Construction and Building Materials 124 (2016) 606–614

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Mechanical properties and durability of volcanic ash based geopolymer mortars

Jean Noël Yankwa Djobo [a,b,*], Antoine Elimbi [a], Hervé Kouamo Tchakouté [a], Sanjay Kumar [b]

[a] Laboratory of Applied Inorganic Chemistry, Department of Inorganic Chemistry, Faculty of Science, University of Yaoundé I, P.O. Box 812, Yaoundé, Cameroon
[b] CSIR-National Metallurgical Laboratory, Jamshedpur 831007, India

HIGHLIGHTS

- Volcanic ash based geopolymer mortars perform well under wet-dry cycles.
- Samples cured at 27 °C have better acid resistance than those cured at 80 °C.
- The interaction of sulfuric acid with geopolymer binder led gypsum formation.

ARTICLE INFO

Article history:
Received 6 June 2016
Received in revised form 27 July 2016
Accepted 29 July 2016

Keywords:
Mechanical properties
Durability
Volcanic ash
Geopolymer
Curing temperature

ABSTRACT

The mechanical properties and durability of volcanic ash based geopolymer mortars synthesized at 27 °C and 80 °C were evaluated. The water absorption and apparent porosity increase up to 28 days, then become almost constant with time. The bulk density of specimens cured at 27 °C decreases continuously with time, whereas it doesn't change considerably with time for specimens cured at 80 °C. Geopolymer specimens cured at 27 °C achieved the compressive strength of 20.5 MPa after 28 days and it no longer increases significantly with time. While a maximum strength of 37.9 MPa is reached at 90 days for specimens cured at 80 °C. Specimens performed well in wetting and drying conditions. Geopolymer specimens obtained at 27 °C developed a better resistance to 5% sulfuric acid than the ones cured at 80 °C. The microstructure of geopolymer specimens after acid exposure revealed the formation of gypsum as a secondary phase due to the reaction between sulfuric acid and calcium from geopolymer gel. The presence of Na-rich gel in specimen cured at 27 °C enhances its acid resistance. The pore structure and permeability are the key factors affecting the durability of volcanic ash based geopolymer mortars.

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1. Introduction

Geopolymers are a new class of three-dimensional inorganic polymer obtained by reaction of an aluminosilicate material (e.g., metakaolin, fly ash, natural pozzolan, etc.) with an alkaline solution. The basic monomer unit is called sialate (O—Si—O—Al—O), which consists of SiO_4 and AlO_4 tetrahedra linked alternatively by sharing all the oxygen [1]. The negative charge due to the substitution of Si^{4+} by Al^{3+} is balanced by alkali metal cation such as K^+, Na^+ or Ca^{2+} etc. Geopolymer materials have drawn more attention in the past decade, mostly because of low CO_2 emission and also due to its good physical and mechanical properties and excellent durability. These properties are closely linked to the nature of aluminosilicate materials used which is the first parameter to consider for geopolymer making. The most used aluminosilicate are metakaolin and fly ash or their mix with some waste materials like slag, red mud, rice husk ash, coal bottom ash etc. For those aluminosilicate materials, many studies ranging from the understanding of their basic synthesis conditions to the assessing of their long-term mechanical and durability properties have been reported [2–6]. Since 10 years some interesting works have been undertaking on the utilization of natural pozzolan such as volcanic ashes (pumice, tuff, and scoria) in geopolymer synthesis [7–12]. Most of these works focused on the understanding of the suitability of volcanic ash for geopolymer synthesis in different synthesis condition by assessing their engineering properties [8,11,13–15]. Furthermore, the durability of volcanic ash based geopolymers has paid less attention, whereas for their wide application such studies should be concerned. The durability

* Corresponding author at: Laboratory of Applied Inorganic Chemistry, Department of Inorganic Chemistry, Faculty of Science, University of Yaoundé I, P.O. Box 812, Yaoundé, Cameroon.
E-mail address: noeldjobo@gmail.com (J.N. Yankwa Djobo).

http://dx.doi.org/10.1016/j.conbuildmat.2016.07.141
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studies of volcanic ash based geopolymer reported in the literature include the work of Bondar et al. [16] who studied the sulfate resistance of alkali-activated volcanic ash based geopolymer concrete, and recorded a loss of compressive strength and percentage of expansion up to 19.4% and 0.074, respectively. The efflorescence occurred in volcanic ash based geopolymer has also been reported [17]. Authors showed that it is controlled by the aluminum availability in the raw material. Thus, by using Al-rich mineral admixtures such as metakaolin, amorphous alumina oxide, bauxite, ground granulated blast-furnace slag or by optimizing the curing conditions to enhance more alumina release from volcanic ash the mitigation of efflorescence was observed [10,15,17,18]. In addition to these studies the acid resistance of volcanic ash based geopolymer mortars and their resistance under sudden changes weather from dry to humid also need to be addressed further. It is worth noting that under acidic medium the geopolymer binders deterioration involves the breakage of Si—O—Al bonds, the increased in the number of Si—OH and Al—OH bond along with the increased of the amount of silicic acid in the geopolymer matrix [19]. This process leads to the de-alumination of geopolymer gel and the rise of its Si/Al ratio, resulting in weight loss. The compressive strength loss is mainly related to cracks appearance inside the geopolymer structure due to the breakdown of the aluminosilicate framework on acid exposure. Regarding the resistance under sudden changes of weather this are measured through wet and dry cycle tests. The deterioration of building materials under these conditions includes the drying shrinkage related to the water evaporation in a hot weather, and to the cracks appearance due the sudden humid climate, which results in strength reduction or materials collapse [20]. This type of weather is typical of the tropical zone such as Cameroon.

Therefore, the work reported herein aimed to study the long-term physical and mechanical properties evolution of volcanic ash based geopolymer mortars obtained at different curing temperatures, along with their resistance to aggressive environment. The physical and mechanical properties evolution was studied over a period of 6 months. The durability tests reported in this work included the sulfuric acid resistance during 180 days and the wet-dry cycling test for 25 cycles. The microstructural analysis has been used to explain the mechanism of sulfuric acid attack on synthesized specimens.

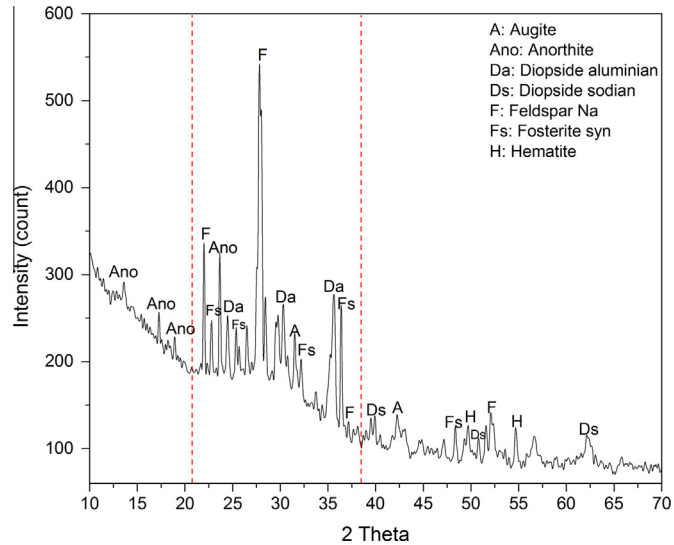

Fig. 1. XRD patterns of volcanic ash.

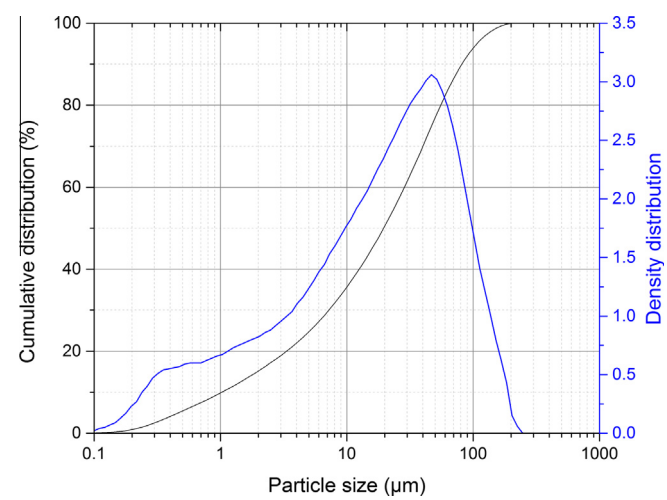

Fig. 2. Particle size distribution of volcanic ash.

2. Materials and experimental methods

2.1. Materials and characterization

Volcanic ash used in this work was collected at the volcanic deposit of Djoungo located N 04° 34′ 57.4″ and altitude 129 m (Littoral Region of Cameroon). This volcanic ash is currently used by a local cement industry (CIMENCAM) as pozzolanic materials. The volcanic ash was ground in a ball mill in order to have a fine powder of particles <200 μm. The chemical composition of volcanic ash carried out by X-ray fluorescence spectrometer (Bruker S8 Tiger) is reported in Table 1. The mineralogical composition of volcanic ash determined using Bruker X-ray diffractometer (D8 Discovery, US), is shown in Fig.1 and includes: Anorthite ($Ca(Al_2Si_2O_8)$, PDF #89-1459); Feldspar-Na ($NaAlSi_3O_8$, PDF #89-8575); Hematite (Fe_2O_3, PDF #03-0812); Forsterite syn (Mg_2SiO_4, PDF #85-1357); Diopside aluminian [(Ca (Mg, Fe, Al) $(Si, Al)_2O_6$), PDF #38-0466]; Diopside sodian [$(Ca_{0.52}Na_{0.29}Fe_{0.10}Mg_{0.09})(Mg_{0.057}Fe_{0.14}Al_{0.27}Mn_{0.01}Ti_{0.01})(Si_2O_6)$, PDF #85-1692];. Augite ($Ca_{0.61}Mg_{0.76}Fe_{0.49}(SiO_3)_2$, PDF #76-0544). The particle size analysis of volcanic ash is depicted Fig. 2 and was determined using laser particle size analyzer (MASTERSIZER S, Malvern, UK). It has a bimodal distribution and mean diameters: d_{10} = 1.03 μm; d_{50} = 19.54 μm and d_{90} = 81.20 μm. The specific gravity of volcanic ash used was 2.62.

The alkaline solution used consisted of a mixture of an analytical grade of sodium silicate and sodium hydroxide, with a final composition in the molar ratio: SiO_2/Na_2O = 1.4 and H_2O/Na_2O = 16.7. This was obtained by mixing sodium silicate solution (SiO_2: 25.5–28.5; Na_2O: 7.5–8.5) and sodium hydroxide solution (12 M) with a mass ratio Na_2SiO_3/NaOH of 2.4.

Table 1
Chemical composition of volcanic ash.

Oxides	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	TiO_2	K_2O	MnO	P_2O_5	LOI	Total
Wt%	46.28	15.41	13.32	9.07	6.74	3.88	2.84	1.42	0.19	0.63	−0.4	99.88

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