Ceramic Stereolithography in Investment Casting: Recent Progress and Applications

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Abstract: Stereolithography-based ceramic additive manufacturing represents a promising technology for creating complex ceramic components with high precision. The technology's ability to form intricate structures and its compatibility with various ceramics make it particularly advantageous for rapid prototyping and low-volume production. This work discusses the recent progress and applications of stereolithography-based ceramic parts in the investment casting industry, particularly in the production of ceramic cores, shells, integrated core-shells, and filters, highlighting its potential to significantly accelerate production and enhance complexity.

Keywords: ceramic stereolithography; investment casting; ceramic core; integrated core-shell; ceramic filter

1 Introduction

Stereolithography-based ceramic additive manufacturing is a promising technology for producing complex ceramic components with high precision. This process involves the use of photo-curable resin mixed with ceramic powders to create suspensions, which are then cured with UV light to form green bodies. Post-processing involves burning out the resin and sintering the ceramic powders to achieve the desired mechanical properties. This technology is advantageous for rapid prototyping and low-volume production due to compatibility with various ceramic materials and ability to form complex structures. The application of stereolithography-based ceramic parts in the investment casting industry can greatly accelerate the production and further increase the complexity.

2 Ceramic stereolithography

There are multiple types of stereolithography devices being used to form green bodies with different characteristics. The mask-projection devices cure an entire layer simultaneously, achieving high efficiency with layer formation times between 10-30 seconds and a resolution of 35 micrometers. However, its maximum forming dimensions are limited by the light source. On the other hand, point-by-point scanning devices use point light sources, with layer formation taking 2-5 minutes. It allows for larger dimensions but has a lower resolution compared to the mask-projection type. The mask-projection scanning type combines the advantages of the previous two, using a movable mask-projection light source to achieve larger dimensions while maintaining high efficiency. It can produce parts up to 600 mm in size with layer formation times of 1-2 minutes.

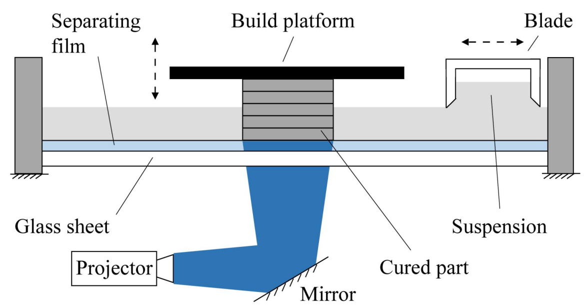

Figure 1. Principle of mask-projection stereolithography device.

3 Application in investment casting

Ceramic cores

Ceramic cores must withstand high temperatures and mechanical stresses. Advances in ceramic stereolithography technology have led to the production of complex double-layer ceramic cores, which are essential for the next generation of aero-engines operating at intake temperatures up to 2500 K. Research has shown that these cores can achieve high dimensional accuracy and surface quality, with examples including successful casting of single crystal blades with complete and high-quality inner cavities [1]. Multi-layer ceramic cores have also been successfully produced with casting verifications of single crystal vane blades [2]. These advancements also allowed the mass production of ceramic cores for industrial applications, significantly reducing costs and production times.

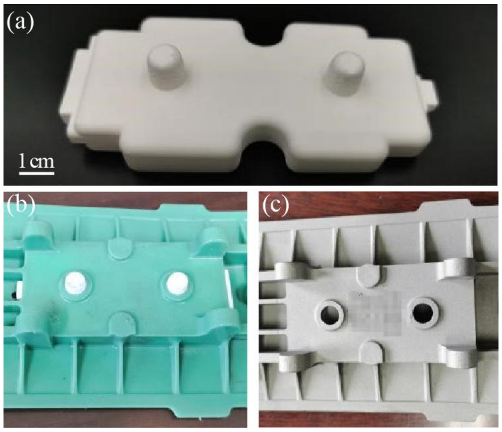

Figure 2. Stereolithography-based ceramic core and the corresponding casting verification.

Ceramic shells

Additively manufactured ceramic shells are designed based on 3D models of castings and have a wall thickness of approximately 1 mm. These shells are assembled into traditional clusters for subsequent processing. The advantages include the elimination of wax costs, higher efficiency in the coating process, and the ability to flexibly control wall thickness, significantly shortening the production cycle. High-accuracy ceramic shells have been demonstrated with systematic cleaning techniques, achieving a dimensional accuracy of 0.1 mm.

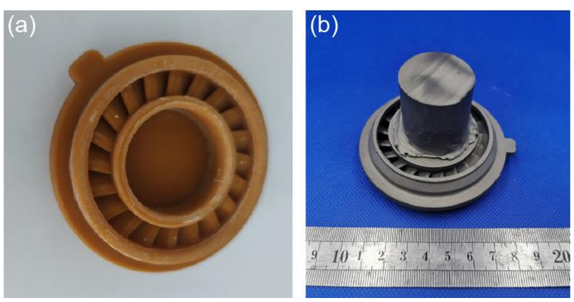

Figure 3. Stereolithography-based ceramic shell green body and the corresponding casting.

Integrated core-shells

The ceramic stereolithography technology allows to produce integrated core-shells. Combining the core and shell into one part reduces the number of molds required, shortening the production cycle from several months to just weeks. Integrated core-shells have shown high accuracy in both external shapes and internal cavities, with no defects detected in the cast parts. Integrated core-shells with pouring cups, cores, and shells have been developed. Permeation tests showed no cracks, and X-ray images confirmed complete and defect-free inner structures. The castings produced with these core-shells exhibited high surface roughness and dimensional accuracy within 0.1 mm.

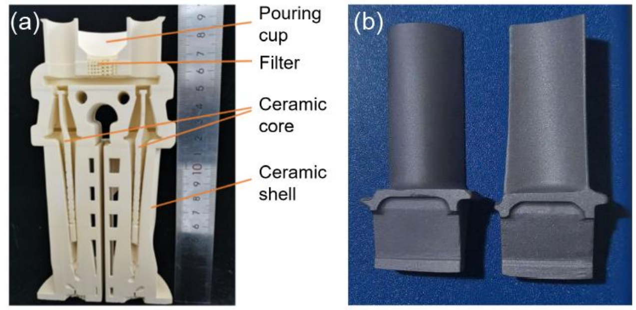

Figure 4. Stereolithography-based integrated core-shells and corresponding casted blades.

Ceramic filters

Traditional ceramic foam filters are prone to defects, while 3D printed filters with regular geometric structures provide better control over melt flow and are less likely to break. These filters enable repeatable pouring conditions and feasible simulations and structural calculations. Gradient filters have been designed and manufactured with 20 PPI in the upper region for impact resistance and 40 PPI in the lower region for inclusion control. This design enhances local temperature control and promotes single crystal growth with fewer stray grains.

4 Summary

Rapid advancements in ceramic stereolithography technology have expanded its applications in investment casting, including the production of ceramic cores, shells, integrated core-shells, and filters. Stereolithography-based ceramic cores have been demonstrated to meet the requirements for single crystal blade casting, with ongoing improvements needed for high-temperature performance. Shells and integrated core-shells have been successfully validated in practical castings, though further development in detection and evaluation techniques is necessary for industrial applications. Lastly, additively manufactured ceramic filters require verification and optimization for industrial use, emphasizing the importance of reducing device costs for widespread adoption in the investment casting industry.

References

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