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Research on Precision Casting Technology of Gear Based on Additive Manufacturing Technology

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ABSTRACT. *This paper studies a precision casting process of cast steel helical gears. This process can directly complete the casting of the tooth profile. Using additive manufacturing technology, silicone rubber mold and epoxy resin mold were manufactured, then casting water glass sand mold and coated sand mold were achieved. Next use casting simulation software for filling analysis and solidification analysis, pouring system and shrinkage system for economical optimization. The results show that the resin molds made by this process have a high surface finish, good surface replication ratio and meet the accuracy requirements.*

KEYWORDS: *Cast steel helical gear, Silicone rubber mold, Epoxy resin mold, Numerical simulation, Additive manufacturing technology*

1. Introduction

Gear is an important aspect of power transmission and movement, the manufacturing process is complex, it is difficult to directly cast the tooth shape, need to follow the tedious processing process. Therefore, more rapid and low cost gear processing method is the research hot spot and market demand[1].

The development of additive manufacturing technology has effectively reduced the manufacturing cost and cycle time of products[2]. However, materials and performance of the product are not able to meet all occasions, rapid tooling technologies (RT) came into being, it is an extension of the additive manufacturing technology[3]. Rapid soft mold technology is tantamount to add some materials with heat resistance, wear resistance and other related properties to make molds in the matrix materials such as silicone rubber or epoxy resin[4]. In some applications, rapid soft mold technology can replace the traditional steel mold, reduce the production cost and production cycle for its fast, simple and low cost. It is more widely used in the development of new products[5-6].

This project is to study the precision casting process of cast steel cylindrical helical gears through additive manufacturing technology. By using silicone rubber mold and epoxy resin mold technology and numerical simulation analysis

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technology, a manufacturing process that can directly cast the gear tooth profile is developed.

2. Experimental Process

Figure 1 shows a three-dimensional model of a cylindrical helical gear with maximum profile size of Φ521mm×115mm. One of the surfaces has a cam, which is an important surface and is placed underneath when casting.

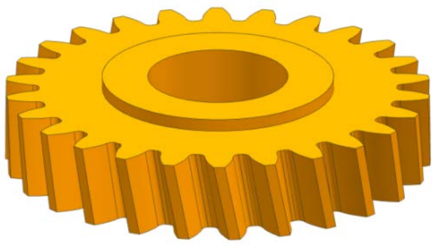

Fig.1 The Three-Dimensional Solid Diagram of Cylindrical Helical Gear

Figure 2 shows the schematic diagram of the process flow for fabricating the silicone rubber mold[7]. The silicone rubber employed in the experiment is coca silicon rubber RTV-2 vulcanized at room temperature. The product is a condensed two-component material, which is composed of two components, agent A and agent B. Agent A is the base material and agent B is the curing agent, and the mixture of agent A and agent B produces a multi-linked reaction to form a flexible elastomer. The mass ratio of agent A silicone rubber to agent B curing agent is 50:1. After mixing evenly, brush several times of the prototype surface until sufficient thickness.

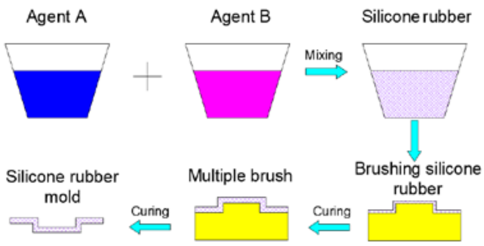

Fig.2 Schematic Diagram of Process Flow for Fabricating the Silicone Rubber Mold

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After the silicone rubber mold is completely cured, locate the prototype and mold, remove the silicone rubber mold, apply parting agent on the prototype, put the silicone rubber mold back of the prototype according to the original location, and apply plaster gypsum backing to sufficient thickness. Figure 3 shows the schematic diagram of fabricating the gypsum backing. The material is α - type high strength gypsum powder, which needs about 40% waters to prepare gypsum slurry. After hardening, the porosity is small, the strength is exalted, and the setting time is about 8 minutes. Depending on the characteristics of volume changed in the process of gypsum condensation, adjust the ratio to ensure the precision of the mold[8].

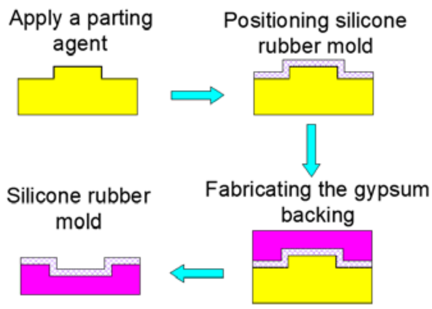

Fig.3 Schematic Diagram of Process Flow for Fabricating the Gypsum Backing

When making epoxy resin mold, the ratio of epoxy resin and curing agent is 4:1. And add some materials, such as glass fiber, aluminum powder, silicon carbide and alumina which can improve the functioning of epoxy resin mold. The addition of aluminum powder is mainly to enhance the thermal conductivity of the mold, glass fiber can improve the toughness of the mold, add alumina and silicon carbide powder, increase the hardness and abrasion resistance of the mold[9]. Epoxy resin and curing agent long-term temperature resistance to 260 ℃, short-term temperature resistance up to 350 ℃, high strength, low viscosity, can flow into the crevices, can effectively replicate the shape of the surface. Aluminum powder is 400 meshes with a purity of 99.7%. The size of the heating tube is Φ 10mm × 100mm, the voltage is 220V, and the power is 300W.

Figure 4 shows the schematic diagram of the production process of the water glass sand upper type. It includes the following steps: designed and machined RP prototypes through casting drawings, as showed in Figure 4(a). The silicone rubber surface layer is made by brushing the liquid silicone rubber on the surface of the RP prototype and curing it, as showed in Figure 4(b). After the silicone rubber mold is cured, apply plaster to the back layer, as showed in Figure 4(c) is the completed silicone rubber mold. After the completion of the silicone rubber mold, the water glass sand pattern can be reproduced, as showed in Figure 4(d) is the water glass sand pattern made with the silicone rubber mold. Figure 5 shows the schematic

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diagram of the production process of the water glass sand bottom type, and the specific process is basically consistent with that described in the upper mold.

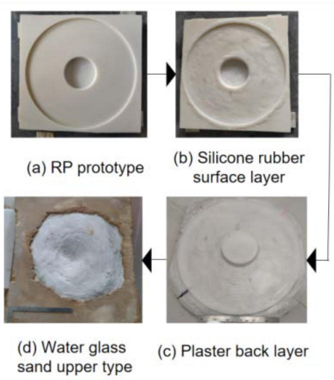

Fig.4 Schematic Diagram of the Production process of the water glass sand upper type

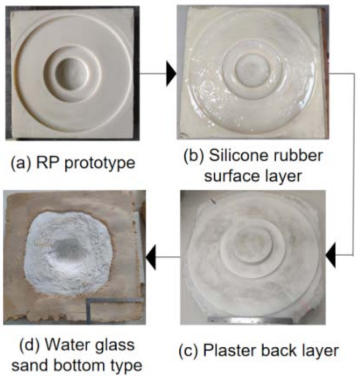

Fig.5 Schematic Diagram of the Production process of the water glass sand bottom type

Figure 6 shows the schematic diagram of the process of making the outer epoxy mold. First make the silicone rubber mold, after it was fully cured, as an intermediate mold for making the epoxy mold, for the role of the bridge, to turn the outer epoxy mold. Figure 6 shows the schematic diagram of the process of making the inner epoxy mold, which are basically the same as the process of epoxy resin outer mold. However, the embedding of the heating pipe needs to be completed in the process of making the back layer, as shown in Figure 7(d).

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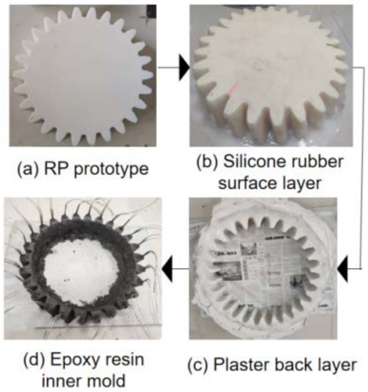

Fig.6 Schematic Diagram of the Production process of epoxy resin outer mold

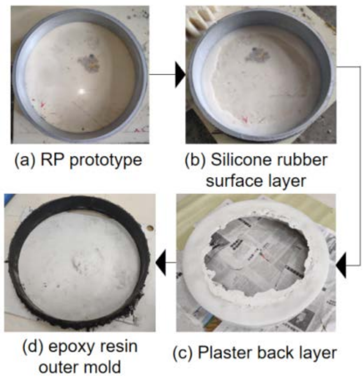

Fig.7 Schematic Diagram of the Production process of epoxy resin inner mold

As showing in Figure 8, the process of making coated sand mold. Position the epoxy resin inner and outer molds to ensure uniform thickness of the caked sand mold. The heating pipe of the epoxy resin inner mold is connected to the power supply for curing the caked sand mold.

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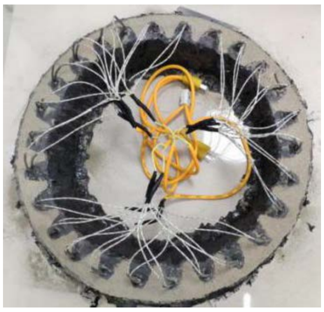

Fig.8 Schematic Diagram of Manufacturing Process of Coated Sand Mold

3. Numerical Simulation Analysis of Casting

The pouring system should control the flow direction and flow speed of the liquid metal. In order to ensure that the molten steel can fill the cavity smoothly and continuously, an open pouring system is selected[10]. The setting of the riser is to compensate the volume shrinkage of the casting in the solidification process and reduce the casting defects.

Material type and sand type are selected from the standard material library. The temperature of mold and cavity is set at room temperature of 25℃. The filling temperature was 1650℃and the filling speed was 20 cm/s. The simulation process requires setting up model parameters related to the shrinkage model, fluid flow model, and oxidation entrapment model.

Figure 9 shows the simulation results of the filling process of the castings. The filling time was 11.2062 s. Through the observation of the filling process, the filling time of the cavity is about 5.6 s, the rising speed of the liquid metal is about 17.2 mm/s. After the liquid metal enters the cavity, it fills the cavity from the bottom at a stable speed, there is no big impact on the wall. The liquid metal in the horizontal direction of the liquid height difference are small, there is no obvious liquid splash phenomenon. The filling process is smooth, the filling speed is appropriate. During the whole filling process, the temperature difference between the metal liquid in the cavity is small, and there is no coagulation phenomenon during the filling process.

Figure 10 shows in the simulation results of the solidification process of the castings. The solidification time was 2899.4712 s. The data of the solidification process is fitted by quadratic polynomial, which is the left part of the symmetry axis of the quadratic curve with opening downward. It can be observed that the solidification speed is faster at the beginning, the solidification speeds to become slower with the increase of solidification time. This is because at the beginning of solidification, sand temperature is low, sand and cavity temperature difference is large, so the solidification rate is faster. With longer solidification time, sand

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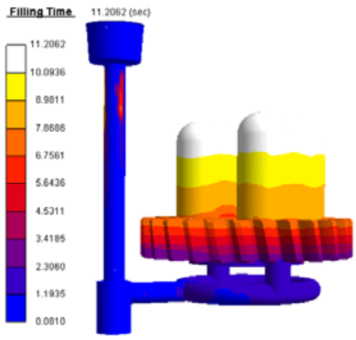
temperature gradually increased, so the temperature difference is smaller and the solidification rate is slower.



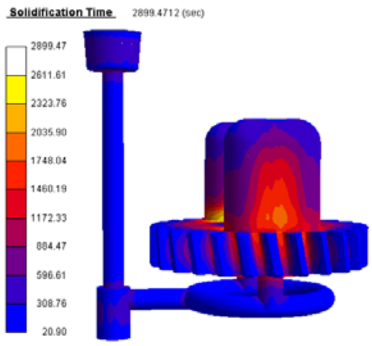


Fig.9 Imulation Result of the Filling Process   Fig.10 Simulation Result of Solidification Process

4. Process Analysis

(1) In this paper, a silicone rubber mold and an epoxy resin mold are made by additive manufacturing technology, direct casting of gear teeth are achieved using a composite molding technology of water glass sand mold and near tooth coated sand mold.

(2) The surface reproduction rate of the silicone rubber mold obtained by silicone rubber mold turning technology is high, and the silicone rubber mold has good elasticity and smooth surface, which ensure the precision of manufacturing resin molds. The choice of gypsum as the backing layer can effectively ensure the shape of the produced silicone rubber mold.

(3) Epoxy resin mold has enough strength, hardness, and good surface quality, this experiment chooses to use high temperature epoxy resin, to ensure that the heating tube heating process, the mold can maintain the original strength. A certain

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amount of aluminum powder, silicon carbide powder and alumina powder are added to ensure the mold's heat transfer and abrasion resistance.

5. Conclusion

(1)By using AnyCasting simulation software, the gating system and feeding system were designed by analyzing the flow of the mold filling process and the temperature field of the solidification process.

(2)Through the three-dimensional software design of the process and the relevant simulation of the program, experiments turn over the mold and sand casting, verification of the simulation analysis results is reliable, and the precision casting process is feasible.

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