Enhanced Properties of Ceramic Shell for Investment Casting by Introduction of Mullite

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Abstract: Ceramic shells are important for investment casting of superalloy castings. Alumina based ceramic shells faced up with insufficient mechanical properties at high temperature during casting process. In this research, a high stable performance of ceramic shell was performed by introducing mullite powders in alumina refractory. XRD results showed that more mullite phases were characterized in ceramic shells with mullite powders addition after sintering and high-temperature heating treatment. By binding strength and thermal expansion measurement, ceramic shells with alumina and mullite powders showed better performance at both room and high temperature compared with traditional alumina based shells, which was because alumina and mullite powders mutually embedded in each interval, forming more compact ceramic slurry part in the shell.

Keywords: Ceramic shell, mullite, binding strength, thermal expansion

1 Introduction

Alumina based ceramic shells are widely used for investment casting, which is a popular method for the fabrication of superalloy castings with high dimension accuracy and surface smoothness. However, it was reported that alumina based ceramic shells faced up with problems that mechanical properties of shells decreased at the temperature around 1300 ℃, which would affect the dimensional accuracy of the blade castings[1].

Based on the demand on the properties of ceramic shells, including binding strength and thermal expansion coefficient at high temperature up to 1500 ℃ of ceramic shells, additives have been produced to the ceramic shell system to facilitating formation of mullite phase in the shell at high temperature for casting[2]. Besides, an ideal refractory fused EC95 with mullite and alumina phase as principal phases has been proposed by Zhang for the preparation of ceramic shells[3]. The increased mullite phase in the refractory significantly enhanced the mechanical performance of ceramic shell at high temperature. However, the mullite phase content in refractory is hard to control, and further research is still in need for enhancing properties of ceramic shells by the introduce of mullite phase needs further research.

In this research, we proposed a new method to realize stabilized mullite phase content in the refractory and an optimized structure of refractory cluster utilizing pure fused mullite with only mullite phase. Ceramic shell with different amount of fused alumina and mullite powders were prepared, the content of mullite phase was measured by quantitative XRD analysis, and the influence of mullite on the binding strength and thermal expansion behavior of ceramic shell were evaluated.

2 Experimental procedure

Ceramic slurry used for fabricating ceramic shells were prepared with pure alumina (marked as Al-Shell) and 75 wt.% alumina with 25 wt.% mullite powders (marked as AlM-Shell). Ceramic shells were sintered at 980 ℃ for 2 hours. XRD measurements were conducted to quantitatively analyze the phase content in shells. The 3-point binding tests were conducted to evaluate the binding strength, while thermal expansion behavior of ceramic shells was measured with thermomechanical analyzer.

3 Result and discussion

Phase characterization results

The XRD results of ceramic shells with and without mullite powders were shown in Fig. 1. Only phases of alumina and mullite are shown in XRD results of each shell. Only alumina and mullite phase are shown in XRD results.

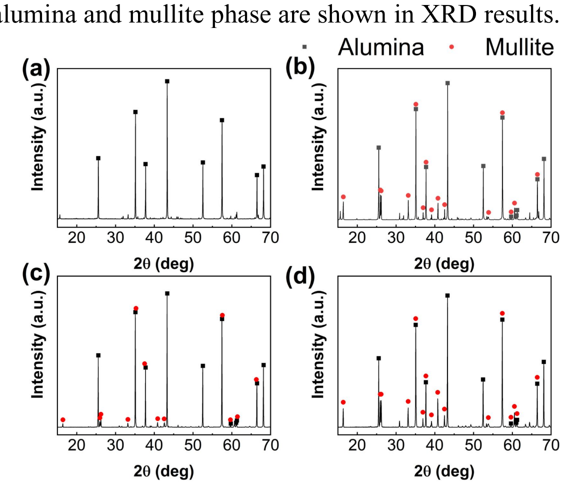

Fig. 1 XRD results for sintered Al-Shell(a) and AlM-Shell (b), and shells after 1500 ℃ heating treatment, (c) Al-Shell (d) AlM-Shell.

Further quantitative analysis results were conducted by WRF refinement method. For Al-Shell, mullite phase content increased from 0 to over 10 wt.% after 1500 ℃ heating treatment. While for ceramic shell with 25 wt.% mullite powders, mullite phase content increased from around 25 wt.% to 32 wt.%. The results show that for ceramic shells both before and after 1500 ℃ heating treatment, the mullite phase content in ceramic shells with 25 wt.% mullite powders are more than that in ceramic shells with only alumina powders.

Binding strength measurements

Binding strength results as shown in Fig. 2 indicate that the addition of mullite powders can help improve the binding strength at room temperature and high temperature. The enhanced binding structure was related to a more compact structure in ceramic slurry parts, with columnar mullite and globular alumina powders mutually embedded in each interval.

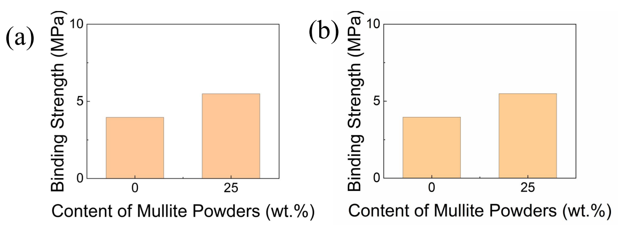

Fig. 2 Binding strength for ceramic shells with and without mullite powders before sintering (a) and at 1500 ℃(b).

Thermal expansion coefficient measurements

The curves of linear thermal expansion increment as temperature increased are shown in Fig. 3. AlM-Shell showed a continuous increasing in the expansion, while Al-Shell faced with change after 1300 ℃. Therefore, the thermal expansion performance of cereamic shells with fused mullite powders is more stable ,which benefits investment casting process.

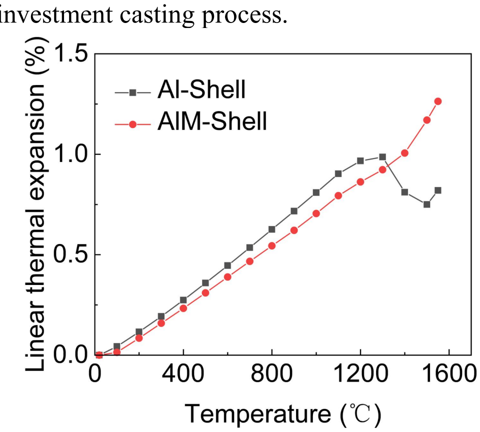

Fig. 3 Linear thermal expansion curve with temperature increasing for Al-Shell and AlM-Shell.

4 Conclusion

By introducing mullite powders as refractory in alumina based ceramic shell, the mullite phase content in the shell was increased. By this means, the binding strength for unsintered shell and sintered shell at 1500 ℃ was increased. Besides, the thermal expansion behaviour of the shell was more regular, which benefits the wax mold design for investment casting.

Acknowledgments

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