SUNTEXT REVIEWS

SunText Review of Material Science
ISSN: 2766-5100

Open Access
Research Article
Volume 4:S1

Effect of Directionally Solidified Parameters on Behaviors of γ-Tial

Xu R*, Anh HJ and Kim K

Gyeongsang National University, Metallurgical Engineering Department, Chinju 52828, Korea

***Corresponding author:** Xu R, Gyengsang National University, Metallurgical Engineering Department, Chinju 52828, Korea; E-mail: james_hur@163.com

Received date: 03 January 2023; **Accepted date:** 06 January 2023; **Published date:** 12 January 2023

Citation: Xu R, Anh HJ, Kim K (2023). Effect of Directionally Solidified Parameters on Behaviors of γ-Tial. SunText Rev Mat Sci 4(S1): 150.

DOI: https://doi.org/10.51737/2766-5100.2023.S2.150

Abstract

The effects of the applied thermal gradient and pulling velocity, the spacing and nucleation cooling are investigated in the present. High value would be found when G was7.8K/mm in contrast to that 0.12~0.06mm was observed when 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 effects of Al content and ternary additions such as Mo, V and Si in as cast γ based alloys made by plasma arc melting on solidification structures and mechanical properties were studied. γ /α2 Columnar lamellar structures in Al-lean alloys because primary solidification had higher room temperature fracture strength and strain than γ phase structures through the reaction of L+α=γ in Al-rich alloys. The fraction of α2 phase was found to decrease with increasing Al content in binary alloys. λ1 is about 140~40 μm, which might be caused by 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 same relation to v in proportional. The reason for the big varies is analysed 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 be explained on changed v that means big v has large value. The temperature of reactions were concluded and the angle between lamellar and growth direction were investigated in the equiaxed and columnar grains meanwhile the concentration of Al and the fraction of α/β and β/L were studied in this paper. The direction between lamellar and growth direction is 0 and 90° upon primary phase β and α respectively. The structures of alloy are equilibrium phases such as $\alpha_2+\gamma$ & γ taken columnar and equiaxed according to Al content. The primary phase and equilibrium phase may be confirmed according to phase diagram for Ti-44~56at. %Al alloys. As for Ti-44at. %Al used $\beta\rightarrow\alpha\rightarrow\alpha+\gamma$ to measure Al concentration, while for above Ti-46at. %Al used $\beta\rightarrow\gamma$.

Keywords: Solidification; Gradient; Velocity; DS; Structure; Undercooling; Concentration of Al; 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. In particular 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 so that their mechanical properties were brittle. Adding elements will move to β stabilization of Al rich was confirmed [5-12]. 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]. An alternative approach for balancing mechanical properties is gained by DS techniques. 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 10~180mm/h. On the other side γ-TiAl with high ratio strength had been promised in the high temperature structures in the future. The TiAl alloys developed by now had excellent casting property so that they could be used for the engine of craft and automobile with good evaluation. For the needs of high temperature, light quality & speed, new advanced materials would be searched: 1) high melting point; 2) low density; 3) elastic modulus; 4) good structure stability & excellent oxidized resistance [13]. In the high temperature application, such as engines. Intermetallic Compounds of Ti2AlNb could compete with lately developed TiAl and the HT titanium base alloys & nickel base materials [14]. Al content which was one of the important factor to affect process and mechanical property was chosen by controlling microstructure in TiAl base alloys. According to Al content the casting structure was obtained with different primary phase. In general, equiaxed grains had been trend to form when primary phase was β, columnar's had been trend to form when primary phase was α. The lamellar structure was still brittle in spite of good toughness. Moreover the course lamellar with no crystallizing was produced with continuous and slow growth so that structure was not easily controlled by heat treatment. However the full lamellar would fit for promoting high temperature strength because the lamellar was possible for use in high temperature. Using β solidified method, lamellar orientation of dendrites must be aligned to grow in the direction [001] [15,16]. An alternative approach for balancing mechanical properties is obtained by DS techniques. The purpose of this study is to examine solidification mechanism such as the effects of the temperature of reactions, and the angle between lamellar and growth direction and the Al concentration on TiAl alloys.

Numerical Procedure

The thermal dynamic super alpha 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. The solute at the S/Liquid interface is distributed, at the local of the secondary dendrite arm spacing by diffusion or convection. 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 between given in as was found to be applicable to a wide range of DS. 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. 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 in spite 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 and 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, with the increasing of v it promotes interface to develop absolutely stability. It has increased the effect of composition undercooling and curvature. With raising growth rate v mushy zone length shrinks shorten to a certain of mushy length. That is a factor of Dendritic-cellular change.

Result and Discussions

The results measured with EDS had been shown. The deviation with 2at% was found. In Fig equilibrium solid was complexed and sensitive to concentration Al. According to the phase diagram above 55at% the primary was been solidified. That means that in the case of Ti-44~48at%Al was transformed with L→β, there are the solidified course as follow. The lamellar structures were

thought to be upon α → (α+γ) L → (α+γ) L to obtain the plate nucleation. It was found that the Ti-44Al was formed to the equiaxed in center and slight columnar in edge with the binary structure. The grain growth was formed from outer to center in the 48Al. On the contrary the fine grain was formed except the growth in the 52at%Al. In 44Al full lamellar structure was shown that was thought to be primary β. In 48Al fine lamellae was formed with the 80~90 ˚direction with growth most. Other boundaries among grain growth were found. Upon Y. that was formed to the primary α from liquid. So it was thought that those rate was fast the primary α. Meanwhile those columnar grains was due to necleate from solidification. The 48Al in the grain obvious dendrite was formed so that coarse lamellae γ/α were grown with different directions in varied grains. It was found that was due to the random growth directions to view in general. That was through the reaction of L+α→γ to form the grains had surround the lamellae. On the other hand those fine structures was upon segregation and heterogeneous. That was the deep Al seperation and non-stead phases was to form the primary α forms the second phase to form the non-equilibrium structures within the boundaries with the peritectic reaction. Moreover it was thought that peritectic transformation α+γ →γ was not to be proceeded upon confining the solid diffusion with kinematics. The separated γ inter dendrites was shown in the 52~54Al obviously so that the following reaction was obtained. L→L+α→ L+α+γsegregation →α+γ segregation. Structure of the A alloy consists of coarse grains, some of which contain the widely spaced lamellar. It shows the general features of the grains. Analysis of the lamellar grain shows that it consists of γ, twin-related γ and α two phases as has been observed by other investigators. It should be noted that while the increase in Ti/Al ration refines the grain size, it has an opposite, and small effect on the inter lamellar spacing. Results above clearly show the beneficial effect of adding on the structure, refinement of grain size and spacing and decrease in volume fraction increase with addition. However the ration greatly refines the size and further lows the tetragonality and unit cell size. There was the gradient-solidified velocity and phase transformation studies at the interface of solid/liquid From the Fig. 1 the decreased trend will be observed the total value is about 140-40μm/s which might be caused by low velocity and a certain cooling rate of 0.5K/s. The low value of 0.3K/s is in low rate approximately. As shown in reference about 20K would be fitting one for 48Al in terms of phase diagram. As seen in Fig. 1 GD is into right as arrow, v is into left. The coarse grain will be gained in low v as a (Figure 1). This is a thermal flow, growth grain has been right part. Left takes role of seed effect, the better state is 10micm/s. usually first v was demanded lowly make sure to be grown with morphology of plane and cell. Heating temperature was 1492˚C taken on Ttip. According to $G = \frac{T_{tip} - T_{base}}{L}$, G=7.8K/mm. L=40~33mm, in the state of primary phase was determined by the lamellae orientation seen as (Figure 2). When the 44 at. pct Al the β upon 6~42 orientation were confirmed, which was the same as described in Chapter III 3. For 48 and 52Al the β may be known according to angle of 80 for 48 at. pct Al a nd 85 & 58 for 52 at. pct Al. According to v that α had been observed for the mostly state in the scope of below 100μm/s. That might be upon the [0001] PGD of primary phase which caused the near 90˚and 45˚partly distribution respectively. The trend would be raised in the speed of below 40μm/s and reduced after 80μm/s that may influence the alignment of lamella orientation a certain. Here the curve for Ti-43Al-3Si was for reference. The positive line is the tendency. Upon Al increased the angle will negatively tend to occur after 40 micm/s, that may been caused by Al amount. A concept of distribution has given a set of measurements of n being angles of TiAl-3Si and Ti-44~52Al here. For measuring change quantitatively analysis has been taken as reference. The high of σ means the high of the deviation. By the analysis the value has better credit than the 7.0. That means the orientation between lamella and growth had more approached angles to near 45~70˚. It was included that no many arrange with orientation of 0~45°should be happen basally in those alloys. It probably should be caused by α solidification more than β, which was thought. The γ solidification may be the one reason for Al rich alloys.

Mean m =58.6

$$\text{Variance } \sigma^2 = 1/n \sum (\text{orie.i-m})^2 = 40$$

Standard deviation σ =6.3

The trend for r and rate is shown that a line was observed to be negative proportional as seen in (Figure 3). That may be explained upon the raising v. That of rate is 10~250μm/s. Here r is the space of dendrite that was influenced by rate. As the rate was low below 20μm/s the trend maintained the near a certain value. The lowest curve would happen to under 10μm/s with least rate. That may be due to the r limiting. Where much nucleation will occur with the minimum velocity. The trend for K and rate is shown that a line was observed to be negative proportional as seen in (Figure 4). That may be explained upon the raising vG. That of rate is 10~1250μm/s. Here λ1 is the space of dendrite that was regulated by K. Where K is 1.75. λ1/K could be high as vG was low. That was to be caused with low cooling rate as predicted. The nucleation growth would occur much. In the meantime the quantity will decrease. The growth directions are shown in (Figure 5) with the lamellar orientation. The certain angels had been arranged along the GD in terms of the primary phases, they may be formed on parallel rule. The lamellar directions are thought to be like as Table 1 which specified two types. One is 0 and the other is 90° upon primary phase (Table 1). The detail investigation is concluded as the same results, being in

accordance with primary phase shown in (Figure 5). The structures of alloy are equilibrium phases such as $\alpha_2+\gamma$ & γ taken columnar and equiaxed according to Al content. The DS course will be stated follow, as for 44~46 at. %Al (I) the growing direction is (110) [001] β, and for 48 at. % (II), 50~54at. %Al (III) that is (0001) [1120] α, for 56at. % Al (III) is (111) [110] γ. The peritectic temperature is 1490°C & 1470°C in terms of β & α and eutectoid reactive with1120°C. As shown in Table 2 detailed reactive results demonstrated the phase transformation states (Table 2). Q was 1.98KJ/mol and 1.04KJ/mol according to peritectic and eutectoid reaction respectively for Ti-48 at. %Al. They reacted as below sequence of I, II & III. The equilibrium phase is the final two phases or singles as shown above. In this study, it is assumed that there is a constant positive liquid thermal gradient.

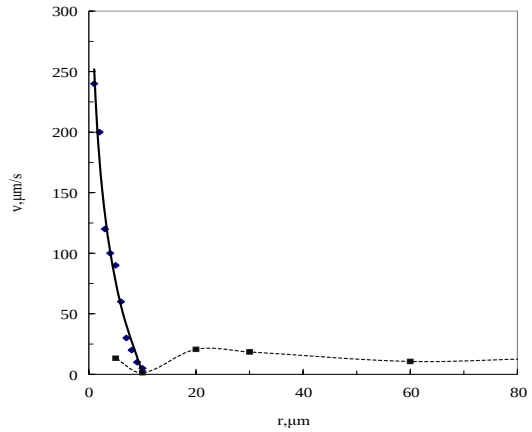

Figure 3: *The curve of velocity & radius for TiAl.*

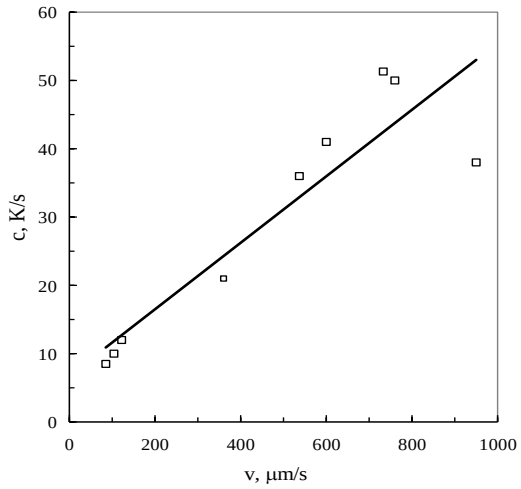

Figure 1: *The curve of v, & G for TiAl.*

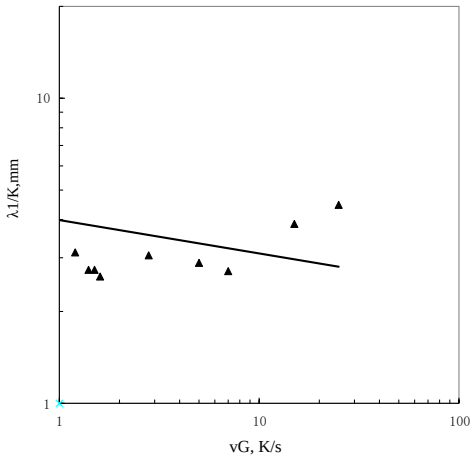

Figure 4: *The curve of v G and λ1/K for TiAl.*

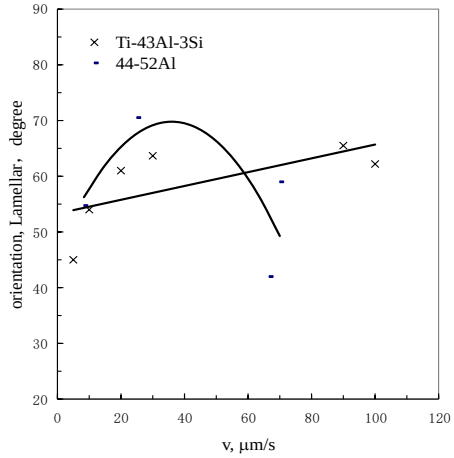

Figure 2: *Curve of orientation & velocity for TiAl.*

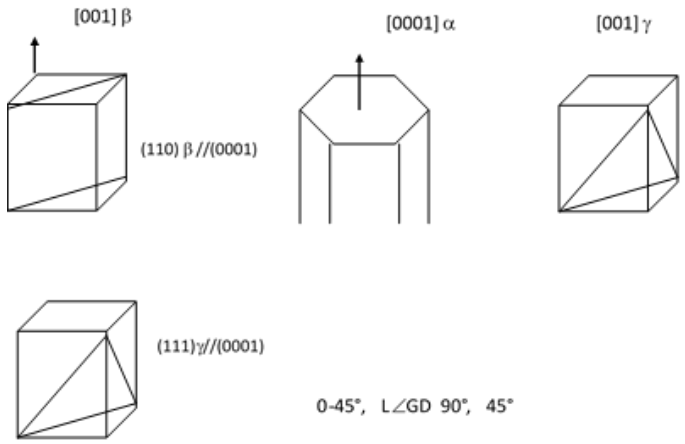

Figure 5: *Relations on grain growth direction in terms of primary phase and lamellar orientation in TiAl.*

Table 1: *Preferred growth direction in γ dendrites.*

Primary	Al at.%	Phases	Grain type	Direction,°	Lamellar ∠GD
β	44	α+γ	equiaxed	0-45	6, 42
α	48	α_2+γ	columnar	90	80
α	52	γ	equiaxed	90	85, 58, 59

Table 2: *Characteristic Temperature for phase transformation in TiAl.*

Content, at.%	Temperature by phase diagram	Temperature by DTA	Reaction
Ti-44Al	1490°C		Peritectic
	1510°C	1518°C	Liquidus
	1490°C	1492°C	Peritectic1
Ti-48Al	1484°C	1478°C	L+α→ α Peritectic2
		>1412°C	γ +α
	>1120°C	>1160°C	Eutectoid γ+α→ α_2+γ
Ti-52Al	1470°C		Peritectic

This simulated material is a Ti-44~56 at. % Al binary alloy, and its properties and the model of parameters used in the simulations are given in reference. Characteristic for phase transformation in binary γ may describe as follow. PGD (110)[001] β is for 44 at.% Al, (0001)[1120] α is for 50 at.% Al, and (111)[110] γ(111)[110] γ is for 56 at.% Al. The primary phase may be β and β (or α) for 44 and 48 at. % Al respectively. The equilibrium phase will be α_2+ γ, (α_2+ γ or) γ for 50 at. % Al. That may be primary α and equilibrium γ for 56 at. % Al. The may be transition phase for 52 at. % Al. The equilibrium phase is α_2+ γ and γ for 44~48 at. % Al and 52~54 at. % Al. The used procedure is similar to the one described above having an explicit relation between liquidus temperature and concentrations. During directional solidification, the change in liquid solute concentration affects the undercooling, and in turn, results in the nucleation and growth processes of the equiaxed grains. In this section, the calculated solute concentration profile ahead of the growth fronts is provided and the solute interaction ahead of growth front is discussed. In solid region, there is a slight increase in solid composition. At the columnar front, there is an exponential drop in solute concentration at the Solid/Liquid interface, quickly decaying to bulk liquid composition along the growth direction in liquid region. It shows the solute variation in the inter-dendritic region between primary columnar dendrites at solidification distance or different time. It can be thought that a gradient in solute concentration is observed in the liquid region, giving a slope of a certain about 1.2 at. %/μm, which agrees well with the predicted values. Comparing the results, because of the low concentration gradient, the greatest undercooling area occurs at the dendrite groove region rather than at the region ahead of the columnar tips, making it a favorite location for the nucleation of the equiaxed grains. It can be seen from the cooling that increasing the thermal gradient decreases the maximum cooling in the liquid along the dendrite axis.

Conclusions

1. The trend would be raised in the speed of below 40μm/s and reduced after 80μm/s that may influence the alignment of lamellae orientation certainly. Upon Al increased the angle will negatively tend to occur after 40 micm/s, that may been caused by Al amount.
2. That means the orientation between lamellae and growth had more approached angles to near 45~70°. It was included that no many arrangement with orientation of 0~45°should be happen basally in those alloys. It probably would be caused by α solidification rather than β.
3. The lowest curve would happen to under 10μm/s with least rate. That may be due to the r limiting. Where much nucleation will occur with the minimum velocity.
4. λ1 is the space of dendrite that was regulated by K. Where K is 1.75. λ1/K could be high as vG was low. That was to be caused with low cooling rate as predicted. The nucleation growth would occur much. In the meantime the quantity will decrease.
5. The primary phase may be β and β or α for Ti-44 at.%Al and 48 at.%Al respectively. The equilibrium phase will be α2+ γ, α2+ γ or γ for Ti-50 at.%Al. That may be primary α and equilibrium γ for Ti-56 at.%Al.. The α may be transition phase for Ti-52 at.%Al. The equilibrium phase is α2+ γ and γ for Ti-44~48 at.%Al and Ti-52~54 at.%Al.
6. The concentration of Al was measured to be 1.6at. % in 46at. pct Al. The calculated value was -2.06at. %. They agreed to each other well. It was thought to be α phase forming element due to the minus.

Acknowledgments

This work was supported in part by the Korea of Science and Engineering Fund, under the Specified Base program Granted as 96-0300-11-01-3.

References

1. Yamaguchi M, Umakoshi Y. The deformation behaviour of intermetallic superlattice compounds. Progress in Materials Science. 1990; 34: 1-48.
2. Appel F, Brossmann U, Christoph U, Eggert S, Janschek P, Lorenz U, et al. Recent progress in the development of gamma titanium aluminide alloys. Advanced Engineering Materials. 2000; 2: 699-720.
3. Kim YW. Gamma titanium aluminides: their status and future. Jom. 1995; 47: 39-42.

4. Pyo SG, Chang YW, Kim NJ. Microstructure and mechanical properties of duplex tiAl alloys containing Mn. Metals and Materials. 1995; 1: 107-115.
5. Hug G, Loiseau A, Veyssiere P. Weak-beam observation of a dissociation transition in TiAl. Philosophical Magazine A. 1988; 57: 499-523.
6. Vedula K, Westbrook JH, Fleischer RL. Intermetallic Compounds, Vol. 2, Practice. Edited by JH Westbrook and RL Fleischer, JOHN WLSEY & SONS. 1995: 199.
7. Blackburn MJ, Smoth MP. On Compo. Proc. of TiAl Alloys for Turbine Engines, USA. 1982.
8. Schneider MC, Gu JP, Beckermann C, Boettinger WJ, Kattner UR. Modeling of micro-and macrosegregation and freckle formation in single-crystal nickel-base superalloy directional solidification. Metallurgical and Materials Transactions A. 1997; 28: 1517-1531.
9. Huang SC, Chesnutt JC. Intermetallic Compounds: Principles and Practice 2, Westbrook, J. H., Fleischer, RL (Edts.). 1994.
10. Shimada Y, Inui H, Yamaguchi M. Proc of the 5th symp on High-performance materials for severe environments. 1994; 23.
11. Shao G, Tsakiropoulos P, Miodownik AP. Role of nucleation in phase competition in binary Ti-Al alloys. Materials science and technology. 1997; 13: 797-805.
12. Qingdong L, Wenqing L, Zemin W, Bangxin Z. 3D Atom Probe Characterazation Of Alloy Carbides In Tempering Martenite I. Nucleation. Acta Metall Sin. 2009; 45: 1281-1287.
13. Jung IS, Jang HS, Wee DM. Mat Sci Eng A. 2001.
14. Li X, Fu H. Acta Met Sinica. 2009; 45: 309.
15. Schneider MC, Kattner UR. Met Mat Trans A. 1997; 28.
16. Wang KF, Guo JJ, Fu HZ. Acta Metall Sini. (Eng. Lett.). 2008; 21: 146.