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Evaluating Shale, Slate, Phyllite and Volcanic Ash as Natural Pozzolanas in Concrete

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Abstract: The role of natural pozzolanas is considered to be important especially when the concrete is subjected to acidic, alkaline, saline or waterlogged conditions. Recently, studies on the influence of pozzolanic material on physico-chemical properties of mortar and concrete have received greater attention. Therefore, this research was carried out to evaluate the influence of natural pozzolanas used as partial substitutes for cement on the pozzolanic properties of lime mortar, cement paste, mortar and concrete. Four natural pozzolanas (i. e., shale, slate, phyllite and volcanic ash) were used as constituent mineral additive in the mortar at the rate of 10, 15 and 20% by mass of cement. In concrete specimens, the pozzolanic replacements were adjusted to 10, 20 and 30% by mass of cement. Compressive strength of the concrete specimens was measured at 7, 14 and 28 days, and flexural strength was measured at the age of 28 days. Lime pozzolana reactivity test was carried out untill 91 days. The use of pozzolanas resulted in substantial reactivity of the limed mortars. The compressive strength of cement paste, mortar and concrete was inversely proportional to the amount of pozzolana replaced. As expected the compressive strength of all specimens increased with time. Replacement with phyllite and shale improved the strength of pastes and mortars better than with slate and volcanic ash irrespective of the specimen type. Water absorption capacity of cement paste specimens decreased but the setting time and density were enhanced by the substitution with pozzolana.
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1. Introduction

The production of ordinary portland cement is economically expensive, energy exhausting and environmentally unsafe. The increasing demand for cement in the construction industry has aggravated the existing environmental condition. Since the cement industries emit a substantial amount of greenhouse gases (i. e., CO_2, SO_2 etc), the use of pozzolanas as ordinary portland cement replacement could contribute to the protection and sustainability of the environment. Natural pozzolana substitution in cement or concrete matrix results in many beneficial properties such as low heat of hydration, high ultimate strength, low permeability, high sulphate resistance and low alkali-silica reactivity (ACI Committee 232 Report). The role of pozzolanic cement concrete is considered important especially where the concrete is possibly subjected to various hazardous environment like acidic water, industrial effluents, sea water, sewerage water and saline or waterlogged soils. Sulfates and chlorides contained in the drained water deteriorate concrete in the drainage canal (Neville, A. M: Properties of Concrete. 4th Edition). Aggressive deterioration in RC concrete is mainly due to saline environment, which could induce corrosion of reinforcing steel embedded in concrete (Joshi. R. C. and R. P. Lohtia: Fly ash in concrete production, properties and uses). There is a need to select natural pozzolanas having favourable physical characteristics that could enhance the durability of concrete. There are also compelling reasons to utilize and extend the practice of replacing cement in concrete and mortars with less energy-intensive processed materials. The use of finely ground mineral admixtures having pozzolanic properties can provide a major economic benefit, as these materials permit a reduction in the amount of portland cement in the mixture. The use of pozzolanic and cementitious materials in relative amount could also provide beneficial results for the sustainability of the cement and concrete industry. This importance is not only related to the energy efficiency and environmental aspects of the cement industry but also with the durability of concrete structures (Mehta, P. K: Role of pozzolanic and cementitious materials in sustainable development of the concrete industry). The principal reasons for the use of clay-based pozzolanas in mortar and concrete are easy availability of materials and the enhancement of durability. Generally, natural pozzolanas are raw or calcinated natural materials that have pozzolanic properties. Pozzolanas are not cementitious by themselves, but when finely ground and mixed with lime they can form cement hydrate due to aluminosiliceous composition . Pozzolana is either a natural or an artificial material that may contain high silica, alumina and other minerals, but generally lesser chemical components than cement. During the hydration process, the reaction of pozzolana with the lime already existing in the cement causes some property changes in cement and the resulting concrete. Such effects of pozzolana depend on the type and amount of pozzolana as well as on the properties of cement and the activity of pozzolana added. Studies on the effects of natural pozzoplanas on the properties of mortars and concrete are insufficient. Therefore, a laboratory experiment was designed to compare the effects of four types of natural pozzolanas namely shale, slate, phyllite, and volcanic ash as replacement material for ordinary portland cement, on the compressive strength of mortars and concrete.

2. Material and Methods

Four different natural pozzolanas namely shale (SH), slate (SL), phyllite (PH), and volcanic ash (VA) were collected from different arid and semi-arid areas of North Western Frontier Province (NWFP) of Pakistan. A brief description of the selected pozzolanas is given below:

Shale is a sedimentary rock composed of several clay minerals. These deposits are characterized by interbedding of clays, silt, sand and conglomerates and show a high pozzolana content. Shale was collected from Cambelpur basin near Harrow Bridge on Peshawar road, Pakistan. The parent rock of slate is shale. Slate is a medium grained, low-graded metamorphic rock and could be recognised by its slate and platy structures. It was sampled from Manki Formation at the right bank of Kabul River, NWFP-Pakistan. Phyllite is a medium grade metamorphic rock that forms when the slate undergoes a metamorphic process. The phyllite could be differentiated from other rocks by its fine platy structure and grayish color. The sample of phyllite was brought from Panjpir area Mardan district, Pakistan. The volcanic ash was sampled from Dodehal in Azad Jammu and Kashmir (AJK), Pakistan. The volcanic ash is coarse-grained and blackish brown colored. These ashes are the product of volcanoes that erupted during the Precambrian era.

2.1. Calcination

The shale, slate and phyllite were initially ground to a size of 20mm (diameter) and then subjected to heat treatment at a temperature of 800 to 950 ^{0}C for 1.5 h in a fixed bed 810B assay furnace to activate the silica. The volcanic ash was not treated with heat as it was considered to contain active silica due to the eruption of hot magma. The calcined materials were again finely ground into powder. The materials were analyzed for their mineralogical properties as given in **Table 1**.

Table 1. Mineralogical characteristics of the pozzolanic material

Pozzolana	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO + MgO	$Na_2O + K_2O$	Loss of ignition
	------------------% by mass-----------------------						
Shale	56.35	17.44	7.70	----	8.14	3.75	6.59
Slate	59.37	27.99	0.11	0.70	5.39	2.93	3.52
Phyllite	34.55	23.50	----	----	19.82	4.11	17.98
Volcanic ash	60.32	23.35	0.28	6.55	1.08	4.98	3.44

2.2. Lime mortar:

Four cube specimens (size: 5.08 × 5.08 × 5.08 cm) were prepared to test the lime reactivity according to the Indian specification [IS-1727: 1967] 5). Lime, pozzolana and sand were mixed with 1: 2M: 9, respectively, where M = specific weight of sample / specific weight of lime. The lime specimens were cured under wet cloth to prevent moisture loss. The compressive strength of the lime mortar specimens was measured at the age of 7, 28 and 91 days.

2.3. Mortar:

Cement mortars were also prepared according to specification of the American Society for Testing and Materials (ASTM) C109. In mortar specimens the cement were replaced by pozzolana at the rate (%) of 10, 15 and 20 by mass. The specimens were cured by immersing in water tank at a room temperature of approximately 25°C and their compressive strength was measured at the age of 7 and 28 days.

2.4. Cement paste:

Cube specimens of 5.08 × 5.08 × 5.08 cm of cement paste were made to determine the reactivity. Pozzolanic material was mixed with cement at the rate of 10, 15 and 20% by mass of cement. The water used in paste preparation was 33% by mass of combined materials. Initial and final setting times for the paste specimens were measured according to the ASTM C191 using Vicat apparatus. The cube specimens were cured as mentioned above and the compressive strength was measured at the age of 7 and 28 days. The density of specimen was measured at the age of 28 days. Water absorption test of paste specimens were conducted at the age of 28 days according to the specification of the ASTM C 642-97. The test was aimed to evaluate the degree of densification of paste specimens at various substituted materials. The absorption ratio was calculated by the following equation: absorption ratio (%) = [(B-A) / A] ×100, where A denotes mass (g) of oven-dry sample in air and B denotes mass (g) of surface-dry sample in the air after immersion into water. The detail of the substitution percentage of SH, SL, PH and VA for cement in the paste and mortars specimens are given in Table 2.

Table 2. Substitution percentage of different pozzolanas used in paste and mortar

Substitution	Treatment	Replacement ratio (%) by mass
Control	C	100 ordinary portland cement
SH	SH1	Cement 90 + shale 10
	SH2	Cement 85 + shale 15
	SH3	Cement 80 + shale 20
SL	SL1	Cement 90 + slate 10
	SL2	Cement 85 + slate 15
	SL3	Cement 80 + slate 20
PH	PH1	Cement 90 + phyllite 10
	PH2	Cement 85 + phyllite 15
	PH3	Cement 80 + phyllite 20
VA	VA1	Cement 90 + volcanic ash 10
	VA2	Cement 85 + volcanic ash 15
	VA3	Cement 80 + volcanic ash 20

2.5. Concrete:

Concrete mix was prepared at water cementitious material ratio of 55%. The mix design of concrete is shown in Table 3.

Table 3. Mix design of concrete

W / C %	Slump cm	Cementitious material kg m^{-3}	Sand kg m^{-3}	Gravel kg m^{-3}
55	10	360	750	1150

Ordinary portland cement was replaced by same pozzolanas (i. e., shale, slate, phyllite and volcanic ash) at the rate of 10, 20 and 30%. Nine cylindrical specimens (size: 15.24 cm in diameter × 30.48 cm in height) were cast for each pozzolanic material. Concrete in the moulds were compacted by a mechanical vibrator. Curing was done by immersing the specimens in water tank at room temperature. The cylindrical specimens were tested for compressive strength at the age of 7, 14 and 28 days. Three beams (size: 15.24 × 15.24 × 76.2 cm) from each batch of concrete were also cast to determine the flexural strength at the age of 28 days.

3. Results and discussion

This study basically aimed to evaluate the effects of natural pozzolanas by using the strength development of paste, mortar and concrete. The compressive strength of the limed mortars added by pozzolanas is shown in **Fig. 1**. With the passage of time the strength of limed specimen was enhanced significantly. The pozzolanic strength of lime mortars was higher in PH and VA than in SH and SL specimens at all ages of testing. The compressive strength varied in the order PH > VA > SL > SH. The compressive strength obtained at 91 days in all pozzolanic materials tested exceeded that of the Indian standardized [IS-1727: 1967] minimum acceptable limit of lime reactivity i. e., 710 psi (4.83 MPa) and the pozzolanas are categorized as high, medium and poor lime reactive at 1200 psi (8.16 MPa), 800 to 1200-psi (5.44 to 8.16 MPa) and 800-psi (5.44 MPa) respectively. Thus from **Fig. 1,** SH and SL samples could be categorized as medium reactive pozzolanas whereas PH and VA may be grouped into high reactive pozzolanas. These tests have also confirmed that the use of natural pozzolanas as a cement replacement material could be practically feasible and productive in the concrete matrix.

The results of the compressive strength of cement mortars as shown in **Fig. 2** demonstrated that the strength values decreased in pozzolana substituted mortars as compared to control mortars irrespective of the amount of pozzolana applied. The highest compressive strength was found in 10% substitution level followed by 15 and 20%. Among the pozzolanas the strength differed markedly in the order SH > PH > SL > VA. Substitution with large amount of pozzolana may cause the degradation of the compressive strength. In case of VA, the strength was positively related to the amount of VA used in the specimens. The mortar strength increased significantly with age.

The compressive strength of cement pozzolana pastes is given in **Fig. 3**. Among the pozzolanas, the compressive strength of paste specimens was similar to that observed for mortar specimens. The cement paste replaced by pozzolanic material at each rate of replacement achieved a reduced level of compressive strength as compared to control. However, in PH1 specimens the strength increased even more than the control. The superiority of PH over other pozzolanas could be attributed to its chemical composition. This may also indicate that the use of natural pozzolana (e. g., PH) could be appropriate as cement replacement material. The strength decreased with an increase in the replacement dose, but in VA paste specimens, the compressive strength was slightly increased with the application rate due to higher pozzolanic behavior. The increase in compressive strength with the increasing dosage of VA indicated that the optimum substitution rate of VA was yet to be achieved.

The data for water absorption, initial and final setting time and density are shown in Table 4.

Table 4. Setting time, density and water absorption ratio of paste specimens with different pozzolanas.

Specimen	Setting time (min.) Initial	Final	Density g cm^{-3}	Water absorption %
C	150	270	1.82	10.35
SH1	175	300	2.14	3.84
SH2	195	324	2.13	3.74
SH3	210	342	2.09	3.50
SL1	225	360	2.21	4.65
SL2	235	372	2.20	4.60
SL3	250	390	2.29	4.3
PH1	200	330	2.11	3.82
PH2	215	348	2.10	3.96
PH3	225	360	2.20	4.10
VA1	160	282	2.14	4.60
VA2	175	300	2.14	4.70
VA3	185	312	2.25	4.78

The result indicates that the water was absorbed in less quantity in natural pozzolanas substituted specimens as compared to control. However, among the pozzolanic materials, the water absorption amount differed in the order C > VA > SL > PH > SH. The initial and final setting times were prolonged by the addition of pozzolana. The longest setting time was observed in SL specimens and the lowest was noted in the VA specimens. The setting time was also directly related to the dose of replacement irrespective of the pozzolanic material. Similarly the density of paste specimens also increased with pozzolana as compared to control. However, the increase was not significant among the pozzolanas.

It is generally recognized that strength development is a function of the chemical interaction between the natural pozzolana and the portland cement during hydration. The effect of natural pozzolana on the strength of concrete varies markedly with the properties of the particular pozzolana and with the characteristics of concrete mixture in which the pozzolana is used. The compressive strength of the concrete specimens at the age of 7, 14 and 28 days differed in the order Control > SL > VA > PH > SH as shown in Fig. 4. The highest compressive strength was recorded at the lowest substitution level of 10% followed by 20 and 30% irrespective of the type of pozzolana used in the concrete. Previous studies 4, 12) have shown that the concrete exhibited higher level of strength development with supplementary cementing materials such as natural pozzolana at the admixture level of about 15% by mass of cement. The compressive strength increased enormously with the age of concrete. Such an increase could be attributed to the higher pozzolanic activities. During this experiment the addition of pozzolana decreased the early mortar and concrete strengths but enhanced the strength of more than 80% of the control specimens at 28 days especially in 10% pozzolanic replaced specimens. Therefore, it is considered that the strength may likely develop further even at the later stages.Mehta [9)] reported that at 28 days the compressive strength of a

10% Santorin-earth cement was higher than the reference portland cement, and at 90 days the 10 and 20% Santorin-earth cement strengths were higher than the reference portland cement.

The increase in the strength of specimens (i. e., paste, mortar and concrete) due to the addition of pozzolana is attributed to the improved aggregate material bond associated with the less porous transition zone and a better interlock between paste and aggregate [2]. The aggregate-matrix bond improvement induced by such pozzolanic materials is probably a result of their combined filler and pozzolanic effects. The filler effect leads to a reduction in the porosity of the transition zone and provides a dense microstructure and thus increases the strength of the matrix. The pozzolanic effect helps the formation of bonds among the densely packed particles in the transition zone. A pozzolanic reaction occurs with the calcium hydroxide liberated during the hydration of portland cement to form extra binding calcium silicate hydrates which lead to further increase in strength [11]. The ratio of flexural strength to compressive strength (FS / CS) of the entire specimens was also calculated (**Table 5**).

Table 5. Substitution percentages and the ratio of flexural strength to compressive strength (FS / CS) of concrete specimens as affected by different pozzolanas.

Specimens		Replacement ratio (%) by mass	FS / CS (%)
Control	C	Cement 100	13.1
Shale	SH1	Cement 90 + shale10	15.5
	SH2	Cement 80 + shale 20	15.4
	SH3	Cement 70 + shale 30	15.1
Slate	SL1	Cement 90 + slate10	14.4
	SL2	Cement 80 + slate 20	15.3
	SL3	Cement 70 + slate 30	15.4
Phyllite	PH1	Cement 90 + phyllite 10	15.2
	PH2	Cement 80 + phyllite20	15.1
	PH3	Control 70 + phyllite 30	14.1
Volcanic ash	VA1	Cement 90 + vol.ash10	14.6
	VA2	Cement 80 + vol.ash 20	15.2
	VA3	Cement 70 + vol.ash 30	15.9

The FS / CS ratio was higher in pozzolanic concrete as compared to control. Several researchers have reported that the higher ratio of FS / CS was associated with higher pozzolanic activity [3, 7] and elastic-plastic behavior of these substituted material within concrete. The decrease in the FS / CS ratios of higher dosages could indicate the brittleness of the material. The FS / CS ratios in the shale and phyllite-substituted specimens decreased with increasing application rate whereas for slate and volcanic ash-substituted specimens the FS / CS ratio increased with the substitution percentage. The decrease in FS / CS ratios in shale and phyllite-substituted specimens could relate to the non-homogenous matrix formed under reduced level of pozzolanic activity. The lower content of active silica and aluminum oxide and higher carbon content as observed in **Table 1**, may also reduce the pozzolanic activity. The higher FS / CS ratio in slate and volcanic ash-substituted specimens could be attributed to the higher active silica and aluminum oxide content.

4.Conclusion

It is concluded that the strength development of mortars and concrete was affected by the addition of pozzolanas. The natural pozzolanas showed a remarkable reactivity in the lime specimens. The pozzolana-substituted specimens exhibited less strength than the control, but at 28 days, the strength improved by more than 80% of the control in all pozzolana-substituted specimens. This was found especially in concrete specimens. The strength was positively related to the age of specimens. In paste and mortars phyllite and shale improved strength more than other pozzolanic materials. The higher density and lower water absorption in paste specimens could enhance durability. Such pozzolanic reactivity may give beneficial results under extreme saline or arid conditions. It is confirmed that the use of cement replacement such as pozzolana at a certain level seems to be economically and technically feasible. However, there is need to validate these results further by using various types of pozzolanas at elongated periods under varying conditions.

References

[1]. ACI Committee 232 Report: Use of natural pozzolans in concrete. *ACI Mater. J.* 91(4) (1994).

[2]. Bache, H. H: High strength concrete development through 25 years. CBL Reprint No. 17, Aalborg Portland, Aalborg, Denmark (1987).

[3]. Costa, U. and F. Massazza: Some Properties of Pozzolanic Cement Containing Fly Ashes. Fly Ash, Silica Fume, Slag and Other Mineral By-product in Cement, ACI Vol-1, SP-79-11 (1983).

[4]. Haque, M. N. and O. Kayali: Properties of high strength concrete using a fine fly ash. *Cem. Concr. Res.* ***8,*** 1445–1452 (1998).

[5]. Indian Standard: 1727: Indian Standard-Methods of Test for Pozzolanic Materials. Indian Standard Institute, Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 1, India (1967).

[6]. Joshi. R. C. and R. P. Lohtia: Fly ash in concrete production, properties and uses. The university of Calgary Alberta, Canada, p-269 (1997).

[7]. Malquori, G: Portland-Pozzolana Cement. Proc. of the Fourth Int. Symp. on the Chem. of Cement (Washington), 983-1006 (1960).

[8]. Mehta, P. K: Role of pozzolanic and cementitious materials in sustainable development of the concrete industry. In Malhotra V. M. (ed.) Proceedings of the 6th International Conference on Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete. *ACI SP-178. ACI International, Farmington Hills, MI*, 1–25 (1998).

[9]. Mehta, P. K: Natural Pozzolanas Supplementary Cementing Material for Concrete. *CANMET-SP-86-8E*, Canadian Government Publishing Center, Supply and Services, Ottawa (1987).

[10]. Neville, A. M: Properties of Concrete. 4th Edition Pearson Education Asia Pte. Ltd (1995).

[11]. Popovics, S: Portland cement-fly ash, silica fume systems in concrete. *Adv. Cem. Based Mater. J.* ***1*****,** 83–91 (1993).

[12]. Shannag, M., R. Brincker and W. Hansen: Interfacial fiber-matrix properties of high strength mortar (150 MPa) from fiber pullout. *ACI Mater J* ***93,*** 480-486 (1996).

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