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Dendritic Growth Pattern and Dendritic Network Distortion in the Platform of a Ni-based Superalloy

*Xiaoli Zhang, Yizhou Zhou**, *Yanyun Han, Tao Jin, Xiaofeng Sun*

Institute of Metal Research, Chinese Academy of Sciences, Shenyang 110016, China

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The pattern of dendritic growth and distortion of dendritic network in the platform have been investigated by one mold casting with different platform length during directional solidification. As the platform length elongates, the symmetry of dendritic growth along left and right edges gradually worsens in platform base. While the platform length reaches 14 mm, the distortion of dendritic network is first observed in outward platform. It is found that the distortion of dendritic network along platform inside is more serious than that along platform edges. Both [001] deviation and accumulated misorientation along platform inside, up to 9° and 16.3°, respectively, are far greater than those along left–outward–right edges. The deformation of dendritic network in a platform may be caused by the asymmetry of the solidification front at the mush zone.

KEY WORDS: Superalloy; Directional solidification; Dendritic growth; Grain orientation; Platform

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1. Introduction

During directional solidification (DS), the preferred growth direction proposed by Kurz and Fisher[1] is <001> orientation in normal cubic structure, such as Ni-based superalloys. Thus, the <001> columnar-grain texture can be produced by DS technique. On the basis of DS, if the selecting or seeding technique is applied, the single crystal (SC) blades can be successfully produced. Due to the elimination of grain boundaries, the SC blades have superior performance and are widely used for the aero-engine[2]. Generally, the commercial SC blade is generally composed of dendrites. Therefore, it is essential to understand the dendrite development in SC blades. However, the geometry of SC blade progressively increases and the shape of SC becomes gradually complex with the improvement of the casting technology. Consequently, the dendritic growth pattern within a platform becomes complicated, which leads to some solidification defects, such as low-angle boundary[3–7], freckle[8], stray grain[7,9,10]. The mechanism of stray grain (freckle) formation has been explained manifestly. Unfortunately, the understanding of low-angle boundary in a platform is not thoroughly clear.

It is generally considered that the formation of low-angle boundary is resulted from the distorted dendrite network. The mosaic dendritic network can be observed usually[3,4,11], but the visible distortion of dendritic network has not been observed. D'Souza et al.[3] have verified that the morphology of secondary or high-branched dendritic stems in a platform is a function of the local cooling rate. Due to the high undercooling of the platform edges, the growth rate of the dendritic tips along the platform edges is far larger than that within blade. Thus, the dendrites along platform edges are finer than those in platform inside. Furthermore, it was also proposed that the mosaic dendritic growth occurred in the presence of asymmetric heat flux[11].

The presence of misorientation from dendrite network has been detected at the platform, but different viewpoints about the formation of misorientation still exist. On the basis of a simple thermo-elastic distortion calculation, D'Souza et al.[3] and Siredey et al.[12] suggested that the origin of low-angle boundary occurred in the solidifying mush zone. The stresses arising during γ' precipitation at the solvus induced the plastic distortion of the dendritic structure, which thus resulted in the formation of low-angle boundary. However, Dahle et al.[13] suggested that the stress developed in the dendritic network resulted from interdendritic fluid flow. The extent or scale of dendritic deformation depended on the distribution of solid fraction in the casting. The solid fraction increased with increasing fluid flow, which accelerated the deformation of dendritic network. In addition, Fabietti and Trivedi[14] showed that the stress inducing the formation of grain boundaries arose from solute inhomogeneity at the solid/liquid interface.

Therefore, the study of distorted dendrite network is beneficial to understanding the formation of low-angle grain boundary. The

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* Corresponding author. Prof., Ph.D.; Tel.: +86 24 23971767; Fax: +86 24 23971758; E-mail address: yzzhou@imr.ac.cn (Y. Zhou).

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Table 1 Nominal composition (wt%) of the superalloy SRR99

Cr	Co	Mo	W	Al	Ti	Ta	Ni
8.4	5.0	–	9.5	5.5	2.1	2.9	Bal.

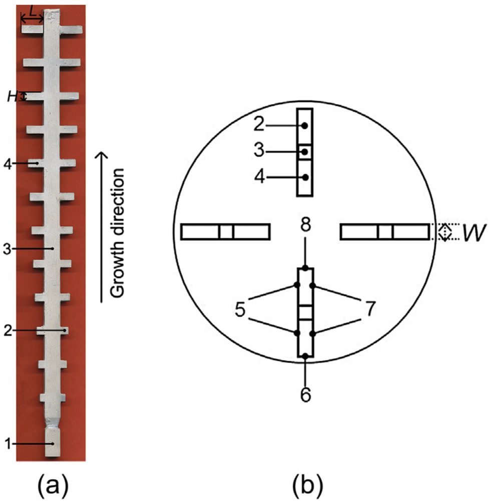
objective of this study is to explore the dendritic growth pattern within platform by means of a new mold casting with different platform length. Furthermore, the reason leading to dendritic network distortion is also analyzed.

2. Experimental

The composition of the superalloy SRR99 used in the present work is listed in Table 1.

A new mold with different platform length was first designed to investigate the dendritic growth in platforms during DS process. Fig. 1(a) shows the mold casting produced by investment casting. For the mold casting, the platform length (*L*) increases along growth direction by degrees. The value of *L* is 3, 10, 11, 12, 13, 14, 15, 16, 17, 20, 23 and 26 mm in turn from the bottom to the top. In addition, the platform height (*H*), platform width (*W*) and distance of adjacent platforms are invariable and they are 5, 10 and 16 mm, respectively. To ensure the symmetry of thermal field around every casting in the DS furnace, four wax molds are arranged symmetrically in a cylindrical wax assembly as shown in Fig. 1(b). The platform close to furnace center was defined as inward platform, while the platform far from furnace center was designated outward platform. The inward and outward platforms were connected by the blade. The four edges of the platform were left edge, outward edge, right edge and inward edge, respectively.

The mold castings in SC form were directionally solidified at a constant rate of 6 mm/min by using a Bridgman high rate solidification (HRS) furnace. A complete introduction of the solidification parameters was available elsewhere[15]. For every casting, a SC seed was used to control the dendritic structure. In order to assure the directions of dendritic growth and thermal gradient to be the same, the [001] direction of every seed was aligned to the growth direction and the [010]/[100] direction was parallel or vertical to the platform edges.



(a) (b)

Fig. 1 (a) Macroscopic image of the mold casting after macroetching and (b) arrangement of wax mold clusters in the cylindrical wax assembly. 1—seed, 2—outward platform, 3—blade, 4—inward platform, 5—left edge, 6—outward edge, 7—right edge, 8—inward edge, *L*—platform length, *H*—platform height, *W*—platform width.

To reveal the grain structure on the platform surface, all castings were macroetched in a mix of HCl and H_2O_2 (volume ratio 1:5). To further observe the dendritic growth in the platform, the mold casting was then sectioned along the base of every platform by using wire electro discharge machining. Then, the platform bases were polished, microetched and observed by the optical microscope. In addition, the electron probe microanalysis (EPMA) was used to measure the element concentrations in dendrite core and interdendrite zone. The electron back scattered diffraction (EBSD) analysis was then used to measure the orientation of dendrites. The [001] deviation and accumulated misorientation were calculated by the Euler angle (φ1, φ, φ2). The [001] deviation was equal to the angle φ. The accumulated misorientation was an angle of every measured position relative to the first position, which was calculated by ResMat–Textools texture analysis software. According to the function of “calculate the misorientation between two grains”, the accumulated misorientation was calculated by inputting the Euler angles (φ1, φ, φ2) of the first position and differently measured positions.

3. Results

3.1. Pattern of dendritic growth

Fig. 2(a) presents the schematic diagram of the whole platform including inward platform, blade and outward platform. The left/right/inward/outward edge of Fig. 2(a) is derived from Fig. 1(b). Platform geometry significantly influences the dendritic growth pattern as shown in Fig. 2(b–e). The two black dashed lines are the platform roots, i.e. the boundaries of the blade and inward/outward platform. The black curves are the boundaries of dendrites with different growth directions.

On the base of the shortest inward platform (Fig. 2(b)), the original grain (A zone) starts to propagate secondary dendrites into the inward platform. As a result of the high undercooling, the secondary dendrites grow fast within inward platform. Therefore, the secondary dendrites are as long as possible and grow like the primary dendrites. Synchronously, the new ternary dendrites vertical to the left/right edge branch out and grow toward platform inside. The initial spacing of the ternary dendrites is very small. However, because of the overgrowth mechanism, lots of ternary dendrites are eliminated and the ternary dendrite spacing increases quickly. While the ternary dendrites along the inward edge grow, the quaternary dendrites also simultaneously branch from ternary dendrites toward the blade. Finally, the well-ordered secondary, ternary and quaternary dendrites with different growth directions overgrow within the inward platform and lead to the formation of grain boundaries. Owing to the boundaries, the inward platform is separated into five zones (B, C1, C2, D1 and D2). According to the direction of dendritic growth, there are two routes of dendritic growth within the inward platform. The first route along left–inward edges is A–B–C1–D1. The second route along right–inward edges is A–B–C2–D2. In the inward platform, the corresponding zones of the two routes are symmetrical and the solidification distances are the same.

However, the two routes of dendritic growth within outward platform are different from those within inward platform. In the