Formation Mechanism of Lamellar Structure and Anisotropy Control of Ceramic Core via Stereolithography Additive Manufacturing

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Abstract: The influence mechanism of zircon distribution on sintering shrinkage was analyzed, and the strengthening mechanism of mullite on cores was analyzed from thermodynamics and dynamics. Through the comprehensive evaluation of the properties of ceramic slurry and core, the best choice of alumina ceramic core was the zircon content of 15%. The bending strength of alumina-based ceramic core increased from 14.8 MPa to 61.54 MPa, an increase of 315.8% at 25 ℃. The bending strength of alumina-based ceramic cores increased from 4.91 MPa to 11.59 MPa, an increase of 136% at 1500 ℃. The shrinkage in the height direction was reduced by 21%, which better weakens the anisotropy of the shrinkage of 3D printing alumina-based ceramic cores. Nano zirconia phase and nano mullite phase were formed by strengthening alumina ceramic cores with zircon, which improved the comprehensive properties of alumina-based ceramic cores. The successful preparation of 3D printing ceramic cores by stereolithography has promoted the industrial application of 3D printing ceramic cores technology in the field of preparing ceramic cores with complex structures.

Keywords: additive manufacturing; ceramic cores; anisotropy; flexural strength; sintering shrinkage

1 Introduction

The hollow blade of single crystal turbine is the key component of aeroengine[1]. The temperature resistance of the blade is affected by the complexity of the hollow structure[2]. The cooling channel inside the hollow blade is formed by the ceramic core, so the preparation of the ceramic core is particularly critical[3]. At present, the traditional hot injection molding technology is facing the challenge of difficult preparation of ceramic core with complex structures[4]. The stereolithography 3D printing has become a new choice of ceramic cores because it is apt to prepare ceramic cores with complex structures with low cost and high accuracy[5]. However, the disadvantage of anisotropy is still the key problem that restricts the wide industrial application of 3D printing ceramic cores technology[6].

In order to improve the strength of the ceramic core and improve the anisotropy of the ceramic cores at the same time, this study used stereolithography 3D printing technology to add zircon to the alumina-based ceramic cores, which significantly improved the anisotropic sintering shrinkage of the ceramic cores and improved the flexural strength of the ceramic cores.

2 Experimental procedure

The ceramic powder was composed of sieved alumina and zircon(sieve aperture 75 μm). The volume fraction of the zircon is 0%, 5%, 10%, 15%, 20%. The ceramic slurry was printed vat photopolymerization 3D printer (Beijing Ten Dimensions Technology Co., Ltd) to obtain 40×10×4 mm ceramic bodies. The laser energy was 3.56 mW/cm^2, the exposure time of each layer was 5 s, and the thickness of each layer was 100 μm. The ceramic bodies were embedded in 100 μm corundum sand and sintered in air.

3 Result and discussion

1. Slurry optimization design

Fig. 1 shows the viscosity of alumina ceramic slurry at room temperature with different zircon content. The viscosity of alumina ceramic slurry with different zircon content was less than 1500 mPa/s, and the viscosity first decreased and then increased with the increase of zircon content.

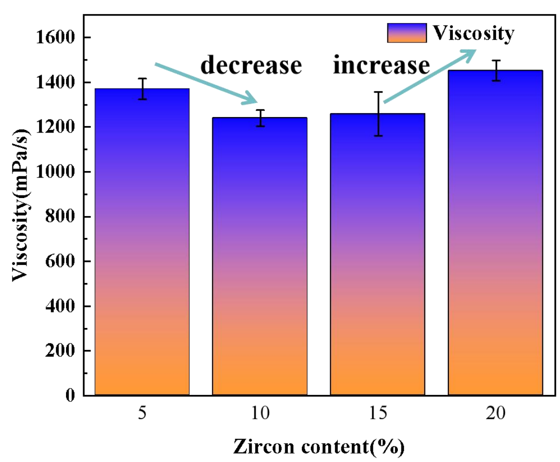

Fig. 1 Viscosity of alumina ceramic slurry with different zircon content: (a)5% (b)10% (c)15% (d) 20%

2. Effect of zircon content on properties

Fig. 2 shows the performance test results of ceramic cores with different zircon contents. After adding zircon, zircon reduced the sintering shrinkage because it was evenly distributed between alumina particles, which hindered the sintering of alumina particles. When the zircon content was less than or equal to 20%, the porosity of the ceramic cores remains above 30%. When the zircon content increased from 0% to 15%, the bending strength of alumina ceramic cores increased sharply at 25 ℃.

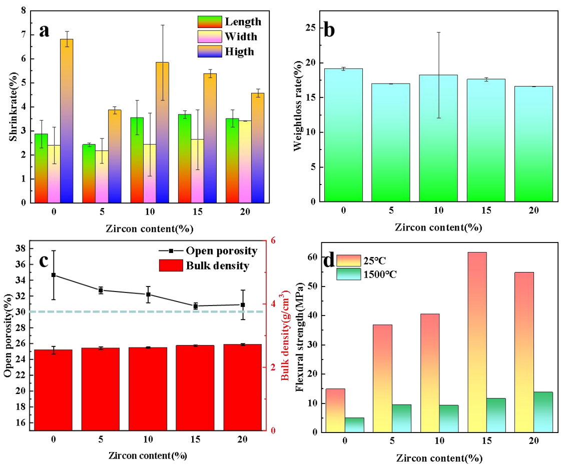

Fig. 2 Properties of alumina ceramic cores with different zircon contents:(a) Shrink rate (b) Weight loss rate (c) Open porosity and bulk density (d) Flexural strength

3. Formation and strengthening mechanism of printing layered interface

Fig. 3 shows the influence of zircon on the interface of alumina core. The distribution of zircon in the interface of ceramic layer. Large zircon particles were mainly distributed in the interior of the lamellar structure, while small ceramic particles were distributed at the edge of the lamellar structure. The decomposition of zircon particles and the diffusion behavior of silicon. The decomposition of zircon was accompanied by the diffusion and migration of silicon to alumina, and viscous flowed in the pores of ceramic core particles, which reduced the porosity of core and hinders crack propagation. Zirconia and silica were precipitated from the surface layer of zircon. Zirconia, which was distributed between alumina and zircon particles as a high-temperature stable phase, migrated to the pores and lamellae of alumina particles and hindered the shrinkage of printing layer. As an unstable phase, silica diffused from zircon to alumina particles, and part of silica filled between alumina particles in viscous flow, which promoted lamellar sintering of alumina and weakened the influence of lamellar on core. In addition, part of silica dissolved around alumina particles to form mullite phase, which further enhanced the interlayer performance of the layer.

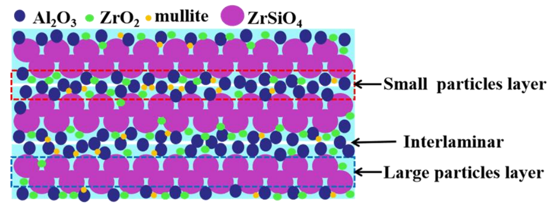

Fig. 3 Formation and strengthening mechanism of printing layer structure.

4 Conclusion

When the zircon content was 15%, the comprehensive performance of alumina ceramic core is the best. By 3D printing zircon to strengthen alumina ceramic core, while maintaining 30% open porosity, the bending strength of alumina ceramic cores at 25 ℃ was increased from 14.80 MPa to 61.54 MPa, and the bending strength at 1500 ℃ was increased from 4.91 MPa to 13.76 MPa.

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