Construction and Building Materials 160 (2018) 66–81

Contents lists available at ScienceDirect

Construction and Building Materials

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

Mechanical and thermal properties of fly ash based geopolymers

Fenghong Fan [a], Zhen Liu [a,*], Guoji Xu [a], Hui Peng [a,b], C.S. Cai [a]

[a] Dept. of Civil and Environmental Engineering, Louisiana State University, Baton Rouge, LA 70803, United States
[b] Dept. of Civil and Architecture Engineering, Changsha University of Science and Technology, Changsha, Hunan Province 410076, China

HIGHLIGHTS

- Preparation of high compressive strength geopolymer with fly ash.
- Studying the thermal behavior of fly ash based geopolymer.
- Investigating the microstructural changes for the geopolymer samples after heating and cooling.

ARTICLE INFO

Article history:
Received 24 June 2017
Received in revised form 2 October 2017
Accepted 8 November 2017

Keywords:
Thermal
Mechanical
Heating
Fly ash
Geopolymer
Microstructure

ABSTRACT

The traditional cement industry consumes a large quantity of energy and emits greenhouse gas CO_2. With the promotion of sustainable development, attentions have been drawn to how to develop a "green" material with similar or even better engineering properties than ordinary Portland cement (OPC), and geopolymer has been recognized as one of the most promising materials. In this study, an experimental investigation on the thermo-mechanical properties of geopolymers prepared using a class F fly ash, KOH and Na_2SiO_3 is presented. Based on the testing results, the effects of water/ash ratio, curing methods, cooling methods, and sealing degree on the compressive strength and thermal properties of the geopolymer products are studied. The tested results show that the geopolymer cured at appropriate conditions can reach a compressive strength of more than 100 MPa and a good residual strength (up to 96 MPa) after 500 °C heating. The geopolymer sample with a water/ash ratio of 0.2 shrinks 2.0% in the longitudinal direction after 500 °C heating, while expanses 9.4% after 800 °C heating. In addition, it is found that the studied geopolymer possesses good spallation resistance when cooled down in water after high temperature heating.

1. Introduction

Concrete is currently one of the most widely used construction materials around the world due to its good engineering properties. However, it has also been identified with problems, such that the production of traditional cement consumes a large quantity of energy and emits greenhouse gas CO_2. Approximately 5% of global CO_2 are produced by the industry of Ordinary Portland cement (OPC) [1,2]. With the promotion of sustainable development, attentions have been drawn to how to develop a "green" material with similar or even better engineering properties than OPC, and geopolymer has been recognized as one of the most promising materials.

Geopolymer, first coined by the French scientist Joseph Davidovits, is an inorganic material formed by alkaline activation of alumina- and silica-containing material through a polycondensation process in which the tetrahedral silica (SiO_2) and alumina (AlO_4) are linked with each other via sharing the oxygen atoms (e.g., $(-Si-O-Al-O-)_n$, $(-Si-O-Al-O-Si-O-)_n$, and $(-Si-O-Al-O-Si-O-Si-O-)_n$). A general chemical structure of geopolymer could be expressed as [2–4]:

$$M_n\{-(SiO_2)_q-AlO_2-\}_n$$

where M denotes an alkali cation, n represents the degree of polycondensation, and q is the Si/Al ratio.

In the past years, research has revealed that geopolymers with high compressive strength, good acid resistance, and good fire resistance could be synthesized from a variety of low cost materials or industrial by-products, such as fly ash, rice husk ash, and furnace slag. These characteristics render geopolymer promising potentials in civil engineering applications as a "green" material [1,5–10].

* Corresponding author.
E-mail address: zhenliu.ce@gmail.com (Z. Liu).

https://doi.org/10.1016/j.conbuildmat.2017.11.023
0950-0618/

Table 1
Composition of fly ash (wt%).

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Loss of ignition	Moisture
52.06	20.54	5.50	14.07	3.29	0.57	0.94	0.69	0.10	0.01

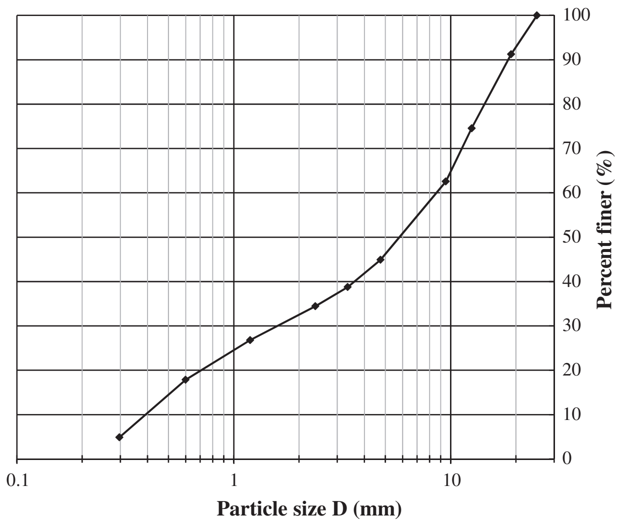

Fig. 1. Particle size distribution curve of the Class F fly ash.

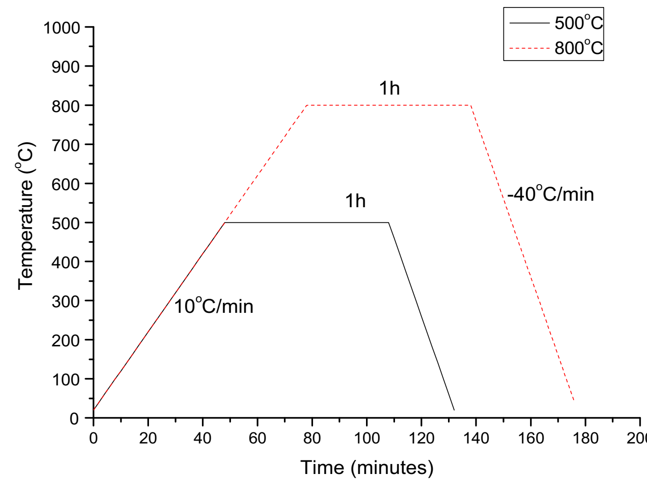

Fig. 2. The heating curve in different temperatures.

Comparing to the ordinary Portland cement (OPC) which degrades in strength irreversibly starting at 200 °C [11], geopolymer has been characterized with a great potential as a fire-resisting material in civil engineering [12–14]. However, there is a lack of research in balancing both the mechanical properties and thermal properties of geopolymer and investigating the effects of cooling methods. Aiming to develop a green material with both high compressive strength and good fire resistance, this paper therefore presents an experimental study to investigate the mechanical and thermal properties of geopolymer. Fly ash, which contains large quantities of reactive silicon dioxide and aluminum dioxide, was selected as the raw material to synthesize the geopolymer. Because the mechanical properties of geopolymer depend on the selection of raw materials, precursors with variant Si/Al molar ratios and water contents were prepared to synthesize geopolymers. In this study, properties of the synthesized geopolymer samples, including the compressive strength, shrinkage, weight loss, and chemical composition have been characterized. Based on the testing results, the effects of the water/ash ratio, curing methods, cooling methods, and sealing degree on the compressive strength and thermal properties of the geopolymer specimens are further studied and analyzed.

2. Materials used and experimental methodology

2.1. Fly ash

A Class F fly ash from Boral Material Technologies, Inc. (Monticello, Texas, USA) was used as the raw material for the synthesis of geopolymer. Based on its chemical composition analysis (Table 1), the Si/Al molar ratio in this class F fly ash is 2.15, with a specific gravity of 2.46. The particle distribution is shown in Fig. 1.

2.2. Geopolymer synthesis

The properties of geopolymer vary with the raw materials and processing conditions [8]. Variant Si/Al molar ratios and water contents were applied with potassium hydroxide (88% purity quotient, Sigma–Aldrich Co., USA) to prepare the precursors. The synthesis of geopolymers was accomplished by mixing the Class F fly ash with the precursors prepared with a commercial sodium silicate solution consisting of 9.07 wt% Na_2O and 29.35 wt% SiO_2 (Aqua Solutions Inc., USA). The mixture combinations and associated designations are shown in Table 2. Samples were casted in plastic cylinders with a dimension of 19.05 mm in diameter and 50.8 mm in height.

Table 2
Geopolymer mixture combinations.

Mixture No.	Water/ash	$Na_2O(SiO_2)_n$/KOH	Curing regime	Si/Al (mol)	Si/M (mol)
1	0.2	1.6	22 °C (24 h)–80 °C (24 h)	2.40	3.60
2	0.25	1.6	22 °C (24 h)–80 °C (24 h)	2.50	3.09
3	0.3	1.6	22 °C (24 h)–80 °C (24 h)	2.59	2.74
4	0.35	1.6	22 °C (24 h)–80 °C (24 h)	2.69	2.47
5	0.4	1.6	22 °C (24 h)–80 °C (20 h)	2.78	2.27
6	0.25	1.6	22 °C (24 h)–80 °C (20 h)	2.50	3.09
7	0.25	1.6	22 °C (24 h)–60 °C (20 h)	2.50	3.09
8	0.25	1.6	60 °C (24 h)	2.50	3.09
9	0.2	1.6	80 °C (24 h)	2.40	3.60
10	0.2	1.6	22 °C (24 h)–80 °C (20 h)	2.40	3.60

Note: All the cases were considered 6% crystal SiO_2 (Quartz) in the fly ash; M = (Na, K).