J. Natn. Sci. Coun. Sri Lanka 1979 7(1) : 57—63

SHORT COMMUNICATION

Some Studies on Pozzolanic Cement

A. THEVARASAH, V. PERAMPALAM
Ceylon Cement Corporation, Kankesanturai, Sri Lanka

AND

M. SELVARATNAM
Department of Chemistry, University of Peradeniya, Peradeniya, Sri Lanka

(*Paper accepted : 6 March* 1979)

Pozzolans[1] are siliceous and aluminous mineral substances which, though having no cementitious qualities themselves, react with lime in the presence of water at room temperature to form compounds possessing cementitious properties. Pozzolans may be naturally occurring or artificially produced. Naturally occurring pozzolans include clays, shales, opaline materials, volcanic tuffs and pumicites. Artificial pozzolans are mainly obtained from industrial wastes and include fly ash (flue dust), silica fume and some slags. The pozzolans available in Sri Lanka include broken bricks, broken wasted tiles and clays. A detailed review of pozzolanic cements their manufacture and use in India, has recently been published.

Pozzolanic cement is obtained when pozzolans are finely ground with Portland cement. Some advantages of pozzolanic cements over Portland cement are that they are cheaper, they have improved plasticity and they have higher resistance to sulphate attack.

Pozzolanic activity is believed[3] to be due to the siliceous compounds in pozzolan reacting with the calcium hydroxide formed during the hydration of cement to form stable cementitious substances involving calcium, silica and water.

Our objective was to study the effect of readily available and cheap pozzolanic materials found in Sri Lanka on the properties of Kankesan Portland cement. Burnt clay (from the clay yard at Kankesanturai ; Murunkan clay) and tile powder (powdered broken roof tiles—an industrial waste) were used. The conditions under which these pozzolans exhibit maximum activity were first found out. The pozzolans were then ground with cement, in various proportions, and various properties (tensile strength, compressive strength, sulphate resistivity, initial setting time, final setting time, consistency, workability) were studied so as to evaluate the quality of the pozzolanic cement obtained.

Various tests[4] have been devised to estimate pozzolanic activity. From the definition of pozzolans, it is clear that the most useful test is chemical reactivity with lime.

To find out the rconditions under which pozzolans exhibit maximum activity chemical reactivities with lime and alkali were investigated.

Clay samples were dried, jaw crushed and ball milled. The clay powder obtained was burnt in a muffle furnace at different temperatures. At about 600°C, the clay changed from greenish black to bright red, above 1000°C it turned to dull red. The chemical composition of the clay used is given in Table I.

TABLE 1. Chemical analysis of clay

	% by weight
SiO_2	61.3
Al_2O_3	16.5
Fe_2O_3	6.7
Loss on Ignition	9.1
CaO	4.4
MgO	1.5
	99.5

Pozzolans, heated at different temperatures for various times, were finely powdered, sieved through 170 mesh sieve and reacted with a one molar solution of NaOH. The percentage reduction in alkalinity under standard conditions (when 100g of solid is added to 1000 ml of 1M NaOH) was found by titrating with a standard HCl solution. The results for clay and tile are given in Tables 2 and 3 respectively.

TABLE 2. Murunkan Clay : % reduction in alkalinity as a function of temperature and time of "calcination"

Temp. of "calcination" °C	1 hour	4 hours	1 day	4 days	6 days	10 days	20 days
300	0.98	1.26	1.42	1.87	2.04	2.23	2.43
600	1.26	1.76	1.20	2.06	2.45	2.65	2.72
800	1.28	1.74	1.79	2.04	2.50	2.64	2.71
1000	0.65	0.70	0.76	1.23	1.45	1.37	2.01
1200	0.52	0.56	0.62	0.62	0.65	0.64	0.12

TABLE 3. Tile Powder : % Reduction in alkalinity

Temp. of "calcination" °C	1 hour	4 hours	4 days	6 days	10 days	20 days	40 days
Room temp. (no heating)	1.32	1.87	2.23	2.85	3.28	4.63	4.62
600	1.20	1.97	2.03	2.53	3.23	4.57	4.57
1000	0.57	1.29	—	1.63	1.64	1.72	1.83
1200	0.52	0.68	0.73	0.74	0.74	0.74	0.74

The results show that percentage reduction in alkalinity, and therefore pozzolanic activity, is maximum when the temperature of calcination of clay is between 600°C and 800°C. For roof tiles, there was no increase in pozzolanic activity on heating. This is understandable in view of the fact that heat pretreatment had already been given during the manufacture of roof tiles. The results also show that the pozzolanic activity of powdered roof tiles is better than that of clay.

By a detailed study of various types of clays, Indian workers have shown[5] that maximum pozzolanic activity is exhibited when the temperature of heating is close to the temperature at which there is collapse of the lattice structure of the clay. Pozzolanic activity would therefore depend on the type of clay and also on the nature and amount of impurities present. The decrease in pozzolanic activity observed (see Tables 2 and 4) when clay samples are heated to higher temperatures has been explained[5] as due to increase in particle size, improvement in crystallinity and the formation and growth of crystals.

TABLE 4. % Lime reacted with clay powder (total lime—free lime)

Temp. of "calcination" °C	1 hour	2 days	7 days	10 days	20 days
300	52.5	53.5	58.8	58.9	58.9
600	58.2	60.3	63.5	68.8	69.3
1000	53.0	56.7	59.3	62.3	64.5

The pozzolan was mixed with calcium oxide and made into a paste by adding water. The amount of lime reacted was determined, using standard procedures, by finding the total lime content and the "free lime" content. The total lime content was determined by converting it to calcium oxalate and titrating with $KMnO_4$. The "free lime" was determined by adding ethylene glycol and titrating with dilute HCl using bromo-cresol as indicator.

The results in Table 4 indicate that pozzolanic activity of clay is optimum when samples were preheated to a temperature of about 600°C. For tile powder (Table 5) preheating did not improve pozzolanic behaviour.

TABLE 5. % of Lime reacted with tile powder

Temp. of "calcination" °C	1 hour	1 day	2 days	7 days	28 days
Room temp. (No heating)	51.26	66.8	72.3	81.3	85.3
600	50.0	66.5	—	80.2	84.4
1000	64.3	—	67.8	79.8	82.2

Tile powder was used for the preparation of pozzolanic cement. The advantage over clay is that no preheating is necessary.

Two methods of preparing pozzolanic cements from tile powder were attempted : (*a*) by grinding portland cement with tile powder (*b*) by "straight grinding" of clinker chips, tile chips and gypsum chips.

To prepare pozzolanic cement by method (*a*), broken tiles were ball milled for about 4 hours in a sample mill, sieved through 170 mesh sieve, mixed with Portland cement, ball milled again for half an hour for proper mixing and then sieved again through 72 mesh.

Difficulties were encountered in the preparation of pozzolanic cement by grinding clinker chips, tile chips and gypsum chips in an one-chambered tube mill. Grinding was not uniform because the grindability indices of cement and tile were different. Furthermore, the fine particles formed had a cushioning effect thereby hindering further grinding. This difficulty may not arise if a three-chambered mill is used.

Various physical properties were studied to evaluate the quality of the pozzolanic cement produced by grinding cement with tile powder.

Cement briquettes were made by hand tampering; water : cement ratio used was 0.3. The briquettes were removed after 24 hours, immersed in water for a number of days, dried for half an hour and tested. The storage water was changed every seven days.

TABLE 6. Tensile Strength (lbs/sq. in.)

Time	3 days	7 days	28 days	2 months	1 year
Portland cement	—	590	710	735	780
Pozzolan cement 20 : 80 (i.e. 20% tile powder + 80% portland cement)	—	525	700	750	800
Pozzolan cement 30 : 70 (i.e. 30% tile powder + 70% Portland cement)	—	495	685	745	825
Portland cement : Sand — 1 : 3	235	330	400	—	—
Pozzolan (40 : 60) : Sand — 1 : 3	230	270	450	—	—
Pozzolan (50 : 50) : Sand — 1 : 3	200	270	410	—	—

Some of the results of tensile strength measurements are given in Table 6. The table also gives (in the last two rows) some results of initial tensile strength measurements of pozzolanic cement : sand (in the ratio 1 : 3) mixes (water : cement ratio = 0.6.).

The results show that the tensile strengths of pozzolanic cements are comparable with those of Portland cement. There are no ASTM specifications for the tensile strengths of pozzolanic cements.

Cubes of side 2.78 inches were made using a vibration machine according to ASTM procedures.[6] Cement : sand ratio used was 1 : 3. Sand was sieved between 18 mesh and 25 mesh. Water : cement ratio was 0.6. The cubes were removed from the moulds after 24 hours and kept immersed in water for several days. After drying for half an hour, compressive strengths were measured. Some of the results obtained are given in Table 7.

TABLE 7. Compressive Strength (lbs/sq. in.)

Time	3 days	7 days	28 days	3 months
Portland cement	—	4480	5230	5590
Pozzolanic cement (20 : 80)	—	3370	4620	5130
Pozzolanic cement (30 : 70)	—	3190	4230	5070
Pozzolanic cement* (40 : 60)	2025	2600	3050	—
Pozzolanic cement* (50 : 50)	1150	2050	3050	—

*Cubes were made by hand tampering.

The results show that our pozzolanic cements have lower compressive strengths than those of Portland cement. The strengths are, however, satisfactory ; they conform to ASTM specifications[6] for pozzolanic cements according to which compressive strengths for Type I and Type II cements after 28 days should be above 3000 lbs/sq.inch. and 2500 lbs/sq.inch respectively.

Briquettes cast with portland cement and pozzolanic cement (30 : 70) were kept in 10% $MgSO_4$ solutions, 10% Na_2SO_4, solutions and in sea water for more than a year for visual observation. It was observed that pozzolanic cement was more stable to sulphate attack than Portland cement.

Some of the other relevant properties of the pozzolanic cements prepared were also tested. The results obtained of the normal consistency, the initial setting time and the final setting time are indicated in Table 8, together with the ASTM specifications.[6] It is seen that all the results conform to the ASTM specifications.

TABLE 8. Normal consistency and setting times of the pozzolanic cements prepared compared with ASTM specifications.

	40% tile powder 60% cement	50% tile powder 50% cement	ASTM specification
Normal consistency	35%	37%	64% (maximum)
Initial setting time	79 minutes	85 minutes	60 minutes (maximum)
Final setting time	145 minutes	155 minutes	10 hours (maximum)

The plasticity and workability, tested qualitatively by a hand trowel, of pozzolanic cement-water mixes also appeared to be better than that of portland cement.

In Sri Lanka, red cement is made by mixing 10 to 15% of red pigment (Fe_2O_3) with Portland cement. The pigment is costly. Visual observations showed that when 30% of tile powder (sieved through 170 mesh) is mixed with 70% cement, only about 3 to 5% pigment is needed to produce the same intensity of colour. Even without red pigment the colour of the pozzolanic cement is reasonably satisfactory. Red pozzolan Portland cement is cheaper than red cement and some of its properties such as water tightness, workability, sulphate resistivity are also found to be better.

Red pozzolan Portland cement could be used not only for flooring purposes but also as a colour wash. It sticks on the walls better than the normal colour washes without the addition of any starch or glues.

The results indicate clearly that good quality pozzolanic cements conforming to ASTM specifications[6] could be manufactured in Sri Lanka by grinding Portland cement with powdered roof tiles (40 to 50% by weight of tile powder). Pozzolanic cements are better than Portland cement for certain applications, and they are also cheaper.

An approximate cost analysis shows that pozzolanic cement will be about 25% cheaper than Portland cement. Broken tiles, constituting an industrial waste, are readily available at various places in Sri Lanka.

To manufacture pozzolanic cement the under-utilized grinding facilities presently available in Sri Lanka could be used. New machinery would not therefore be required.

We thank Mr. A Kumarasuriyar former Works Manager, Kankesan Cement Works and Mr. K. Sanmuganathan, Acting Works Manager, Kankesan Cement Works, for their encouragement and suggestions. We are also grateful to Mr. E. A. B. Savundranayagam, Research Superintendent, Kankesan Cement Works, for doing the physical testing. Finally we should thank the Ceylon Cement Corporation for financing the collaborative research program between the Ceylon Cement Corporation and the Department of Chemistry, Peradeniya Campus.

References

1. BLANKS, R. F. & KENNEDY, H. L., (1955)—*The technology of Cement and Concrete*—, I, New York, John Wiley.
2. CHOPRA, S. K., (1968),—*Pozzolana Cements—UNIDO Document.*
3. CHOPRA, S. K., (1968),—*Pozzolana Cements—UNIDO Document*, P 17.
4. CHOPRA, S. K., (1968),—*Pozzolana Cements—UNIDO Document*, P 38.
5. Handbook of ASTM standards part 10, *ASTM specification Portland—Pozzolan Cement* C—340—64T (1964), Philadelphia, U.S.A.
6. SRINIVASAN, N. R. (1965)—*Surkhi (ground bricks) as a Pozzolana—Research paper No.* 1, Central Road Research Institute, New Delhi P 74.