Research on the method for improving mechanical properties of sand mold based on 3D printing process

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Abstract. Aiming at the problem of strength instability of casting sand mold under immature process, a study on the strength influence factors and the method for improving the performance of casting sand mold. With the same typical casting sand mold printing process as the experimental conditions, the comparison experiments were carried out from the change of the 3D printing process parameters, the increase of the mechanical vibration to increase the sand density and the introduction of the heat source to speed the sand mold curing speed, The influence of the above methods on the strength of printing sand mold is analyzed. Comparative experimental research shows that the test methods have effectively improved the strength of the sand mold, and the combination of that three methods has a better effect. 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

The casting industry provides near net shape metal casting for a wide range of industries. However, the casting process has changed little over centuries [1], except for incremental improvement in materials. With the development of society, it is often a major bottleneck in new product development that the requirement for mold production tooling and the design constrained production method [2].

The traditional casting sand mold is mostly used by manual molding or mechanical processing [3]. After assembly, it is used to cast a cavity that is in accordance with the size of the needed casting parts. The commonly used mold has sand mold, wood model, plastic mold, metal mold so on. The casting molds obtained by these materials and methods often have problems such as difficult manufacturing, long cycle and high cost, and cannot respond quickly to complex parts and customized products [4]. With the development of 3D printing technology, casting sand mold 3D printing is more and more widely used in casting mold manufacturing [5]. Compared with the traditional die making method, the sand mold 3D printing technology can realize the rapid production of the virtual design mold to the realistic mold, and truly realize the digital manufacture. Therefore, compared with the traditional mold manufacturing method, the casting time can be shortened to 50% ~80%, and the superiority of the production of the complex shape casting can be more embodied [6]. At present, many policies have been issued at home and abroad to support and accelerate the R & D and improvement of the casting sand mold 3D printing equipment, and encourage and promote the transformation of the foundry industry from the traditional rough manufacturing mode to the advanced green intelligent manufacturing model.

In spite of this, the application of casting sand mold 3D printing technology in the casting industry is still in the beginning and groping stage [7 - 9], and there is still a certain gap from the industrialization application. It mainly focuses on how to reduce the cost of 3D printing casting sand mold [10], improve the printing efficiency [11], and improve the strength of casting sand mold [6]. The first two are mainly focused on the research of materials and equipment. This paper mainly discusses how to improve the strength of core to meet the requirements of diversified foundry.

2. Technology principle and application 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. With the gradual deepening of the application of the technology, traditional foundry has brought about disruptive changes. Casting manufacturing is simple, quality and efficiency enhanced. Manufacturing process is people-oriented and green manufacturing. It provides an exemplary role for transformation and upgrading of foundry industry. Figure 1 shows the comparison between the traditional casting process and the sand mold 3D process. It can be seen that the four processes of die making, core making, molding and closing in the traditional casting are all replaced by a 3D printing process. Figure 2 is a sand mold product for casting sand mold 3D printing, the following features are embodied in the application process.

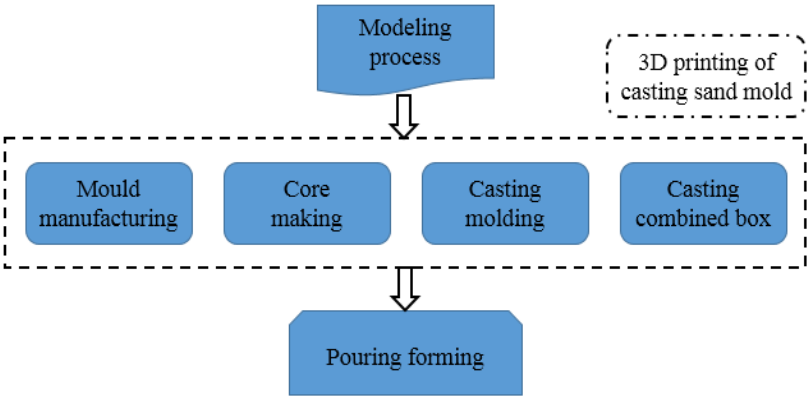

Figure 1. Comparison diagram of the principle for traditional casting and 3D printing

a) 3D printing technology shortens the casting process. The casting process directly creates complex sand mold from 3D graphics data, and changes the traditional casting method of mold, core making, molding and closing the box.

b) 3D printing improves casting quality and improves production efficiency. The precision produced by this process is high, and the sand and sand cores are quickly integrated to form, greatly reducing the R & D and production cycle of the products.

c) The product design is flexible, saving cost and reducing manufacturing difficulty. This process has the advantages of flexible modification of model design and so on. It can improve the precision of product and reduce the effect of sand iron ratio. It is especially suitable for the production of complex internal structure castings.

d) Green casting and intelligent casting have been realized. The foundry environment is greatly improved and the labour intensity of the workers is reduced; the human cost of the machine change is greatly reduced, and the typical digital manufacturing has greatly improved the intelligent level of the casting production.

Figure 2. A type of sand type printing product

Therefore, the industrial application of 3D printing technology will have a far-reaching significance for the transformation and upgrading of the foundry industry, the foundry intelligent manufacturing and the construction of the future foundry intelligent factory.

3. The influence of printing process parameters on the strength of sand mold

3.1. Resin concentration and amount of spray

Different resins, such as phenolic resin and furan resin, are used for different printing sand in the casting sand mold 3D printing process. In order to meet the needs of the printing head spray, the solution is also needed to dissolve and dilute the resin. The dissolution of the resin generally goes through two stages of swelling and dissolution. First, the solvent molecules permeate and diffuse to the macromolecules of the resin, weaken the interaction between the molecules and expand the volume. Then the movement of the chain and molecular chain accelerates, the molecular chain loosens and the entanglement reaches the two way diffusion to complete the solution.

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

$$J = -D\frac{dc}{dx} \tag{1}$$

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

From the formula (1), it can be seen that the greater the concentration of the dissolved agent, the greater the concentration gradient at the solid liquid interface, the faster the diffusion process, the greater the dissolution rate, the more the dissolved resin molecules, the increase of the area of the bond bridge after precipitation, which is beneficial to the improvement of the bond strength.

In the same way, the content of the resin binder can be improved when the amount of the solution is evaporated, thus increasing the area of the bond bridge and increasing the strength after the sand mold bonding. It is important to note that the better the spray quantity is, the increase of the spray amount will significantly increase the diffusion of the binder in the sand layer, which leads to the reduction of the precision of the molding casting sand mold, so it is necessary to consider the requirements of the precision and strength of the sand mold to choose the appropriate amount of liquid.

3.2. Dosage of curing agent

A representative molding method in the field of casting sand mold 3D printing is considered. The main consideration is to mix the raw sand and the curing agent as forming material, and use the printing nozzle to spray resin and solidify 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.

3.3. Printing layer thickness

The basic principle of 3D printing is to form by layer by layer (see Figure 3), so the thickness is the key parameter affecting printing effect. The most intuitive impact is, the smaller the thickness of the printing layer, the more time the unit height is printed and the lower the printing efficiency of the equipment; on the contrary, the greater the thickness of the printing layer, the higher the printing efficiency. In the actual printing, it can be seen that the smaller the thickness of the printing layer, the more thorough the bond between the layer and the layer is, the higher the strength of the molding sand mold is, in advance of the same spray volume and the curing dose. This is due to the smaller the thickness of the layer, the more easy the resin binder passes through the sand to the next layer, the more full the bond, the greater the thickness of the layer, the more difficult the resin binder passes through the sand, on the other hand, the proportion of the resin binder and the sand can be reduced, which may lead to the insufficient content of the resin bonding agent and the insufficient area of the bond bridge. In order to fully connect the two layers of sand, the molding sand mold has low strength and easy to slice. The other effect of increasing the thickness of the printing layer will reduce the precision of the molding sand, and even see the clear printing level through the naked eye, which will affect the casting precision. The determination of the thickness of the printing layer is also related to the grain size of the sand. The 3D printing commonly used sand is 70~140 mesh. The finer the grain size of the sand, the denser the sand layer is, the less the binder is diffused, so the thickness of the printing layer needs to be determined by the size of the concrete sand.

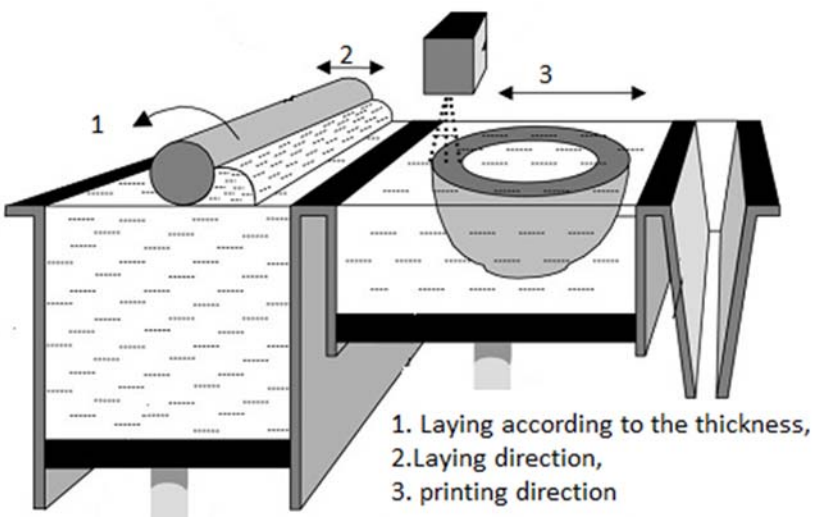

Figure 3. Laying in accordance with the specified thickness

4. Influence of vibration compaction on sand mold strength

The vibration function is not arranged in the sand laying device of common sand mold 3D printing equipment in China, and the vibration structure is only transferred to the lower sand silo to help the sand. The vibration mechanism built in sand laying equipment in sand mold 3D printing equipment produced by Exone in Germany is not only beneficial to the sand, but also to the direct connection between the vibration source and the sanding plate, and the sand plate is transformed into the vertical component by the fixed rotating shaft on the side, and the sand plate of the high frequency motor also realizes the high frequency vibration, because the high frequency vibration is realized by the sand plate of the high

frequency motor. The sand can be flapped tightly during the course of sand spreading. It is proved by practice that under the same sand layer thickness setting, the vibration compaction can increase the initial molding sand strength by more than 30%. This is due to the increase of sand volume in the sand layer with equal thickness after vibration, and the sand particles are more closely contacted with the binder, and the density of the molding sand is obviously improved. Under the condition of constant printing parameters, the main factors affecting the strength of molding sand are vibration frequency, vibration amplitude, sand volume and sand speed. In a certain range, increasing the vibration frequency and amplitude can increase the compaction degree of the sand layer. Increasing the amount of sand and reducing the speed of sand laying can improve the sand bearing capacity of the sand layer, which is beneficial to the improvement of the strength of the initial molding sand mold.

5. The influence of heat energy on the strength of sand mold

In actual printing, according to the characteristics of the resin binder used, we can also consider introducing heat energy to promote the formation of resin bonded bonding bridge. If the phenolic resin is used to accelerate its curing reaction with sand, the infrared heating tube can be added at the bottom of the sand distributor. The reference setting temperature is 300~500 C. Because the moving path of the sand paving machine is scanning running along the surface of the sand layer, the heating tube set in the bottom of the sand paving device can be heated in the full cover of the sand layer at a close distance, and the heating efficiency is higher. At the same time, the heating unevenness caused by the ambient temperature heating is avoided. In the printing process, the heating of the sand layer is introduced, which can effectively improve the strength of the initial molding sand. The other effect of the introduction of heating is to reduce the diffusion of effectively.

In addition, the strength of the initial molding sand, which is obtained by the introduction of heat energy in the printing process, is still not sufficient to meet the requirements of the casting. The final heating treatment can be introduced, such as the common microwave oven, with a reference setting of 200~280 C, which can also significantly increase the ultimate strength to achieve higher casting requirements.

6. Conclusion

Through repeated optimization of the above methods, we have printed multiple batch of typical castings, and the following conclusions are obtained for the combination of the three methods applied to the 3D printing process of the casting sand type.

Increasing the concentration of resin and spray, increasing the proportion of the curing agent and reducing the thickness of the printing layer can help to improve the strength of the initial molding sand mold, but the increase of the diffusion of the spray amount will reduce the precision of the core.

Mechanical vibration or sound wave can improve the strength of the initial molding sand.

The introduction of heat in printing helps to improve the strength of the initial molding sand, and subsequent proper heating can also improve the strength of the final sand mold.

The three methods mentioned in the paper are applied to casting sand mold 3D printing process, the sand mold obtained has better dimensional accuracy and mechanical properties.

References

[1] H. Shangguan, J.W. Kang, C.Y. Deng, Y. Hu, T. Huang, 3D-printed shell-truss sand mold for aluminum castings, Journal of Materials Processing Technology. 250 (2017) 247-253.

[2] C.Y. Deng, J.W. Kang, H.L. Shangguan, Y. Hu, T. Huang, Z.Y. Liu, Effects of hollow structures in sand mold manufactured using 3D printing technology, Journal of Materials Processing Technology. 255 (2018) 516-523.

[3] M. Upadhyay, T. Sivarupan, M.E. Mansori, 3D printing for rapid sand casting—A review, Journal of Manufacturing Processes. 29 (2017) 211-220.

[4] H.H Choi, E.H. Kim, H.Y. Park, G.H. Cho, Y.G. Jung, J. Zhang, Application of dual coating process and 3D printing technology in sand mold fabrication, Surface and Coatings

Technology. 332 (2017) 522-526.
[5] J.W Kang, H.L. Shang, C.Y.g Deng, Y. Hu, J. Yi, T. Huang, Additive manufacturing-driven mold design for castings, Additive Manufacturing, Available. (2018) 2214-8604.
[6] P. Hackney, R. Wooldridge, Optimisation of Additive Manufactured Sand Printed Mould Material for Aluminium Castings, Procedia Manufacturing. 11 (2017) 457-465.
[7] A.N. Chen, J.M. Wu, Y.X. Liu, R.Z. Liu, L.J. Cheng, W.L. Huo, Y.S. Shi, C.H Li, Fabrication of porous fibrous alumina ceramics by direct coagulation casting combined with 3D printing, Ceramics International. 44 (2018) 4845-4852.
[8] A.C.M. Bekker, J.C. Verlinden, Life cycle assessment of wire + arc additive manufacturing compared to green sand casting and CNC milling in stainless steel, Journal of Cleaner Production. 177 (2018) 438-447.
[9] T.D. Ngo, Al. Kashani, G. Imbalzano, K.T.Q. Nguyen, D. Hui, Additive manufacturing (3D printing): A review of materials, methods, applications and challenges, Composites Part B: Engineering. 143 (2018) 172-196.
[10] B. Zareiyan, B. Khoshnevis, Effects of interlocking on interlayer adhesion and strength of structures in 3D printing of concrete, Automation in Construction. 83 (2017) 212-221.
[11] .J. Pucci, B.R. Christophe, J.A. Sisti, E.S. Connolly, Three-dimensional printing: technologies, applications, and limitations in neurosurgery, Biotechnology Advances. 5 (2017) 521-529.