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Investigation on characteristics of blended cements containing pumice

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HIGHLIGHTS

- We studied effect of pumice on properties of blended cement pastes and mortars.
- Pumice usage decreases mechanical properties of mortar while increasing durability.
- Specific gravity is decreased by the usage of pumice.
- Pumice decreases shrinkage strains of mortars.

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ABSTRACT

In this experimental study, the effects of 10, 20, 25, 30 and 40 wt.% pumice addition on properties of blended cement pastes and mortars were investigated. Pumice blended cements with a high fineness were produced by intergrinding Portland cement clinker, pumice and gypsum. Characteristics such as particle size distribution, soundness, setting times, chemical analysis, compressive and bending strengths, drying shrinkage, autoclave expansion and sulfate resistance were determined. In addition, the microstructures of some samples scanned by scanning electron microscopy were photographed. Compressive strengths of mortars produced with pumice blended cements were lower than that of Portland cement tested ages up to 360 days. Pumice blended cements increase durability, sulfate expansion, shrinkage and autoclave expansion.

1. Introduction

Concrete and mortar are most widely used construction materials in civil engineering applications such as building, road, dam, flooring, precast elements etc. Their consumption has increased due to new developments in construction technologies, population growing, increasing of living standard and urban transformation of residence causing more building construction. Although polymer concretes and mortars have been used for strengthening structures and repair applications, their high cost restricts usage of them. In this respect, cement based concretes and mortars are most widely used. Thus, cement consumption increases. Since the cement industry demands vast amount of energy, any increase in cement manufacturing increases it. And this causes environmental pollution. Cement production is responsible for 8% CO_2 emision in the world. Significant part of cement production cost is due to energy consumption during the clinker production. 1.6 ton raw materials are used to produce 1 ton cement. Therefore, the attempts to decrease clinker production have been done. Manufacturing of cement with additive is an economic and feasible method due to the decreasing of clinker ratio in cement. For this purpose, pozzolans can be used in the cement production. Amorphous silicates in pozzolanic materials react with $Ca(OH)_2$ during the hydration of cement and form new CSH gels. Productions of cements containing fly ash, silica fume and blast furnace slag are common worldwide.

Pumice is a natural pozzolan of volcanic origin produced by release of gases during cooling and solidification of lava. Porous structure of pumice is formed by the bubbles or air voids when gases in molten lava is trapped during cooling. Air voids are elongated and parallel to one another. They are sometimes interconnected. Pumice has been used as aggregate in lightweight concrete. Structural concrete which is two to three times lighter than normal concrete with high thermal performance can be manufactured. Pozzolans improve durability and strength while reducing hydration heat.

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Comprehensive researches on cement additives such as nut shell, wood and tea waste [1], fly ash [2–4], blast furnace slag [5], silica fume [6], rice husk ash [7,8], diatomite [9,10], perlite [11] and zeolite, fly ash and waste glass [12] were carried out. But, evaluation of pumice in cement production is limited. Turkey has a significant abundance of pumice with about 3 billion cubic meter reserve. In 2012, Turkey produced 71.3 million tons cement. Turkey with 49 cement factories and 18 grinding facilities is one of pioneer cement producers in the world. The usage of natural pozzolans in cement affects significantly properties of cement. Also the usage of 1% natural pozzolan in the blended cement production decreases the cement cost in the ratio of 0.5. Also cement production is responsible for the 8% CO_2 emision in the world. In this respect, the production and usage of the blended cement with pozzolans should be increased. Thus, further studies should be done. The purpose of this study is to investigate the usability of pumice as an additive in the blended cement production and determine its performance properties as a function of pumice addition.

2. Materials and methods

In this study, CEM I 42.5R cement produced according to TS EN 197-1 [13] was used for comparison aim as reference (Coded as RF here after). Clinker was obtained from Set Ankara Cement Factory, Ankara. Properties of cement are presented in Table 1.

Pumice was obtained from Erzincan territory of Turkey. The pumice was dried in the oven and then ground up to the size of Portland cement. Particle size distribution of pumice is presented in Fig. 1. Chemical and some physical properties of pumice are given in Table 2. Pozzolanic activity index of pumice was determined according to ASTM C 311 [14]. A scanning electron microscope (SEM) was used to observe the morphology of pumice sample. SEM images of the pumice are presented in Fig. 2. As seen from Fig. 2, image (a) is enlarged 250 times and image (b) is enlarged 1000 times. Porous microstructure of the pumice are clearly seen in the images. The microstructure of the Erzincan pumice is very similar to Isparta, Kars, Kayseri and Nevşehir pumices [15]. The clinker used was obtained from Set Ankara Cement Factory, Ankara. Properties of cement are presented in Table 3.

For the production of the samples of blended cement with pumice, laboratory type ball mill with 3 kg capacity was used. Clinker was replaced with pumice by weight. Gypsum content was kept constant in all mixtures. Clinker, pumice and gypsum were put into the ball mill and interground together for 80 min in order to obtain pumice blended cement. Clinker, pumice and gypsum were crushed before intergrinding. In blended cement production, natural pozzolans can be used up to 40% ratio. According to Neville [16] and Erdogan [17], there is no great significance in the upper limit on natural pozzolan content. Also according to TS EN 197-1 [13], the maximum usage ratio of natural pozzolan in blended cement production is 35%. The pumice was investigated in the ratios of 10–40% in this study. Reference cement sample is coded as RF. Blended cement samples with pumice admixture are coded as M1, M2, M3, M4 and M5. Mix proportions are presented in Table 4. 25 kg blended cement were produced from each mixtures. And then experiments were carried out.

Table 1
Properties of cement.

Chemical composition	(%)
CaO	64.02
SiO_2	20.31
Al_2O_3	5.64
Fe_2O_3	3.27
MgO	1.64
SO_3	2.86
K_2O	0.80
Na_2O	0.87
Free CaO	1.48
Loss on ignition	0.90
C_3S	55.55
C_2S	16.50
C_3A	9.41
C_4AF	9.95
Physical and mechanical properties	
Specific gravity (g/cm^3)	3.11
Specific surface (cm^2/g)	3489
Volume expansion (%)	2
Initial seeting time (min)	145
Final setting time (min)	230
Compressive strength @7 day (MPa)	38.8
Compressive strength @28 day (MPa)	45.78

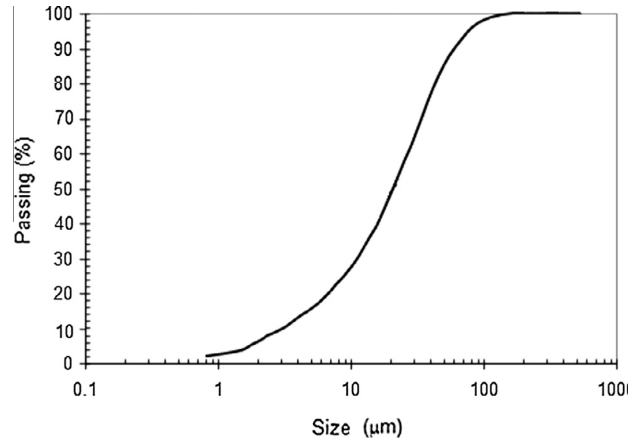

Fig. 1. Particle size distribution of the pumice.

Table 2
Properties of pumice.

Chemical composition	%
CaO	5.20
SiO_2	58.44
Al_2O_3	15.96
Fe_2O_3	4.69
MgO	6.30
SO_3	0.04
K_2O	2.64
Loss on ignition	4.11
$SiO_2 + Al_2O_3 + Fe_2O_3$	79.09
Physical properties	
Specific gravity (g/cm^3)	2.50
Specific surface (cm^2/g)	3697
Pozzolanic activite index (%)	77.42

Following tests were carried out on the cements produced. Chemical analysis is carried out according to TS EN 196-2 [18]. Density is determined according to ASTM C 188 [19]. Fineness is determined according to TS EN 196-6 [20].

A series of experiments are carried out to determine the effects of pumice on normal consistency, setting times, volume expansion (Le Chatelier) and autoclave expansion. Three tests were conducted and averages were taken based on TS EN 196-3 standard [21] from each cement types. Autoclave expansions of the produced cements were done according to ASTM C 151 [22]. Water demands of mortars were determined according to ASTM C 1437 [23].

Mortar specimens were prepared according to TS EN 196-1 [24] in a cement laboratory with 50–60% relative humidity. Proportions for the mortars were 1 part of cement, 3 parts of sand and 1/2 part of water. 225 g water, 450 g cement and 1350 g standard sand (Rilem–Cembreu) were used for each mortar. The silicon dioxide (SiO_2) content of sand was at least 90%. The water/cement (W/C) ratio was 0.485. Mortar mixtures were prepared in a laboratory mixer with a capacity of 5 L.

Cement and sand were mixed at low speed for 1 min to provide homogeneity. After adding water to the mixture, it was mixed at low speed during the first minute, at a high-speed for the second minute. After the mixing process, three mortar specimens were cast in moulds of 40 × 40 × 160 mm for the tensile test. Portions of prisms broken in bending test were used for compressive strength test. Six specimens were cast in moulds of 25 × 25 × 285 mm for the sulfate resistance and shrinkage tests.

Specimens were kept in the room with 20 °C temperature and 90% relative humidity for 24 h. The specimens were removed from the moulds after 24 h. They were placed in pools at a temperature of 20 °C until the tensile and compressive strength tests day. The pool water was constantly ventilated and changed once every 14 days. The tensile and compressive strengths of the mortars were determined according to TS EN 196-1 [24]. The sulfate resistance of the produced specimens was determined according to ASTM C1012 [25]. The mortar specimens were immersed in a 50 g/l Na_2SO_4 (sodium sulfate) solution. The lengths of the specimens