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ARTICLE

Orientation Characteristics of Single Crystal Superalloys with Different Preparation Methods

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Abstract: Single crystal superalloys have been prepared separately by a grain selector and a seeding technique in a high temperature gradient directional solidification furnace. The orientation characteristics were measured by XRD. Results indicate that for the grain selector method, the crystal solidification begins at the cooling plate with random nucleation, and through mutual competitive growth at the starter block. The grains enter the spiral selector, and finally the single crystal superalloys which are close to <001> direction are obtained. By the seeding technique, by epitaxial growth of partially melted seed crystals, single crystal superalloys which have the same orientation as the seed crystal are obtained.

Key words: directional solidification; crystal orientation; single crystal superalloys; grain selector; seeding technique

Single crystal superalloys have been applied as the critical high-temperature structural materials of advanced aero-engine[1]. D'Souza et al[2] pointed out that when the single crystal with <001> direction is parallel to the specimen's longitudinal axis, the thermal stresses are reduced, which greatly improves high temperature performance of the castings. It is expected that during the preparation of single crystal superalloys, castings with preferred orientation will be obtained. Walton and Chalmers[3] have reported that the preferred orientation <001> of single crystal superalloys is the fastest growing direction; thus during the directional solidification process, it can weed out other grains very easily and be preserved. During the actual process of directional solidification, because of the changes in the preparation method, solidification parameters and the relative positional relationship of the grains, the preferred orientation of single crystals is often not fully consistent with the direction of heat flow, and even single crystals with non-preferred orientations will be obtained. As a result, high temperature performance of single crystal castings will be affected[4]. Studies on crystal orientation characteristics during the single crystal preparation process have attracted a large number of scholars around the world.

A grain selector and a seeding technique are the methods employed to obtain single crystal superalloys. In order to obtain single crystals which can meet the orientation requirements, the studies were focused on the structure of the crystal selector. Carter et al[5] simulated the grain selection during the solidification of single crystal superalloy castings and the results indicated that only when the length of the starter block was greater than 20 mm or more, other grains were possibly eliminated and single crystals can be obtained. The results obtained by Gao et al[6] showed that the competitive growth of grains at the starter block affected not only the selection of single crystals, but also the orientation. Esaka et al[7] applied an engineering model to the single crystal casting process; it indicated that

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the parameters of the pigtail, such as the angle, width and length, affected the yield rate of the single crystal. Dai et al[8] studied the effect of spiral design on grain selection during investment casting through a series of experiments. It was found that the spiral design effectively reduced the grain number but was not able to optimize axial grain orientations during solidification. For the seeding technique, the cut seed crystals that met the orientation requirements deposited at the bottom of the master alloy, and were partially melted after pouring liquid metal. The crystals grew along the same crystal orientation as the seed crystals. Jackson et al[9] studied the origin of equiaxed zone in castings and found that when the seeding technique was adopted to prepare single crystals, the directional solidification in the interface between the semi-solid seed and the molten alloy (the melt-back mush) could be the origin of defective grains that were highly misoriented from the desired seed orientation. Stanford et al[10] also found that small islands of random orientation were observed throughout the melted-back semi-solid by the quenching technique for the CMSX-4 superalloy. The results of competitive growth between the defective grains and the seed crystal affected the crystal orientation.

In the present paper, single crystal superalloys were prepared separately by the grain selector and the seeding technique in a high temperature gradient directional solidification furnace. XRD was used to measure the orientation and the deviation angle of single crystals, and the characteristics of the crystal orientation under different preparation methods were comparatively analyzed, which could provide a reference for the study and control of single crystal orientation.

1 Experiment

First generation nickel-based single crystal superalloys DD407 were used, of which the nominal composition (mass fraction, %) was: Ni-7.82Cr-5.34Co-2.25Mo-4.88W-6.02Al-1.94Ti-3.49Ta. The modified Bridgman directional solidification furnace was employed. During the preparation of single crystals with the grain selector, geometric parameters of the spiral grain selector were based on the findings of Gao et al[11]. When single crystals were prepared with the seeding technique, in order to obtain seed crystals which can meet the requirements, the orientation of the seed crystal was measured and cut, as shown in Fig.1, where θ represents the orientation of the deviation angle of the single crystal and θ_{seed} represents the orientation of the deviation angle of the seed crystals which were cut from the single crystal.

2 Results

2.1 Single crystals prepared by grain selector

2.1.1 Grain structure evolution

Grain structure evolution within the starter block was observed by macrostructure and microstructure observation. Fig.2a shows the macrostructure of the longitudinal section of the starter block, while Fig.2b, 2c and 2d show the optical microstructure of different locations at the longitudinal section of the starter block. It can be observed that the grains with random orientation at the chill plate, through competitive growth, shift to columnar structures. After the solidification process, the grains with preferred orientation are gradually in a dominant position because of competitive growth, and the grains with a larger deviation angle are eliminated, as shown in Fig.2c. When reaching the top of the starter block, the remaining grains which have gone through competitive growth are mainly columnar crystals with preferred orientation and small angular deviation from the axial direction, as shown in Fig.2d.

Fig.3 shows the dendritic structures of cross sections at different locations of the grain selector. Fig.3a shows a schematic view of the grain selector and Fig.3b~3e show a cross-sectional view of the dendritic structures of corresponding

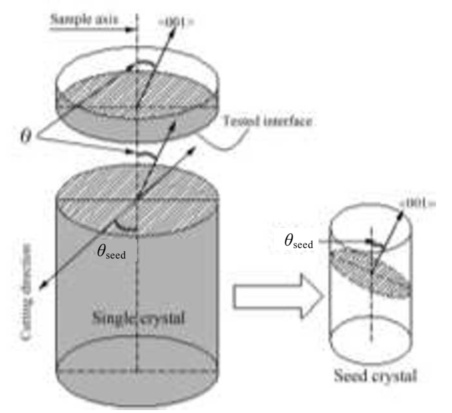

Fig.1 Schematic diagram of the seed crystal cut from the single crystal

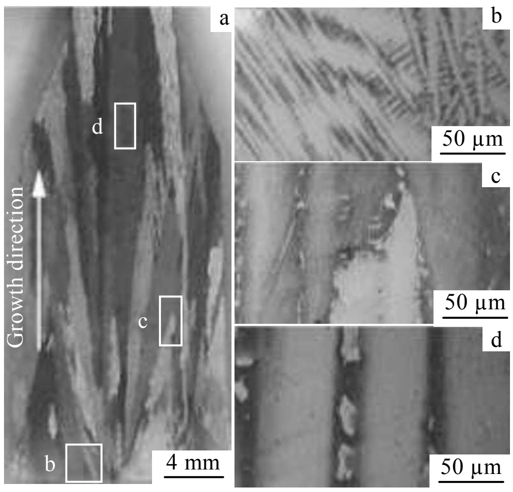

Fig.2 Macrostructure of longitudinal section of starter block (a) and corresponding microstructures (b~d) in Fig.2a (V=100 μm/s)