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Study of the effect of cementitious materials on 3D printed mortars

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Abstract
3D printing technology has been developing rapidly in recent years and has become a research focus for industrial automation and technological advancement. Especially in industrial production, building construction, bioengineering and other industries, the application is becoming more and more prominent. For 3D printing construction technology, 3D printing concrete is the main application method at present, but the 3D printing layer-by-layer stacking construction method will reduce the interlayer effect of 3D printing concrete. The use of 3D printed mortar (3DPM) can reduce the initial setting time of the printed material, reduce the deformation, and improve the early strength, etc. based on the improvement of the interlayer action. Efficient printing of 3DPM needs to consider the printing properties of cementitious materials, and in addition, different compounding materials will affect the mechanical strength of 3DPM. Therefore, it is an urgent problem to explore the influence of different materials on the printing performance and on the mechanical properties of specimens.
Keywords: *3D printed mortar(3DPM), cementitious materials, printability, mechanical properties.*

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I. INTRODUCTION

With the continuous improvement of industrial automation and intelligent requirements and technological development, 3D printing has gradually emerged in various industries, which is based on the principle of two-dimensional printer to complete the in-plane printing, and then the printed entities with a certain thickness are stacked layer by layer to obtain a three-dimensional design model [1]. Concrete material is one of the most widely used and high-performance building materials in the global construction industry, which makes concrete 3D printing technology the most researched 3D printing technology for construction. Different from the traditional concrete moulding process, concrete 3D printing technology, as a new moulding technology, does not require formwork support during the printing process, and can print a variety of free-form architectural solids according to demand. Therefore, it is of great significance to study and apply 3D printing technology in the field of civil engineering [2]. 3D printed mortar is a special type of concrete that can be poured layer by layer by 3D printers without any formwork support and vibration process. Its important performance indicators, including ease, setting and hardening time, and mechanical properties, can be optimized by material selection and printing parameters.3D printed mortar is stacked layer by layer, which leads to anisotropic and weak interfaces in the mortar structure. On the one hand, its anisotropy leads to differences in compressive and tensile properties of 3D printed mortars in different directions (X, Y, Z) [3]. On the other hand, the weak interface between layers requires us to consider how to enhance the bonding properties at the interface [4].

During the printing process, nozzle style, nozzle height and printing speed affect the interlayer strength of 3D printed mortar Admixture dosage at the mixing stage, printing speed and curing conditions affect the interfacial bond strength of 3D printed mortar, and the printing parameters and the rheological properties of the mixtures are the key to affect the strength [5]. Hojae Lee et al. pointed out that as the number of printed layers increases, the quality of the print of the interlayer has a strength The effect of printing generated pores has no significant effect on the damage of mortar [6]. The interlayer interface of the printed layer is the weak region of 3D printed mortar members, and under shear and tensile loading, 3D printed mortar specimens will experience shear and tensile brittle damage of the printed layer interface [7]. Moelic found that the use of retained SAP (highly absorbent polymers) favored thixotropy and rate of stiffness increase [8]. Many authors have also worked on the printing solution itself and the printing equipment to improve the printing results. Xin Huang et al. investigated the effect of printing parameters (layer height, speed and time interval) on the bond strength between 3D printed concrete layers [9].

II. 3DPM Comprehensive Performance

2.1. Printability

To accommodate most 3D printing equipment, fine sand with a much smaller fineness modulus needs to be used as an aggregate. At the same time, due to the strength requirements of the early mortar and construction requirements, often need a smaller water-cement ratio, and the smaller the water-cement ratio will lead to the consistency of the mortar becomes smaller, the slurry fluidity is reduced, the pumpability, extrudability deterioration, and when the water-cement ratio becomes larger, although the consistency of the concrete becomes larger, the slurry fluidity is increased, but the strength of the mortar is reduced cannot meet the needs of the project, and the slurry's water retention will be poorer, prone to water secretion The phenomenon of water seepage. In the study of 3DPC printing performance, the main consideration is thixotropy, fluidity, extrudability, early strength and so on. Among them, fly ash and blast furnace slag can be used as a substitute for cementitious materials to improve the early performance of 3DPM. When using polystyrene foam particles instead of sand as a composite aggregate model to print a lightweight mortar, it can show that a higher static yield stress can reduce polystyrene foam particles particle floating and thus improve the uniformity of the printed mortar.

(a) coal ash **(b) blast furnace slag**

Fig.1 Common 3D printed mortar reinforcement materials

In addition, when rubber aggregate (RA) was added, the printability and rheological properties of 3DPM changed, with the extrudability of the finished print decreasing and the workability improving, and the effect was more pronounced at higher addition levels and finer particle sizes. The water absorption of the cracks in the surface of the RA increased the static and dynamic yield stresses of the concrete, which in turn decreased the extrudability and improved the workability. Heat treatment partially closes the cracks on the RA surface, thereby reducing its water absorption and substantially improving its extrudability while maintaining constructability. Preparation of 3DPM by incorporation of nano silica sol (NSS) in the remix can change the flowability, extrudability, setting time and microstructure of concrete. This is manifested by the ability to thicken the admixture, shorten the setting time, and change the thixotropy of 3DPM. In addition, when the amount of NSS is controlled in the range of 0.5-1.5 %, the seven-day early strength of 3DPM can be greatly improved.

2.2. Interlayer bonding properties

Due to the layer-by-layer structure, 3DPM may exhibit anisotropy and weak interfaces. The former can lead to changes in the compressive and tensile strength of the mortar in different directions (X, Y, Z), while the latter can lead to structural instability, making the printed structure susceptible to fracture and damage, which are affected by the properties of the materials used for 3D printing. The fragility of the interlayer connections of 3D printed cementitious materials calls for the exploration of methods to enhance interfacial bonding. To address these challenges, various methods such as varying the amount of reinforcement material, adjusting printing parameters and numerical simulations can be used to optimize the design. The interfacial bond strength of the printed layer can be affected by the additive dosage and the environmental conditions during the material mixing phase. Printing parameters and the rheological properties of the mixture are also key factors influencing the overall strength of the printed material. These parameters must therefore be carefully considered and optimized to ensure successful printing and the strength of the final product. The strength of 3D printed mortar is affected by the printing material, printing scheme, printing equipment and many other influences, and the adjustment of the process parameters can change the geometry of the interlayer, and the enhancement of compaction during the printing process to enhance the continuous layer friction between them [10].

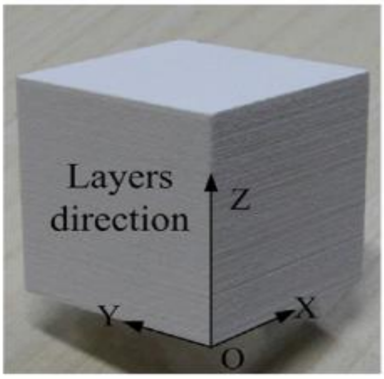

Fig.2 3D printed mortar specimen

Essentially, the shear strength of the 3DPM determines the effectiveness of the interlayer bonding action. Currently, the primary method of increasing the shear strength of 3D printed mortars is to incorporate materials that enhance the bonding effect of the mortar. For example, materials such as fly ash and finely ground blast furnace slag can increase the apparent viscosity and shear stress of mortar, while silica fume can enhance its mechanical properties. In addition, the selection of kaolin, for example, can improve the mechanical properties of 3D printed mortars by reducing drying shrinkage and improving early and hardening properties. Fibres can also be used to improve the average shear bond strength and tensile strength. The interlayer interface of the printed layers is the weak area of 3DPM. Under shear and tensile loading, 3DPM is prone to brittle damage at the printed layer interface. Some scholars have found that techniques such as microwave heating, carbon fibre lateral reinforcement, and steel fibres can effectively improve the interlayer bond strength of 3D printed mortars. The use of polymer-modified mortar as an interlayer interface reinforcement material can improve the weakening effect of surface moisture on the interlayer bond strength of specimens.

2.3. mechanical properties

In the study of mechanical properties of 3D printing materials, most scholars mainly consider 3 directions of compressive properties, interlayer bonding properties, and flexural properties.

Among them, the printing process parameters can change the mechanical properties of 3D printed materials, which mainly lie in the printing speed, layer height, time interval and the geometry of the printed layer. With the increase of printing layer height and nozzle diameter, the printed material changes from overlapping to wavy oscillation; the increase of printing speed leads to the decrease of the height and width of the printed concrete. The effect of time gap on concrete bond strength shows a tendency of decreasing and then increasing. Increasing the printing area or enhancing compaction during the printing process, thus increasing the friction between successive layers, can increase the interlayer bond strength under shear by 41%. The selection of medium-biased kaolin as an additive can accelerate the change in damage mode from plastic to shear damage, improve the mechanical properties of 3D printed mortar and slow down the drying shrinkage to improve the early and post-hardening properties. Fibers can be used to enhance the average shear bond strength and tensile strength [11]. Lower yield stress and plastic viscosity can reduce the bond strength gap between printed and cast specimens. The use of surface-coated reinforcement in fresh cement paste can effectively improve the bond strength of reinforcement 3DPM, and it is important to control the quality of reinforcement 3DPM by optimizing the rheological properties. Fiber-reinforced polymers with different breaking strains affect the axial compressive properties of concrete to varying degrees. In addition, high temperature conditions also have an impact on the mechanical properties of the material, with similar decreasing trends in compressive and flexural strengths of 3D printed and cast specimens using the same mixture. The addition of recycled sand and polyethylene fibers to 3DPM can change its pore structure and reduce the risk of explosive spalling.

III. CONCLUSION

The role of cementitious materials in influencing 3DPM is mainly in two areas:1. Rheological properties and thixotropy affect the printability and early strength of the compound. When the fluidity is too high, the printed mortar is easy to collapse; when the fluidity is too low, the viscosity is reduced during printing and dry shrinkage is easy to occur. 2. The compressive strength is divided into 3 directions. When the viscosity of the printed cementitious material is too low or when it will lead to a reduction of the interfacial bonding between the 3DPM layers, the compressive strength along the X-axis direction is the lowest, which also leads to a reduction of the interlayer shear strength.

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