Strength Enhancement of Portland Cement Part-I: Pozzolanas as Partial Replacement for the Portland Cement

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Summary: This paper presents the production of blended cement, based on the intergrinding of Portland cement and pozzolanic materials such as phyllite, slate, and shale. Portland cement was replaced with pozzolana upto 25% and the effect on compressive strength and other properties were studied. Maximum compressive strength of 11,150 PSI as compared to 5,800 PSI of ordinary Portland cement was obtained. Mortar (1:3 ratio) based on high performance cement demonstrated good strength (upto 5,400 PSI) as compared to 4,350 PSI of OPC.

Introduction

The most recent developments in the science of cement and concrete can be earnmarked as the growing demand and proposals for high strength concrete and effective structures utilizing such concrete. The continuous growth of knowledge allows the development and application of super-high strength concrete with compressive strength of 250 MPa, high flexural strength and remarkable ductility [1,2]. The use of chemical admixtures has become one of the essential parts of modern concrete technology. Added to concrete mixture in relatively small amounts, the chemical admixtures change significantly the required parameters and behaviour of fresh or hardened concrete. Developed from industrial waste, requiring utilization into special formulations engineered for the optimal interaction with concrete, modern admixtures can offer the right remedy for overcoming almost any problematic property of concrete [3,4]. According to wide scale investigations [3-7], the performance of concrete with controlled volumes of industrial by-products and waste (IBPW) can be significantly improved. Well-investigated IBPW, or mineral additives include granulated blast furnace slag, fly ash, and slica fume. Such IBPW brings about not only improved concrete properties and economical effectiveness (which can be measured as cost/strength ratio), but it can also improve the eco- and energy-balances of these materials [8].

The present study deals with the production of blended or mineral additive cement based on partial replacement of Portland cement with calcined pozzolanas such as phyllite, slate and shale. It increases compressive strength of the ordinary Portland cement, improves durability of the cement-based materials, and at the same time it permits the utilization of inexpensive indigenous mineral additives.

Results and Discussion

Compressive strength of Portland cement/pozzolana mixture

The test results of compressive strength are presented in Table-1. According to the test results the best 90-day compressive strength value of 10,600 PSI was obtained by pozzolana cement (CEM III) produced with 10% addition of shale as pozzolana material. This value is quite similar to strength demonstrated by optimized sample of CEM I (10,575 PSI) containing 10% phyllite as the additive. The 10% slate and NPC mixture gave the maximum compressive strength of 9025 PSI after 90-day curing. The reference sample of NPC demonstrated compressive strength of 5,560 PSI, while the strength of investigated high strength cements in the one-year age demonstrated an increase in the range of 5.4-6.6%.

As the contents of pozzolana increase beyond 10%, the strength of the pozzolana cement gradually decreases. Nevertheless, all the demonstrated strengths obtained with the addition of the pozzolanas upto 20% are higher than demonstrated by the reference sample of normal Portland cement (NPC).

Compressive strength of mortars

The test results of 1:3 mortars are presented in Table-1. A similar pattern of strength increase as demonstrated above was observed in the case of mortars prepared by using high strength cement and

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Table-1. Compressive strength of pozzolana cement and 1:3 mortar.

% Replacement of Portland cement with pozzolana		w/c ratio	Compressive Strength PSI Plain Cement				1:3 Mortar			
			7 days	28 days	90 days	1 year	7 days	28 days	90 days	1 year
Phyllite	10	0.29	5,175	9,450	10,575	11,150	2,025	4,350	4,720	5,350
	15	0.32	4,580	8,500	8,920	9,250	1,950	4,200	4,535	5,225
	20	0.29	4,215	7,125	7,450	7,725	1,825	3,835	4,225	4,650
	25	-	-	-	-	-	1,800	3,725	4,150	4,570
Slate	0	0.33	3,225	5,200	5,560	5,800	2,500	3,650	4,025	4,350
	10	0.33	5,000	8,650	9,025	9,625	2,025	4,325	4,650	5,325
	15	0.33	4,450	8,475	8,835	9,150	2,000	4,175	4,525	5,250
	20	0.33	4,200	7,050	7,375	7,650	1,800	3,825	4,150	4,600
	25	-	-	-	-	-	1,750	3,715	4,100	4,550
Shale	10	0.30	5,250	9,625	10,600	11,200	2,050	4,385	4,750	5,425
	15	0.28	4,595	8,520	8,950	9,275	1,975	4,250	4,570	5,300
	20	0.31	4,235	7,200	7,650	7,950	1,900	3,850	4,250	4,675
	25	-	-	-	-	-	1,850	3,750	4,200	4,590

Table 2. Chemical Composition of Cementitiouss Materials(%).

	Phyllite	Slate	Shale	NPC	CEM I	CEM II	CEM III
SiO_2	42.60	59.37	56.35	19.40	22.67	23.65	23.48
Al_2O_3	23.25	27.99	17.44	4.80	7.17	7.24	6.18
Fe_2O_3	0.25	0.11	7.75	3.60	3.27	3.25	4.07
CaO	11.00			63.70	58.68		
MgO	0.36	5.39	8.14	1.90	1.75	59.60	59.91
Na_2O	1.20			0.20	0.33		
K_2O	1.32	2.97	3.85	0.80	0.88	1.21	1.31
SO_3	1.57	-	-	2.70	2.62	2.43	2.43
L.O.I	18.14	3.62	6.79	2.90	2.63	2.62	2.62

NPC: Normal Portland Cement
CEM I: Optimized high strength cement comprising of NPC + Phyllite
CEM II: Optimized high strength cement comprising of NPC + Slate
CEM III: Optimized high strength cement comprising of NPC + Shale

sand in 1:3 ratio. A maximum of 4,750 PSI and 5,425 PSI compressive strengths were observed after test periods of 90 days and one year respectively with the pozzolana cement containing 10% shale while replacing the Portland cement with 10% phyllite gave the next highest strength of 4,720 PSI and 5,350 PSI as compared to the reference NPC mortars which demonstrated 4,025 PSI and 4,350 PSI after the above test periods respectively.

Experimental

Materials

Three different reactive slica components were used for partial replacement of normal Portland cement (NPC). These were (i) phyllite, collected from Panjpir area in Mardan district (ii) slate of Manki and (iii) shale of Cambelpur area. Portland cement was received from Kohat cement Factory while standard sand form Nizampur area was used for preparation of the mortars.The chemical composition of these materials as well as of the optimized high strength cements CEM I, CEM II and CEM III is given in Table 2.

Calcination

Optimum calcination temperatures were established by firing the pozzolanas at different temperatures and then subjecting the resulting materials, after fine grinding (-200 mesh) to lime reactivity tests [9]. The pozzolanas were found to have maximum reactivities after firing at 850-950°C. The results are presented in Table 3.

Table 3 Heat Treatment and Lime Reactivity Test

Pozzolana	Heat treatment	Lime reactivity strength (PSI)		
		7 days	28 days	90 days
Phyllite	950°C	275	575	2150
Slate	900°C	260	455	1125
Shale	850°C	250	425	925

Replacement of Portland cement with pozzolana

Portland cement was replaced with 10-20% pozzolana and 2"x2" specimen cubes for compressive strength evaluation were made from the cement/ pozzolana mixture, using water/cement + pozzolana ratio of about 0.3.

The cubes were cured according to the standard practice for 7,28,90 days and one year. The pozzolana component consisted of phyllite, slate and shale. The results of compressive strengths after different aging periods are presented in Table 1.

Addition of Portland cement to pozzolana mortar

Different mortars of pozzolana cement were prepared using Portland cement/pozzolana mixture and sand in 1:3 ratio. 2" specimen cubes were prepared, cured for different aging periods and tested for compressive strength measurements. The results are shown in Table 1

Conclusions

1. Reactive silica additives like phyllite, slate and shale increase early and ultimate strength of cement and concrete. These properties can be improved significantly if reactive silica additive is used as a component of complex admixture for application in high strength cement. Completed tests showed very similar behaviour of different reactive slica additives in high strength cement.

2. It is suggested that the strength of high strength cements should not be less than that of normal Portland cement. In the test results a maximum of 90% strength increase was observed with the addition of 10% pozzolana to NPC.

The development of a new standard for high strength cements are required to encourage the wide scale application of these cements.

References

1. H.H. Bache, Design for Ductility, Concrete Technology: New Trends, Industrial Applications, Proceedings of the International RILEM Workshop, E&FN Spon, London, (1993).
2. C. Dauriac and B.Dowd, Reactive Powder Concrete, The construction Specifier, No.12, (1996).
3. V.G Batrakov, Modified Concrete, Stroyizdat, Moscow, Russia, (1990).
4. V.S. Ramachandran, Concrete Admixtures Handbook, Second Edition, Noyes Publications, New Jersey, U.S.A, (1995).
5. K.G. Sobolev, High-Strength Concrete with Low Cement Factor, Ph.D. Dissertation, Chemical Admixtures Lab, Scientific and Research Institute of Concrete and Reinforced Concrete, Moscow, Russia, (1993).
6. V.M. Malhotra, High-Performance High-Volume Fly Ash Concrete, High-Performance High-Strength Concrete Material Properties, Structural Behaviour and Field Application, Perth, Australia, pp.97-122 (1998).
7. K.G. Sobolev and S.V. Soboleva, High Performance Indigenous Cement, XXIVth World Housing Congress, Ankara, Turkey, pp.189-202, (1996).
8. K.G. Sobolev and S.V. Soboleva, Eco-Balance of High Performance Cement, International Symposium on Mineral Admixtures in Cement, Istanbol, Turkey, (1997).
9. Compressive Strength of Hydraulic Cement Mortars by Cube, ASTM C 109-80, (1981).