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REPLACEMENT OF PORTLAND CEMENT WITH POZZOLANA

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Pozzolanas prepared from kaolinitic clays of the Mianwali area have been studied for their effect on cement mortars and concretes. Portland cement was replaced by pozzolana upto 40 % in concrete compositions and portland cement was added to mortar compositions comprising pozzolana and the effect on compressive strength and other properties were studied.

Key words: Pozzolana, Portland cement, Kaolinitic clays.

INTRODUCTION

The principal reaction responsible for strength gain in concrete with pozzolana is that of lime with silica in the presence of water to form stable calcium silicate hydrates. Although investigations differ as to the crystalline structure of these hydrates, it is generally agreed that they are in the form of tobermorite [1], the main strength producing binder present in hardened Portland cement concrete. Lime for this reaction is available as free calcium hydroxide. The amount of amorphous silica present in pozzolana is sufficient to react with any excess lime initially present in the clinker and with any free lime produced as a resultant by-product during subsequent cement hydration. The amorphous compounds of silica, as well as those of aluminium and iron are principally reactive and produce much of the early strength gain [2]. Crystalline forms of these compounds, in addition to small amounts of magnesium oxide, may contribute to the long term strength gain [1].

In comparing concretes with and without pozzolana it has been quite customary to regard pozzolana as a substitute for a portion of the cement that would be otherwise employed. This is spoken of as a cement replacement. However, pozzolana is not really a substitute for Portland cement but is an extra ingredient [3] of concrete. It is employed for the purpose of enhancing some of the important properties of concrete. Its use should and usually will lead to the reduction in the cement requirement of a mix and may lead to other changes in the concrete mix design such as reduction in sand content.

From the results of many laboratory investigations [4] and field applications of pozzolana, it can be concluded that the addition of suitable pozzolanic materials in appropriate amounts to Portland cement concrete would be of benefit in nearly all types of construction. The effectiveness in improving workability, reducing bleeding and segregation and in lessening the cracking tendency of concrete would indicate that these materials should be used far more widely. Anything that can be done within economic limits to improve the properties of concrete, so that concrete structures will better serve the purpose for which they were designed and better survive the environment to which they are subjected should of course be the aim of all engineers.

EXPERIMENTAL

Materials used. Kaolinitic clays (No. 2,4,6) from the Mianwali area were selected for this study. The nature of their mineral content was determined by differential thermal analysis [5]. These clays consisted of material rejected for ceramic purposes.

Calcination. Optimum calcination temperature was established by firing the clay at different temperatures and then subjecting the resulting material, after fine grinding (−200) to a lime reactivity test [8]. The clays were found to have maximum reactivity after firing at 800° [3].

After grinding the clays were tested for surface area [6], specific gravity [7] and lime reactivity [8]. The results are presented in Table 1.

Table 1. Physical properties of pozzolana used.

Pozzolana No.	Specific gravity	Air permeability fineness (Sq.cms./g)	Lime reactivity strength (PSI)
2	2.52	9010	1100
4	2.43	8600	980
6	2.50	10120	1210

Replacement of portland cement in concrete. Portland cement was replaced with 5-40 % pozzolana (Surkhi) and

6" specimen cubes for compressive strength evaluation were made with a concrete composition of 1:2:3 ·

using the formula: $\frac{\text{water}}{\text{Cement + Pozzolana}} = 0.5$

The cubes were cured according to the standard practice for 3:7:28 days, 6 months and one year. The pozzolana component consisted only of burnt clay. Portland cement used in these investigations was the Zeal Pak cement. The results of the compressive strengths after different ageing periods are presented in Table 2.

Table 2. Compressive strength of concrete mix.
Portland cement: Sand: Coarse aggregate
1 : 2 : 3 by weight with W/C+S = 0.5

% Replacement of portland cement by Pozzolana		Compressive strength PSI				
		7 days	28 days	3 months	6 months	1 year
Pozzolana 2.	0	2860	4220	5010	5620	5890
	10	2930	4240	5060	5630	5920
	15	2920	4260	5080	5630	5920
	20	2820	4210	5000	5600	5900
	25	2780	4200	5000	5570	5870
	30	2760	4180	4940	5600	5800
	40	2740	4190	4920	5580	5770
Pozzolana 4.	10	2700	4160	4860	5480	5800
	15	2740	4190	4890	5540	5860
	20	2800	4200	4900	5580	5900
	25	2740	4180	4870	5530	5870
	30	2660	4020	4800	5500	5810
	40	2600	4010	4740	5440	5760
Pozzolana 6.	10	3180	4400	5310	5910	6000
	15	3200	4430	5400	6000	6130
	20	3210	4480	5510	6050	6170
	25	3100	4320	5180	5700	6020
	30	3000	4060	5000	5530	5920
	40	2900	4020	4950	5480	5880

Addition of portland cement to pozzolana mortar. Different mortars of pozzolana No. 2,4 and 6 were prepared using lime, pozzolana and sand (1:3:12) and Portland cement was added to these mortars upto 40 % by weight of the mortar. 2" specimen cubes were prepared, cured and used for compressive strength measurements. The results are reported in Table 3.

Replacement of portland cement by pozzolana. A mortar of Portland cement and sand (1:3) was prepared. Then the cement was replaced by pozzolana No. 2,4 and 6 up to 40 %. 2" cubes were prepared, cured and used for compressive strength measurements. The results are shown in Table 4.

Table 3. Compressive strength PSI (Mortar).

$\frac{\text{Lime}}{1} : \frac{\text{Poz}}{3} : \frac{\text{Sand}}{12}$

	Sr. No.	Addition of portland cement to pozzolana	28 days	3 months	6 months	1 year
Pozzolana 2.						
	1.	0	1100	1280	1730	2040
	2.	5	1180	1410	1790	2130
	3.	10	1270	1570	1840	2260
	4.	15	1360	1620	1930	2340
	5.	20	1480	1720	2050	2360
	6.	25	1810	1940	2140	2580
	7.	30	2370	2410	2560	2880
	8.	40	2530	2670	2820	3210
Pozzolana 4.						
	1.	0	980	1090	1490	1840
	2.	5	1040	1160	1520	1880
	3.	10	1160	1280	1630	1980
	4.	15	1280	1340	1740	2020
	5.	20	1620	1690	1890	2340
	6.	25	1810	1930	2020	2460
	7.	30	1920	2030	2200	2600
	8.	40	2130	2340	2680	2800
Pozzolana 6						
	1.	0	1220	1480	2280	2800
	2.	5	1300	1560	2300	2830
	3.	10	1410	1640	2390	2890
	4.	15	1620	1780	2440	2940
	5.	20	1820	1910	2600	3000
	6.	25	2160	2200	2700	3080
	7.	30	2410	2520	2820	3140
	8.	40	2680	2730	2980	3330

RESULTS AND DISCUSSION

Replacement of Portland cement by pozzolana in cement mixtures prepared for various construction purposes leads to improved properties of such mixtures. Pozzolana has less water requirement as compared to Portland cement for achieving a certain level of consistency and overall paste volume is also increased due to lower specific gravity of pozzolana. This addition may also compensate the defficiency of fines in a sand and break the continuity of bleed water channels in the matrix.

Pozzolana generally slows the setting of cement mixtures, although both initial and final setting times remain within specified limits. Set retardation due to pozzolana is

Table 4. Compressive strength PSI 1:3 portland cement: sand mortar.

Sr. No.	%Replacement of portland cement (Zeal Pak) by pozzolana	3 days	7 days	28 days	96 days	6 months	1 year
Pozzolana No. 2							
0	0	3270	4380	4470	4690	4880	5600
1	5	3300	4400	4490	4720	4900	5720
2	10	3330	4420	4530	4760	4960	5830
3	15	3410	4460	4570	4800	5030	5890
4	20	3420	4470	4590	4800	5040	5900
5	25	3430	4470	4600	4820	5050	5910
6	30	3410	4440	4590	4810	5030	5890
7	35	3380	4410	4530	4760	5000	5860
8	40	3360	4390	4500	4740	4910	5810
Pozzolana No. 4							
1	5	3280	4390	4480	4720	4880	5700
2	10	3300	4400	4490	4720	4890	5710
3	15	3320	4420	4510	4740	4900	5760
4	20	3340	4450	4520	4770	4930	5800
5	25	3380	4440	4560	4780	4960	5810
6	30	3320	4420	4510	4740	4880	5770
7	35	3300	4410	4480	4700	4880	5760
8	40	3290	4360	4480	4700	4860	5720
Pozzolana No. 6							
1	5	3330	4480	4530	4780	4960	5680
2	10	3360	4520	4570	4800	4970	5700
3	15	3400	4530	4580	4830	4990	5740
4	20	3460	4560	4630	4840	5080	5780
5	25	3470	4560	4630	4840	5000	5730
6	30	3430	4560	4610	4820	4990	5760
7	35	3410	4540	4590	4840	4980	5730
8	40	3390	3530	4580	4840	3970	5710

influenced by the proportion, fineness and chemical composition of the pozzolana, although the cement fineness, water content of the paste and the temperature of the environment usually have a much greater effect on setting times than the addition of pozzolana. Pozzolanic properties of burnt clays are related to the mineralogical composition of the clays and kaolinitic clays are the best material for producing pozzolana.

Pozzolana usually slows the rate of hardening and reduces to some extent the early compressive strength of cement mixtures. The long term compressive strength values approach the values obtained for pure Portland cement mixtures. Compressive strength values obtained with Zeal Pak cement as well as its mixtures with pozzolana having pozzolana content from 5 to 40 % are presented in Table 2. These values confirm the behaviour of pozzolana additions described above. Strength values slightly higher than those of pure Portland cement are obtained when Portland cement is replaced by pozzolana upto 15 %. The strength values then decrease slightly beyond 20 % pozzolana. This happens with all the three pozzolanas studied. This pattern is followed in strength values measured upto one year. Comparing surface area values in Table 1 and compressive strength values in Table 2, we find that pozzolana No. 6 has the greatest surface area and this is the reason for higher compressive strength values for this pozzolana. In all cases compressive strength values show a regular increase with the passage of time. As the benefits of pozzolana most often outweight the undesirable effects, the decision of adding pozzolana in

many instances may be based not only on economy but also on performance.

When pozzolana in mortar compositions is replaced with Portland cement from 0.40 % there is a regular increase in strength at all ages as should be clear from Table 3. The trend of increasing strength is similar in case all the three pozzolanas. Pozzolana No. 3 shows comparatively higher strengths at all ages and this is due to its higher surface area as shown in Table 1.

Incorporation of cement in pozzolana mortars besides increasing compressive strengths, contributes to early hardening and less early shrinkage.

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