Visualization and Monitoring of Shell-making Process in Investment Casting

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Abstract: Shell-making process is a critical step in investment casting for shape control, and breaking through the "black box" of this process remains a challenging issue in its research. This paper introduces blue light scanning technology into the study of investment casting shell processes, using samples with cantilever beam structures as research objects. It explores the influence of cantilever structure inclination angles on shell wall thickness and deformation. The feasibility and effectiveness of this method are demonstrated through numerical simulation results. This approach achieves visualization and digitalization of the layer-by-layer shell preparation process, providing a new technical pathway for investigating shell formation mechanisms.

Keywords: investment casting; ceramic shell; shell quality monitoring; dimensional deformation

1 Introduction

The fabrication of high-quality ceramic shells with dimensional stability and uniform wall thickness is a critical prerequisite for achieving near-net-shape investment casting. To ensure shell quality, real-time monitoring and analysis of key parameters, such as shell wall thickness, are essential during the preparation phase. However, current research methodologies predominantly rely on post-fabrication or post-dewaxing evaluations using techniques like industrial CT[1], which precludes real-time data acquisition of crucial factors such as layer thickness uniformity and deformation during the shell preparation process. This limitation impedes the timely detection and correction of potential quality issues, thereby increasing the risk of shell rejection. To address this challenge, there is an urgent need to develop novel technologies and methodologies capable of real-time monitoring of key quality metrics during the layer-by-layer fabrication process of ceramic shells.

2 Experimental procedure

A cantilever beam sample model was prepared using additive manufacturing technology, referencing the local features of castings, as shown in Figure 1. The upper part of the model is the shell-making area. Cantilever beam structures with inclination angles ranging from 30° to 150° are evenly distributed on both sides of the model at 15° intervals, forming narrow spaces of varying degrees at the roots of the cantilever beams. Referencing the actual investment casting shell-making process, the shell-making area of the model was immersed in slurry and then evenly sprinkled with refractory powder (sand). This process was repeated after each layer was completely dry to complete the shell preparation work. After each shell layer dried, blue light scanning equipment was used to collect surface data of the model.

To achieve precise fitting of data with different layer thicknesses, a calibration area that does not participate in the shell-making process was designed on the model. The calibration area consists of a truncated cone and a plane, which can achieve complete alignment of six degrees of freedom in the spatial coordinate system. Feature structures for evaluation were also designed in the calibration area. When all feature structures show good positional coincidence, it indicates that the two models have achieved complete alignment, allowing for further extraction and analysis of surface data.

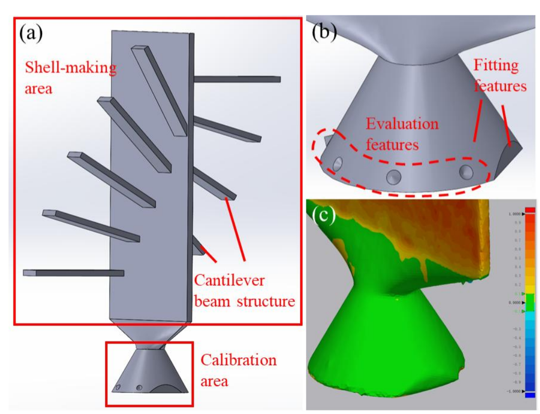

Figure 1. Experimental sample with cantilever beam structure. (a) Whole sample, (b) Calibration area, (c) Alignment status.

3 Result and discussion

Tracking the shell-making process

Figure 2 shows the thickness cloud map of the sample's surface layer shell. It can be observed that the wall thickness uniformity on both sides of the shell is relatively good, with the shell thickness at corresponding positions on both sides being essentially at the same level. However, the shell thickness at the bottom is greater than at the top, which is due to the slow downward flow of the slurry under the influence of gravity before it is completely dry. The cantilever beam structure significantly reduces the uniformity of the shell thickness. There is a noticeable increase in shell thickness at the root of the cantilever beam, reflecting the downward flow process of the slurry. In contrast, as shown in Figure 2, the shell thickness in the bottom area of the cantilever beam is significantly lower.

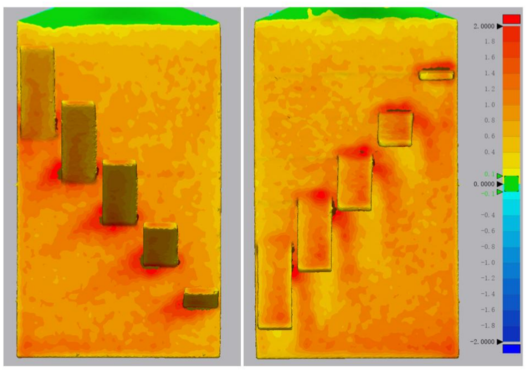

Figure 2. Thickness cloud map of the surface layer shell.

Shell deformation status

In addition to visually tracking the shell preparation process, the deformation during the shell-building process can be characterized using external calibration markers. Figure 3 illustrates the displacement of calibration markers at various positions on the cantilever beam sample, revealing three types of deformation behavior: (1) All cantilever beams move downward, indicating downward bending deformation of the cantilever beams under the gravitational force of the coating material. (2) Both calibration markers 1 and 2 move downward, indicating that the entire sample undergoes clockwise bending deformation along the X-axis. (3) Compared to calibration marker 1, calibration marker 2 shows more severe displacement with a degree of leftward offset, suggesting torsional deformation along the Z-axis at the bottom of the sample.

Numerical simulation verification results demonstrate that the displacement changes of external calibration markers can effectively reflect the deformation of the sample during the layer-by-layer shell preparation process. This method has been applied to the shell preparation process of actual casing castings, revealing the inward shrinkage deformation of its outer ring during the initial shell-making and burnout stages.

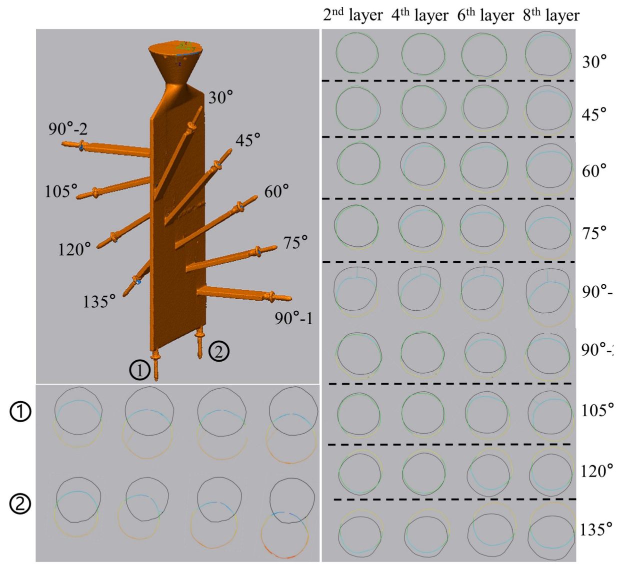

Figure 3. Displacement of calibration markers at different positions on the cantilever beam sample.

4 Conclusion

This study introduces blue light scanning technology to investment casting shell preparation, addressing challenges in analyzing layer thickness uniformity and deformation during shell-making. By aligning surface data from different stages using calibrated regions, it enables visualization and digital analysis of the shell preparation process, providing reliable evidence for quality assessment. Using a cantilever beam sample, the study investigates the impact of beam inclination on shell thickness uniformity and deformation, validated through numerical simulations. This method is then applied to actual production, analyzing radius and roundness data of large casing outer rings during shell-making. This reveals the inward shrinkage pattern of the casing outer ring during initial shell preparation and burnout stages.

References

[1] Liu C. Study on stream of variation modeling and robust control method for complex thin-walled parts in the investment casting process. (Doctoral dissertation). Shanghai Jiao Tong University, China.