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Novel geopolymer based composites reinforced with stainless steel mesh and chromium powder

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HIGHLIGHTS

- Two geopolymer composites, reinforced by stainless steel mesh (SSM) or Cr_p, are prepared.
- The mechanical properties can greatly improve after the introduction of SSM.
- The presence of Gr_p can effectively reduce the debonding between matrix and SSM.

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ABSTRACT

In this study, two novel geopolymer composites, namely, stainless steel mesh/geopolymer and stainless steel mesh/Cr_p/geopolymer, were designed and prepared, in which the layers of stainless steel mesh were 4, 7 and 10, respectively, and particle size of chromium powder (Gr_p) were 74, 38 and 13 μm, respectively. The Gr_p content was 40 wt% of metakaolin used to fabricate the resulting geopolymer composites. Phase composition, microstructure, mechanical properties and fracture behavior of the resulting composites were studied. The results suggested the incorporation of stainless steel mesh could significantly improve the mechanical properties of the composites. The flexural strength, elasticity modulus and work of fracture reached the maximum values, 97 MPa, 11 GPa and 4.2 kJ/m^2, respectively, for the composite with seven-layers of stainless steel mesh. The presence of Gr_p could further enhance the mechanical properties of geopolymer composites, especially for the work of fracture, and the mechanical properties gradually improved with the decreasing of particle size of Gr_p. The reason for the performance improvement after the introduction of Gr_p was because that the presence of Gr_p can effectively reduce the debonding between matrix and stainless steel mesh. All composites showed typical pseudo-plastic behavior that offers potential to prevent catastrophic failure of the geopolymer matrix.

1. Introduction

The term 'geopolymer' is coined in '70s by Prof. J. Davidovits, and is applied to a class of solid materials synthesized by a geopolymerization reaction between aluminosilicate oxides and alkali-metal silicate solutions under alkaline conditions producing inorganic polymers with partially or fully amorphous structures containing tetrahedral SiO_4 and AlO_4 randomly distributed along the polymer chains [1–4]. As a potentially revolutionary material, geopolymers current attract increasingly widespread attention due to their low cost, ease of synthesis and useful characteristics including high performance/cost ratio, low shrinkage, acid-resistance, fire-resistance and low thermal conductivity, as well as low manufacturing energy consumption for construction and engineering applications [5–11].

Multiple geopolymer composites with different fibers have been designed and processed recently. One requirement that must be met for construction applications is graceful failure, as catastrophic failure during service can result in significant loss of life [12]. Several studies on geopolymer composites have demonstrated that incorporation of the fiber, such as C_f, SiC_f, basalt fiber, steel fiber and some organic fibers [13–22], can greatly enhance toughening and flexural strength and also converts the failure mode from brittle into ductile by controlling crack propagation under different loading or environmental effects such as shrinkage [23–25]. Timakul et al. reported that basalt fiber at an optimum

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Table 1
Sample code of geopolymer composites with different composition.

Sample Code	Stainless steel mesh		Cr_p	
	Layer	vol (%)	wt (%)	particle size (µm)/(mesh)
S4	4	9	0	–
S7	7	16	0	–
S10	10	23	0	–
R2	7	16	40	74/200
R4	7	16	40	38/400
R10	7	16	40	13/1000

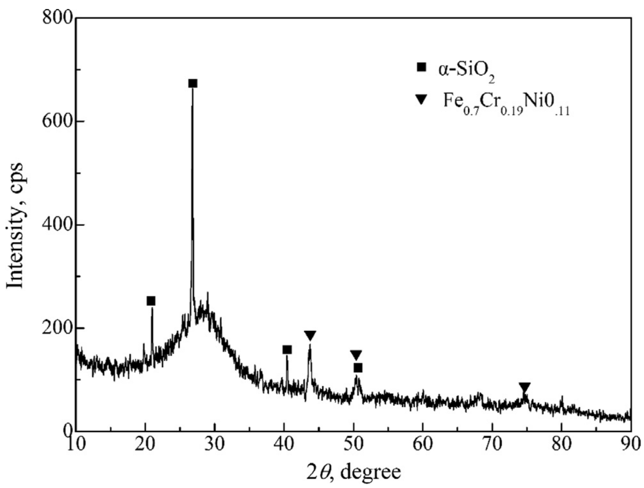

Fig. 1. XRD patterns of **S10**.

mass fraction of 10% significantly improves compressive strength of Class C fly ash-based geopolymer matrices [26]. Zhang et al. reported the introduction of PVA fiber increases greatly the ductility of fly ash based-geopolymer composites, especially for high volume fractions of fiber, changing impact failure from brittle to ductile [14]. Lin et al. fabricated geopolymer composites reinforced with sheet-like short carbon fiber and evaluated the effect of fiber length on the performance of composites [27].

Compared with fiber and other reinforcements, it is advantageous to use metal mesh or wire, due to low costs and easy preparation. It is well known that incorporating randomly distributed short discrete steel fibers, mesh or wire into concrete mixes improves their tensile properties and post cracking behavior of concrete and provided better structural integrity. However, the systematic influence of these reinforcements in geopolymer materials has not as yet been studied [28–30].

Thus, we report here on efforts to investigate the mechanical performance of geopolymer composites reinforced with stainless steel mesh and Cr_p. A series of stainless steel mesh/geopolymer composites and stainless steel mesh/Cr_p/geopolymer composites were designed and prepared. Stainless steel mesh with 4, 7 or 10 layers was incorporated. The average particle size of chromium powder (Gr_p) was 74, 38 and 13 µm, respectively, and the content of Gr_p was 40 wt% of metakaolin used to fabricate the resulting geopolymer composites. The effect of the content of stainless steel mesh and the particle size of Cr_p on the microstructure, mechanical properties and fracture behavior of the resulting geopolymer composites were compared and investigated.

2. Experiments

2.1. Material and synthesis

Geopolymer resin with a composition of $SiO_2/Al_2O_3 = 4$, $SiO_2/K_2O = 2$ and $H_2O/K_2O = 11$ (mole ratio) was obtained by mixing metakaolin powder with potassium silicate solution. The metakaolin was prepared by calcining kaolin (Shanghai Fengxian Indus, China) at 800 °C for 2 h and the potassium silicate solution was prepared by dissolving amorphous silica (Shanghai Dixiang Indus, China) into KOH (Tianjin Fuchen Indus., China) solution stirring for 48 h in order to dissolve the silica completely. Then the metakaolin powder and Cr_p were gradually added into the potassium silicate solution under ultrasonic-assisted high-shear mixer. To prepare composite samples, stainless steel mesh layers (major composition $Fe_{0.7}Cr_{0.19}Ni_{0.11}$, Harbin Yongxin Indus., China) were impregnated with the geopolymer resin and laid on top of each other. The lamination structure was formed by vacuum-bag technique and pressed at ~3 MPa for 1 h, followed by curing 3 d at 60 °C. After demolding the hardened geopolymer composites were

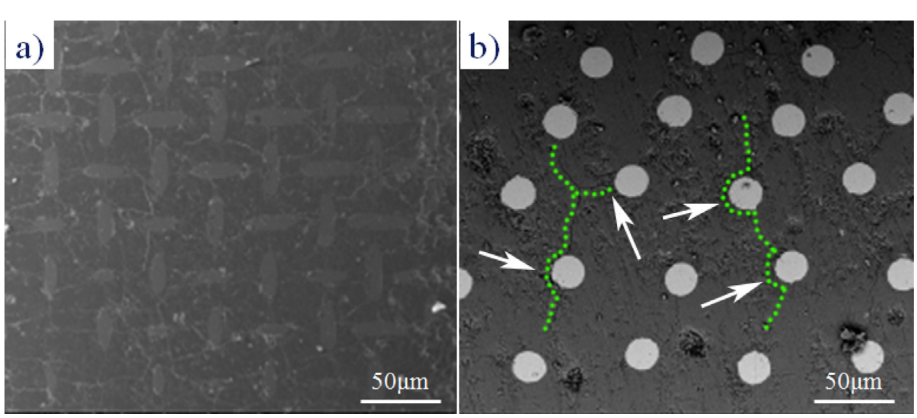

Fig. 2. Surface and cross-section morphology of **S7**, a) surface, b) cross-section.