Effect of Cold Crucible Levitation Melting Process on the Solidification Microstructure and Tensile Properties of K4169 Casting

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Abstract: Aiming at the problems such as the crucible impurities and uneven grain size distribution existing in the Vacuum Induction Melting (VIM) technology, the influences of single-chamber Cold Crucible Levitation Melting (CCLM) technology on the mold filling capacity, purity, grain structure and tensile properties of K4169 superalloy have been investigated. The results show that a 200mm×50mm×3mm thin-wall plate can be completely filled by using of the CCLM technology. Moreover, Compared with the VIM technology, the CCLM technology can be used to improve the purity of liquid metal, which significantly reduces the inclusion defects in the casting and refine the grain structure and improve the tensile properties of the casting obviously.

Keywords: K4169 superalloy, CCLM, grain structure, tensile properties

1 Introduction

It is important to control the purity of the liquid metal and the grain size in the solidification microstructure of cast superalloy. Numerous studies have shown that the presence of inclusions will significantly reduce the service performance of superalloy, and the grain refinement and homogenization contribute to improve the mechanical properties of medium temperature conditions[1].

CCLM technology uses electromagnetic force in the smelting process to make the molten metal material in a suspended or quasi-suspended state, and its most outstanding advantage is that the melt contamination of crucible material can be excluded at high temperature. Previous experimental investigation already proved that the purity and casting surface quality can be significantly improved by the using of this technology [1]. However, due to the use of water-cooled copper crucible, the molten metal overheat is relatively low and the casting temperature is difficult to accurately control, limiting its application in superalloy thin-wall castings. In this project, large-area thin-wall plates were used to investigate the influences of single-chamber CCLM process and VIM process on the mold filling, grain structures and tensile properties of K4169 alloy, providing reference for the application and development of CCLM process in the superalloy thin-wall castings.

2 Experimental procedure

The K4169 alloy bars were selected as the raw materials . The main chemical composition of K4169 alloy was 0.058C, 19.07Cr, 5.06Nb, 3.10Mo, 0.95Ti, 0.55Al, 0.31Co, and Ni others. In order to investigate the application feasibility of CCLM process in the K4169 alloy investment castings, thin-wall plates with a height of 50mm, a length of 200mm and the thicknesses of 3mm, 5mm, and 7mm were designed. The single-chamber CCLM furnace and three-chamber VIM furnace were used to smelt and cast the alloy. The W-Re thermocouples with a diameter of 0.5mm and temperature acquisition device of MV2000 were used to record the temperature variation histories of the metal liquid and the mold shell during the pouring. The thin-wall plate mold shells and the thermocouple positions are shown in Fig. 1.

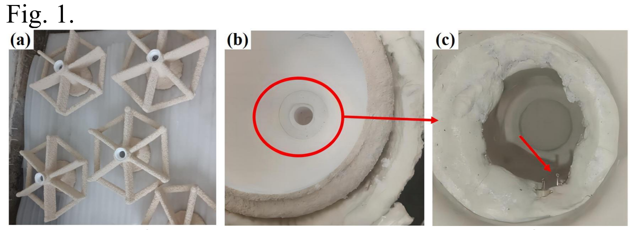

Fig.1 Part of experimental sets: (a) the mold shells of thin-wall plates, and (b),(c) the positions of thermocouples

The main process parameters of the experiment are shown in Tab. 1, in which C1, C2 and C3 denote the CCLM processes, and CC denotes the VIM process.

Tab. 1 Parameters of the main processes

Process	C1	C2	C3	CC
Molding methods	Single mold shell with thermal insulation cotton	Buried sand	Buried sand	Buried sand
Preheating Temperature of mold shell /℃	1000	1000	1000	1000
Melting time/min	30	30	40	30
Measured pouring temperature/℃	1413	1409	1458	1450
Measured mold shell	642	812	782	/

temperature/℃				

3 Results and discussion

The thin-wall plate castings

Fig. 2 shows the experimental mold filling results of the thin-wall plate castings under the conditions of different processes and plate thicknesses. As can be seen from Fig. 2, the thin-wall plates can be completely filled for the CC process, but appears serious misrun situations for the 3mm and 5mm plates manufactured by using of C1 and C2 processes, and under the condition of C3 process, the 3mm and 5mm plates can be basically completely filled. The mold filling ability of the casting is related to the pouring temperature, the mold shell temperature and the characteristics of the casting alloy and mold material. Because the CCLM process adopts a single-chamber furnace, the smelting process and the mold shell insulation process cannot be carried out at the same time, so the cooling time of the mold shell is long, leading to a low mold shell temperature when the pouring is carried out, which results in serious misrun. In the C3 process, the melting time of metal liquid is extended, although the mold shell temperature decreases slightly, the pouring temperature is increased and the mold filling effect is obviously improved. So under the condition of C3 process, the 3 mm plate has been basically completely filled.

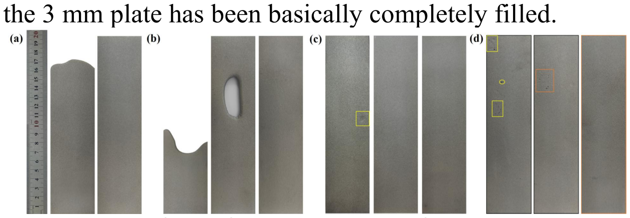

Fig. 2 Results of mold filling experiments of the 3 mm, 5mm, 7mm plates under the conditions of (a) C1, (b) C2, (c) C3, (d) CC, and the surface defects.

4 Grain structures

Fig. 3 shows the grain structures of different thickness thin-wall plates under the conditions of C3 and CC processes. It can be seen from the Fig. 3 (d) ~ (f), when the CC process is applied, the grain structures of the plates are coarse equiaxial crystals with uneven distributions, and with the decrease of the thickness, the distribution of grain is more uneven. However, when the C3 process is applied, the grain structures of the plates become fine and uniform equiaxial crystals. The nucleation rate is an important factor that determines the grain size.

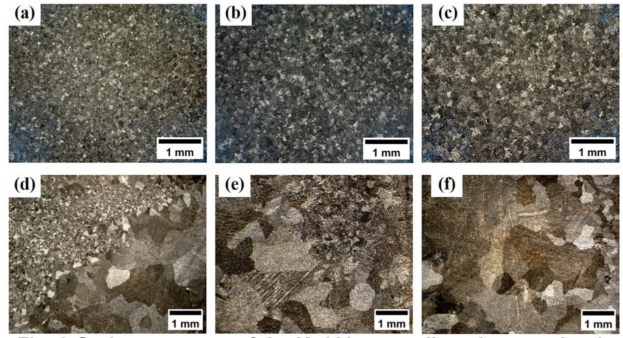

Fig. 3 Grain structures of the K4169 superalloy plates under the conditions of different processes and thicknesses: (a) C3, 3 mm, (b) C3, 5 mm, (c) C3, 7 mm, (d) CC, 3 mm, (e) CC, 5 mm, (f) CC, 7 mm.

5 Tensile properties

Tab. 2 shows the tensile properties of the K4169 superalloy under the conditions of different processes and temperatures. Compared with the CC process, the ultimate tensile strength (UTS) and yield strength (YS) at 20 ℃ and 600 ℃ of the test rods manufactured by the C3 process increased by 4.2%, 3.9% and 4.8%, 3.2%, respectively, which is ascribed to significant inclusion reduction and fine grain structures when the C3 process is applied.

Tab.2 Tensile properties of the K4169 superalloy under different conditions

Process	T/℃	UTS/MPa	YS/MPa	EL/%
C3	20	1119	925	9.5
CC		1072	889	7.0
C3	600	934	770	15.5
CC		889	745	13.5

6 Conclusions

By using the single-chamber CCLM process and the C3 process parameters, excellent mold filling and surface quality of thin-wall plate with thickness of 3 mm can be obtained. Compared with the VIM technology, when the CCLM technology is applied, the purity of the metal liquid can be improved, and the grain structure can be significantly refined, leading to the increasing of tensile properties .

References

[1] Okumura T, Yamamoto K, Shibata M. Large scale cold crucible levitation melting furnace with bottom taping nozzle[C].Proceeding of the 6th International conference. Electromagnetic Proceeding of Materials EMP2009, Oct. 19-23, 2009, Dresden, Germany, 521-524.