



# Durability performances of wollastonite, tremolite and basalt fiber-reinforced metakaolin geopolymer composites under sulfate and chloride attack

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## HIGHLIGHTS

- A geopolymer was proposed based on metakaolin blended with mineral particles and fiber.
- The mineral particles and fiber play a reinforced role.
- The resistance to the sulfate and chloride attack was enhanced.
- MK blended with 5% WS, 5% TR and 2% SBF exhibits the optimal strength.

## ARTICLE INFO

### Article history:

Received 19 May 2016

Received in revised form 24 October 2016

Accepted 21 December 2016

Available online 29 December 2016

### Keywords:

Geopolymer  
Metakaolin  
Durability  
Sulfate attack  
Chloride attack  
Mineral particles  
Fiber

## ABSTRACT

This paper aims to investigate the durability related performances of geopolymer composite materials that synthesized by alkali activation of metakaolin (MK) with reinforcement of wollastonite (WS), tremolite (TR) and short basalt fiber (SBF). The resulting geopolymer composites were exposed to sodium sulfate ( $\text{Na}_2\text{SO}_4$ ) solutions (concentration 5–20%) and sodium chloride (NaCl) solution (concentration 5–20%). The compressive strengths, morphological evolution, microstructure and pore structure of the geopolymer composite specimens were examined to evaluate their durability performance. The result showed that the mix of a MK with addition of 5% WS, 5% TR, and 2% SBF exhibits the highest compressive strength in the studied range of mixture design. The compressive strength of geopolymer composites decreased with increasing of the concentration of  $\text{Na}_2\text{SO}_4$  and NaCl solutions, and with the extension of exposure period as well. The average pores size of geopolymer shifted from 22 nm to 92 nm after the sulfate exposure, and the total porosity also increased. This is in agreement with the compressive strength development. The findings of this study suggest that reinforcement by mineral particles and fibers is an effective approach to increase the compressive strength of geopolymer; and it is also beneficial to the enhancement of the resistance to sulfate and chloride attack.

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## 1. Introduction

Demand of concrete as a construction material increased significantly in the last few decades due to rapid urbanization and it will continue in the foreseeable future. The ordinary Portland cement (OPC), which is the most important ingredient of concrete, has been used in construction 200 years [1]. In 2013, the world production of cement was about 4 billion tons, with China occupying the

largest part [2]. Cement production is intensive of emission of carbon dioxide ( $\text{CO}_2$ ). It is reported that the cement industry contributes to 5% of global  $\text{CO}_2$  emissions [3]. The manufacture of 1 ton of cement releases about 0.8 tons of  $\text{CO}_2$  into atmosphere [4]. The production of ordinary Portland cement (OPC) also emits  $\text{SO}_3$  and  $\text{NO}_x$ , which leads to greenhouse effect and acid rain [5]. Finding an alternative binder for concrete in order to meet the demand of construction increase and environmental preservation is a challenge of current cement and concrete industry.

Geopolymer, which was introduced by Davidovits in 1970 [6,7], received great attention due to its low  $\text{CO}_2$  emission and excellent properties in many aspects [8]. It has shown indicated potential in

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construction material [9], heavy metal immobilization [10], fire resistance ceramics [11], composites [12] and other aspects [13].

In terms of material nature, geopolymers are generally regarded as a type of amorphous or semi-crystalline binder materials, which are synthesized by alkaline activation of aluminosilicates natural minerals and/or industrial waste solids at ambient or elevated temperatures [14]. The reaction mechanisms include three steps: (1) the aluminosilicate oxide of solid materials are dissolved in concentrated alkaline solutions to form free  $\text{SiO}_4$  and  $\text{AlO}_4$  tetrahedral units, followed by (2) the condensation reaction of the alumina/silica-hydroxyl species to form inorganic polymer gel phase and finally, (3) the gel phase gradually harden to form geopolymers [14].

Geopolymers possess advantages, compared to OPC, including simple production process, low energy consumption, and better mechanical properties in many cases [15,16]. However, despite of these features, geopolymers exhibit higher brittleness and less deformation capability compared to OPC materials [17]. Because of this, geopolymer application in civil engineering as structural elements is limited [18]. Research on composites, including particulate, continuous fiber and short fiber reinforced geopolymer composites, has been reported [18], which are broadly employed in various cementitious materials to improve flexural, impact behavior, toughness and to change failure mode [17]. Fiber-reinforcement mechanism is that it prevents micro and

macro-cracks through a fiber bridging effect; in addition, it changes the post-cracking behavior of the material, from a brittle fracture mode to a ductile format due to its enhanced strain energy dissipation ability [19]. In addition, different fibers may have different mechanisms and result in various properties; for example, basalt fibers have excellent resistance to alkali, acidic and salt attack compared with glass and aramid fibers [20].

Geopolymer synthesized from blend of MK and fly ash has shown good performance in strength, durability and sulfate attack resistance [21]. Nevertheless, limited study has been reported on the performance and durability of metakaolin geopolymer containing mineral particles reinforcement, especially in sulfate and chloride environments. This study aims to investigate the compressive strengths and microstructure of MK-based geopolymer with addition of mineral reinforcement including WS, TR and SBF. A fundamental investigation into this MK blended system will allow researchers and industry to design the most promising mix design for various applications.

## 2. Experimental

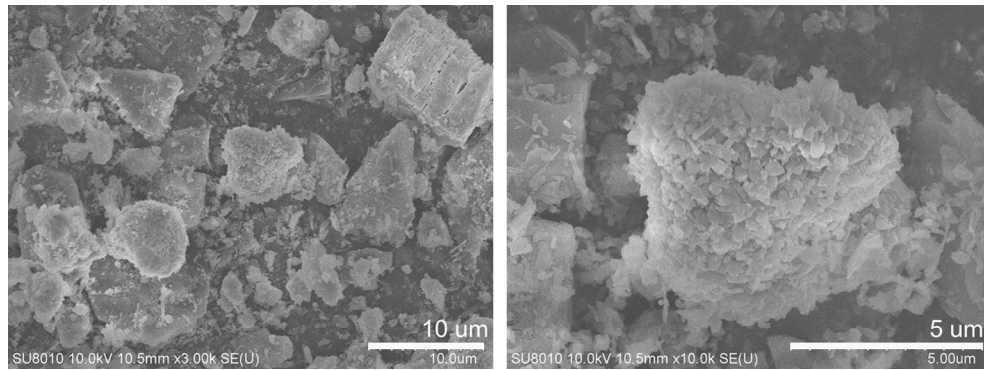
### 2.1. Materials

MK, sourced from Yunnan, China by calcination of kaolinite at 800 °C was utilized as main starting material to prepared

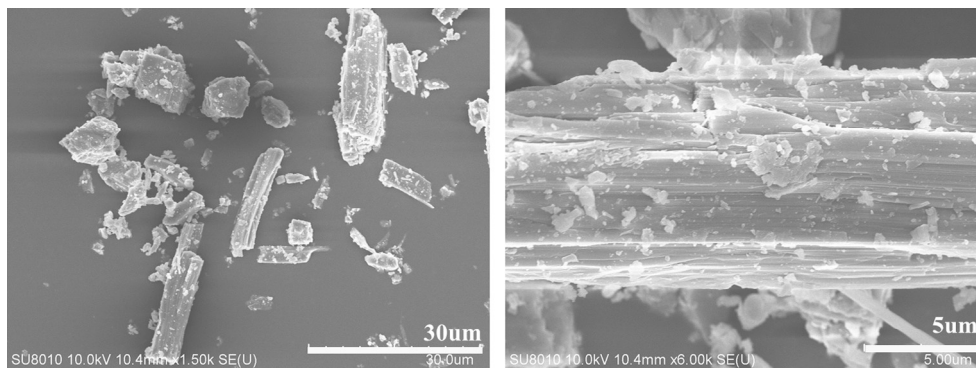
**Table 1**  
Chemical compositions of MK, WS and TR by XRF analysis (mass%).

	$\text{SiO}_2$	$\text{Al}_2\text{O}_3$	$\text{Fe}_2\text{O}_3$	MgO	CaO	$\text{Na}_2\text{O}$	$\text{K}_2\text{O}$	MnO	$\text{TiO}_2$	LOI
MK	52.36	42.12	1.95	0.15	0.060	0.46	0.55	0.014	0.56	1.71
WS	22.32	0.24	0.13	8.77	39.92	0.11	0.015	0.016	0.008	28.38
TR	32.13	0.82	0.55	19.26	23.49	0.55	0.46	0.02	0.03	22.69
SBF	51.61	15.16	8.79	5.15	6.18	3.67	2.06	0.13	0.81	5.92

Loss on ignition.



**Fig. 1.** The micrographs (SEM) of MK.



**Fig. 2.** The micrographs (SEM) of WS.

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