Construction and Building Materials 167 (2018) 216–224

Contents lists available at ScienceDirect

Construction and Building Materials

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

Effect of Organic Polymers on the Properties of Slag-based Geopolymers

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HIGHLIGHTS

- The effect of polymers on the mechanical properties of geopolymers was investigated.
- C–O–Si bond and mean chain length of tetrahedra were affected with doping polymers.
- The toughness of geopolymers was improved with the incorporation of PAAS and PAM.

ARTICLE INFO

Article history:
Received 30 July 2017
Received in revised form 25 December 2017
Accepted 6 February 2018

Keywords:
Organic polymers
Blast furnace slag powder
Geopolymer
Mechanical performance
Microstructure
Toughening modification

ABSTRACT

In this paper, the effects of polyethylene glycol (PEG), polyacrylamide (PAM) and sodium polyacrylate (PAAS) on the mechanical properties of slag-based geopolymers (SG) were studied. Several characterization methods including mercury intrusion porosimetry (MIP), Fourier transform infrared spectroscopy (FT-IR) and ^{29}Si nuclear magnetic resonance (^{29}Si NMR) were employed to determine the pore size distribution, bonding, and the degree of [SiO_4] tetrahedral polymerization of SG. The study in the mechanical characterization of SG showed that after curing for 28 days, the bending toughness coefficient of the specimen increased as much as 53.7% with the incorporation of 0.6 wt% PAAS. The MIP results showed that the larger capillary pores in SG matrix can be filled with the three organic polymers, resulting in a significant reduction in the pore size. The FT-IR results confirmed the formation of the C–O–Si bond after the incorporation of PAAS and PAM, and the ^{29}Si NMR results indicated a reduction in the degree of [SiO_4] tetrahedral polymerization and a change in the mean chain length (MCL) of [SiO_4]/[AlO_4] tetrahedra. From the above results, it can be concluded that the organic polymers, PAAS and PAM were involved in the formation of the network structure of SG, decreasing the degree of polymerization [SiO_4] tetrahedra and increasing the MCL, thus improving the toughness of SG.

1. Introduction

In view of their use as a class of green cementitious materials, geopolymers have been extensively studied owing to their resistance to high temperatures, acids, alkalis, large compressive loads, and radiation from nuclear waste [1–3], and have been deemed as an attractive alternative to Portland cement. It is synthesized by the geopolymerization interaction between the alkali-activator and aluminosilicate materials (metakaolin, fly ash, slag, etc.) with pozzolanic activity or potential gelling activity [4]. The formation of the geopolymer structure is the fracture-reorganization process of [SiO_4] and [AlO_4] tetrahedra, further forming a three-dimensional network structure [5]. The geopolymer structure mainly contains three different sialate units, namely poly sialate (–Si–O–Al–), poly sialate-siloxo (–Si–O–Al–O–Si–) and poly sialate-disiloxo (–Si–O–Al–O–Si–O–Si–). The formation process of the geopolymer network structure is similar to that of the zeolitic precursors or amorphous analogs [6].

The mechanical properties of geopolymers often show the characteristics of high compressive strength and poor toughness [7–10]. Astutinigsih et al. used steel slag as the main aluminosilicate material to prepare the geopolymer mortar. The results showed that the compressive strength of samples at 28 days was 84 MPa while the flexural strength was 11.7 MPa, and the ratio of the flexural to compressive (F/C) strength was only 0.14 [11]; Kim et al. considered that when the compressive strength of geopolymers was 50 MPa, the coefficient of flexural toughness was only 0.55 J [12]. Some studies on the toughening modification of geopolymers have been conducted with a view to improving the mechanical properties of geopolymers. The effects of steel mesh and fibers such as basalt fiber, carbon fiber, and steel fiber on

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https://doi.org/10.1016/j.conbuildmat.2018.02.031
0950-0618/

Table 1
Chemical composition of slag (wt%).

Chemical composition	Al_2O_3	MgO	SiO_2	CaO	Fe_2O_3	SO_3	R_2O	LOI
Content	15.01	9.02	34.38	37.51	0.27	2.03	0.68	1.10

Table 2
Relevant information on the chemical reagents used in the experiment.

Reagent	Chemical formula	Reagent status	pH	Density (g/cm^3)	Purity (%)	Manufacturer
WG*	$Na_2SiO_3{\cdot}3.2H_2O$	Solution	11.0–13.0	2.614	AR	Qingdao Best Line Chemical Technology Co., LTD
NaOH	NaOH	Granular solid	>11	2.130	96	Sinopharm Chemical Reagent Co., LTD
PEG	$HO[CH_2\ CH_2\ O]_nH$	Flaky solid	4.0–7.0	1.276	AR	
PAM	$[C_3H_5ON]_n$	Flaky solid	6.0–8.0	1.302	AR	
PAAS	$[C_3H_3O_2Na]_n$	Granular solid	6.0–9.0	1.325	AR	

* WG = waterglass.

Table 3
Mixture proportions of specimens in weight (g).

Specimen Code	Organic Polymers		Slag	Sand	Alkali-activators		Water
	Species	Weight			NaOH	WG	
S0	–	–	450	1350	27.49	80.73	171.72
A1	+PEG	1.8	450	1350	27.49	80.73	171.72
A2	+PEG	2.7	450	1350	27.49	80.73	171.72
A3	+PEG	3.6	450	1350	27.49	80.73	171.72
A4	+PEG	4.5	450	1350	27.49	80.73	171.72
B1	+PAM	1.8	450	1350	27.49	80.73	171.72
B2	+PAM	2.7	450	1350	27.49	80.73	171.72
B3	+PAM	3.6	450	1350	27.49	80.73	171.72
B4	+PAM	4.5	450	1350	27.49	80.73	171.72
C1	+PAAS	1.8	450	1350	27.49	80.73	171.72
C2	+PAAS	2.7	450	1350	27.49	80.73	171.72
C3	+PAAS	3.6	450	1350	27.49	80.73	171.72
C4	+PAAS	4.5	450	1350	27.49	80.73	171.72

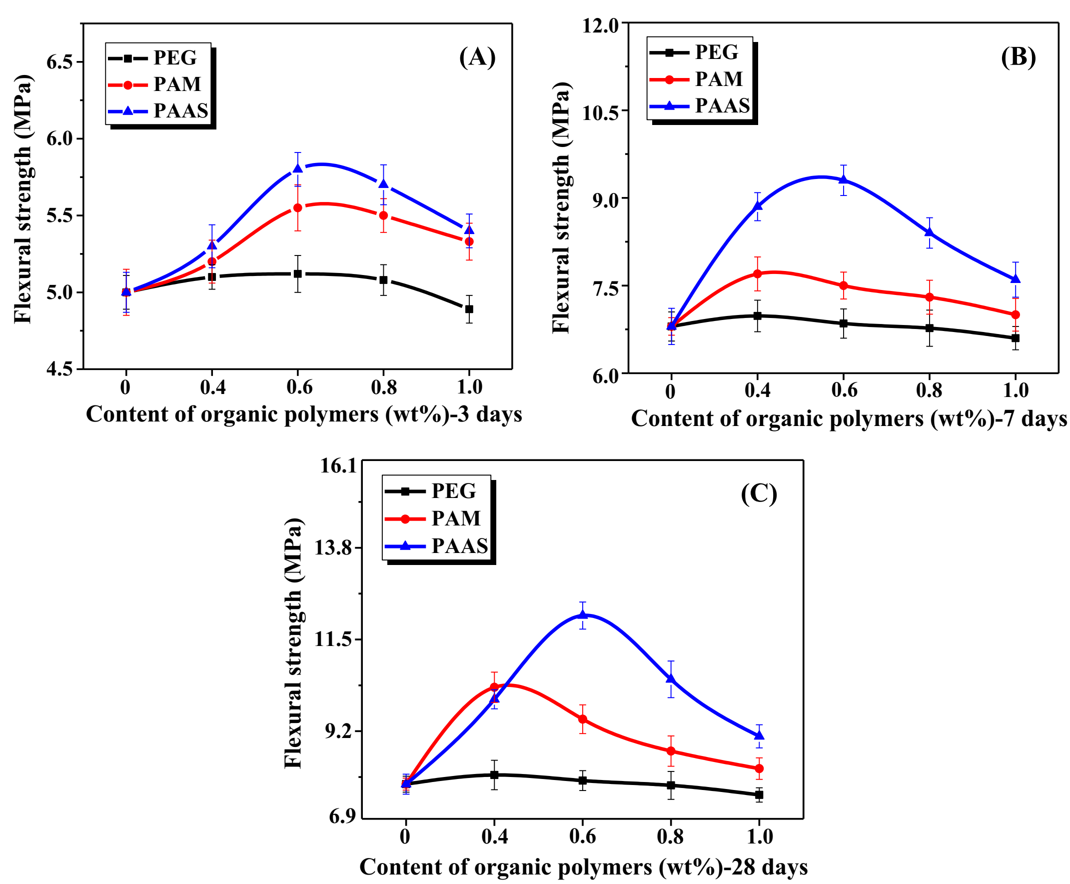

Fig. 1. Effect of organic polymer content on the flexural strength of SG.