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The study of the structure rebuilding and yield stress of 3D printing geopolymer pastes

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HIGHLIGHTS

- Extrudability of printing geopolymer was evaluated by structure rebuilding ability.
- Buildability of printing geopolymer linked to the development of yield stress.
- Lower Si/Na ratio useful improve the workability of printing geopolymer.

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ABSTRACT

For 3D printing construction materials, workability and interlayer force of fresh printing pastes were necessary to ensured extrudability and buildability in the period from extrude to hardened of pastes. The workability and interlayer force of 3 Dimensional printing geopolymer pastes related to its rheological property and more particularly to its structure rebuilding and yield stress. The present study is aimed at investigating structure rebuilding and yield stress of 3 Dimensional printing geopolymer pastes at different Si/Na ratio of alkali activator by rheology method. Results revealed that rheology is an important research method for the extrudability and buildability of 3D printing geopolymer pastes. Structure rebuilding ability (SRE) and fast-growing yield stress of 3 Dimensional printing geopolymer ensured the stability of structure in the period from extrude to hardened of paste. Si/Na ratio of alkali activator has significantly influences on extrudability and buildability of 3D printing geopolymer pastes. High Si/Na ratio of alkali activator decreases the viscosity, yield stress and development rate of fresh pastes. Si/Na ratio of alkali activation significantly influences rate of structure rebuilding of pastes, and low Si/Na ratio of alkali activator exhibited high ability of recovery of pastes.

1. Introduction

Until recently, 3 Dimensional (3D) printing techniques were used to high value adding sectors such as aeronautical, biomedical, manufacturing industries, and so on. 3D printing technology had also made great progress in construction industry, for example large-scale 3D printing construction and bridge [1]. Unlike conventional methods, 3D printing concrete process is a novel digitally controlled method [2] which can build architectural and structural components without formwork. Compared with traditional construction, the advantages of 3D printing construction include: a) Freedom construction--producing novel finishes and construction; b) Mechanized construction--achieving automotive building that reduces the costing of labor and formwork; c) Green construction-- calculating building materials that reduces materials consumption. Therefore, 3D printing concrete has been an advanced building technology.

With the world's energy consumption increasing dramatically, cement printing materials are facing the following problems: (1) enormous energy consumptions: limestone decarbonation and raw mix lead to a great quantity of energy consumption; (2) relatively high production cost; (3) emission of greenhouse gases [3]: the manufacture of 1 tons of cement generates approximately 1 ton of CO_2 and others. In light of these problems, alternative materials are being studied in this regard. Geopolymer which produced from the reaction of alkaline activator with solid wastes such as fly ash, limestone, slag, and metakaolin, is a kind of green building material [4]. Geopolymer not only substantially reduces the CO_2 emissions by the cement manufacturing process, but also promote the recycle of solid wastes [5]. Simultaneously, many literatures [6–9] have reported that geopolymers exhibited higher

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compressive strength, greater fire resistant, thermally resistant, and durability.

High-performance printing concrete [10] need extrudability and buildability relates with workability and interlayer force (as shown in Fig. 1). Different from conventional concrete, 3D printing concrete had especial workability that high flowability and low viscosity in pump system and molding system in just the opposite. The transformation of fresh pastes between pump and molding system linked to thixotropy of cementitious fresh pastes causing by the flocculation and particles nucleation at early age [11]. However, the effective measuring methods of thxiotropy lacked in the cementitious, especially printing cementitious materials. The thxiotropy of printing materials was evaluated by structure rebuilding in this paper. And the buildability of printing concrete was linked to its rheology and more particularly to its yield stress [11]. During the layer by layer printing construction, the lowermost layer undergoes the heaviest load. In order to ensure the construction stability before open time, yield stress and structure rebuilding are main factors to sustain layer-layer load [12]. Yield stress and structure rebuilding are closely related to rheology of fresh pastes. And the workability and buildability of 3D printing concrete materials can be evaluated by rheological method.

Alkaline activator was basic constituents of geopolymer, which activates the potential pozzolanic activity of aluminosilicate minerals. Alkaline activators have a significant effect on the properties of geopolymer [13]. The use of hydroxide and silicate activation as basic activator can not only accelerate the dissolution of Si and Al components in the raw materials, but also promote the formation of Si-O-Al and Si-O-Si-O-Al and other prepolymer formation. In this paper, alkaline activators included sodium metasilicate and sodium hydroxide. For 3D printing geopolymer pastes, there was little research on the effects of alkali activator (especially Si/Na ratio) of fresh pastes. Therefore, the aim of this paper is studying structure rebuilding and yield stress of the fresh properties (especial early age) on 3D printing geopolymer pastes at different Si/Na ratio of alkali activator.

2. Experimental

2.1. Raw materials

A class S95 (as per GB/T18046-2000) Granulated blast furnace slag (abbreviate as BFS) in this study was sourced from Capital iron and steel company in Beijing, China. Steel slag in this paper was sourced from Shandong, China. The chemical compositions of raw materials were shown in Table 1. The particle size distribution of the raw materials is shown in Fig. 2.

The geopolymer binders were usually activated by the alkaline activators, which included sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). In general, the alkaline activators were prepared

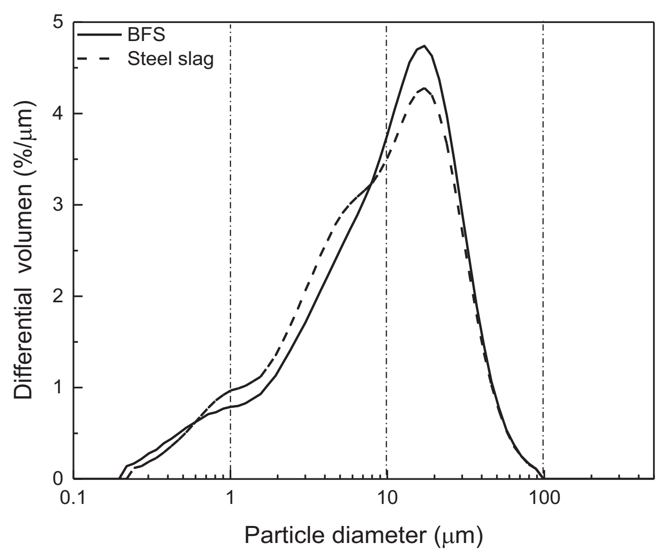

Fig. 2. Particle size distribution of the raw materials determined by laser diffraction.

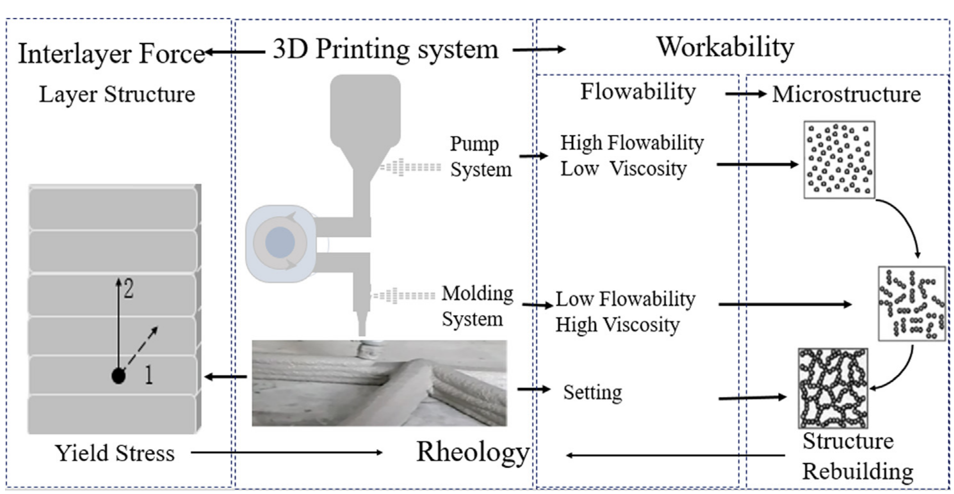

Fig. 1. Workability of 3D printing concrete.

Table 1
Chemical composition of the raw materials.

%	CaO	SiO_2	Al_2O_3	MgO	Fe_2O_3	SO_3	Na_2O	K_2O	LoI	Total
Blast furnace slag	36.25	35.03	14.94	9.31	0.62	1.13	0.12	0.38	2.01	99.79
Steel slag	32.65	14.47	4.06	5.14	37.27	0.78	–	0.04	3.35	97.76