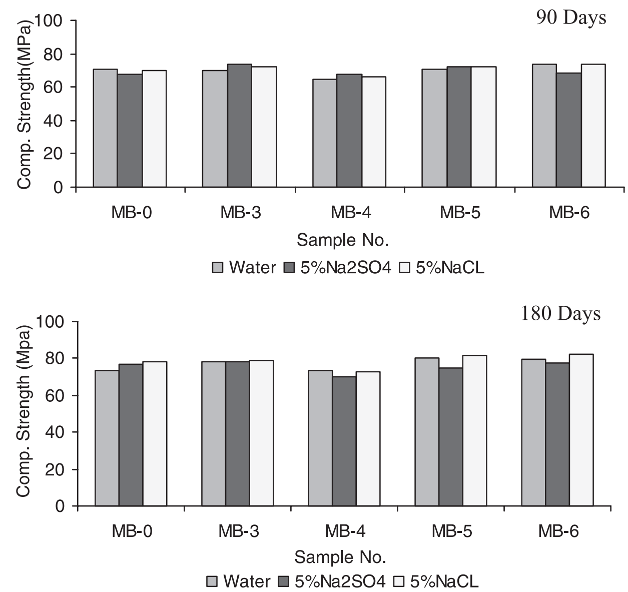

Fig. 3. Performance of multiblended cement in aggressive environment.

microsilica in variable proportions. Samples were tested for physical performance (Table 3). The results show that all the parameters change with the change of composition. Compressive strengths are highest at 7–365 days for M_8 sample.

4.1. Curing in aggressive environment (5% Na_2SO_4 and 5% NaCL)

The results of compressive strength development of multiblended cements containing 10–25% total pozzolanic material (fly ash + calcined clay) when cured in 5% sodium sulphate and 5% sodium chloride solution separately are illustrated in Fig. 3. It indicates that at 90 days of curing, combined effect of pozzolanas is better against sulphate environment. Whereas at 180 days, the effect seems to be declining after 15% addition of calcined clay + fly ash. The reason for such a decrease in strength may be due to calcined clay, which does not seem to be a good pozzolanic material in comparison to fly ash, and hence unable to exert a positive effect on strength for longer period in aggressive medium. The strength of all the samples in NaCl solution either improves slightly or remains unchanged, which indicates that NaCl contribute very little in strength development.

5. Conclusion

From the results, it is concluded that it is possible to prepare blended cements, which are better than the ordinary Portland cement especially with reference to compressive strength retention in corrosive environment.

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Table 3
Physical properties of multiblended cements

Sample No.	Composition	Blaine cm^2/gm	Water of Consistency (%)	Setting time (minutes)		Compressive strength (MPa)					
				Initial	Final	3 days	7 days	28 days	90 days	180 days	365 days
M 0	Control OPC (with 5% G)	2800	26	165	230	33.8	45	60.6	71	73.6	75
M 1	5% L, 4% G	3127	28.5	195	225	33.2	46.8	63	71.8	75	76
M 2	5% F, 2.5% L, 5% G	3000	27	195	250	36.2	42.1	62.9	64	71	79.6
M 3	5% F, 5% C, 3% L, 4% G	3600	27.5	170	205	33	48.2	58.2	70	78	80
M 4	15% C, 2.5% L, 3% G	3700	29.5	165	220	33.2	40.4	51.1	64.4	73.6	84
M 5	10% F, 10% C, 4% G	3800	28	185	220	25.6	36	59	71	80	81
M 6	20% F, 5% C, 3% L, 4% G	4000	26.5	190	210	24	37.8	55.6	73.6	79.6	80
M 7	5% F, 5% MS, 3% G	4000	27	170	220	39.6	52.6	65	75.2	79.8	83.4
M 8	15% F, 5% MS, 3% G	4400	26.5	185	230	38.4	54	75.4	79.8	82.8	85
M 9	25% F, 5% MS, 3% G	4500	28	160	215	26.8	40	65	71	77.8	83.4

F = fly ash "A", L = limestone, C = calcined clay pozzolana, MS = microsilica, G = gypsum.

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