Research on the influence of furan resin addition on the performance and accuracy of 3D printing sand mold

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Abstract. Aiming at the problem of performance and dimensional accuracy instability of casting sand mold under immature process, a study on the influence of different content of furan resin on the performance and dimensional accuracy of casting 3D sand mold was carried out. With the same tensile test block, compression test block and standard size measurement test block printing process as experimental conditions, based on industrial grade 3D printing equipment, the changing rule of parameter change of furan resin added is studied. On this basis, a variety of different resins are used to print the test block, each group takes the same number of test blocks. Mechanical properties and dimensional accuracy were measured. The influence of resin addition on product performance and dimensional accuracy was studied by range analysis. The experimental results show that there is a relationship between the interaction and dependence between the numerical addition and the mechanical and dimensional precision of the 3D print sand mold. The mechanical and dimensional precision of the sand mold can be reached to the best level in a certain range of resin added. The research results provide guidance and direction for further promoting the application of 3D printing technology in the foundry industry, and provide a theoretical basis for the application of 3D printing sand in different casting situations.

1. Introduction
Many of the casting sand molds used in the past have been made by manual molding or mechanical processing. The commonly used molds are sand mold, wood model, plastic mold, metal mold and vanishing die. These molds are produced after the assembly process, which should be used for casting after the cavity of the required casting parts. However, the casting molds obtained by these materials and methods often have some outstanding problems such as long period [1], manufacturing difficulty [2], high cost [3] and so on, especially for complex parts and customized products cannot make quick response [4-5].

With the development of 3D printing technology, sand mold 3D printing is more and more widely used in casting mold manufacturing. Compared with the traditional mold manufacturing method, the sand type 3D printing technology can realize the rapid production of the virtual design mold to the realistic mold, and truly realize the digital manufacture, which embodies the remarkable superiority [6]. But at present, the process parameters in the casting sand type 3D printing process are still not fixed in [7], and the fixed parameters are still used in different casting situations to print production, which leads to the defects in the mechanical and dimensional accuracy of the obtained sand type products. This leads directly to the casting sand type 3D printing products which cannot be used in different casting situations. This greatly restricts the further development of casting 3D printing technology [8]. Many policies have been introduced at home and abroad to encourage and promote the transformation
of the foundry industry to the advanced green intelligent manufacturing model, and to support and accelerate the development and improvement of the sand type 3D printing equipment. In spite of this, the application of sand type 3D printing technology in the foundry industry is still in the beginning and groping stage, and there is still a certain gap from the industrialization application. It mainly focuses on how to reduce the cost of 3D printing sand type, and improve the printing efficiency and improve the strength of the sand type [9-10].

In view of above, this paper studied the problem of poor printing quality which needs to be solved in the casting sand type 3D printing, and discusses the relationship between the mechanical performance and the size precision of the sand mold and the ink jet quantity of the key parameters of the process, so as to lay a theoretical foundation for the application of the foundry 3D printing products in different casting situations.

2. Technology principle of casting sand mold 3D printing

3D printing technology is one of the specific implementation contents of innovation driving the transformation and upgrading of China's manufacturing industry, and is playing a more and more important role in the development of the national economy.

In the field of casting sand mold manufacturing, 3D printing is applied by the way of using sand powder to bond materials and constructing sand mold by casting layer by layer.

The working process of the casting sand type 3D printing equipment using sand powder material as the printing material: first laying a layer of printing material on the working table, then spraying the furan resin on the printing material as the binder, spraying the whole sand surface, then laying the material again, then spraying the resin again, repeating the above circulation, until the above circulation. The entire product is stacked up by stacking printing material. The whole process of casting sand mold 3D printing is shown in Figure 1 a). The laying principle of sand powder and furan resin is shown in Figure 1 b).

![Figure 1. The schematic diagram of sand mold 3D printing](image)

Generally, the structure parts of the spray furan resin have a certain distance from the sand powder surface, and the driving system controls its position according to the printing data. It starts at one side of the sand powder working table, runs at a constant speed to the other side of the worktable, and is at the end of the worktable. In the process, the print server sends the generated 2D picture data through the data cable to the device and emit furan resin. This process has the following characteristics in casting sand mold 3D printing application.

a) The casting can directly produce complex sand patterns from 3D graphics, which has changed the traditional casting method.
b) The method has high forming accuracy and the sand mold can be formed quickly and integrally. The process of this method is flexible and can easily modify the parameters of printing process. The effect of improving the performance and precision of the product is very obvious. It is suitable for rapid forming of complex structure castings. Therefore, the application of 3D printing technology in casting sand mold has a revolutionary significance to the transformation and upgrading of the traditional casting industry.

3. The method of obtaining the different amount of furan resins

3.1. Resin concentration and the different amount of resin added
In accordance with the forming requirements of casting industry, different types of foundry sand are used on different occasions. With the different sand powder, different resins, such as phenolic resin and furan resin, can be used in the 3D printing process.

Furan resin has been widely promoted because of its excellent self-hardening properties, collapsibility and high dimensional accuracy of castings. When the furan resin sand was applied to 3D printing, the quality of the sand core was different from the traditional molding method. Furan resin was used as a binder to study the relationship between the size of the addition of the furan resin and the properties of the product.

According to the first law of Fick kinetic equation shown in Formula (1),

$$J = -D \frac{dC}{dx}$$

(1)

$J$ is the diffusion flux of the solute somewhere in the diffusion field (the mass of solution per unit area in unit time $\text{mol/} (\text{m}^2\text{s})$), $D$ is the diffusion coefficient $\text{m}^2\text{s}^{-1}$.

It can be seen from the formula that the greater the concentration of the dissolved agent, the greater the concentration gradient at the solid liquid interface, which can accelerate the diffusion process and the greater the dissolution rate, which is beneficial to the improvement of the bond strength.

The main parameters that affect the amount of the resin are derived from the voltage signals applied to the inkjet device, as shown in Figure 2 a), and there are 5 parameters (delay time, rising time, holding time, drop time, release time). A large number of experiments have been carried out to find that by changing the length of the above time parameters. As shown in Figure 2 b) and Figure 2 c) the droplet situation under different parameters. Through these methods, we get 6 groups of different numerical values, such as Table 1.

![Figure 2. Different values of the furan resin added](image)

Table 1. Volumes relation of six kinds of resin adding parameters

| Order | 1     | 2     | 3     | 4     | 5     | 6     |
|-------|-------|-------|-------|-------|-------|-------|
| Value | $V_0$ | $0.5V_0$ | $0.8V_0$ | $1.5V_0$ | $3V_0$ | $4V_0$ |
3.2. Products with different volume of resins

In this study, 70~140 silica sand was used as the sand powder to lay the working face, and the industrial grade 3D printer was used as the manufacturing equipment for different batch products. According to the parameters of the resin added in Table 1, the test blocks are printed separately. Each group of parameters is printed with 5 intact specimens. The size of the specimen is 40 mm*60mm of the cylinder. Each block is marked and recorded respectively. After printing, all the test pieces are placed into the same drying oven for rapid hardening and then cooled to room temperature. XQY- II intelligent sand strength machine is used to determine its compressive strength, tensile strength, and the same batch as a group. The test results are recorded and the average value is the final performance reference value of the product of this batch. The three coordinate measuring machine is used to test the size accuracy of each test piece under each batch, and each position size is recorded. The printed test block is shown in Figure 3.

![Print results of test block](image)

Figure 3. Print results of test block

Due to the influence of sand powder device width, sand layer thickness and compact plate angle on the strength of sand core during the printing process, the mixture of raw sand and curing agent is considered as forming material, and the spray resin is used to form the resin with the curing agent. From the angle of the chemical reaction between the resin and the curing agent, the proportion of the two is suitable. The increase of the content of the resin and the curing agent can improve the strength of the initial molding sand mold. But the increase of the content of the curing agent may lead to the problem that the curing agent and the sand are too bad after mixing the sands, and even lead to the interruption of the printing. So the proportions of the curing agent are suitable. Therefore, in order to ensure that the test data can truly reflect the effect of resin addition, other parameters will remain the same during the experiment.

4. Influence of resin addition on the performance and precision of sand mold

Through the classification of detection of the above experiments, each experiment data were averaged to obtain the experimental data as shown in table 2. The experimental data analysis on the addition of 6 groups of different resins shows that the tensile strength of the sand type specimen increases obviously with the increase of the amount of resin, while the compressive strength increases slightly. When the resin addition is 3 times the theoretical standard addition (V0), the tensile strength and compressive strength of the sand mold are 1.56 times and 1.07 times the original value respectively. Therefore, the tensile strength of sand mold is more sensitive to the change of resin addition, while the compressive strength remains basically unchanged.

| Order | 1  | 2  | 3  | 4  | 5  | 6  |
|-------|----|----|----|----|----|----|
| Value / (pL) | V₀ | 0.5 V₀ | 0.8 V₀ | 1.5 V₀ | 3 V₀ | 4 V₀ |
| Tensile strength / (Mpa) | 2.05 | 1.32 | 1.78 | 2.55 | 3.21 | 4.18 |
| Compressive strength / (Mpa) | 7.44 | 5.43 | 6.72 | 7.90 | 7.98 | 8.56 |
A high precision three coordinate measuring instrument is used to measure the size accuracy of the size precision test block of sand type, and the 100 coordinate points on each sand type specimen are measured and analyzed, and Figure 4 is the measurement result. As can be seen from Figure 4, as the amount of resin increases gradually, the number of points that conforms to the range of dimensional accuracy increases first, then decreases, and has a larger change. This means that the change of the amount of resin has great influence on the size accuracy. According to the standard requirement of the normal production of the sand mold (the size qualification rate is more than 90%), the change of the resin addition will be very concerned. It is necessary to change the amount of the resin in the range of a small area, otherwise the size error of the sand type product will eventually exceed the standard. But it is not normal to enter the follow-up production.

![Fig. 4. Relationship between resin addition and qualified rate of sand mold size](image)

It can be concluded that the increase of the amount of resin will effectively improve the mechanical properties of the sand type products, but at the same time it will lead to the larger size error of the product and affect the normal subsequent production. Therefore, in different casting occasions, the specific amount of numerical addition should be determined according to the requirements of the casting process for the strength and size of the sand mold. Otherwise, the amount of resin added blindly will not be applied.

5. Conclusions
Through the principle analysis of the inkjet device of the casting sand type 3D printing equipment, the influence relation between the amount of the furan resin added and the control parameters is obtained. On this basis, the mechanical property test block and the size precision test block are repeatedly printed and produced by different resin adding amount, and the amount of resin added and the sand are obtained. The relationship between type tensile strength, compressive strength and dimensional accuracy is restricted.

With the increase of resin content, the tensile strength of sand type specimens increased significantly, while the compressive strength increased slightly. The tensile strength of sand mold is more sensitive to the change of resin addition.

With the gradual increase of resin content, the number of measurement points that meet the size accuracy range increases first and then decreases. This means that the change of resin addition has a great influence on dimensional accuracy, and the resin content can only be changed within a range of cells.

On the one hand, the increase of the amount of resin will effectively improve the strength and other mechanical properties of the sand type products, but at the same time it will lead to the larger size error of the product and affect the normal subsequent production.
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