Comparison of mix proportion design between 3D printed concrete and ordinary concrete

Wanli Xing*

College of Civil Engineering, Qingdao University of Technology, Qingdao 266500, China

*Corresponding author: 1345974557@qq.com

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Abstract: In order to compare and analyze the differences in mix design between 3D printed concrete and ordinary concrete, the differences between 3D printed concrete and ordinary concrete are studied in terms of design principles, cementitious materials, aggregates, mineral admixtures, admixtures and fiber materials. Because the 3D printing concrete building is formed by spraying concrete layer by layer through the nozzle of 3D printing equipment, it has certain particularity. It is necessary to select materials on the basis of fully considering the workability, strength, durability and other factors of concrete. In addition, it is also necessary to meet certain green building requirements. Therefore, find out the raw materials such as cementitious materials, aggregates, mineral admixtures, admixtures and fiber materials that meet the requirements of 3D printing concrete, and discuss and analyze the advantages and disadvantages of the materials. Finally, it puts forward some technical innovations and innovative ideas for 3D printed concrete, analyzes and summarizes the problems and limitations faced by 3D printed concrete technology, and puts forward some suggestions to solve the problems.

1. Introduction

Concrete is a raw material of a building, which has a profound impact on the construction industry, and is the core material of a building. Now it has become the most used and widely used building materials in the construction industry. However, with the continuous development of industrialization and urbanization, the demand for concrete is constantly increasing, which leads to the increasing pollution caused by concrete production. With the continuous development of green building concept, there is more and more need for green production of concrete.

With the continuous advancement of information and intelligence, 3D printing technology arises spontaneously. 3D printing technology is a kind of fast molding technology, which is a technology based on three-dimensional digital model, using adhesive materials, through continuous printing layer by layer to construct objects. It has the characteristics of high precision, strong design and shortened production cycle. With the continuous development of 3D printing technology, its application is becoming more and more widely in the construction field. This paper discusses the mix ratio design [1] of 3D printed concrete at home and abroad, and analyzes the working properties, mechanical properties and test indexes of 3D printed concrete [2].The design principles, coagulation materials, aggregates, mineral admixture, admixture, fiber materials and so on were studied, and the raw materials that meet the requirements of 3D printed concrete were found out and the advantages and disadvantages were analyzed. In addition, the innovation point of combining 3D printing concrete mix ratio design with computer information is also put forward, which enriches the technical requirements of 3D printed concrete.

2. Comparison of the mix ratio design between 3D printed concrete and ordinary concrete

2.1 Comparison of concrete design principles

For ordinary concrete, the mix ratio design of concrete is mainly to meet the concrete and flexibility, strength, durability and other requirements. By determining the relationship between water glue ratio, sand rate and unit water consumption to meet the design requirements, in addition, a certain amount of admixture, mineral admixture, fiber and other components may be needed to further improve the performance. The accuracy of concrete designed by ordinary concrete mix ratio design principle is not very high. In the design principle, the concrete compaction volume principle and cement ratio must be followed in the design there is also the principle of minimum unit of water consumption. Finally, we should follow a certain green building concept, such as using industrial waste slag to replace part of part of cement to reduce a certain cost [3].

For 3D printed concrete, not only need to meet the requirements of concrete accessibility, strength, durability, but also according to the particularity of 3D printing concrete equipment. Since 3D printed concrete is concrete through the nozzle, the aggregate affects the size of the nozzle. Secondly, because the concrete is a layer by layer stacked, which requires the concrete to have a certain tightness and strong interlayer bonding strength. Finally, because it is difficult to add reinforcement to 3D printed concrete, the importance of concrete strength needs to be considered. High-performance concrete mix can be used in the calculation process of concrete mix ratio design Composite design [4], from the aggregate accumulation density as the starting point, with the concrete design strength to determine the water glue ratio, sand rate, unit water consumption and other indexes.

2.2 Impact ison of cementing materials

For ordinary concrete, the calcium three-calcium silicate and second-calcium silicate in silicate cement are the main components of forming concrete strength. Tricalcium silicate has high hydration heat and fast hydration speed, which can provide the early strength of concrete. Dicalcium silicate has low hydration heat and slow hydration speed, which provides the late strength of concrete. With the improvement of dicalcium silicate content, the hydration heat of the cement material will also be reduced, and the strength of the concrete will be improved. Tricalcium aluminate has high hydration heat, fast hydration speed, high content of cement with high early strength but high temperature increase, easy to shrink and crack. Therefore, the higher content of the second calcium silicate and the lower content are used Tricalcium aluminate can improve the strength and durability of concrete.

For 3D printed concrete, due to its lack of steel bar support, its working performance has strict requirements for the construction industry. General 3D printing concrete gel material for Portland cement, Portland cement is characterized by low strength, condensation time, due to its resistance to the bending moment and shear capacity of [5], only rely on the strength of gel material itself is far from meet the requirements, so need to improve the strength of the gel material itself. The experimental results show that [6] can improve the layer of the cementing material by adding phenyl propylene liquid emulsion and butylene benzene liquid emulsion to the cementing material The bond strength between, and with the improvement of admixture content, the bond strength is more obvious, in addition, but also can reduce the shrinkage rate of cement, improve the retarding effect.

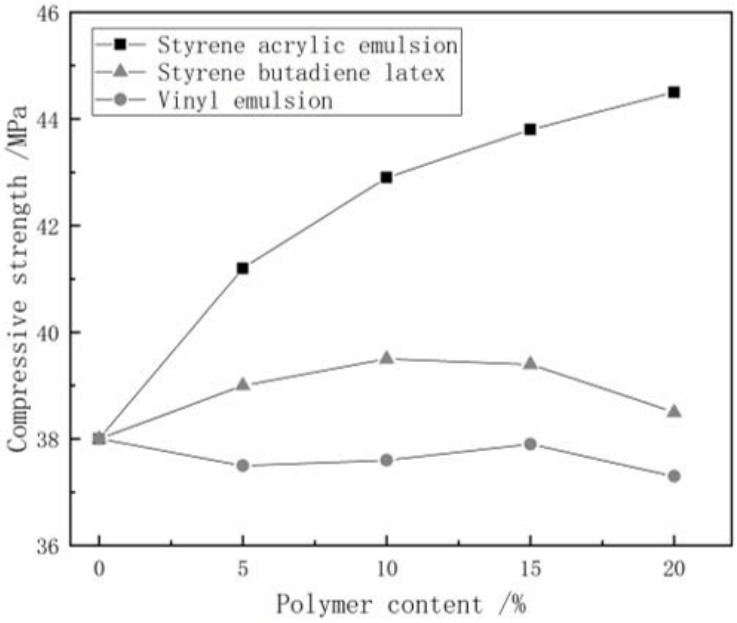

Fig 1. Influence curve of polymer emulsion on compressive strength of cement 28d.

Due to the characteristics of 3D printing concrete equipment, requires 3D printing concrete has the characteristics of fast condensation speed, and the original silicate cement condensation speed is slow to meet the demand, so the condensation speed of fast sulfur aluminate cement mixed into ordinary Portland cement [7], to improve the condensation speed of concrete, and improve the accuracy of 3D printing concrete.

Table 1. Effect of different polymer emulsions on the basic properties of cement paste.

Type	Mixed amount/%	Initial setting time/min	End coagulation time/min
Benchmark specimen	0	120	200
Vinyl emulsion	5	128	210
	10	130	215
	20	135	223
Butyl benzene emulsion	5	143	230
	10	152	242
	20	164	255
Styrene acrylic emulsion	5	120	203
	10	112	191
	20	100	180

2.3 Comparison of aggregate effects

With the sustainable development and the continuous promotion of the concept of green building, the utilization rate of recycled aggregate has been greatly improved. For ordinary concrete, the strength of the recycled aggregate has a better bonding interface and a strong bonding strength. The experiment shows that the recycled coarse aggregate is instead of the strength of the recycled concrete is [8] higher than the ordinary concrete. In addition, due to the high water absorption rate of the recycled aggregate itself, it will reduce the effective water glue of the concrete Compared with, thus improving the strength of the concrete by [9].

For 3D printed concrete, the selection of aggregate is particularly important.3D printing concrete equipment through the nozzle ejected a layer of concrete, each layer of concrete thickness is thin, a layer of concrete stacked into 3D printing buildings. If the particle size of the aggregate is too large, it may block the nozzle, and it also affects the mixing and transportation of the recycled aggregate. Therefore, high strength, low density, spherical-like recycled aggregate are often used in 3D printed concrete [10].Experiments show that when the particle size of regenerated coarse aggregate is less than

4.75mm, the compressive strength of reclaimed concrete gradually increases with the increase of the particle size of regenerated coarse aggregate Big [11].In addition, the addition of regenerated crude aggregate can effectively reduce the amount of cementitious material used, thus reducing the cost. For the recycled fine aggregate, with the increase of the added amount of the recycled fine aggregate, the concrete fluidity and water retention have been improved. When the substitution rate is about 33%, the increase range is the most obvious, and the reduction of concrete strength is also the least [12].

2.4 Impact ison of mineral admixture

For ordinary concrete, adding a certain amount of mineral admixture can improve its strength and durability. With the increase of silicon powder content, the compressive strength and wear resistance of concrete also increase. When the mixing amount of silicon powder increases to 4%, the increase value of compressive strength and wear resistance is the largest. Adding a certain amount of fly ash will slightly reduce the compressive strength of concrete, but it will significantly reduce the dry shrinkage deformation of concrete [13].

For 3D printed concrete, because the building application of 3D printed concrete needs the concrete structure to have a certain tightness and durability, and the concrete itself has a certain gap between the aggregate cannot meet the requirements, which needs to add a certain mineral admixture to improve its density and durability. With the increase of fly ash content, the density of 3D printed concrete can be continuously increased due to its own filling effect. However, excessive fly ash will lead to the reduction of concrete strength, wear resistance is also reduced, for this case, the fly ash and ore powder can be mixed to improve the pore structure of concrete, improve mixing Condenser strength. For silicon powder, because it itself has a certain activity, it can be reacted with cement to produce a strength of hydration silicate gel products. On the other hand, through the mixing of fly ash and silicon powder can improve the early strength of concrete, increase the bonding strength of concrete, reduce the mutual extrusion between materials, so as to reduce the bleeding phenomenon, improve the accessibility of [14].

2.5 Effect ison of admixtures

Today's construction engineering for concrete performance requirements are more and more strict, not only need the strength of concrete to meet the requirements, but also need concrete to have easy molding, curing, good durability and other characteristics. This has prompted the rapid development of concrete admixture.

For ordinary concrete, often introduce water reducer, early agent, air agent and retarder four admixtures. The water reducing agents are mostly surfactants. After adding the aqueous solution, the hydrophilic group in its molecules points to the solution, and the water repellent group points to the air, solid and directional arrangement, forming a directional adsorption film to reduce the surface tension of water and the interface tension of the two phases. This activity is the main reason for the enhancement effect of the water reducing agent. Water-reducing agent can also enhance the fluidity of concrete and reduce the loss of concrete slump through adsorption, dispersion, lubrication and moisture action. The hydration of cement can be accelerated by adding a certain amount of early agent And hardening process, shorten the curing cycle, improve the early strength of concrete [15].But if mixed with a large number of early strengthening agents, the chloride ions will accelerate the corrosion of steel bars, resulting in concrete cracks. Adding gas inductant can improve the compatibility of concrete mixture, improve its impermeability and frost resistance, but at the same time due to the production of a certain amount of bubbles will reduce the strength of concrete. Adding a certain amount of retarder can reduce the hydration heat and prolong the condensation time of concrete.

For 3D printed concrete, because the concrete printing is a layer of layer stacked, the concrete needs to have a certain strength and density, and at the same time needs to strictly control the condensation time. Due to the water reduction enhancement effect of water reducing agent, adding a certain water reducing agent in 3D printing concrete can increase the interlayer bonding strength of concrete, reduce the pores in concrete, and improve the fluidity of concrete by [16].To control the condensation time, a certain amount of retarder [17] should be added to the 3D printed concrete to alleviate the reaction of

water and other components through the adsorption and wrapping of the retarder, and then reduce the hydration speed The role of controlling the condensation time. In addition, adding gas guiding agent in the process of 3D printing concrete can increase the compactness of concrete and reduce water drainage phenomenon. Gas agents are often used with other admixtures. The results show that [18] is found at 0.005% and 0.06%.There is good compatibility between gas agent and other admixtures, further enhance the plasticity of concrete.

Table 2. Slump retention capacity of concrete mixed with plasticizer and air entraining agent.

Plastic agent/%	Air entraining agent/%	Slump at 0min/cm	Slump at 60min/cm
0.03	0.005	13.8	11.5
0.03	0.007	16.0	14.0
0.03	0.009	18.3	16.9
0.06	0.009	20.1	18.5
0.06	0.005	18.6	17.1
0.06	0.007	21.0	17.8
0.09	0.007	22.9	20.2
0.09	0.009	23.7	21.6
0.09	0.005	20.5	19.9

2.6 Influence comparison of fiber materials

For ordinary concrete, steel fiber and carbon fiber are often added to improve the strength of the concrete. The study shows that [19], a certain amount of carbon fiber can improve the compressive strength of concrete. When the mixing amount of carbon fiber is less than 0.08%, the compressive strength growth range is larger. With the increase of the mixing amount, the compressive strength is further improved, and when reaching a certain mixing amount, [20] is stable. Adding steel fiber can improve the folding strength and improve the ductility of concrete.

For 3D printed concrete, due to the lack of forced reinforcement in concrete, it is particularly important to improve its tensile resistance. Research shows that [21] add polyethylene and polypropylene fiber can effectively improve the fluidity of 3D printing concrete, because the elastic modulus of polypropylene fiber is lower than the elastic modulus of concrete, adding polypropylene fiber can to a certain extent restrain the deformation of concrete structure, improve the crack resistance of concrete, increase the toughness of concrete, reduce concrete shrinkage phenomenon. In addition, a certain amount of polyethylene fiber can improve the bending resistance of 3D printed concrete by [22].But too much The addition of fiber will affect the impermeability of the concrete, and may also plug the nozzle of the 3D printing nozzle.

3. Thinking on technological innovation

At present, there is still a lot of room for the development of 3D printing concrete technology. Here are some ideas for technological innovation.

Because 3D printing concrete requires high-precision controlled printing, computer matching can be used to calculate the concrete mix ratio. The calculation parameters and calculation coefficient of 3D printed concrete are calculated and analyzed by using computer Internet technology. By comparing the data relationship between multiple groups of water-glue ratio, sand ratio and unit water consumption, the best experimental data of concrete and ease, strength and durability are selected. SAS, Matlab and other software are used for regression analysis of data errors to realize data visualization processing, and the quantitative relationship between data is determined through JAVA programming, At the same time, LINDO software can be used to solve the linear planning and secondary planning, predict the mechanical properties of concrete, and optimize the final mix ratio relationship of concrete. Moreover, BIM software can be used to design the concrete building model of the computer, compare the designed model with the concrete parameters, adjust the final

design parameters of concrete, so as to greatly improve the design accuracy and rationality of the concrete mix ratio.

The 3D printing concrete technology can also be innovated through the principle of bionics. The shell of the conch is a threaded structure and can bend naturally. The strength of its structure is very high, and the shape of the 3D printed concrete can be designed according to the shape of the conch shell. Steel fiber is added to the 3D printed concrete, so that the concrete has a certain structural support, and then through the laminated composite material layer by layer cross, reduce its pores, improve the strength, with this method of 3D printed concrete designed strength has been improved compared with ordinary concrete. This concrete can be applied to structures with are curved, such as arch bridges, arches, etc. In addition, the steel fiber added can be To be made into a mesh structure, inserted in multiple directions of concrete, compared with a single steel fiber has better tensile force and durability, enhance the strength and toughness of concrete.

3D printing technology can also be combined with artificial intelligence technology and intelligent robotics technology. By inputting a large number of deep learning algorithms into the intelligent robot to control the robotic arm printing concrete of the intelligent robot, to realize the high precision and automation of 3D printing concrete. Not only that, but also a mobile robot can also be designed to print the concrete in all directions. In addition, cameras can also be placed inside the intelligent robot to monitor the whole process of 3D printing concrete in real time. If errors are found in the printing process, they can be timely corrected through the artificial intelligence error learning algorithm to further improve 3D beating Automation and intelligence of printing concrete technology.

4. Suggestions on problems with 3D printing technology

(1) Most of the current 3D printing concrete equipment has a small nozzle size, if the designed concrete needs a large aggregate particle size, it is easy to block the nozzle. And the small nozzle size also limits the size of the construction, only through a module of assembly to form a 3D printed building. Therefore, it is suggested that 3D printing concrete equipment can develop towards large size, which means that the transportation and distribution of raw materials and automatic module data need to be matched with large size 3D printing equipment.

(2) The design of 3D printed concrete is very different compared with the ordinary concrete design. Nowadays, various theoretical systems of ordinary concrete are relatively perfect, which can achieve many requirements of concrete production. And the various theories of 3D printing concrete are still vacant, which cannot achieve any required 3D printing. Therefore, it is suggested to explore the theoretical knowledge of the material configuration, mechanical properties, and evaluation indexes of 3D printed concrete through a large number of experiments. In addition, it is also necessary to improve the test methods and acceptance specifications of 3D printed concrete to improve the reliability and safety of 3D printed buildings.

(3) The fineness of 3D printed concrete is still relatively low. At present, the 3D printed concrete is still relatively rough, with low strength and large gap. It often needs to carry out secondary deep processing after one printing to improve the fineness of concrete. Therefore, it is suggested to combine 3D printing concrete equipment with computer optimization technology, and monitor the 3D printing process in real time with Internet cloud computing. This requires 3D printing equipment and 3D printing computing method, which are indispensable. In addition, it is also necessary to be combined with architectural software such as BIM to predict the designed 3D printed buildings in real time to further make the 3D printed concrete Fine, modularized.

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