Minimal Sintering Shrinkage Aluminum-Based Ceramic Cores Fabricated by Stereolithography

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Abstract: This study explores the stereolithography-based fabrication of aluminum-based ceramic cores, aimed at minimizing sintering shrinkage. Stereolithography-based ceramic cores often exhibit significant shrinkage during sintering, limiting their applications. In this work, by adding silica and kyanite into the alumina, high mechanical performance while minimizing shrinkage were achieved. Results demonstrate that cores with 22% silica and 8% kyanite show nearly zero shrinkage, making them suitable for complex, high-precision investment casting applications.

Keywords: stereolithography; ceramic cores; alumina; sintering shrinkage

1 Introduction

Ceramic cores play a crucial role in forming the intricate cooling channels within turbine blades used in gas turbine engines. These cores must exhibit high mechanical strength, thermochemical stability, and precise dimensional accuracy [1]. Ceramic stereolithography can achieve high-precision, high-performance, and complex core manufacturing. However, a significant challenge with stereolithography-based cores is their tendency to experience significant sintering shrinkage due to the high binder content [2,3]. This research addresses this challenge by modifying the ceramic composition to control shrinkage while maintaining mechanical integrity.

2 Experimental procedure

Aluminum-based samples were prepared with varying contents of silica and kyanite to evaluate their individual and effects on sintering shrinkage and mechanical properties. The contents are shown in Table 1. The samples were firstly solidified with a digital light processing stereolithography device under a UV light intensity of 15 mW/cm² and a layer thickness of 100 μm and sintered at 1500°C or 1600°C for 2 hours. Room-temperature flexure strength tests and high-temperature creep deformation analysis were then conducted.

Table 1. Contents of samples

Samples	Al_2O_3 (wt.%)	SiO_2 (wt.%)	Kyanite (wt.%)
K5S25	70	5	25
K6S24	70	6	24
K7S23	70	7	23
K8S22	70	8	22
K9S21	70	9	21
K10S20	70	10	20

3 Result and discussion

Microstructural analysis

SEM images (Figure 1) and XRD results showed that silica addition increased particle contact areas, promoting liquid-phase sintering and forming mullite through reaction with alumina. Kyanite decomposed into primary mullite and silica at lower temperatures, which further reacted with alumina to form secondary mullite.

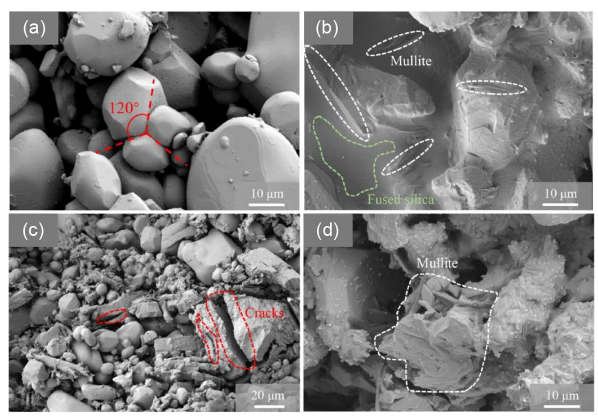

Figure 1. Microstructures of the samples: (a) original alumina; (b) silica added; (c) and (d): kyanite added.

Thermogravimetric analysis.

As shown in Figure 2, the DTA curve for the sample with 30 wt.% kyanite shows a 15% mass loss between 200°C and 600°C due to the oxidation and removal of the photosensitive resin. Above 600°C, an endothermic peak at 1221°C indicates kyanite decomposition into primary mullite. An exothermic peak at 1321°C signifies the reaction between resultant silica and alumina, forming secondary mullite.

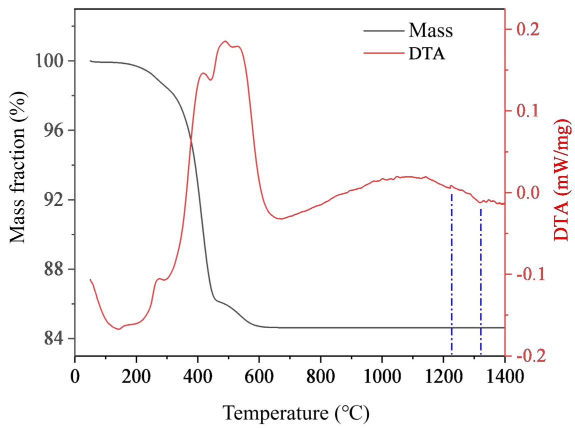

Figure 2. TG-DTA curve of binder removal and sintering.

Sintering shrinkage and mechanical properties

By comparing the effects of silica and kyanite on aluminum-based ceramic cores, it was found that adding silica increases sintering shrinkage and reduces deflection. Initially, flexure strength improves due to enhanced bonding between alumina grains and the formation of mullite, but it declines with further silica addition due to micro-cracks from cristobalite's phase transformation. On the other hand, kyanite reduces sintering shrinkage, even causing volume expansion. This initially decreases flexure strength due to cracks formed during kyanite decomposition, but strength improves with additional kyanite as more mullite forms, enhancing mechanical properties.

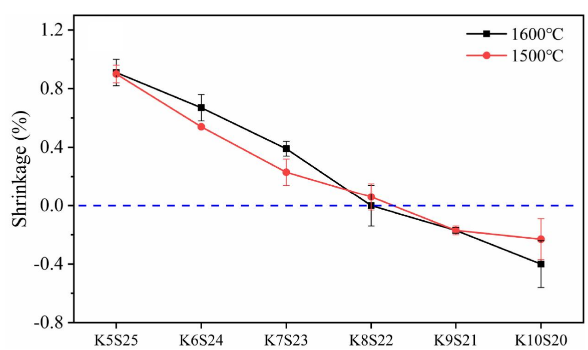

Figure 3. Sintering shrinkage of the samples.

Combining silica and kyanite leverages their complementary effects: while silica increases shrinkage, kyanite reduces it. A composition of 22% silica and 8% kyanite achieves minimal sintering shrinkage, with a deflection of 0.04 mm and a flexure strength of 29.4 MPa. This optimal powder system compensates for shrinkage while maintaining mechanical strength, enabling the production of high-precision ceramic cores suitable for practical applications.

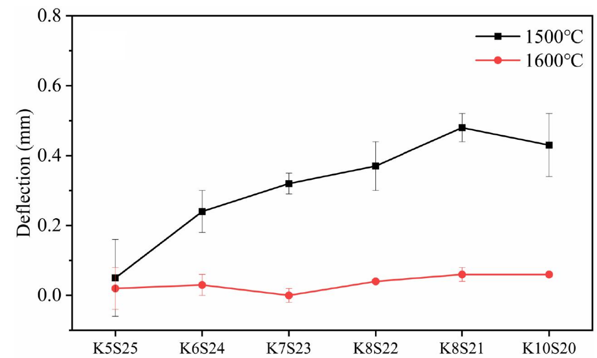

Figure 4. Deflection of the samples.

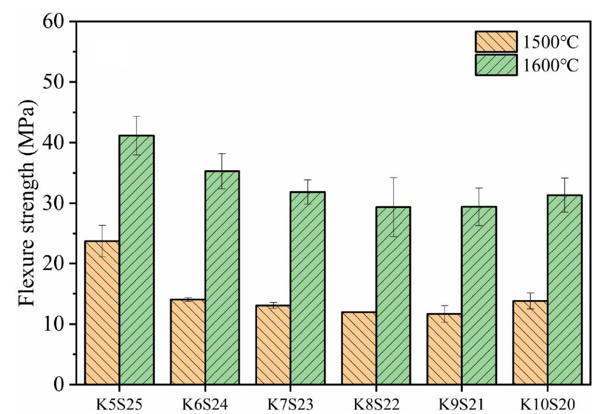

Figure 5. Flexure strength of the samples.

4 Conclusion

By optimizing the ceramic composition with silica and kyanite, we successfully minimized sintering shrinkage while maintaining high mechanical performance. This innovation addresses a key limitation in stereolithography-based ceramic core manufacturing, enabling the production of complex, high-precision turbine blades. Further work will focus on practical casting verifications and scaling up to mass production.

References

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