EFFECTS OF THREE DIMENSIONAL DIRECTION OF SECOND DENDRITE ON COMPETITIVE GRAIN GROWTH IN DD8 SUPERALLOY①

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ABSTRACT Effects of three dimensional direction of DD8 nickel base single crystal superalloy on its competitive grain growth were investigated by seed crystal method. Experimental results showed that ⟨100⟩ × ⟨100⟩ (the first direction parallel to temperature gradient direction, the second direction perpendicular to temperature gradient direction and the contact plane of two half column seed crystal) grain competed with ⟨110⟩ × ⟨110⟩ grain for growth under the conditions of $G = 250$ K/cm, $V = 47.6$ μm/s, and the former eliminated the later; however at the same experimental conditions, ⟨100⟩ × ⟨110⟩ grain competed with ⟨110⟩ × ⟨100⟩ grain for growth, and the later eliminated the former. Metallographic observations of cross sections of specimens showed that the migration velocity at various locations of grain boundaries was different in the process of competitive grain growth. It is indicated that the three dimensional direction of second dendrite is a key factor in the competitive grain growth, and the nonequilibrium grain boundary migration in the competitive grain growth is associated with the stagger between the grain dendrites.

Key words second dendrite nickel base superalloy three dimensional direction competitive grain growth

1 INTRODUCTION

Lately the developement of advanced gas turbine demands the materials for turbine parts have higher creep strength at high temperature, higher fatigue strength and oxidizing corrosion resistance, which the normal blade with equiaxed grains can not reach. Ref. [1] pointed out that single crystal blades have better properties, consequently single crystal blade is an inexorable trend of gas turbine developement. However for developing single crystal blades, it needs first to make clear the law of competitive growth between grains with various crystal direction especially when controlling the three dimensional crystal directions of single crystal blades, Over a long time[2-6] more attention was paid to the effects of crystal direction on solidification microstructure and morphology, but less to the effects of crystal direction on macro competitive grain growth. He Guo[7] took the nickel base single crystal superalloy DD8 as experimental material, and as viewed from two dimensions, he investigated the competitive grain growth law when preferred crystal direction ⟨100⟩ was at various angles away from temperature gradient direction, and drew three conclusions: (1) the larger the angle of the preferred direction ⟨100⟩ away from temperature gradient direction, the more rapid the velocity for the grains to be eliminated; (2) grain boundary migration law appears to be linear in competitive grain growth; (3) competitive grain growth takes that second dendrite creates 3rd dendrite and 3rd dendrite creates high order dendrite as the mechanism to migrate grain boundary. After careful examination of the competitive grain growth mechanism drawn by He Guo, it can be deduced that the three dimensional direction of second dendrite is a key factor in the competitive grain growth, and it is not important whether or not the preferred direction ⟨100⟩ is away from the tempera-

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ture gradient direction. According to such a deduction, the authors took the nickel base superalloy DD8 as experimental alloy, and made two experiments by seed crystal method: (1) coupling competitive grain growth between ⟨100⟩ × ⟨100⟩ and ⟨110⟩ × ⟨110⟩ seed crystal; (2) coupling competitive grain growth between ⟨100⟩ × ⟨110⟩ and ⟨110⟩ × ⟨100⟩ seed crystal to examine the truth of this deduction, and to compare with He Guo's results. The experimental results showed that grain boundary migration in competitive grain growth is nonlinear, and the grain whose preferred crystal direction is away from tempeature gradient direction can eliminate the grain whose preferred crystal direction coincides with temperature gradient direction.

2 EXPERIMENTAL MATERIAL AND PROCEDURE

The material for experiments was corrosion resistant nickel base superalloy DD8, its chemical compositon was 16% Cr, 8.5% Co, 6.0% W, 3.9% Al, 3.8% Ti, 1.0% Ta, less than 0.01% C and Ni the balance. DD8 nickel base superalloy was machined as a bar with a size of d 6.5 mm × 50 mm for experimental alloy. After crystal direction was examined by X-Ray diffraction equipment, the single crystal lump DD8 made by crystal selection method was cut into four groups of half column with a size of d 6.9 mm × 20 mm and various crystal directions by thread cutting machine for seed crystal. The crystal directions of the four groups of half column seed crystal are shown in Tab. 1. Combining the first group with the second group, and the third group with the foarth group of half column seed crystal into one seed crystal respectively, then together with the base alloy bar it was put into a Al_2O_3 tube of d 7mm in diameter, and then was unidirectionally solidified in a self-made LMC directional vaccum solidification furnace with high temperature gradient after heated up to 1548 ℃ and held for 15min under the conditions of G = 250K/cm, V = 47.6μm/s which was controlled by single board microcomputer. Starting at the beginning of solidification and taking 10mm as interspace to intersect the specimens, the competitive grain growth results on the total cross section were observed with a photo microscope. The area fraction of eliminated grain and eliminating grain on various cross section was measured by a square mesh method to describe the trend of the competitive grain growth.

Table 1 crystal direction of four groups of half column seed crystal

Group number	1	2	3	4
Axial direction	⟨100⟩	⟨110⟩	⟨100⟩	⟨110⟩
Direction perpendicular to rectangular plane	⟨100⟩	⟨110⟩	⟨110⟩	⟨100⟩

3 EXPERIMENTAL RESULTS

Metallographic observations showed that ⟨110⟩ × ⟨110⟩ grain was gradually eliminated in the coupling competitive growth of ⟨100⟩ × ⟨100⟩ grain with ⟨110⟩ × ⟨110⟩ grain, as shown in Fig. 1. Fig. 2 is the result of coupling competitive growth of ⟨100⟩ × ⟨110⟩ grain with ⟨110⟩ × ⟨100⟩ grain, in which the grain whose preferred crystal direction coincided with the temperature gradient direction was eliminated by the grain whose preferred direction was away from the temperature gradient direction, although at that moment another crystal grain close to ⟨100⟩ × ⟨110⟩ was created, and which tended to grow at the initial drawing stage, but it was still eliminated at last. Careful observations could also find nonequilibrium of grain boundary migration when the two groups of coupled grains competitively grew, as shown in Fig. 3 (a) and (b). The area fraction measured by square mesh method appeared to be a step changing with the drawing distance, as shown in Fig. 4(a) and (b).

4 ANALYSES AND DISCUSSIONS

4.1 *Analyses on Competitive Grain Growth*

From Fig. 1, it can be seen that ⟨110⟩ ×

Fig. 1 Coupling competitive grain growth of 〈100〉× 〈100〉 grain with 〈110〉× 〈110〉, at various distance from the start of solidification(10×)
(a) —10 mm; (b) —20 mm

〈110〉 grain is eliminated by 〈100〉 × 〈100〉 grain in the competitive grain growth, which agrees with the result in Ref. [7] and be can described that the grain whose prefered crystal direction 〈100〉is in agreement with temperature gradient direction eliminates the grain whose preperred crystal direction〈100〉makes an angle of 45° to the temperature gradient direction. However, in Fig. 2, it can be seen that 〈110〉× 〈100〉 grain with 45° angle of the preferred crystal direction 〈100〉away from the temperature gradient direction eliminates〈100〉× 〈110〉 grain whose preferred growth direction 〈100〉 is in agreement with the temperature gradient direction.

Why does such a result appear? As view from three dimension of two groups of coupling competitive grain growth, it can be seen that, as for the eliminating grain in the competitive grain growth in Fig. 1, besides its preferred crystal growth the direction 〈100〉is in agreement with temperature gradient direction, and its second dendrite direction i. e. 〈100〉is perpendicular to the boundary between the two half column seed crystal. However, as for the eliminated grain both directions mentioned above are not the preferred growth direction. Consequently, it is natural that 〈100〉× 〈100〉 grain eliminates 〈110〉 × 〈110〉 grain, which also coincides with the general law of this alloy: it grows fastest when the preferred direction parrallel to temperature gradient direction. But the result in Fig. 2 is more complicated, the eliminated grain has a preferred direction 〈100〉in agreement with temperature gradient direction, and the eliminating grain has a preferred direction〈100〉 deviating from the temperature gradient direction for 45°, which is just opposite to the first conclusion in Ref. [7]. Careful examination of the experimental results can find that although the preferred direction 〈100〉 of the eliminated grain coincides with the temperature gradient direction, the direction perpendicular to the boundary between two half column seed crystals is not its preferred direction, on the contrary, although the preferred direction of the eliminating grain deviates 45° angle from the temperature gradient, the direction perpendicular to the boundary between two half column seed crystals is its preferred direction 〈100〉. Consequently the second dendrite of the later migrates more rapidly towards grain boundary in the competitive grain growth, which consumes more alloy liquid between the two grains and suppresses the growth of the for-

Fig. 2 Coupling competitive growth of 〈100〉× 〈110〉 **grain with**〈110〉× 〈100〉 **grain at various distances from the start of solidification**(10 ×)

(a) —10 mm; (b) —20 mm; (c) —30 mm; (d) —40 mm

Fig. 3 Nonequilibrium migration of grain boundary (32 ×)

(a) —〈100〉× 〈100〉 coupled with 〈110〉× 〈110〉

(b) —〈100〉× 〈110〉 coupled with 〈110〉× 〈100〉

Fig. 4 Area fraction changes with the drawing distance
(a) —〈100〉× 〈100〉 coupled with 〈110〉× 〈110〉;
(b) —〈100〉× 〈110〉 coupled with 〈110〉× 〈100〉

mer second dendrite, and creates a migration of grain boundary towards 〈100〉× 〈110〉 grain, and makes 〈110〉× 〈100〉 grain as a winner in the competitive grain growth. If it can not be determined, three dimensional direction of either the primary dendrite or the second dendrite is a key factor resulting in the competitive grain growth between 〈100〉× 〈100〉 grain and 〈110〉× 〈110〉 grain, then it is completely realized that the three dimensional direction of second dendrite is a more important factor as viewed from the competitive grain growth between 〈100〉× 〈110〉 grain and 〈110〉× 〈100〉 grain, i. e that the grain whose three dimensional direction of second dendrite perpendicular to the grain boundary will at last become a winner in the competitive grain growth, whether the primary dendrite direction (preferred direction) coincides with the temperature gradient or not.

4. 2 *Analyses on Nonequilibrium in Grain Boundary Migration*

It has been observed by metallographic microscope that there is a nonequilibrium in the boundary migration of competitive grain growth, as shown in Fig. 3, among which Fig. 3 (a) shows that the high order dendrites growing from second dendrite cut 〈110〉× 〈110〉 grain into two parts. Area fraction measuring results show that grain boundary migration velocity is different at various drawing distances when grains compete to grow, as shown in Fig. 4(a), (b), which is different from the linear results concluded by Ref. [7].

It is indicated from those phenomena mentioned above that not only a slow and stable forward migration but also a rapid forward migration exist in the competitive grain growth, Ref. [7] indicated that the larger the angle of 〈100〉 crystal direction of nickel base superalloy DD8 deviating from the temperature gradient direction is, the larger the primary dendrite interspace (λ_1) and the second dendrite interspace (λ_2) are, which indicated that the primary and second dendrite interspaces of 〈100〉× 〈110〉 grain are different from those of 〈110〉× 〈110〉, and those of 〈100〉× 〈110〉 grain are different from 〈110〉× 〈100〉 grain in the coupling competitive grain growth in the nickel base superalloy DD8, which leads to a collision between dendrites at some locations of grain boundary and a stagger of dendrites at other locations. At the collision locations the second dendrites in the eliminating grain, which are perpendicular to the grain boundary, grow faster, but due to the impeding of the other grain dendrites, the faster growing second dendrites only suppress dendrite development of the other grain and lead to a solw migration of grain boundary. At the stagger locations, the second dendrites of the eliminating grain can grow into the interior of the eliminated grain, consume more alloy liquids and impede the dendrite development of the other grain comprehensively, and even cut the eliminated grain into two parts at a suitable growing environment, as shown in Fig. 3(a), and consequently speed up the grain boundary migration at such a location, and which leads to a nonequilibrium of migration at grain boundary. The result of nonlinear relation of the area fraction of two grain with the drawing distance shown in Fig. 4 also indicates the nonequilibrium in grain boundary migration.

It can be seen from the analyses and discussions stated above that although the crystal direction of ⟨100⟩ × ⟨110⟩ grain parrallel to the temperature gradient direction is its preferred crystal direction ⟨100⟩, the direction perpendicular to the grain boundary is the nonpreferred crystal direction ⟨110⟩, which suppresses its second dendrite growth at grain boundary and makes it eliminated at last. On the opposite side, in spite that the crystal direction of ⟨110⟩ × ⟨100⟩ grain parralel to the temperature gradient direction is the nonpreferred crystal direction ⟨110⟩, but its crystal direction perpendicular to the grain boundary is the preferred direction ⟨100⟩, and its second dendrites grow towards grain boundary so fast that it becomes an eliminating grain in the competitive grain growth. From those analyzed above, it can be deduced that in the competitive grain growth between ⟨100⟩ × ⟨100⟩ grain and ⟨110⟩ × ⟨110⟩ grain, the reason of the former eliminating the later is not the preferred growth direction parrallel to the temperature gradient direction, but the preferred growth direction perpendicular to grain boundary, i.e. the direction of second dendrite. However, the nonequilibrium in grain boundary migration is because that grain dendrite interspace is different due to their different crystal direction, which causes a collision at some locations of grain boundary and a stagger at the other locations, leads to a slow grain boundary migration at the collision location and a fast grain boundary migration at the stagger location, and finally a nonequilibrium migration of grain boundary.

5 CONCLUSIONS

(1) Who is the eliminating or eliminated grain in the competitive grain growth depends on their three dimensional direction of second dendrite instead of their three dimensional direction of primary dendrite.

(2) The grain boundary migration when grain competitively grow is in nonequilibrium.

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