Construction and Building Materials 162 (2018) 613–627

Contents lists available at ScienceDirect

Construction and Building Materials

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

Printable properties of cementitious material containing copper tailings for extrusion based 3D printing

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HIGHLIGHTS

- Printable properties of mixtures with six substitute ratios of tailing to sand are investigated.
- Optimal mixture that enables structures achieve a favourable buildability is determined.
- Critical value of controlling parameters to achieve sufficient printability are specified.
- Mechanical strength of the printed and the casted samples are measured.
- Extrudability and buildability coefficients are firstly proposed for optimizing design.

ARTICLE INFO

Article history:
Received 11 May 2017
Received in revised form 7 November 2017
Accepted 6 December 2017

Keywords:
3D printing
Cementitious material
Printability
Fresh property
Extrudability
Buildability

ABSTRACT

3D printing for cementitious material is an innovative and promising construction method that is rapidly gaining ground in recent years. Utilizing waste or recyclable materials as the primary raw material to produce cementitious material for 3D printing can greatly promote the 3D printing to reach its maximum cost-effective potentials. This paper proposes an environmental friendly cementitious mixture that is compatible with an extrusion based printing process. In this study, six replacement ratio of tailing to sand from 0% to 50% are investigated. A single nozzle printing system is developed and the operational process is illustrated. Experimental tests are performed to determine the printable properties of mixtures containing various content of tailings, including the extrudability, buildability, flowability, open time, fresh and hardened properties, etc. Based on the measurements, the optimal mixture is determined as substituting natural sand with 30% mass ratio of mining tailings, which enables structures achieve a favorable buildability and a relatively high mechanical strength. In particular, the critical value of controlling parameters to achieve sufficient printability are specified. And the compressive and flexural strength of the printed and the casted samples are measured and compared. To conclude the present research, extrudability and buildability coefficients are proposed for optimizing design.

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1. Introduction

3D printing is a novel and promising process to build up structures in a layer by layer manner based upon a computer designed file, which has been successfully applied in various fields [1–4]. Recently, the building industry has made a series of attempts to apply this technique on a practical construction scale due to its outstanding flexibility in both architectural and structural design. Premixed materials are extruded through a nozzle to build structural components layer-upon-layer without the facilitation of formwork or any subsequent vibration [5–8]. Various manufacturing methods of largescale 3D printing have been continuously developed and improved. Contour crafting developed by Dr. Behrokh Khoshnevis is a well-known process for construction-scale 3D printing [9]. Some specific implementation practices have been presented. For example, the five-story apartment 3D printed by WinSun [10], the BigDelta project [11] of a castle printed in-situ [12], etc., which have all demonstrated the great potential and feasibility of 3D printing in constructing large-scale building components.

Rapid application of this innovative technique in the construction field rely on the development of high performance cementitious materials that are compatible with 3D printers. Le et al.

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https://doi.org/10.1016/j.conbuildmat.2017.12.051
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[13] developed a high-performance fiber reinforced printing mixture for concrete printing process. A high cementitious materials content of low water/cementitious materials ratio of 0.26 was employed to achieve desirable fresh state properties and a 28-day compressive strength of 110 MPa. Pshtiwan et al. [14] proposed a new type of 3D printing powder modified by cement powders which is designed to fabricate scaffold (structure) by powder based 3D printer. Manuel et al. [15] provided first insights into a 3D-printed composite of Portland cement paste and reinforcing short fibers (carbon, glass and basalt fibers), which exhibit high flexural (up to 30 MPa) and compressive strength (up to 80 MPa). Gosselin et al. [16] developed an ultra-high performance concrete for large-scale 3D printing system. Even though, it is still of high requirement to expand the current severely limited scope of materials that can be used in an extrusion based 3D printing process.

Mine tailings (MT) are the solid residues left after valuable minerals have been extracted from the ores. Few reuse and large stockpile of tailings have led to a number of environmental, financial and social problems [17,18]. Disposal of mine tailings have been a major concern in mining industry [19,20]. Utilizing mining tailing as the primary raw material to produce cementitious material for 3D printing can greatly promote the 3D printing to reach its maximum cost-effective and environmental-friendly potentials. From another aspect, it is also in agreement with the objective of strategy of resources recycling and building energy efficiency of China. In current practice, mine tailings have been utilized as a kind of substitute material for concrete mixtures and the feasibility of utilizing mine tailings for production of eco-friendly materials has been validated [21–25]. However, despite some explorations have been conducted regarding to adopting the mining tailings in concrete preparation, the application of tailings in cementitious materials for 3D printing is extremely insufficient and the coordination effect with printing systems is yet to be explored.

Appling mining tailings as the raw material for extrusion based 3D printing shall meet certain vital criteria to be compatible with the printing processes. Different from the castable concrete, the mixtures are designed to be easy-extrusive, low-slump, well-buildable, fast-setting and with good mechanical strength in order to produce a continuous paste from the printing nozzle and to ensure a rapid modelling of freeform construction [7,26–28]. The goal of the printability controlling is to ensure that each printed layer has the capacity to retain its original shape and sustain subsequent layers right after extrusion, and yet stay viscous enough to bond the adjacent layers avoiding the formation of a separate voids. There exists a sensitive balance between the material properties (flowability, extrudability, buildability, open time, etc.) and the process parameters (printing speed, nozzle opening, extrusion rate, etc.) [29,30]. Ali Kazemian et al. [31] proposed a series of test methods for evaluation of the printing quality and shape stability of fresh mixtures. In particular, the time limit for printability and blockage are suggested and specified.

Despite several cement-based materials for 3D printing in construction sector have been proposed, attempts and studies are little available about the application of mining tailings in manufacturing cementitious materials for 3D printing. A series of tests have been conducted to investigate the relevant extrudability, buildability, flowability, open time, fresh and hardened properties of the proposed material to find the optimal mixture proportion that is well compatible to the printing process. In particular, the critical values of controlling parameters to achieve sufficient printability are specified. And the compressive and flexural strength of the printed and casted samples are measured and compared. This research develops eco-friendly materials for 3D printing, improves the efficiency in resource management and the automation in construction industries.

2. Cementitious material extrusion system

Fig. 1 illustrates schematically the set-up of a cementitious material extrusion system. In general, this system comprises of a

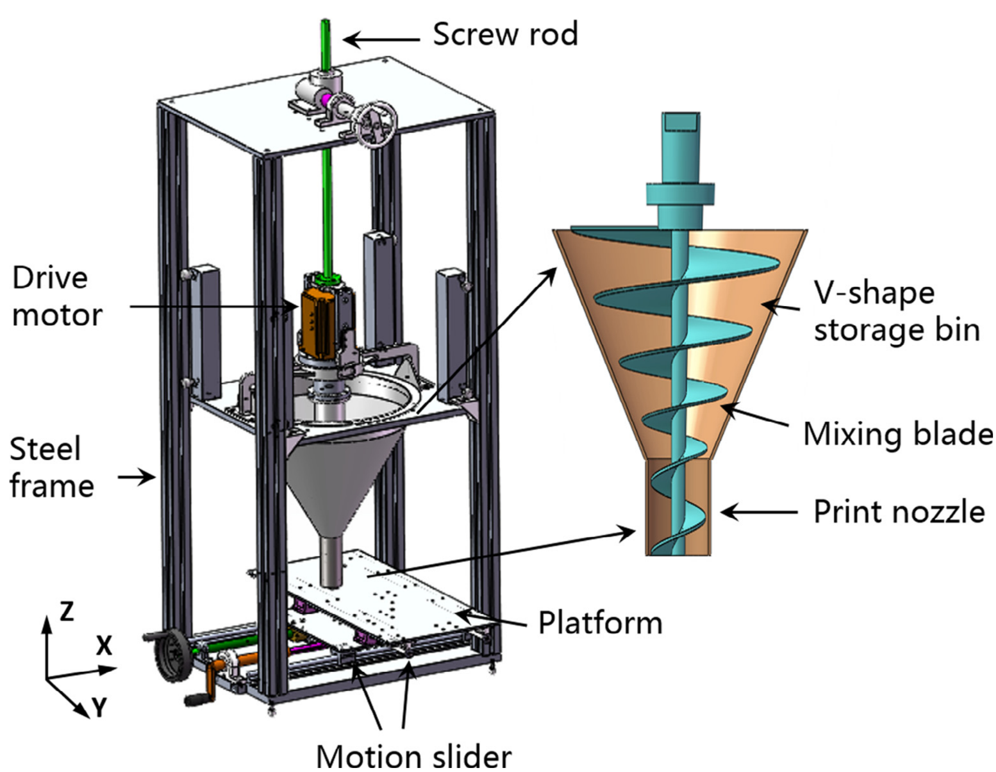

Fig. 1. Design sketch of the cementitious material extrusion system.

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