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Application and development prospect of 3D printing concrete material in construction field

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Abstract. This paper reviews the research progress of 3D concrete printing in the whole construction field, summarizes the basic principles and related processes of this technology, deeply analyzes the necessary properties of concrete materials for 3D printing, and gives a detailed description of its research status. In addition, the article also collates the current challenges in the field of technology and the direction of future development, aiming to provide a constructive reference for the future research and exploration of concrete 3D printing technology.

Keywords: 3D printing concrete material; building; energy saving and high efficiency; Development prospects.

1. Introduction

3D printing technology has flourished in the field of science and technology in the 21st century, and Economic Talent has commented that 3D printing technology will become a powerful propellant for the third global industrial revolution. It is an advanced manufacturing technology that transforms digital models into physical objects, also known as Additive Manufacturing (AM)[1].

For concrete materials, the core element of modern architecture, the application of 3D printing technology has become an important opportunity for the development of this field towards energy saving, material saving and high efficiency. As a new construction technology in the construction industry, concrete 3D printing technology has the characteristics of no mold, high efficiency and high precision, and has a large number of applications in military, flight navigation, power equipment and other industries, showing great potential and prospects. This paper focuses on the application of 3D printing concrete materials in the field of construction, and analyzes its development prospects, which provides new ideas for the application of 3D printing technology in the field of construction concrete materials.

2. Fabrication and performance of 3D printed concrete

2.1 Concrete production method

The implementation process of 3D printing technology mainly includes three aspects: 3D printing design, imaging graphics slice processing and post-printing. Firstly, computer modeling software is used for three-dimensional modeling, so that the graphics are imaged as a whole, and then slicing processing is carried out. After manufacturing design and image slicing processing, printing materials can be filled for printing according to actual needs. The printing process is shown in Figure 1.

At present, the main body of the device used in 3D printing technology can be summarized into three components: mixing unit, transmission unit and extrusion unit. It is found that the performance evaluation of three-dimensional printing concrete mainly focuses on five core indicators, including material flow characteristics, extrusion performance, construction feasibility, setting time and material mechanical characteristics.

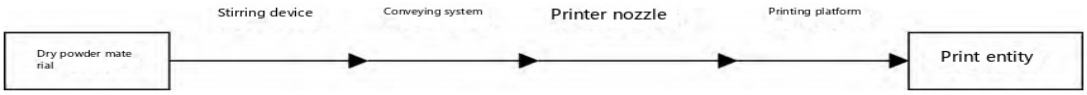

Figure 1 Schematic diagram of 3D printing process [2]

2.2 Performance introduction

2.2.1 Liquidity

The actual printing effect of 3D printing concrete is determined by different parameters, among which the fluidity is one of the main factors. By adjusting the ratio of cement to water and mixing polymer powder to enhance its fluidity, Perrots team produced concrete suitable for 3D printing technology and achieved a higher construction speed[2]. In the process of transporting the pipeline, if the concrete slurry is sticky, sticky, caking and other agglomeration phenomena, there will be signs of blocking the pipeline, which can not meet the construction requirements.[3] If the ratio is too small, the mixture will become dry and hard, and cannot be conveyed smoothly through the conveying pipeline; if the ratio is too large, the later strength will be affected[2]. Reasonable use of water reducing agent can save cement and other raw materials and properly enhance the strength of concrete products.

2.2.2 Extrudability

Concrete materials used for 3D printing need to have good extrudability, that is, the ability to print materials smoothly from the storage bin continuously through the conveying pipeline and to accumulate concrete. In addition, the ratio of the diameter of the extrusion nozzle to the particle size of the aggregate is also one of the key factors to determine its performance. According to the research results of Zeinas team, if the maximum particle size of aggregate does not exceed one tenth of the diameter of the nozzle, the adhesive will be smoothly extruded through the nozzle[2]. However, Malaebs research points out that red ucing the amount of sand and increasing the proportion of cement will improve the extrusion of concrete[4]. Liu Qiaoling et al. studied the relationship between mortar extrudability and fluidity (a) and bulk density (B), and the experimental data are shown in Figure 2. The study found that if there is no polymer addition in the mortar formula, its performance is difficult to meet the standard of printing mortar, resulting in the mortar can not be successfully extruded[5].

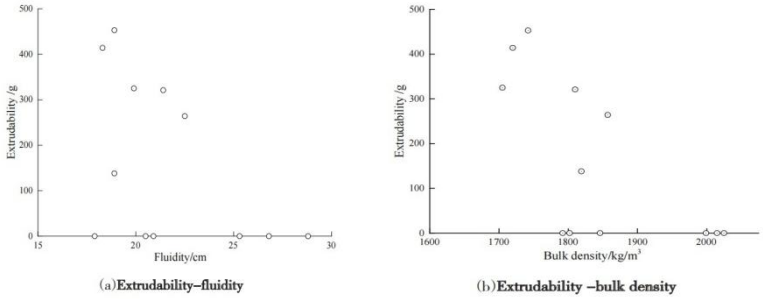

Figure 2 Extrusion characteristics of 3D printing construction mortar and correlation analysis between its rheological property (a) and mass per unit volume (B)[5]

2.2.3 Setting time

Setting time will directly affect many characteristics of 3D concrete, too long time will affect the setting strength and printing effect, too short time will affect the fluidity and extrusion effect, so reasonable control of setting time is conducive to improving the quality of printing concrete, adding admixtures is still the main method to adjust the setting time of the mixture. Sun Jinqiao, Huo Liang and others found that the setting speed of 3D printing concrete materials is usually faster than that of ordinary concrete, but if the setting speed of materials is too fast, premature hardening may occur, affecting normal extrusion. The relationship curve between strength and time of relevant concrete 3D printing materials is shown in Figure 3[6].

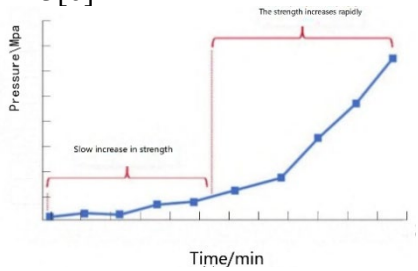

Figure 3 Curve of material strength changing with time[6]

2.2.4 Constructability

Constructability is one of the key parameters to determine the 3D printing ability of concrete materials, which involves the stability of the material after extrusion under the dual influence of its own gravity and upper load, as well as its resistance to deformation caused by external loading. The latest research shows that while increasing the proportion of sand used, the incorporation of mineral batch materials and additives also has positive benefits for the construction process. Using CFD numerical simulation method, Zhou Jiangang found that the printing speed and the diameter of the printing nozzle are the main factors to change the contour state of the printing body[7]. Academics such as T. T. Le of Loughborough University pointed out that the ease of extrusion and construction of freshly mixed 3D printed building materials is essentially the most critical attribute, and there is a close link between the workability of printed materials and the effective time of their operation[8].

2.2.5 Mechanical properties

Due to the weight of the upper strip and the deformation of the printing layer caused by the extrusion force during the extrusion process, when the load exceeds the material yield stress, the base layer will flow and deform, thus affecting the stability of the printing structure[9]. Combined with the experiment of Zhang Tao et al., the equivalent compression curve of reinforced 3D printing concrete was obtained through the compression test of prism specimens (the experimental device is shown in Fig. 6)[10]. Figure 7 shows the average compressive strength of the printed concrete at different delay times and test directions. Anisotropy in the compressive strength of the printed concrete can be observed, depending on the orientation of the loading direction with respect to the layer[10].

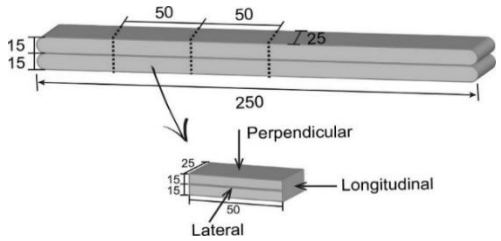

Figure 4 Experimental cutting diagram of compressive strength of 3D printed concrete[10]

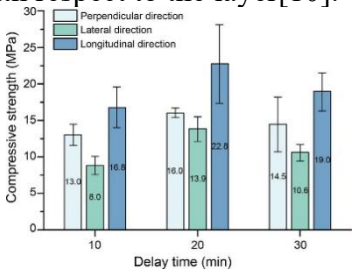

Figure 5 Compressive strength of 3D printed concrete[10]

In the study of 3D printing concrete flexural experiment, Liu Hua-wei found that most of the strip interfaces in the printing body are parallel to the direction of stress, and the strength is high; some of the strip interfaces in the printing body are parallel or approximately parallel to the splitting tensile plane, and the strength is low; The interface of the printing body strip is perpendicular to the splitting tensile plane, and the strength is high[11]. Wu Leis tea m used the three-point bending method to apply pressure to the upper and lower surfaces of the 3D component during the printing process, as shown in Figure 8. Studies have shown that in 3D printed concrete materials, interfacial activators have very limited effect on improving the bending resistance of materials[12].

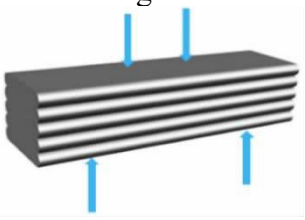

Figure 6 Loading Direction of Bending Test[12]

The experimental research of Wei Wei and Yang Tao shows that the bending strength of 3D printing fiber concrete increases with the increase of fiber content, and the anisotropy of the material increases with the increase of fiber content, as shown in the force-deflection curve of three groups of concrete materials in Fig. 10[13].

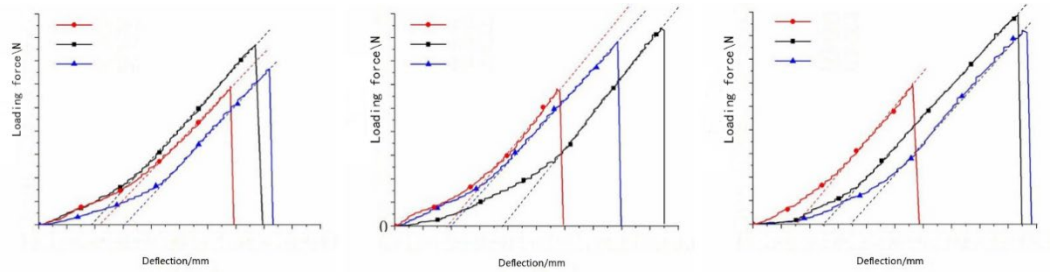

Figure 7 Force-deflection curve of W0, W1 and W2 in three loading directions[13]

3. Advantages and challenges of 3D printing concrete technology

3.1 Advantages of 3D printing concrete technology

3D printing concrete technology replaces the traditional template construction method, significantly improves the construction speed, reduces the construction cost, meets the requirements of green environmental protection, is suitable for the construction of personalized structures, breaks the restrictions of traditional concrete structure design, and gives architects more design freedom. In addition, it can also realize the cross-application of mechanics, acoustics, optics, thermal insulation and other aspects in the construction process[14].

3.2 Problems and challenges of 3D printing concrete technology

At present, three-dimensional concrete printing is not perfect enough in terms of manufacturing process, mechanical properties of equipment, allocation of raw materials and precise formation of solid structure. Therefore, it is urgent to formulate relevant technical specifications and implement engineering practices to guide technology development, aiming at promoting its wide application in the industrial field[14].

Unlike ordinary concrete structures, 3D printed concrete structures require specific design and construction standards and national specifications, and there is still a lack of relevant standards and acceptance specifications[15]. At the same time, it is still difficult for most 3D printing equipment to print directly on the construction site [14]. In order to meet the higher strength requirements, we must also deal with the bonding problem between the printing material and the steel bar or special fiber.[16].

4. Development trend and prospect of 3D printing concrete technology

4.1 Development trend of 3D printing concrete technology

In order to improve the printing efficiency and reduce the cost of building materials, it is urgent to design a printing equipment for coarse aggregate concrete. In addition, the shaping and flow properties of the coarse aggregate concrete need to be regulated in order to deliver the concrete smoothly to the printer head. It also shows better plasticity and constructability in the construction process.[14]。

In order to overcome these limitations and match different building requirements, further improvements and upgrades need to be made to large 3D printers and supporting transportation systems. The use of building information modeling (BIM) technology to integrate various reinforcement layout methods can effectively improve the efficiency of 3D printing concrete building structure construction.[16].

4.2 Application prospect of 3D printing concrete

In order to make full use of the benefits brought by 3D printing concrete technology, universities and research institutions should deepen cooperation, concentrate scientific research resources and share their achievements, so as to promote the further large-scale development of engineering practicability of 3D printing concrete technology.

Professor Wang Hong Kong of Southeast University led his research team [17] .Successfully used 3D printing concrete technology to quickly build a detection shelter for epidemic prevention and control in Nanjing, Xiongan and Puzhou. In the UK, Arup is promoting 3D printing technology to construct steel structures, an innovative approach that can reduce carbon dioxide emissions by 75% and material consumption by 40% during construction[15].

5. Conclusion

1) Concrete is one of the most commonly used materials in the construction industry. 3D printing concrete technology has great potential and incomparable advantages over traditional buildings, which are mainly reflected in the following aspects: 3D printing technology can build the entire building structure in a short time, greatly accelerate the construction speed, reduce labor costs, and greatly improve construction efficiency; 3D printing technology can achieve highly accurate construction and more innovative and personalized architectural design.

2) 3D printing concrete technology is regarded as a key technology for the transformation of the construction industry, which has a vital impact on the future development of the construction industry. However, the potential of this technology is huge, and it is urgent to develop it by clarifying development ideas, solving related problems and formulating development strategies.

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