Construction and Building Materials 186 (2018) 62–70

Contents lists available at ScienceDirect

Construction and Building Materials

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

Mechanical properties, microstructure and drying shrinkage of hybrid fly ash-basalt fiber geopolymer paste

Wonsiri Punurai [a], Wunchock Kroehong [b,*], Adam Saptamongkol [b], Prinya Chindaprasirt [c]

[a] Department of Civil and Environmental Engineering, Faculty of Engineering, Mahidol University, Salaya Campus, Nakhonpathom 73170, Thailand
[b] Department of Civil Engineering, Faculty of Engineering and Architecture, Uthenthawai Campus, Rajamangala University of Technology Tawan-ok, Bangkok 10330, Thailand
[c] Sustainable Infrastructure Research and Development Center, Department of Civil Engineering, Faculty of Engineering, Khon Kaen University, Khon Kaen 40002, Thailand

HIGHLIGHTS

- Basalt fiber in geopolymer composites significantly improves the strength.
- Setting times were found to increase with the increase of basalt fiber content.
- Basalt fibers in geopolymer pastes resulted in reduced drying shrinkage of paste.
- Fly ash geopolymer paste containing basalt fiber was more homogeneous and denser.

ARTICLE INFO

Article history:
Received 1 December 2017
Received in revised form 20 April 2018
Accepted 16 July 2018

Keywords:
Geopolymer
Basalt fiber
Strength
Microstructure
Drying shrinkage

ABSTRACT

This paper evaluates the mechanical properties, microstructure and drying shrinkage of hybrid fly ash-basalt fiber geopolymer paste. Fly ash was replaced with basalt fiber at the replacement levels of 0, 10, 20, 30, 40 and 100%. Na_2SiO_3/NaOH ratio of 1.0 and liquid to binder (L/B) ratio of 0.60 were used for making geopolymer pastes. Setting time, strength and drying shrinkage of geopolymer pastes were tested. The results showed that the replacement of fly ash with basalt fibers in geopolymer pastes resulted in increased setting times and strength and reduced drying shrinkage of paste. The basalt fiber acted as small reinforcing fibers and enhanced the development of CSH, CASH and NASH which further enhanced the properties of paste. In addition, the total porosity and critical pore size of fly ash geopolymer paste reduce with increasing replacement content in fly ash which makes the paste more homogeneous and dense compared to fly ash geopolymer.

1. Introduction

The manufacture of ordinary Portland cement employs a large amount of energy and results in substantial global greenhouse gas emissions [1]. Geopolymer, an alternative binder with low energy consumption and low CO_2 emissions was discovered in 1978 by Joseph Davidovits [1]. Geopolymeric materials have been widely studied and show a great potential with environmental and technical benefits [2]. The mechanical properties and durability of geopolymer materials have been rated as similar to or better than those of Portland cement. Several researchers have studied the use of geopolymers in various civil engineering applications such as pavements [3,4] masonry structures [5] repair materials [6] and reinforced geopolymer concretes [7,8].

Fly ash (FA) is a waste material from coal fired power plants. A large amount of fly ash produced in Thailand comes from the largest coal power plant owned by the Electricity Generating Authority of Thailand in Mae Moh district, Lampang Province in northern Thailand. To produce geopolymers, fly ash can be activated with NaOH for the dissolution of Al and Si, and with Na_2SiO_3 for geopolymerization leading to the hardening of the geopolymer. A number of researchers have proposed ways to make good fly ash based geopolymers. Rattanasak and Chindaprasirt [9] found that the concentration of NaOH of 10 M and the weight ratio of Na_2SiO_3 to NaOH of 1 are suitable for making high calcium fly ash geopolymer binders with satisfactory properties. Pangdaeng et al. [10] showed that the high calcium content enhanced the strength development of high calcium fly ash geopolymer. The presence of calcium leads to the development of calcium silicate hydrate (CSH) and aluminium calcium silicate hydrate (CASH). These products co-exist with sodium aluminosilicate hydrate (NASH) type gels which are connected to the initial setting and hardening of

* Corresponding author.
E-mail address: wunchock_k@hotmail.com (W. Kroehong).

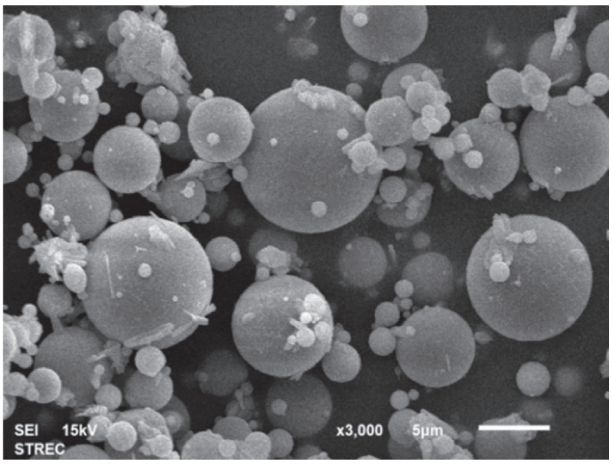
https://doi.org/10.1016/j.conbuildmat.2018.07.115
0950-0618/

fly ash geopolymer at ambient temperatures. Lately, it has been shown that the mechanical properties of geopolymer could be enhanced with the use of binary starting materials with the resulting integration of reaction products [10,11].

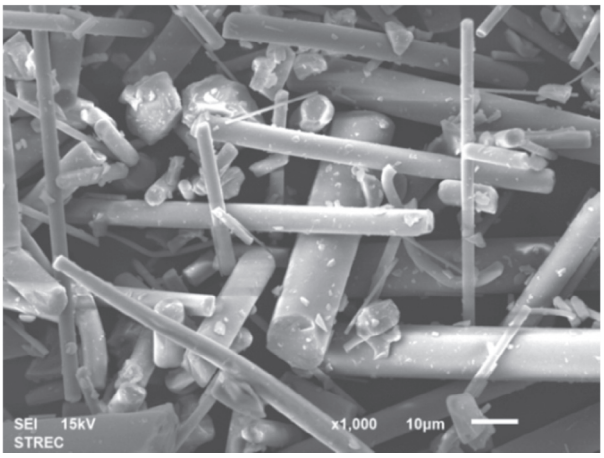
Other researchers described the effect of calcium content on drying shrinkage of geopolymers. It has been shown that the participation of high calcium content in geopolymer leads to the improvement of compressive strength and reduction in drying shrinkage. Yusuf et al. [12] studied geopolymer pastes using a blend of palm oil fuel ash and steel slag and reported that the shrinkage of geopolymer could be reduced by incorporating more than 50% steel slag. Lee et al. [13] also found that the incorporation of 10–30% slag gave a denser matrix with reduced drying shrinkage. Ridtirud et al. [14] reported that the drying shrinkage of geopolymer was closely related to the strength of material and was also affected by the liquid content and the curing temperature.

Basalt fiber (BF) is a modified natural material obtained from basalt rock through a melting process with an environment friendly, non-toxic, non-carcinogenic and non-hazardous nature [15]. This material has recently gained acceptance as a potential additive in concrete reinforcing applications due to improved mechanical properties [16]. The main chemical compositions of basalt fibers are SiO_2 and CaO [17]. BF helps improve the strength and fire resistance of concrete [15,18,19]. In addition, the shrinkage of concrete was much reduced with the addition of BF [20]. It has also been shown that the increase in compressive strength was correlative to the Ca/Si ratio of geopolymer. The increase of CSH in geopolymer structures provides a denser matrix which results in an increase in compressive strength.

Several researchers have studied the strength and durability of basalt fiber reinforced concrete, but few studies have been conducted and reported concerning the prevalence of hybrid FA-BF geopolymer. This research objective is to study the setting time, strength and drying shrinkage of hybrid high calcium fly ash-basalt fiber geopolymer paste. The fundamental understanding of such properties gained from the findings of the present study will promote the use of fly ash and basalt fiber for making good geopolymer-based hybrid composite systems in various applications.



(a) Fly ash



(b) Basalt fiber

Fig. 1. SEM image of fly ash and basalt fiber.

2. Experimental details

2.1. Materials

The chemical compositions of binder materials are given in Table 1. Fly ash (FA) contains 33.4% SiO_2, 17.8% Al_2O_3, 11.9% FeO_3 and 17.0% CaO meeting the standard chemical requirements of ASTM C618 [14] and can be classified as class C fly ash ($SiO_2 + Al_2O_3 + Fe_2O_3 \geq 50\%$, CaO > 10%). Basalt fiber (BF) contains high content of silica and alumina. The material is considered as pozzolan and can react with calcium hydroxide to form additional hydration products. BF contains 32.8% SiO_2, 13.2%Al_2O_3 and 31.3% CaO. According to the SiO_2 content, this BF can be classified as alkaline basalts ($SiO_2 \leq 42\%$). The particle shapes of FA and BF were determined by scanning electron microscopy (SEM) as shown in Fig. 1. From Fig. 1(a), it can be seen that the FA particles are spherical with smooth surface. For BF [Fig. 1(b)], it can be seen that the particles are mostly cylindrical in shape. The mean diameter is in the range of 5–10 μm while the mean length is in the range of 20–100 μm with a small amount of crushed particles. Particle size distribution of FA and BF are presented in Fig. 2. The measured d_{50} of FA and BF were 21.9 μm and 25.9 μm, respectively. The specific gravity of FA and BF specimens were tested and are reported to be 2.13 and 2.37, respectively. The X-ray diffraction (XRD) analyses of FA and BF are presented in Fig. 3. The appearance of the corresponding peaks in the XRD spectra

Table 1
Chemical compositions and physical properties of FA and basalt fiber.

Chemical compositions and physical properties	FA	BF
SiO_2	33.4	32.8
Al_2O_3	17.8	13.2
Fe_2O_3	11.9	0.81
CaO	17.0	31.3
MgO	2.05	6.39
K_2O	2.36	0.42
Na_2O	1.52	0.46
SO_3	3.57	0.67
LOI	1.23	0.45
Specific gravity	2.13	2.37
Median particle size d_{50} (μm)	21.9	25.87

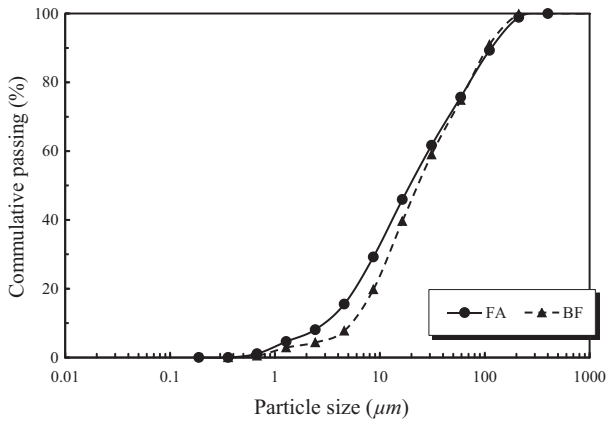


Fig. 2. Particle size distribution of FA and BF.