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Influence of Directionally Solidified Parameters with Drawing Velocity on Behaviours of γ-Tial

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Abstract

The effects of the applied thermal gradient and pulling velocity, the spacing and nucleation cooling are investigated in the present. The high value would be found when G was7.8K/mm in contrast to that 0.12~0.06mm was observed when the high G was 10K/mm. That would be caused upon high v. The value of measured and literature has agreed with the curve of 10K/mm. The λ1 is about 140~40 μm, which might be caused by the low velocity approximately. The value ΔTn with 10K is a little smaller than that of 1K. So the well choice is 10K for a bit high v. The ΔTt are in the same relation to v proportionally. The reason for the big varies is analysed as the nucleated temperature vary. The G with 10K/mm fit to the large v, and the value of both G and ΔTt is smaller than 1K/mm. That might be explained on the changed v that means the big v has large value.

Keywords: Gradient; Velocity; Radius; Primary dendrite space; Directionally solidification; TiAl

Introduction

TiAl alloys have had high strength and high temperature strength compared with other high temperature (HT) alloys, anti-oxidized and better creep properties, was dominant as very promising material to substitute for Ti and Ni base alloys. In particular directionally solidification (DS) TiAl alloys with an aligned lamellar microstructure (MS) have a very good combination of strength and ductility over a wide temperature range that columnar dendrite structures are desired. As for the mechanical mechanism, Hunt developed the first analytical model to predict transition on the basis of equiaxed grains nucleated in the constitutional undercooling region ahead of a columnar front blocking the advance of the front if they occupy a sufficient volume fraction [1]. It was estimated that the preferred growth directions of β dendrite grown at HT near melting point was in the [001] β direction at a growth rate of 30mm/h and in the [111] direction at a growth rate of 90mm/h. The mechanical properties controlled by microstructures had inverse relationship in them, which had been reported [2-3]. A β solidified directional solidification (DS) method has used seed crystals, while the initial solidification must be crossed into full transformation [4]. However in binary TiAl, Al contents with the full β transus were low at RT（room temperature) so that their mechanical properties were brittle. Adding elements will move to β stabilization of Al rich was confirmed. In the full β transus the thermal gradients was low with Bridgman method and high with Floating zone method (FZM) to be used. Using β solidified method, lamellar orientation of dendrites must be aligned to grow in the direction [001]. The calculation results indicated that the columnar branch spacing depends not only on the thermal gradient and the pulling velocity, but also on number. A spacing adjustment can occur to develop to new columnar grains. As for the effect of them on the thermal gradient and velocity, qualitatively agrees well with the literature. By analysis it was evaluated that the preferred growth directions of primary β dendrite near the melting point had been in the β and α primary phase at 2.77~50μm/s.

Numerical Procedure

The thermal dynamic super α cooling has been to avoid or eliminate heterogeneous nucleation role, promote Gcr, hold back

homogenous nucleates making alloys or metal difficult to arrive cooling on the general status. Super cooling method had changed thermal dynamic to obtain high cooling. Herlach had demonstrated super cooling melt and rapid cool, liquid alloys or metal had same mechanism being rapid solidification [5]. The solute at the Solid/Liquid interface is distributed, at the local of the secondary dendrite arm spacing by diffusion or convection [6]. It is to show the effect of coarsening can be accounted for in a conventional segregation model by a back-diffusion term. That results in a net diffusion process. The solidified condition is for homogeneous nucleation, here ΔG is change of system free energy and r is radius of nuclear crystal. The primary dendrite arms space generally decreases with increasing cooling rate, and it is crucial to take that effect into account. The relatively simple relationship was found to be applicable to a wide range of DS [7, 8]. It is thought to be ideal directional solidification. It is specified by the average temperature gradient G, and a speed v, so the mean cooling rate is described as

$$Lg\lambda 1=-0.338lgC+2.16 \quad (2\text{-}1)$$

$$\lambda 1 = AG\text{-}1/2v\text{-}1/4 \quad (2\text{-}2)$$

The method of exponent would be used to the following equation

$$\lambda 2 = A(1/C)1/3 \quad (2\text{-}3)$$

$$R=\lambda_1^2 G/(3\Delta T) \quad (2\text{-}5)$$

The proportional method was used as following

$$\lambda_2 = KR \quad (2\text{-}4)$$

The extent of convection in the procedure is the relation used to calculate the local permeability of the mushy zone as a function of the liquid volume fraction and primary dendrite arm space λ1. It implies a lower space leads to lower permeability and a higher resistance to flow in the mush zone. A best fit of calculated data was for parallel and perpendicular to λ1. The value of λ1 generally decreases with increasing cooling rate. It was found to apply to a range of DS alloys inspite of preciser' done no bad. The procedure to solve the conservation equations. A phase equilibrium in this zone offers a way to calculate the solid volume fraction. Some modifications necessary to the use of equilibrium instead of a relation between lquidus temperature and concentration. In the evolution of the morphology of solid liquid, growth velocities have made important and complicated roles. In the low velocity zone, with the growth v increased, make plane interface unstable, however, in the high velocity zone, the increasing of v it promoted interface to develop absolutely stability. It has increased the effect of composition undercooling and curvature [9]. With raising growth rate v mushy zone length shrink, which shorten to a certain mushy length. That is a factor of Dendritic-cellular change.

Result and Discussions

At a relatively high thermal gradient, increasing pulling velocity decreases the space of the crystal. It occurs after introduce of the seeds and nucleation of new columnar grains. Nucleation of seeds is not likely to be impeded by solutal interactions. As for low pulling velocity the solute diffusion length is so large that many the seeds never reach the specified nucleation undercooling. It can be found that a gradient in solute concentration had given a slope of 1.22at.%/μm, which agrees well with the predicted values. It can be shown that increasing the thermal gradient decreases the maximum undercooling in the liquid along the central dendrite axis from 2K to 0.5K as (Figure. 1). If the nucleation undercooling ΔT is greater than 2K, no equiaxed grains could form. If the nucleation undercooling is 1K nucleation would take place as the thermal gradient is smaller than 30K/mm. The maximum undercooling varies between 1K and 2K depending on the thermal gradient. They all are behind the columnar tips. The G was appropriated proportion to v in the condition of 1K/mm. on the other hand larger variation was occurred in 10K. ΔTt are both similar proportional relation with v. The reason for the bigger varies is analysized as nucleated temperature vary. G=10K/mm fit to large v, and the value of both G and ΔTt is smaller than 1K/mm. It might be explained on changed v that means big v has large value. It was found that the equiaxed growth generally occurs under condition of high pulling velocity and low thermal gradient. Conversely columnar growth is trend to low velocity or high thermal gradient. Equiaxed growth occurs if the thermal gradient is less than the value by Hunt's model. In terms of Hunt's model, the tip undercooling is thought to as a function of the velocity. The constant is a function of the material properties only. From further models, the tip temperature depends on the thermal gradient too and not exactly relation to v. It should be viewed as an attempt to better understand the present predictions relative to Hunt's model. The approximate agreement indicates that the dependence on the thermal gradient and pulling velocity. Furthermore at low Gl it occurs at a constant v, and at high Gl it separates the two grain structures. Here 1.33 and 3.5×108 /m2 of N was used for 0.5 and 2.5K. Compared with literature approaching trend would be seen. It was found that the same slope and curve had been occurred. The big velocity had high gradient in terms of the results. Tip temperature was proportional to v, it would reach about 50 as v is 0.03mm/s, and 130 as v is 1mm/s. G is 60K/mm when v is 0.4, while 50 and 40K/mm respectively when v is 0.01.The value G of 10 is a little smaller than that of 1. So the well choice is 10 for a bit higher v above 0.01mm/s. There is line relation in the liquid phase temperature gradient G and interface velocity v. It is a function between interface velocity and drawing velocity v. From the curve in the Fig. 2 the exponent function relation can be found. It was formed to be decreasing proportion. K is analysed to about 0.25. Using

the equation of (2-1) it is determinates upon measured values. The equation of C=Gv was used to calculate. The original value was of 0.25 and 0.16 mm in terms of the 0.025 and 0.1 mm/s respectively. The mother G is 7.8K/mm and has gained the state of 24K/mm. The trend is shown in Figure 2, the calcultional results is good fit to measure in the case of the 7.8-24K/mm (Figure 2).

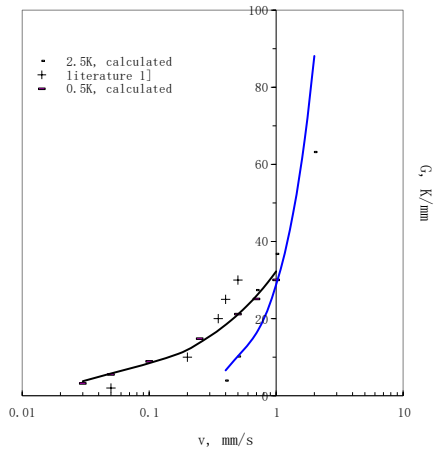

Figure 1: *The trend of v, G and ΔTt for DS of ΔTn=0.5 and 2.5K.*

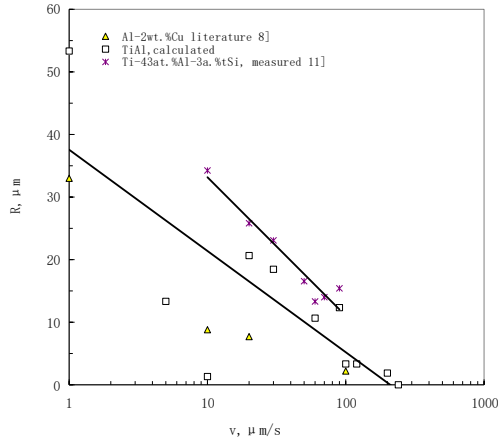

Figure 2: *The trend of R-v for the calculational and measured value.*

The value of 74K/mm is lightly higher than the literature [10]. The varies will be thought with G. The process of TiAl-3Si would be done by Directional solidification used seeding material as reference. The k = 1.4 and A for 0.157 were used to taken proportional and exponent method for n = 0.5 respectively, seen in Fig. 4. They were corresponded to each other and measured data well [11]. As seen in Fig. 3 higher value would be found when G=8.8K/mm scope of λ1 is 0.8~0.12mm (Figures 3,4). In contrast to that 0.12~0.06mm was observed when high G=24K/mm. That would be caused upon high v. The value of measured and litre. Has agreed with the curve of 24K/mm. Maybe there was a difference in A= 0.292. That was derived from (2-1). In the right condition G is 24 being little bigger than 7.8. In terms of formula (3-4), λ1 is AG-1/2v-1/4.

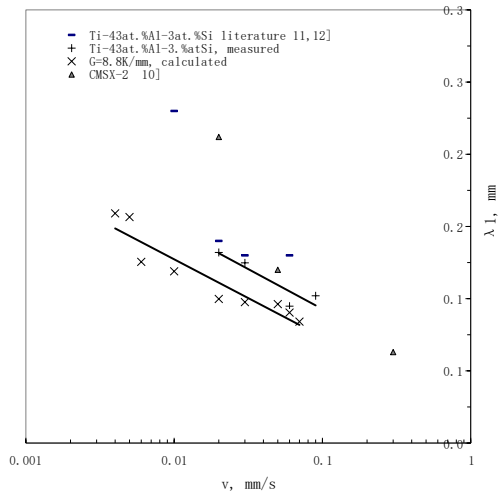

Figure 3: *The trend of λ 1 and v calculated.*

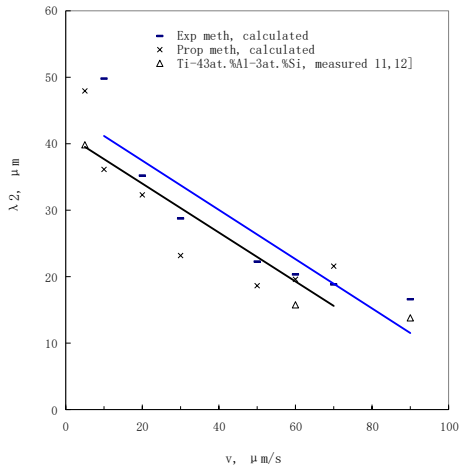

Figure 4: *The trend of λ2 as a function of v. The line of dark for proportion method, light for exponent method.*

The variation will fit to TiAl-3Si in the scope of 0.1~1μm/s well. The ones of measured Ni base CMSX-2 and TiAl-3Si would be slightly above the line calculated. The solid-liquid interface had relation with λ1, R and v to alloy Al-2%Cu. That of Al-2%Cu would be referring to 8], that was 100K/cm. The method of exponent would be used to the following equation (2-3). Here v was 10 to 70mm/s as G=10K/mm. Exponent 1/3 was used by 1/2 in order to simplify the equation. According to (2-4) the proportional method was used as follow. Here K=1.12.

$$R = 1.2(M \times 10 + 25.8 - 20 \times M);\ M = \frac{R_1 - R_2}{v_1 - v_2}$$

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From Fig. 3.3 the cooling rate would be arranged to be 1~2.5~6 K/s with raised v 20~240 μm/s. That may agree well with principle of solidified course. A negative proportion between R and v shown in total. R will be changed from 2 to 55 μm. On the basis of (2-5) the result was obtained. The curve for v-R relation had been seen in Fig. 1 R will be decreased in accordance with increasing v. The maximum value could reach above 400 μm. The value of λ1 is higher than that of λ2 through measured and calculated shown as Figure 3 & 4. The measured and literature was not much varies. They may be the same cooling condition ie. The same G. Discussion detailed will be done as below. λ1 was computed under 7.8~24K/mm the fit more to approaching 24K/mm. That is about 0.1mm which had less than measured. The high C had low G under a certain v. That means high G caused slow solidification. In the state of high G the low λ1 could be formed. Here series had been computed by using on λ2=A(ΔT/(RG))1/3. On the basis of equation R= λ_2^2*G/(3 ΔT′), the G was 25K/mm and ΔT′was 10K. As seen in calculation higher value would be found as G=7.8K/mm scope of λ1 is 800~120μm. According to G = (Ttip-Tbase)/L it could calculate the G. In contrast to that 120~60 μm was observed when high G=24K/mm. That would be caused upon high v. The value of measured and liter. Has agreed with the curve of 24K/mm. Maybe there was a difference in A= 0.292. In the right condition G is 24 being little bigger than 7.8. In terms of formula (3-4), λ1 is AG-1/2v-1/4. The variation will fit to TiAl-3Si in the scope of 0.1~1micm/s well. That may be explained upon the raising vG. The value of v is 10~1250 μm/s. Here λ1 is the dendrite space which is regulated by A. As the G is 10K/mm the data in reference has agreed with it well. That λ1 will reduce to 100 μm with reducing v to 0.1mm/s. below 10μm that would be beyond 200 μm. It has followed the below equation. Thermal equilibrium equation in DS is obtained according to (2-2).

Conclusions

In this study an influence on solidification behaviors of DS in γ had been obtained. The main results were as follow.

1. A critical primary dendrite space agrees well with the experimental data. As for more unstable alloys the value is much lower, as expected. Meanwhile numerical results for cooling rate as for coarsening, well choice would be chosen. The value ΔTn with 10K is a little smaller than that of 1K. So the well choice is 10 for a bit higher v above 0.01mm/s. ΔTt are both in same relation with v in proportional. The reason for the bigger varies is analyzed as nucleated temperature vary. The G with 10K/mm fit to large v, and the value of both G and ΔTt is smaller than 1K/mm. That might explained on changed v that means big v has large value.
2. The λ1 is about 140~40 μ m, which might be caused by low velocity and a certain cooling rate of 0.5K/s in low v approximately. The high value would be found when 7.8K/mm in the scope of λ1 is 800~120 μm. In contrast 120~60 μm was observed as high 24K/mm. That would be caused upon high v. The value of measured has agreed with the curve of 10K/mm.

Acknowledgments

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