Effect of the Casting Methods on Microstructure and Room Temperature Mechanical Properties of K4800 Superalloy

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Abstract: The microstructure and room temperature mechanical properties of K4800 alloy test pieces cast by conventional gravity casting, centrifugal casting and adjusted pressure casting were comparatively studied. The results showed that both centrifugal casting and adjusted pressure casting could refine grain size, the typical grain size was 4.52 mm for normal gravity casting sample, but refined to about 0.28 mm for the sample of adjusted pressure casting, and about 2.22 mm for the sample of centrifugal casting. Meanwhile, the area fraction of shrinkage porosity was decreased from 1.75% of gravity casting sample to 0.27% and 0.25% of centrifugal and adjusted pressure casting samples, respectively. As-cast K4800 alloy by using different casting methods had similar microstructures, namely rod-shaped MC carbides and lamellar borides at grain boundaries, as well as the fine γ' phase within grains, but the sizes of the precipitates were refined for the centrifugal and adjusted pressure casting samples. Due to the reduction of casting defects, as well as the refinement of grain size and γ' phase, K4800 alloy samples prepared by adjusted pressure casting exhibited the much higher room temperature mechanical properties, with yield strength, ultimate tensile strength and plasticity of 798 MPa, 1152 MPa and 11.6%, respectively. Compared with gravity and centrifugal casting, its ultimate tensile strength has increased by 39.9% and 21.8%, and plasticity has increased by 70.4% and 52.5%.

Keywords: K4800; Centrifugal casting; Adjusted pressure casting; Microstructure; Mechanical properties

1 Introduction

With the thrust to weight ratio of aircraft engines further increase, the temperature bearing capacity and mechanics performance of the rear casing components need further improved[1]. The service temperature of the new Ni-based K4800 superalloy significantly increased from 620 ℃-725 ℃ of the existing K4169 superalloy to 800 ℃-850 ℃, exhibiting excellent application potential[2]. The complex structure of the rear casing components restricts the application of traditional welding forming and directional solidification, and most of them are currently prepared by using precision casting methods[3]. Among precision casting methods, there are mainly conventional gravity casting, centrifugal casting and adjusted pressure casting, each with its own advantages[4].

In this paper, As-cast K4800 superalloy test pieces cast by gravity casting, centrifugal casting and adjusted pressure casting, and its microstructure and room temperature mechanical properties were comparatively studied.

2 Experimental procedure

K4800 superalloy was the raw material of rear casing test pieces, and its chemical composition (wt.%) measured by inductively coupled plasma analyzer (ICP, Plasma 400) was Cr 18.0, Co 10.0, Al 2.0, Ti 3.7, Nb 1.9, W 1.4, Mo 2.0, C 0.1, Ni balance. The mold shells of three casting methods were all made of silica sol and zircon sand, and the pouring temperature was all 1530 ℃. The centrifugal speed and holding time of centrifugal casting were 100 rpm and 300 s, respectively. The filling pressure and holding time of adjusted pressure casting were 42 KPa and 1200 s, respectively.

The samples used for microstructure characterization and mechanical property test were prepared by wire electrical discharge machining, and the sampling positions of the three casting methods were all outer ring flanges. The microstructures were characterized by OLYMPUS-GX71 optical microscopy, TESCAN VEGA3 scanning electron microscopy equipped with energy dispersive spectrometer. The dog-bone samples used for mechanical testing were 12.5 mm in gauge length and 3 mm × 2 mm in cross-sectional area. These samples were performed by the Instron 3382 material test machine with a constant speed of 0.75 mm/min, and repeated three times to ensure the accuracy of mechanical properties.

3 Result and discussion

As shown in Fig. 1(a-c), the average grain size of gravity casting sample was about 4.52 mm, while the average grain size was refined to about 2.22 mm of centrifugal casting sample, and about 0.28 mm of adjusted pressure casting sample, respectively. Compared to the adjusted pressure casting, the grain size refinement of centrifugal casting was not significant. Meanwhile, the area fraction of shrinkage porosity in gravity casting sample was about 1.75%, while the proportions of centrifugal casting sample and adjusted pressure casting sample were decreased to about 0.27% and about 0.25%, respectively (Fig. 1(d-e)). Both centrifugal casting and adjusted pressure casting increased the fluidity of the melt, which was conducive to shrinkage and led to a reduction in shrinkage porosity. The adjusted pressure casting not only increased the fluidity of the melt, but also caused the overlapped dendrite skeleton to break, refining the grain size by increasing nucleation sites. In addition, the melting subcooling increased under pressure, inhibiting the grains growth. Therefore, adjusted pressure casting exhibited excellent grain size refinement effects.

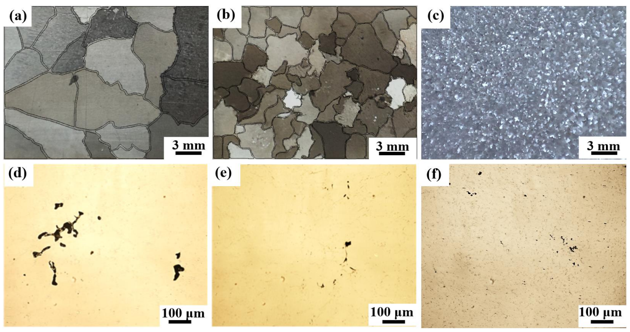

Fig.1. the optical microscopy images of as-cast K4800 superalloy under different casting methods: (a, d) gravity casting, (b, e) centrifugal casting, (c, f) adjusted pressure casting.

It could be clearly observed from Fig. 2 that as-cast K4800 superalloy under different casting methods had similar microstructures, namely rod-shaped MC carbides and lamellar borides at grain boundaries, as well as the γ' phase within grains.就 Meanwhile, compared to the gravity casting sample, both centrifugal and adjusted pressure casting samples refined the size of these precipitates, the size of γ' phase was refined from about 457 nm to about 287 nm and about 105 nm, respectively. In addition, the γ' phase of centrifugal casting sample still presented clusters similar to gravity casting sample, while it was uniformly distributed in adjusted pressure casting sample.

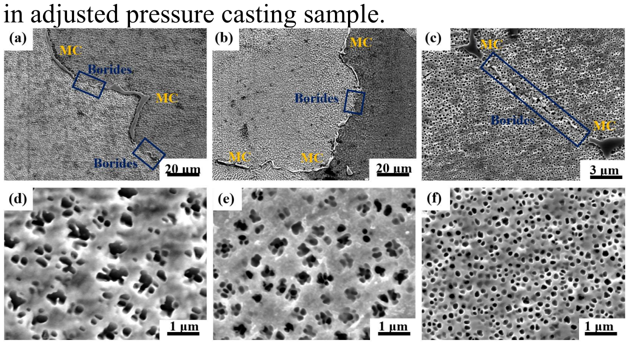

Fig.2. the grain boundary and intragranular phases of as-cast K4800 superalloy under different casting methods: (a, d) gravity casting, (b, e) centrifugal casting, (c, f) adjusted pressure casting.

As shown in Table 1, the as-cast K4800 alloy prepared by adjusted pressure casting exhibited much higher room temperature mechanical properties among three casting methods, with yield strength, ultimate tensile strength and plasticity of 798 MPa, 1152 MPa and 11.6%, respectively. Compared with the gravity casting and centrifugal casting, its ultimate tensile strength has increased by 39.9% and 21.8%, as well as plasticity has increased by 70.4% and 52.5%. The excellent room temperature mechanical properties of adjusted pressure casting sample was mainly attributed to the reduction of casting defects, as well as the refinement of grain size and γ' phase.

Table 1. The room temperature mechanical properties of as-cast K4800 superalloy under different casting methods

Casting methods	Yield strength/MPa	Ultimate tensile strength/MPa	Plasticity /%
gravity	619±7	823±9	6.8±0.5
centrifugal	699±10	946±15	7.6±0.7
adjusted pressure	798±8	1152±18	11.6±0.8

4 Conclusion

(1)The average grain size was 4.52 mm for gravity casting sample, both centrifugal casting and adjusted pressure casting could refine grain size, with average grain size of 2.22 mm and 0.28 mm, respectively.

(2)The area fraction of shrinkage porosity was decreased from 1.75% of gravity casting sample to 0.27% and 0.25% of centrifugal and adjusted pressure casting samples, respectively.

(3)Although the size of precipitates in centrifugal and adjusted pressure casting samples was refined, the microstructure of as-cast K4800 alloy prepared by different casting methods was all composed of the rod-shaped MC carbides and lamellar borides at grain boundaries, as well as the fine γ' phase within grains.

(4)K4800 alloy sample prepared by adjusted pressure casting exhibited the much higher room temperature mechanical properties, with yield strength, ultimate tensile strength and plasticity of 798 MPa, 1152 MPa and 11.6%, respectively. Compared with gravity and centrifugal casting, its ultimate tensile strength has increased by 39.9% and 21.8%, and plasticity has increased by 70.4% and 52.5%.

5 Acknowledgments

This work was supported by the National Science and Technology Major Project (grant number J2019-VI-0004-0118)

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