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The effects of silica modulus and aging on compressive strength of pumice-based geopolymer composites

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HIGHLIGHTS

- Pumice based geopolymer cement is a good alternative for ordinary cement.
- The aging before 28 days has a remarkable effect on compressive strength gaining in pumice based geopolymer.
- Geopolymer has economic benefit in countries like Turkey that are rich in pumice resources.
- Pumice based geopolymers can be used as a structural material.
- Pumice based geopolymers has potential for using as green building material.

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ABSTRACT

The environmental impact of Portland cement is significant. In the procedure of cement production, production of one ton cement releases about one ton CO_2 in environment. To enhance material greenness and produce alternative binders as a geopolymer, the physical and mechanical properties of Hasankale based pumice geopolymer has been discussed in this study and to identify the best geopolymer mix ratios, varying silica modulus (Ms = SiO_2/Na_2O), water/binder (w/b) and Na_2O content have been investigated via trial and error approach. Hence nine series of geopolymer pastes differing in Na_2O content (4%, 7% and 10%), silica modulus (0.52, 0.6 and 0.68) and w/b ratios (0.36, 0.40 and 0.44) were manufactured to activating Hasankale based ground pumice in this study. The test results indicated that the mix with Ms = 0.68, Na_2O = 0.10%, w/b = 0.36 gave the higher compressive strength approximately 40 Mpa. These test results indicated that the produced geopolymers compressive strength were high enough and can be used as a structural material. Turkey is one of the richest countries in terms of pumice resources in the world. Regarding to the reduction of necessary energy to produce Portland cement, it is expected to have economic benefit too.

1. Introduction

Under the 2009 Copenhagen treaty, more than 120 countries have agreed to keep global average temperature increase below 2 °C. This is an urgent goal, because many scientists estimate that the concentrations of CO_2 in the atmosphere already exceed the safe level [1,2]. Buildings are energy consuming sector that have large impact on global climate change. Buildings are responsible for almost 40% of the total primary energy consumption and 70% of electricity consumption. About 40% of CO_2, 50% of SO_2, and 20% of NO_x emissions are produced in the USA as a result of building related energy consumption [3] and concrete made from ordinary Portland cement is second only to water as the most material used by mankind today and the cement production contributing for concrete product 5–8% of global CO_2 emission in the world [4]. The geopolymerization of aluminosilicates constitutes radical change in construction materials chemistry and synthesis pathway compared with the calcium silicate hydrate chemistry which underpins Portland cement. Demand pull by carbon conscious market continue to be the key driver for the short term adoption of Geopolymer cement.

2. Geopolymers

Geopolymers are amorphous three dimensional aluminosilicate materials with ceramic-like properties that are produced and hardened at ambient temperature. Compared to Portland cement, the

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Table 1
Chemical composition of Hasankale ground pumice.

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	$K_2O + Na_2O$	Others	LOI
67.08	14.06	1.91	0.87	0.25	0.11	15.72	3.94

Table 2
Some of determined materials in the Hasankale pumice from XRD.

No	Mineral name	Framework formula
1	Cristobalit, high	SiO_2
2	Silicium dioxide	SiO_2
3	Labrodorit	$(Na_{0.4}Ca_{0.6})Al_{1.6}Si_{2.4}O_8$
4	Cristobalit, low	SiO_2
5	Albit, high, sodium-tectosilicate	$Na(AlSi_3O_8)$

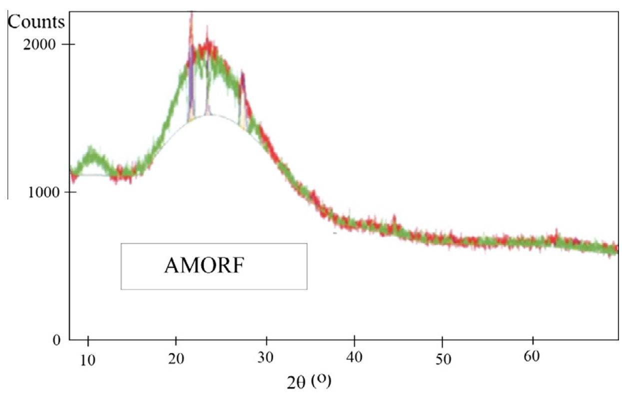

Fig. 1. X-ray diffraction pattern of Hasankale pumice.

Fig. 2. The mill used for grinding the pumice.

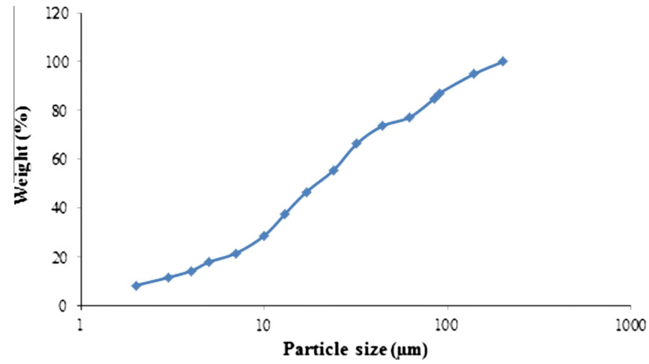

Fig. 3. Particle size distribution of ground Hasankale pumice.

basic properties of geopolymers are quick compressive strength development, low permeability, resistance to acid attacks, good resistance to freeze–thaw cycles, and a tendency to drastically reduce the mobility of most heavy-metal ions contained within the geopolymeric structure [5–7]. These characteristics enable geopolymers to be promising building, high-strength, toxic-waste immobilizing, sealing, and temperature-resistant materials [8,9]. Moreover, compared to Portland cement, geopolymers have significant advantages in the preparation process. The preparation does not require high temperatures for calcining or sintering, meaning that the polymerization reaction could be performed at room temperature. Almost no generation is created of NO_x, SO_x, and CO, and the emission of CO_2 is also significantly low [10]. Under highly alkaline conditions, in the presence of alkali hydroxide and silicate solution, polymerization takes place when reactive aluminosilicates are rapidly dissolved and free $[SiO_4]$ and $[AlO_4]$ tetrahedral units are released in solution [11,12]. The tetrahedral units are alternatively linked to polymeric precursors by sharing oxygen atoms forming thus amorphous geopolymer. Positive ions such as K^+ or Na^+ that are present in frame work cavities, balance the negative charge. For the chemical designation of geopolymers based on silica-aluminates, the term poly(sialate) that is an abbreviation for silicon-oxo-aluminates has been proposed. Poly(sialates) are chain and ring polymers with Si^{4+} and Al^{3+} and their general formula is $M_n[-(SiO_2)_z\text{-}AlO_2]_n{\cdot}wH_2O$ where M is a monovalent cation such as K^+ or Na^+, n is the degree of poly-condensation and z is 1,2 or $z \gg 3$. Chains and rings are formed and cross linked together always through a sialate Si–O–Al bridge [11,13–17].

3. Materials and methods

3.1. Mineralogy and definition of pumice

The name pumice is derived from the Latin word pumex, meaning foam. Pumice is usually White or gray and is a highly vesiculated pyroclastic material which at the moment of effusion was almost liquid. In other word pumice is superheated lava spewed into the air and cooled. Depending on what minerals are in the lava, its color ranges from white to gold to brown and even, in black. With all those bubbles inside, it is comparatively light in weight, and when it falls in water, or is washed into a river by rain or flood, it may float many miles from the point where it fell to earth. Natural pumice used in present study has been obtained from Hasankale region near Erzurum located in the east of Turkey. The pozzolan firstly has been characterized for its chemical composition. The chemical composition has been

Table 3
Physical and chemical properties of sodium hydroxide, sodium silicate and super plasticizer.

Alkaline liquids properties	Chemical formula	SiO_2	Na_2O	Appearance	H_2O	NaOH	Specific gravity (20 °C)
Sodium hydroxide	$NaOH{*}H_2O$			Gel	67–68	32–33	1.35
Sodium silicate	$Na_2O{*}SiO_2$ colorless	22–24	11–12	Gel	64–67		1.38–1.40
Super plasticizer's properties	Density (g/cm^3) (20 °C)	Chlorine% (En 480-10)	Color	Homogenity	Chemical content		
	1.023–1.063	<0.1	Green	Homogenous	Synthetic polymer based		