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Properties of concrete with pumice powder and fly ash as cement replacement materials

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HIGHLIGHTS

- The effect of pumice powder and fly ash on concrete properties was investigated.
- Pumice powder and fly ash improved physical properties of concrete.
- Strength of concretes with pumice powder and fly ash were comparable to reference.
- Pumice powder and fly ash contributed to sulfate resistance of concrete.
- Pumice powder can be used in concrete where sulfate resistance is desired.

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ABSTRACT

Turkey is rich in natural pozzolan and pumice is abundantly found in several regions of the country. In this study, pumice powder (PP) and fly ash (FA) were used as cement replacement materials and the effect of partial replacement of PP, FA and their blends by cement on physical, mechanical and durability properties of concrete was investigated. Test results showed both PP and FA addition resulted in lower mechanical strength at early ages, but comparable strength at later ages compared to the reference concrete. Replacement of cement with PP, FA and their blends resulted in concretes with decreased water absorption, sorptivity and void content and higher magnesium sulfate resistance compared to the reference concrete. Since pumice is abundantly found in Turkey, this material might be used as an additive in concrete applications or as a precaution against magnesium sulfate attack.

1. Introduction

Environmentally friendly cement-based materials is a topic of interest and cement replacement materials play an important role in the construction industry considering economical, technological and ecological points of view [1,2]. Therefore, the search for alternative binders or cement replacement materials has been the subject of many publications. Concrete materials should not only possess good workability, excellent mechanical properties and durability, but also offer environmental and economic benefits [3]. Besides cost reduction and enhancement of workability of fresh concrete, the use of pozzolans might help improve the durability of concrete such as resistance to thermal cracking, alkali-aggregate expansion, and sulfate attack [4].

A pozzolana is defined as a natural or artificial material which contains reactive silica [5]. A more detailed definition is given in Ref. [6] and pozzolans are defined as materials that have little or no cementitious value by themselves, however, when finely divided and in the presence of moisture they will chemically react with alkalis to form cementing compounds. The silica in a pozzolana has to be amorphous, or glassy, to be reactive [6]. Natural pozzolans are generally derived from volcanic rocks and minerals [4]. Turkey is rich in natural pozzolan, where almost 20% of the country is covered by Tertiary and Quaternary-age volcanic rocks [1], and pumice can be found in several regions of the country. Pumice is a natural lightweight material of volcanic origin produced by the release of gases during the solidification of lava. The cellular structure of pumice is created by the formation of bubbles or air voids when gases contained in the molten lava flowing from volcanoes become trapped on cooling [7]. When lightweight aggregates of pozzolanic materials were ground to very fine powder, they could possess certain cementitious properties. At the same time, when they mix with a certain amount of cement and lime, their binding property increases [8]. Therefore the use of pumice powder (PP) as cement replacement material has been

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the topic of a number of studies in the literature [1,2,7–10]. As reported in a previous paper [11], the importance of using natural pozzolans in the cement industry requires a complete evaluation of their effects on concrete and therefore there is still a need for further studies on the use of such natural pozzolans as cement replacement materials, and their effects on concrete properties should be investigated. In this study pumice is chosen as a natural pozzolan because of its availability in Turkey and that it can be easily grinded to obtain its powder without requiring high amount of energy.

The most common artificial pozzolana is the fly ash (FA) which is precipitated electrostatically or mechanically from the exhaust gases of coal-fired power stations [5]. ASTM C 618 [12] classifies FA into two groups as Class F and Class C, where Class F FA has pozzolanic properties and Class C FA in addition to having pozzolanic properties, also has some cementitious properties.

ASTM C 618 [12] presents chemical and physical requirements for FA and natural pozzolana for use in concrete. ASTM 311 [13] defines strength activity index to determine whether artificial (fly ash) or natural pozzolan results in an acceptable level of strength development when used with hydraulic cement in concrete. There is also a pozzolanic activity index with lime, which determines the total activity of pozzolana [5,14]. EN 196-5 [15] defines a direct test for determining the pozzolanicity of pozzolanic cements which is also known in the literature as the Frattini test [16,17]. This test is based on chemical titration and can accurately define the pozzolanic activity of blended Portland cements measuring the CH consumption released during PC hydration [17].

This study presents the results of the research conducted to assess the effect of partial replacement of PP, FA and their blends by cement on physical, mechanical and durability properties of concrete. Therefore, seven concrete mixtures with various pozzolana contents up to 20% were cast and tested in order to evaluate the effect of PP, FA and their blends on standard consistency and setting times of cement pastes and workability, void content, water absorption, sorptivity, compressive strength, splitting tensile strength and magnesium sulfate resistance of concrete mixtures. It should also be noted that chemical composition and properties of pumice can vary place to place and might have different effects on concrete properties; therefore the results reported here represents the materials with particular properties.

2. Experimental study

2.1. Materials and mix proportions

The materials used in the research consist of limestone coarse and fine aggregates, cement, chemical admixture, PP and FA. Physical properties and particle size distribution of the aggregates are presented in Tables 1 and 2, respectively. The type of cement used throughout the study was CEM I 42.5 R. PP was obtained by initially oven drying the coarse pumice aggregates at around 100 °C to eliminate the free water and then grinding them by a laboratory type disc grinder. The powder was then sieved from 63 μ and the passing material was used throughout the research. Physical properties of pumice aggregates used in this study can be found in Ref. [18]. F type FA was also used in some mixtures as an artificial pozzolana. Chemical and physical properties of cement, PP and FA are presented in Table 3.

It can be clearly seen from the chemical analysis (Table 3) that the main component of PP and FA is SiO_2, where the main component of cement is CaO. ASTM C 618 [12] requires that the sum of SiO_2, Al_2O_3 and Fe_2O_3 be more than 70% for natural pozzolans and F type FA. Table 3 shows that both PP and FA used in this study confirm this and that the sum of the cementitious compounds is much above than the limit value of 70%. Pozzolanic activity of PP and FA were also investigated according to the procedure explained in EN 196-5 [15]. Test results verified that both materials show pozzolanic activity (Fig. 1).

Polycarboxylic ether based superplasticizer was used in all mixtures at a constant amount of 1.5% of the binder by weight and the slump values of concretes ranged between 18 and 25 cm.

Table 4 summarizes the mix proportions and fresh concrete properties. Mixing was performed in a 45 L capacity pan mixer with a vertical rotation axis and fresh concrete properties were determined after the mixing. A total of seven concrete mixtures were prepared with constant water to binder ratio and binder content of 0.42 and 500 kg/m^3, respectively. The mixtures were coded according to the pozzolanic material addition and content, where "R" defines the reference concrete with no pozzolana, "P" and "F" defines PP and FA inclusion, respectively, and the numbers 5, 10 and 20 after P and F define the substitution ratio of regarding pozzolana by cement by weight.

Table 1
Physical properties of aggregates.

Aggregate	Particle size (mm)	Particle density (kg/dm^3)
Fine aggregate	0–4	2.76
Coarse aggregate	2–11.2	2.81

Table 2
Particle size distribution of aggregates.

Sieve opening (mm)	Cumulative passing (%)	
	Fine aggregate	Coarse aggregate
16	100	100
11.2	100	87
8	100	55
4	100	0
2	75	0
1	50	0
0.5	35	0
0.25	15	0

Table 3
Chemical and physical properties of cement, pumice powder and fly ash.

Chemical compound (%) and physical properties	Cement	Pumice powder	Fly ash	ASTM C 618 requirements	
				Natural pozzolana	F type fly ash
SiO_2	20.23	77.52	60.13	–	–
Al_2O_3	5.14	12.99	19.00	–	–
Fe_2O_3	3.87	1.5	8.98	–	–
$SiO_2 + Al_2O_3 + Fe_2O_3$	29.24	92.01	88.11	Min 70%	Min 70%
CaO	63.14	0.1	1.90	–	–
MgO	1.25	0.4	4.77	–	–
SO_3	2.89	0.52	0.95	Max 4%	Max 5%
Loss on ignition	1.55	5.42	1.69	Max 10%	Max 6%
Cl^-	0.0435	0.0096	–	–	–
Na_2O/K_2O	0.27/0.90	0.12/0.95	–	–	–
Free CaO	1.2	–	–	–	–
Specific gravity	3.14	2.32	2.21	–	–
Specific surface (cm^2/g)	3780	4400	3545	–	–

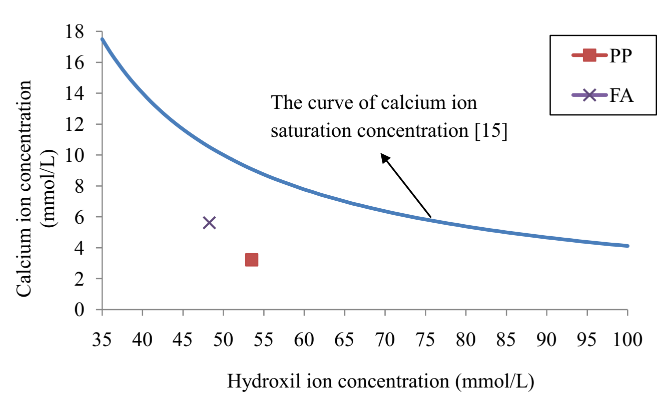

Fig. 1. Diagram for assessing pozzolanicity of PP and FA.