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Effect of heat treatment on pozzolanic activity of volcanic pumice used as cementitious material

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ABSTRACT

Volcanic pumice (VP) is a highly vesicular material derived from acidic lavas. It substantially contains amorphous silica, and widely used in many industry, such as construction, textile, chemical and agricultural industries, due to its physical properties. The study is aimed to evaluate the suitability of finely ground (−20 μm) and/or heated (at 1000 °C) volcanic pumice powder to be used as a supplementary cementitious material. Mortar cylinders were prepared using finely ground natural pumice powder, and heated (1000 °C) pumice powder (0–20%) at different mixes ratios as cement replacement. The results from this study showed that the heat treatment significantly affected the pozzolanic activity of VP, and use of heated-ground pumice as a supplementary cementitious material increased the strength of mortar up to 7% in 90 days as well as 7- and, 28-day strengths.

1. Introduction

Portland cement is one of the most significant inventions in the history of humanity. At the end of the first decade of the third millennium, the cement production in the world has been reached up to 3.7 billion tonnes [1]. On the other hand, 3 billion tonnes of CO_2 (known as greenhouse gas) is emissioned per year because of the cement production, which is more than 5% of CO_2 released in the planet [2–4].

Recently, many researchers [5–14] have focused on finding alternative binders or cement replacement materials (pozzolan) reducing the amount of the emission of CO_2 from the social, economical, technological, and particularly ecological points of view. These studies showed that fly ash (FA), blast furnace slug (BFS), rice husk ash (RHA), silica fume (SF), volcanic ash (VA), and volcanic pumice (VP) could be used as cement replacement materials in the concrete. Cement replacement materials containing pozzolans have many other beneficial features besides their strength properties.

A pozzolan is a siliceous or siliceous and aluminous material, which in itself possesses little or no cementing property but will, in a finely divided form – and in the presence of moisture – chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties [15–19].

Kiattakamol et al. [19] reported that fly ash mortar containing 20% FA reduced the strength of the control mortar (CM) by 10% at 28 days. Li [20] found that late compressive strength (112 days) of FA concrete gave a 6% lower strength than that of CM when replaced with cement by 20%. Tangpagasit et al. [21] studied the effect of FA with different sizes as a mineral admixture. They also observed that FA mortar containing 20% FA with smaller particles size (d_{50} = 2.7 μm) showed a higher compressive strength than that of with larger particles size at 28 days. Additionally, they reported that the mortars made with raw FA gave a lower strength than that of CM.

Hossain [5] investigated the pozzolanic activity of VA. The results indicated that that VA as a cementitious material decreased the compressive strength of CM. Additionally, the strength activity index (SAI) value ranged between 67% and 100% at 28 days, and the SAI values for the mixes with 10%, 20% and 30% of VA content was higher than 75%. However, the compressive strength of VA mortars generally decreased with the increase in the VA content.

Nehdi et al. [22] reported that using Egyptian RHA at the weight of 7.5%, 10%, and 12.5% cement replacement increased the compressive strength of concrete up to 20%, 27%, and 40% at 56 days, respectively. de Sensale [23] reported that the use of RHA (20%) contributed by up to 14% to the strength of CM at 91 days.

Qing et al. [24] showed that substituting SF with cement at 2%, 3%, and 5% increased the 28-day-strength of the paste up to 6%, 16%, and%20, respectively. Furthermore, the compressive strength of the SF pastes at the 60 days curing time increased to 7%, 10% and 13%, respectively. Nehdi et al. [22] found that the use of SF as a cement replacement at 12.5% increased the compressive strength of concrete by up to 22% at 56 days. Rao [25] reported that

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using SF (20%), a supplementary cementitious material, increased the compressive strength of mortar by up to 40% at the end of 90 days. They also suggested that SF content should be in the ranges between 15% and 22%.

As known from the literature, supplementary cementitious materials used for making very high strength concrete must have a higher SAI than that of corresponding PC concrete. Even tough, they are pozzolanically active mineral admixtures, FA, VA, and VP has always a lower SAI than 100%. On the other hand, the SAI of RHA and SF are higher than 100% at the ranges of optimum content, especially at the late ages of the concrete. Therefore, SF, beyond other benefits, is chosen as favourite additive for very high-strength concretes. But, the available amount of SF is insufficient to be used as the supplementary cementitious material because of increasing demand of high performance concrete.

Volcanic pumice contains a great amount of amorphous silica (SiO_2) which combines with lime (CaOH) and forms a cementitious material. Some researchers [5,26–29] studied the use of finely ground volcanic pumice (VP) as a cement replacement material. And, these studies showed that VP as a mineral admixture showed a pozzolanic effect but decreased the SAI of CM. Although ultrafined VP and SF are the products of high temperatures and sudden cooling, and their amorphous silica contents, VP as the replacement material decreased the SAI of CM unlike SF.

Several studies in the literature indicated that heat treatment may increase the physical properties of minerals [30–32]. As already known, pumice is a highly vesicular material derived from acidic lavas and produced in very large quantities, and substantially contains amorphous silica (SiO_2). Meanwhile, Turkey received over 3 billion cubic meters of pumice, which is 14% of the world deposits [38]. In this context, the aim of this study is to investigate the pozzolanic activity of finely ground VP after the heat treatment process. And, this study presents the results of the effect of the heat treatment on the pozzolanic activity and SAI of VP replaced with Portland cement at 90-day strength of mortar as well as 7-day, and 28-day strengths.

2. Experimental investigation

2.1. Materials

The volcanic pumice (VP) used in this study was supplied from the Isparta region in the Southern of Turkey. Normal Portland cement (PC) which is comparable to ASTM Type I (42.5 N/mm^2) was used in this study. The sand used in this study was obtained from Limak cement factory (Istanbul, Turkey) satisfying the standards of TS-EN 196-1 [33].

2.1.1. Characterization of materials

In order to investigate the effect of the heat treatment on pozzolanic activity of VP, the pumice specimen was first separated into two groups; natural volcanic pumice (NVP) and heated volcanic pumice (HVP). First, NVP was crushed in a primary crusher, and then dry ground by a ball mill. On the other hand, HVP was first subjected to the heat treatment up to 1000 °C, and then suddenly cooled down to the room temperature (25 °C ±1). Finally, it was crushed and ground.

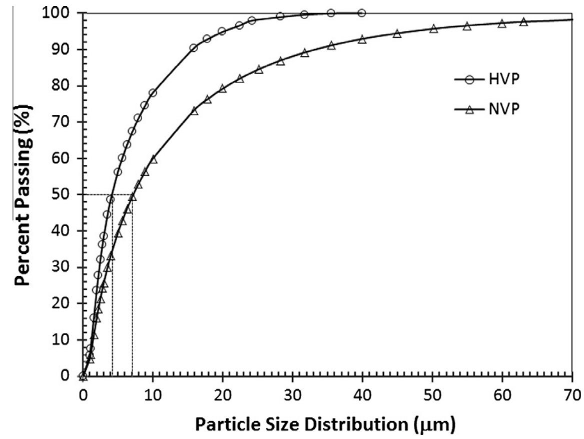

Fig. 1. Particle size distributions of NVP and HVP.

The chemical analyses of NVP and HVP were determined separately in order to understand the chemical chances on the sample composition after the heat treatment, and the results are presented in Table 1 additionally with the chemical properties of PC, alternatively SF [6], RHA [23], and FA [8], which are used as supplementary cementitious materials. As clearly seen from Table 1, the heating process showed no significant effect on the chemical compositions of the samples. According to the chemical analysis, the pumice is very rich in silica content. Because of its high silica content the composition of VP is similar to those of SF. While the sum of the contents of $SiO_2 + Al_2O_3 + Fe_2O_3$ of SF is equal to 86.86%, this value is 89.21% for VP.

It is known that the fineness of cementitious material is one of the most important properties affecting the pozzolanic activity of the supplementary mineral admixtures. For this reason, the particle size distributions of NVP and HVP were obtained by using 3600 Laser particle size analyser manufactured by Mastersizers Malvern Instruments, UK. The results shown in Fig. 1 indicate that the average particle sizes of the both samples are less than 10 μm (d_{50} of NVP and HVP is 7 and 4 μm, respectively) which prove that the samples were ground to fine sizes.

The physical and mechanical properties of NVP, HVP, PC, and SF are presented in Table 2. Blaine's fineness of NVP and HVP were found to be 16,400 cm^2/g and 21,400 cm^2/g, respectively. This difference can be attributed to their particle size distributions. On the other hand, the other properties of the samples are quite similar. As seen in Table 2, SF has the lowest bulk density compared with PC, NVP, and HVP. Additionally, the specific gravity of SF is less than that of NVP and HVP due to their higher Fe_2O_3 (14%) and Al_2O_3 (2%) contents.

Thermal gravimetric analysis (TGA) of NVP was made for determination of changes in physical and chemical properties as a function of increasing temperature. The TGA results of NVP (Fig. 2) showed that there was no significant change on the weight of the sample indicating no specific calcination occurred during the

Table 1
Chemical analysis of PC, NVP, HVP, SF, RHA, and FA.

Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	LOI	$SiO_2 + Al_2O_3 + Fe_2O_3$
PC	20.62	5.65	4.05	62.08	2.55	2.57	0.81	0.12	1.55	30.32
NVP	72.58	14.49	2.14	1.08	0.11	0.06	4.92	4.03	–	89.21
HVP	72.53	13.86	1.82	1.03	0.09	0.03	5.06	3.40	–	88.21
SF	85.9	0.64	0.32	0.70	4.91	0.63	NA	NA	NA	86.86
RHA	88	–	0.1	0.8	0.2	–	2.2	0.7	8.1	88.10
FA	59.9	21.6	4.7	2.9	1.4	0.2	2.3	0.4	5.8	86.20