Research on Slurry Extrusion-based Additive Manufacturing Process for Bauxite Shell Mould

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Abstract: Directly fabricating casting shell mould through additive manufacturing technologies can simplify the process, shorten the manufacturing time, and enhance the rapid manufacturing and trial production capabilities of castings. A slurry extrusion-based additive manufacturing process for casting shell mould was proposed in this paper, which can fabricate green shell parts by extruding and stacking bauxite slurry. An additive manufacturing equipment with Delta mechanism was designed and manufactured, with a recommended extrusion speed of no more than 100 mm/s, a ratio of feeding speed to extrusion speed of 1.0, and a layer height of 80% of the nozzle diameter. By analyzing the rheological properties and extrusion formability of the slurry, it is recommended to use 42.5 vol.% bauxite and 51 vol.% silica sol in the slurry, with a yield stress range of 300-400 Pa for the best forming effect. When the infill pattern is the honeycomb pattern and the filling density is 80%, the bending strength, porosity, and shrinkage are 11.62 MPa, 41.6%, and 1.9%, respectively, and the thermal conductivity is also good. Finally, the feasibility of this additive manufacturing process was verified through the preparation of sample shell mould and their trial casting.

Keywords: slurry extrusion; additive manufacturing; shell mould; bauxite

1 Introduction

Investment casting is a precision casting process used to create complex and intricate metal parts. It is used in industries such as aerospace, automotive, jewelry, and medical devices. Additive manufacturing technologies can directly fabricate shell mould for investment casting, eliminating the wax pattern preparation, repeated wet dipping and stuccoing, and wax removal processes in traditional investment casting [1]. It can greatly simplify the process, shorten the manufacturing time, and enhance the rapid manufacturing and trial production capabilities of castings. The additive manufacturing technologies used for shell mould mainly include SLS (Selective Laser Sintering), SLA (Stereolithography), 3DP (Three Dimensional Printing), and slurry extrusion-based additive manufacturing. SLS uses a mixture of organic binder and ceramic powder; SLA uses a mixture of UV laser cured photosensitive resin and ceramic powder; 3DP selectively sprays organic binders onto ceramic powders. There are many organic binders in the moulds prepared by these methods, and post-treatment may have a negative impact on the environment. The slurry extrusion-based additive manufacturing uses aqueous ceramic slurry with shear thinning characteristics to prepare shell mould [2], which is simple in process, suitable for a variety of materials, and environmentally friendly. The main problems faced are the specialized equipment, materials and supporting processes. It is necessary to further research on the equipment, ceramic slurry, preparation process, and shell mould post-treatment, to promote the development and application of the slurry extrusion-based additive manufacturing process.

2 Experimental procedure

Firstly, the CAD model of the shell mould is designed and then the STL file is output. G codes are generated through the slicing software. The bauxite slurry is extruded from a nozzle that moves according to the G codes, and the extruded filaments are stacked layer by layer to obtain a green part, which has a wall structure composed of the outline layer and the internal infill. Finally, the green part is vacuum dried for 24 hours in a freeze dryer, and then sintered at 1100 ℃ for 4 hours in a resistance furnace.

The composition of ceramic slurry includes 40-50 vol.% bauxite powders, 45-55 vol.% silica sol, 3.5-4.5 vol.% sodium polycarboxylate, 3 vol.% glycerol, and 1 vol.% PEG400. The mixture of silica sol, sodium polycarboxylate, glycerol, PEG400 is prepared by magnetic stirring for 20 minutes. Then the bauxite powders are added to the mixture in batches during the ball milling process. After ball milling for 12 hours, the viscosity of the bauxite slurry is adjusted with an acidic thickener, and then subsequent experimental tests and fabrication of shell mould can be carried out.

3 Result and discussion

Additive manufacturing equipment

A slurry extrusion-based additive manufacturing equipment for shell mould preparation was developed at Lanzhou University of Technology, as shown in Figure 1. It adopts a Delta mechanism composed of a fixing plate and three groups of guide pillars, pulleys and connecting rods, and has a relatively small footprint but a large motion range. The maximum workspace is 700 mm × 700 mm × 950 mm. A stepping motor in the push-rod feeding device provides pressure to push the slurry in the barrel to be transported to the extrusion head. The screw in the extrusion head rotates to extrude the slurry from the nozzle and the extruded filaments deposit layer by layer.

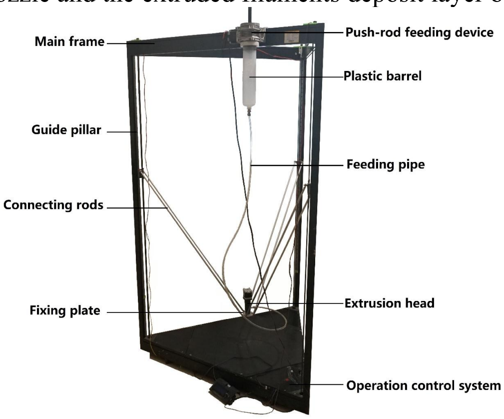

Figure 1 Slurry extrusion-based additive manufacturing equipment for shell mould

To balance preparation efficiency and part quality, the printing speed should not exceed 100 mm/s and not be less than 20 mm/s. When the feeding speed does not match the printing speed, the extrudate will accumulate or become too thin. Generally, the ratio of feeding speed to printing speed is set to 1.0. 80% nozzle diameter as the layer height can achieve a finer surface while ensuring strong interlayer bonding.

Bauxite slurry

The effects of composition on slurry properties and the extrusion process were analyzed. With the increase of silica sol content, the viscosity of the slurry after ball milling gradually decreases, and the average width of the extruded filament increases. Based on the principles of moderate viscosity and yield strength, as well as uniform and smooth extrusion, a silica sol content of 51 vol.% is selected. The optimized slurry composition also contains 42.5 vol.% bauxite and 4.1 vol.% sodium polycarboxylate. The rheological properties of bauxite slurry are important indicators determining the quality of additive manufactured shell mould. A suitable slurry should have shear thinning characteristics. The viscosity is very high at low shear rate, and the slurry can quickly form after extrusion; Viscosity rapidly decreases at high shear rate, reducing extrusion resistance. Through adjusting by the thickener, the yield stress of the slurry is within the range of 300-400 Pa. The slurry shows a very obvious shear thinning characteristic and can have good extrusion fluency and self-supporting ability.

Infill pattern

The porous shell mould with three infill patterns (rectilinear, grid, and honeycomb) was prepared using bauxite slurry, and the effects of the infill pattern on properties were evaluated. The different filling paths of the infill patterns lead to changes in the stacking form and connections of the extruded filaments, resulting in differences in the number and shape of pores formed in the wall, which affects the properties of the shell moulds. The samples prepared with the honeycomb pattern have the highest bending strength (11.62 MPa) and porosity (41.6%), as well as good heat-transfer ability, with an average shrinkage rate of 1.9%. The honeycomb pattern has more comprehensive advantages compared to the other two infill patterns.

A trial casting was carried out for shell mould prepared by the slurry extrusion-based additive manufacturing process. Figure 2 shows an example of additive manufactured shell mould and trial cast part.

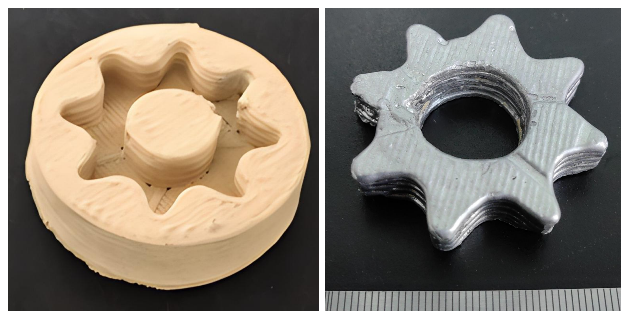

Figure 2 Prepared shell mould and trial cast part

4 Conclusion

The shell mould can be innovatively designed and fabricated using the slurry extrusion-based additive manufacturing developed in this paper. This work provides an attractive feasibility for fabricating shell mould with complex shapes, lightweight, high-strength and controllable hierarchical porous walls.

Acknowledgments

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References

[1] Tang S, Yang L., Fan Z., et al. A review of additive manufacturing technology and its application to foundry in China. China Foundry, 2022, 18(4): 249-264.
[2] Liu H, Su G and Li Y. Effect of Wall Structure on the Dimensional Accuracy of Shell Mould Prepared by Slurry Extrusion-based Additive Manufacturing Process. International Journal of Cast Metals Research, 2022, 35(4): 102-110.