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INVESTIGATION OF PORTLAND SLAG CEMENT ACTIVATED BY WATERGLASS

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ABSTRACT

The relatively poor reactivity of Indian BF slags results in lower strength of slag cement in comparison to OPC. In this investigation, a dosage of waterglass as an activator has been optimised. Percentage substitution of slag, concentration of waterglass, and their effects on properties of activated PSC have been studied. Up to 60% slag substitution and use of 1% waterglass as activator have yielded the best results. The activator has also acted as a grinding aid. Long-term storage of activated slag cement has been found to be detrimental. *© 1998 Elsevier Science Ltd*

Introduction

Ground granulated blast-furnace slags (GGBFS) are increasingly being used in India and abroad for manufacture of Portland slag cement (PSC). This application has gained importance due to the superior properties of PSC with regard to sulphate and chloride attacks. Unfortunately, however, when compared to GGBFS produced in Europe and other countries, the Indian slags are inferior in having higher alumina content or low lime content or both (1–5). Under the circumstances, Indian slags have low reactivity, as a result of which the strength of PSC, mainly in early ages, is lower in comparison to OPC.

As reported by Wang et al. (1), among several activators such as waterglass, sodium sulphate, sodium carbonate, and sodium hydroxide, waterglass was found to be most effective. The present paper reports some experiments for activation of PSC with waterglass (WG). This is in continuation to our earlier study (2) where the activation behavior for different systems was investigated.

Experimental

The chemical analysis of the materials is given in Table 1. Waterglass having silica modulus 3 and pH 11.7 was used. The control cement (96% clinker + 4% gypsum) was ground to 3200 cm^2/gm fineness. The properties of cement (as per IS:455–1976) are given in Table 2.

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TABLE 1
Chemical analysis of components.

Component	Clinker	Slag	Gypsum	Waterglass
% SiO_2	21.65	33.07	32.70	21.61
% Al_2O_3	5.92	19.52	8.37	-
% Fe_2O_3	4.35	2.16	4.85	-
% CaO	64.92	33.36	17.65	-
% MgO	1.42	9.42	Tr.	-
% K_2O	0.40	0.98	0.31	-
% Na_2O	0.19	0.20	0.42	7.20
% SO_3	0.32	Tr.	24.94	-
% Cl	0.00	-	0.21	-
% P_2O_5	0.12	-	0.45	-
% MnO	-	0.76	-	-
% TiO_2	0.48	-	-	-
% IR	-	0.33	7.69	-
% LOI	-	-	17.21	-

For optimisation of the dosage of waterglass used as an activator, Portland slag cement containing 50% slag was ground with different percentages of waterglass (from 0–2%, with the increment being 0.5), maintaining Blaine range 3500 to 3600 cm^2/gm. The strength values are graphically represented in Figure 1.

Normal Portland slag cement marked as NPSC (clinker + slag + gypsum) and activated Portland slag cement marked as APSC (clinker + slag + gypsum + WG) were ground up to the Blaine fineness range of 3500 to 3600 cm^2/gm for the entire range of slag substitution (from 30 to 80% slag). 4% gypsum was used for each of these experiments, and 1% WG was used for each activated slag cement. NC, setting time, compressive strength (up to 90 days), autoclave and Le Chatelier tests were conducted (as per IS:455–1976) for each of the samples. Table 3 furnishes the results of water demand and setting time for NPSC and APSC. Comparison of strength results between NPSC and APSC are graphically represented in Figures 2-7.

Five slag cement batches having same composition (50% slag + 46% clinker + 4% gypsum) were ground with different percentages of WG (0 to 2%, with the increment being 0.5), keeping other parameters constant to check the properties of WG as a grinding aid. Blaine values of each samples are plotted against percentage of WG (Fig. 8).

TABLE 2
Properties of control OPC sample.

Blaine (cm^2/gm)	NC (%)	Setting time (min.)		Compressive strength (MPa)					
		Initial	Final	1 day	3 days	7 days	28 days	45 days	90 days
3122	28.00	115	175	25.3	47.2	62.2	74.5	76.4	80.7

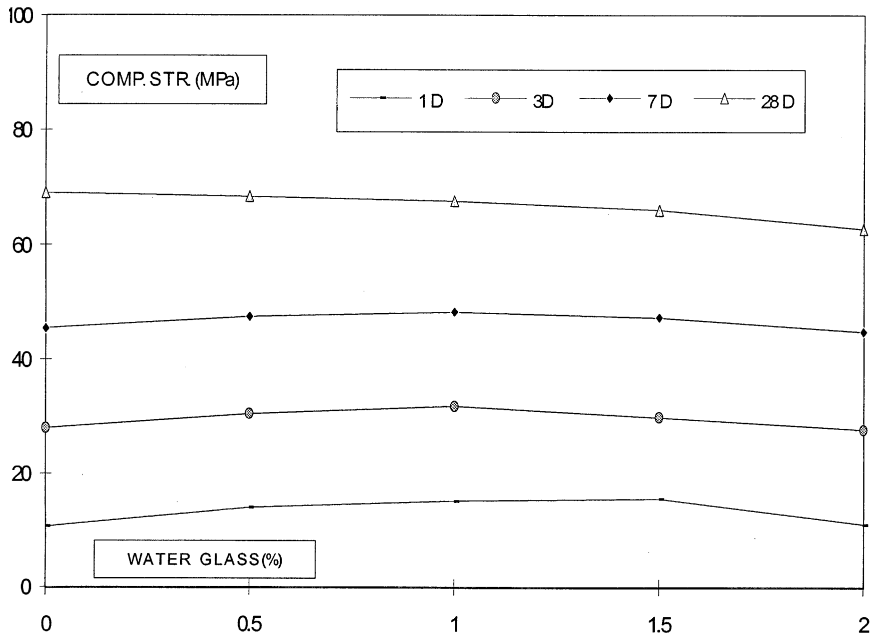

FIG. 1.
Optimisation of % WG on slag cement.

NPSC (46% clinker + 50% slag + 4% gypsum) and APSC (45% clinker + 50% slag + 4% gypsum + 1% WG) were kept for 3 months in airtight bags to check the deterioration of strength values. The strength values up to 28 days were checked for samples both in the

TABLE 3
Water demand and setting time of NPSC & APSC.

Blaine (cm^2/gm)	% GGBFS in PSC	% WG	% NC	Setting Time (min.) Initial	Setting Time (min.) Final
3585	30	-	29.00	140	205
3593	30	1	27.50	120	185
3588	40	-	29.25	135	205
3573	40	1	27.75	120	180
3587	50	-	29.75	170	230
3538	50	1	27.75	150	205
3561	60	-	30.50	175	235
3578	60	1	28.00	160	210
3556	70	-	30.75	180	235
3566	70	1	28.00	160	215
3593	80	-	30.75	190	250
3588	80	1	28.25	175	225

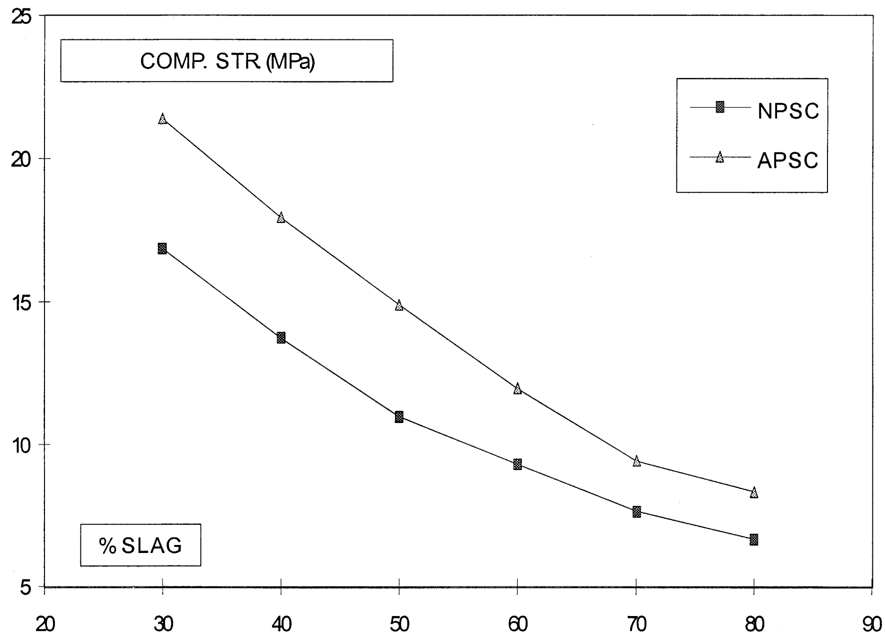

FIG. 2.
Comparative 1-day strength of NPSC and APSC.

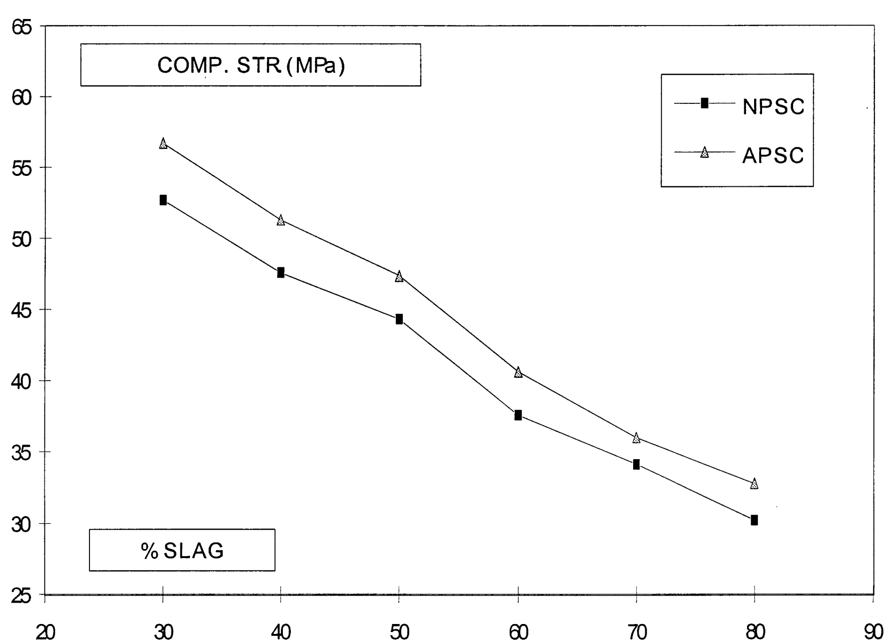

FIG. 3.
Comparative 3-day strength of NPSC and APSC.

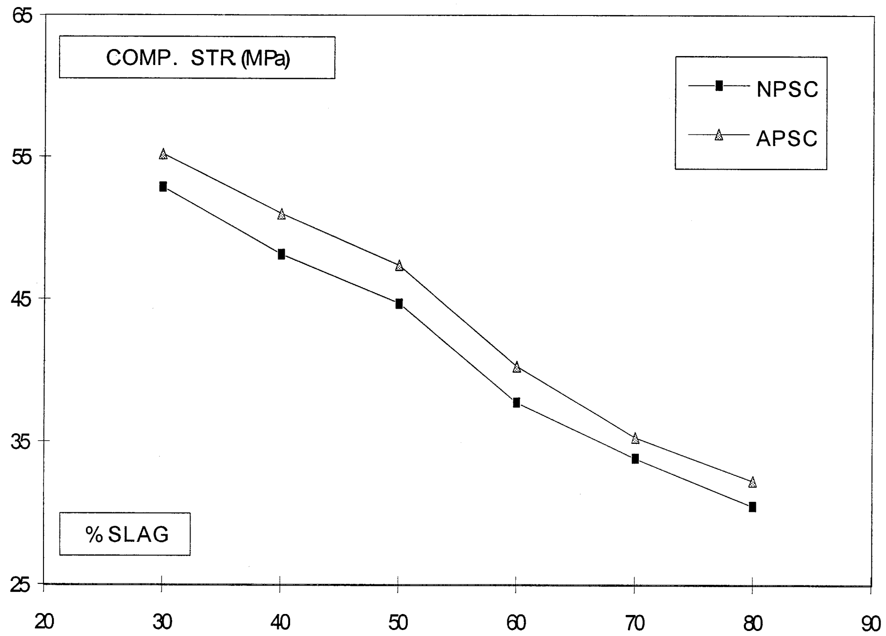

FIG. 4.
Comparative 7-day strength of NPSC and APSC.

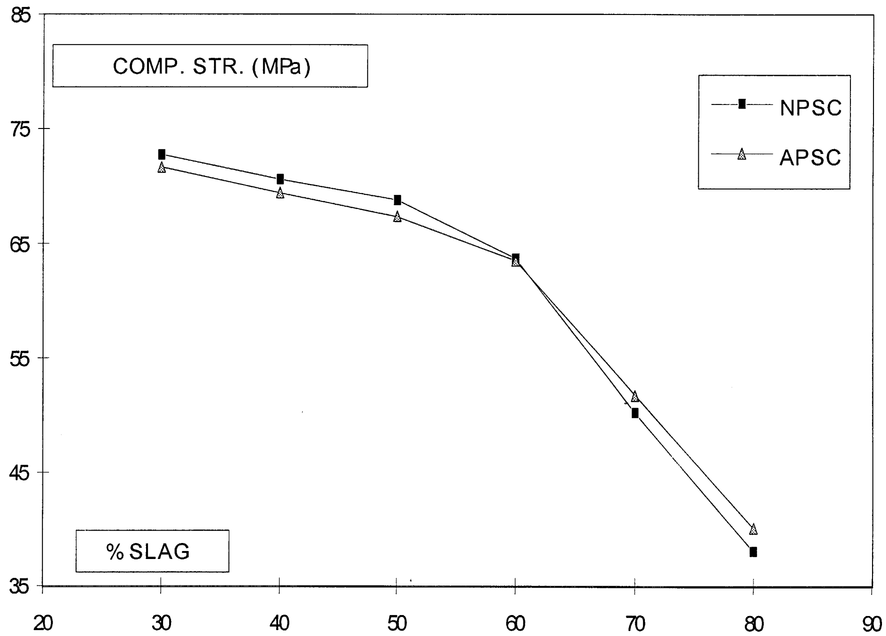

FIG. 5.
Comparative 28-day strength of NPSC and APSC.

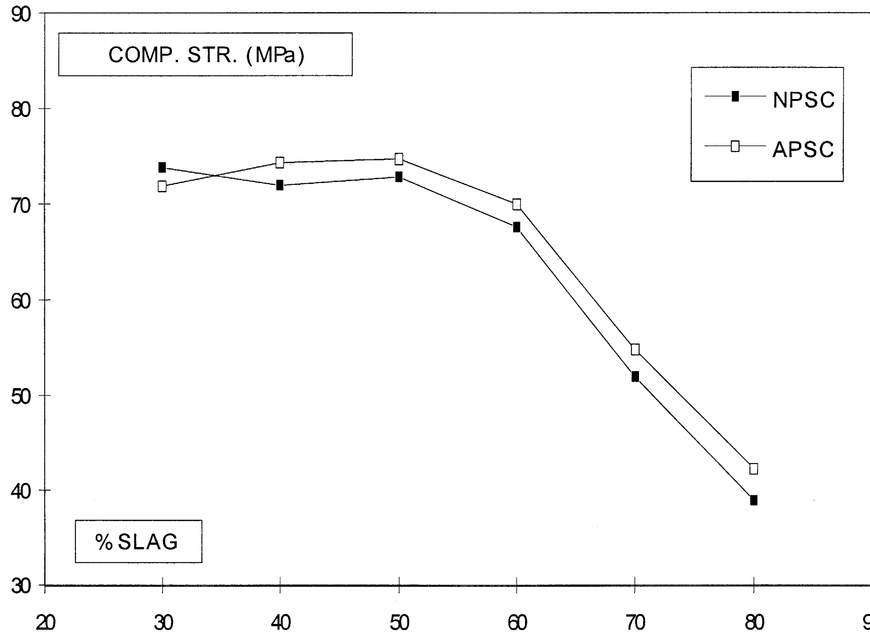

FIG. 6.
Comparative 45-day strength of NPSC and APSC.

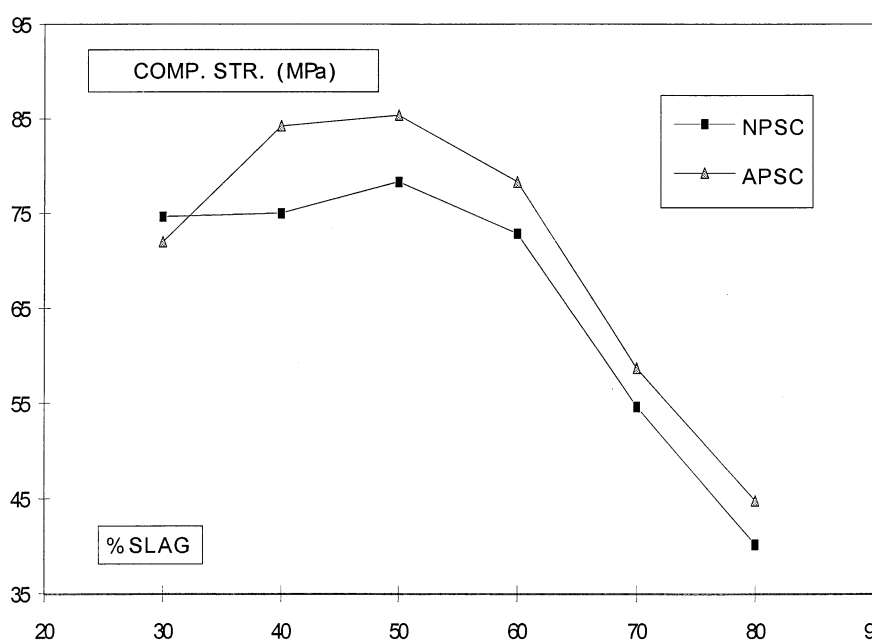

FIG. 7.
Comparative 90-day strength of NPSC and APSC.

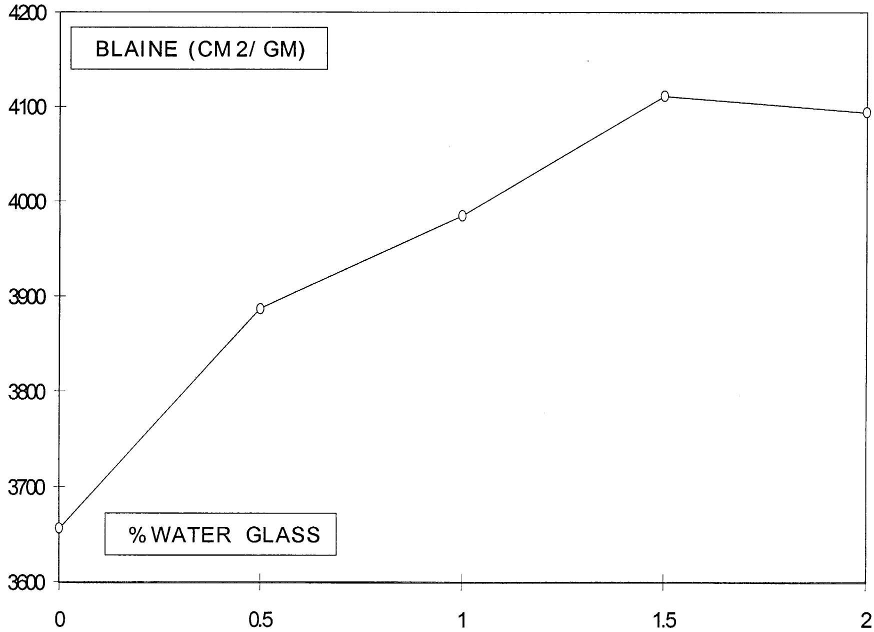

FIG. 8.
Effect of waterglass on Blaine.

fresh and 3-months-aged condition. The strength falls of 3-months-aged samples in percentage with respect to original strength are shown in Figure 9.

Results and Discussion

1. Optimisation of WG dosage: From Figure 1 it was observed that 1% WG gave best results as far as strength values were concerned, in the case of PSC having 50% substitution by slag. It also showed desirable normal consistency and setting time.

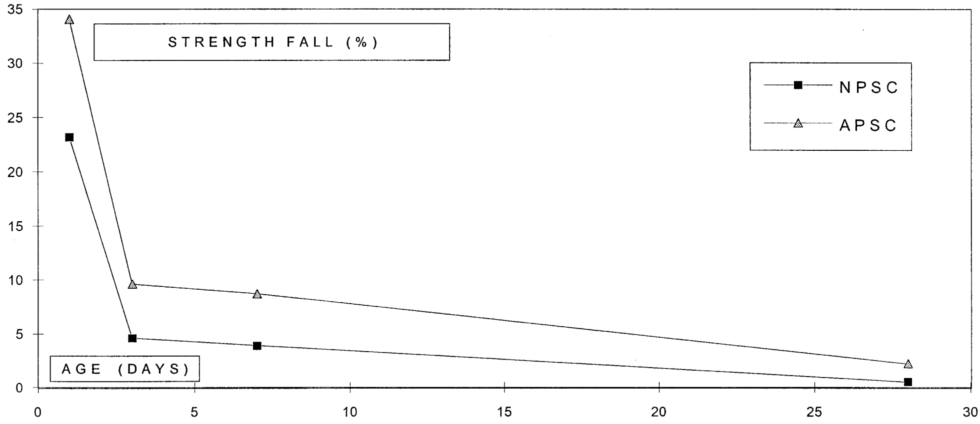

FIG. 9.
Strength fall of NPSC and APSC after 3 months storage.

2. Effect on strength: Figures 2–4 confirm several past observations (2,5) that alkali-activated slag cement (APSC) shows higher early strength than that of normal Portland slag cement (NPSC). It indicates that certain fraction of slag particles are activated to react with $Ca(OH)_2$ released from cement phases probably forming hydrated phases, i.e., tobermorite, like calcium silicate, hexagonal tetracalcium aluminium hydrate, and ettringite type phases.

   Figure 5 shows that later strength, i.e., 28 days, of NPSC is higher than that of APSC for up to 60% slag substitution. Beyond 60% substitution, APSC shows higher strength compared to NPSC, whereas in case of 45 days and 90 days (Figs. 6 and 7, respectively) this situation arises between 30 to 40% slag substitution. Figure 9 shows that after 3 months' storage of the cement samples, the percentage decrease of strength is higher in the case of APSC than NPSC and it is more in early ages. It is very clear that strength of slag cement decreases with increase of slag substitution, but beyond 60% substitution the rate of decrease of strength is very high (Fig. 7).

3. The presence of waterglass reduces the water demand (normal consistency) as well as setting time.
4. WG as a grinding aid: Figure 8 shows that with the increasing percentage of waterglass up to 1.5, Blaine value has increased from 3656 to 4111 cm^2/gm for the same grinding time, and beyond that it is not effective as grinding aid.

Conclusions

The following points were concluded from the above observations:

- 1% Waterglass gave best results for APSC having slag substitution between 40 to 60%.
- At early ages (up to 7 days) the strength of APSC was always higher than NPSC, irrespective of percentage of slag substitution.
- 28-day strength of APSC was lower than NPSC when slag substitution was below 60%, but the opposite was true beyond that substitution.
- The sequence of strength gain percentage of APSC with respect to NPSC at different ages is: 1 day $>$ 3 days $>$ 7 days $>$ 28 days.
- 1% WG reduces the NC up to 3.5%, and setting time up to 50 min.
- WG also acts as a grinding aid. Only 1.5% WG increases the Blaine fineness to 250 cm^2/gm.
- Strength deterioration of APSC after 3 months was much higher than NPSC at early ages. So, it is advisable to use the APSC as early as possible after manufacturing.

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