



# The Modelling Of Cooling Rate between Solidification Speed and Dendrite Secondary Arm Space in TiAl Intermetallic Compounds II

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## Abstract

According to the secondary dendrite arm space  $L$  and composition at solid and liquid interface in solidification the line model of temperature and cooling rate in dendrite has been established. Meantime the cooling rate and the secondary arm space has been discussed. In the intersection the cooling rate of solid and liquid  $\Delta T$  is gained. According to dendrite therefore the secondary dendrite arm space can determine temperature. The period one of cooling rate is from 8K/s to 0.7 K/s in speed of 1360mm/hr at the solidified length to be 210mm. The cooling rate will decrease with increasing solidified length. When cooling rate is 1,360mm/hr the biggest one in these three conditions will happen with 8K/s when it is 10 $\mu$ m and the solidified length with 210mm. The rate will increase from 4.3K/s to 7.7 K/s when the composition of Al increases from 0~1. From it it is observed that the cooling rate is 4.7K/s in Ti3Al meanwhile it becomes 5.5K/s in TiAl. In addition the cooling rate is 6.4K/s in TiAl3, so the directional solidification will be easy in Al rich alloy since they are big cooling rate. When the composition increases from 0 to 100% the dendritic secondary arm space will increase from 19 $\mu$ m to 35 $\mu$ m. It is concluded that TiAl3 is easier to form than TiAl which is easier than Ti3Al too in general. The easy degree turn is TiAl3.>TiAl >Ti3Al in Ti-Al intermetallic compounds.

**Keywords:** Modeling; TiAl; Dendrite; The secondary arm space; Analysis; Temperature; Cooling rate; Composition difference; Gibbs free energy

## Introduction

The change of temperature in the solid and liquid in solidification transformation can deduce the related formula. The curve expresses its trend better. From this relation their secondary dendrite arm space composition will change when the transformation happens. It is known that the temperature in solidification can solve their relationship. In this study in terms of these equations the deduction and analysis is done. Here the solid and liquid equation is explored within line and find the simple formula which make us to calculate the cooling rate rapidly [1,2]. Therefore in this study the model of temperature and composition has been established to observe the trend and intrinsic relationship between them. TiAl as a promise materials has been searched and developed for many years. However the cooling rate with

compositions is not much yet, so in this study the equation is established through temperature and composition according to the phase diagram. It is modelled with cooling rate and composition difference too in directional solidification test. The detail value is combined through phase equilibrium line and it is compared with thermal dynamics. The research scope is from 0 to pure Al here [3]. On the other side the relationship with cooling rate and energy difference & temperature has been investigated according to varied speed and  $\Delta S$  respectively for the application. According to the solidified crystalline and phase diagram the application will be known. In addition relationship between cooling rate and energy difference & temperature are drawn for further research in this study. To calculate the cooling rate is our destination in the end in terms of the composition in TiAl alloys.

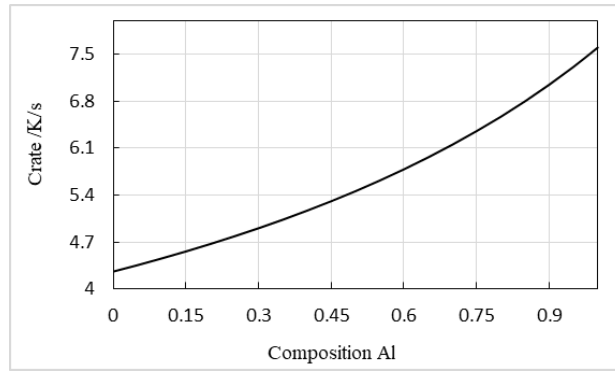
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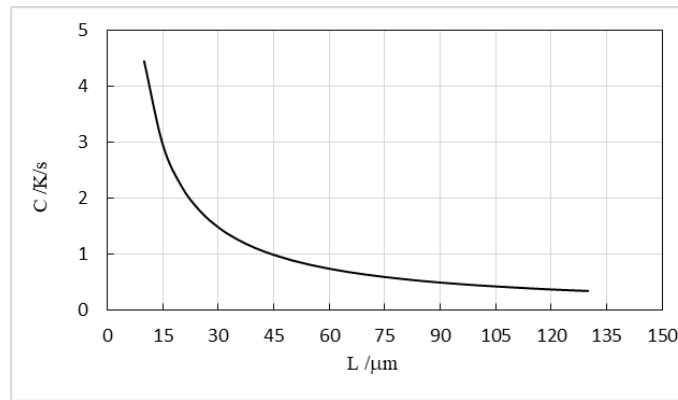
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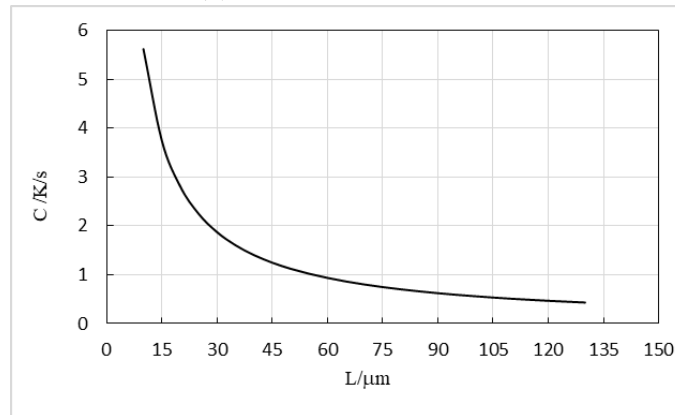
Therefore the establishment equation between temperature and cooling rate in terms of the equilibrium diagram [4-9] (Figure 1).



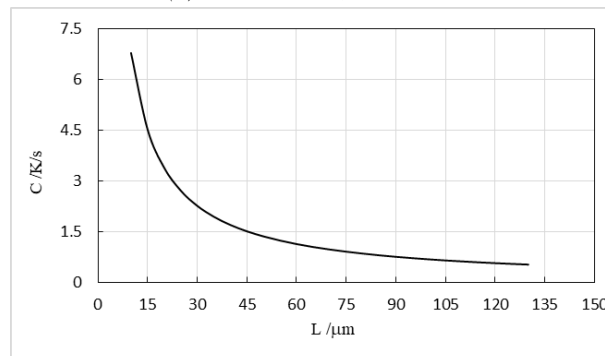
**Figure 1:** The relationship between *Crate* and Al composition in TiAl.



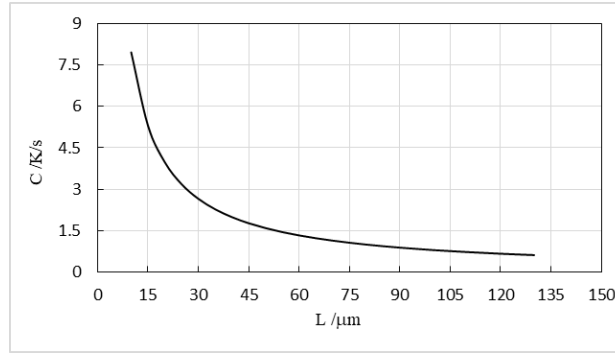
(a)  $v=760\text{mm/hr}; l_s=210\text{mm}$



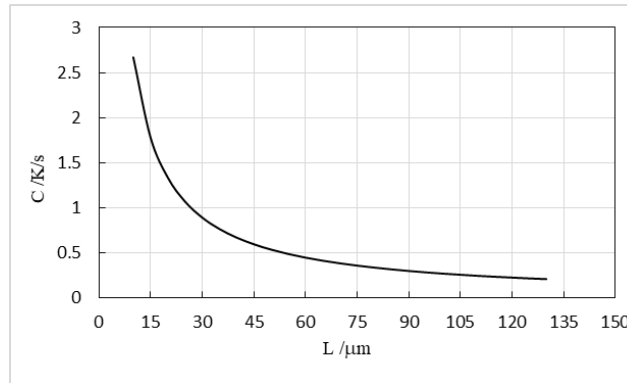
(b)  $v=960\text{mm/hr}; l_s=210\text{mm}$



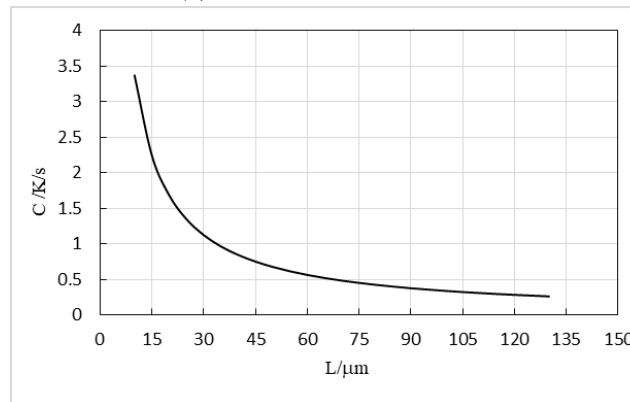
(c)  $v=1160\text{mm/hr}; l_s=210\text{mm}$



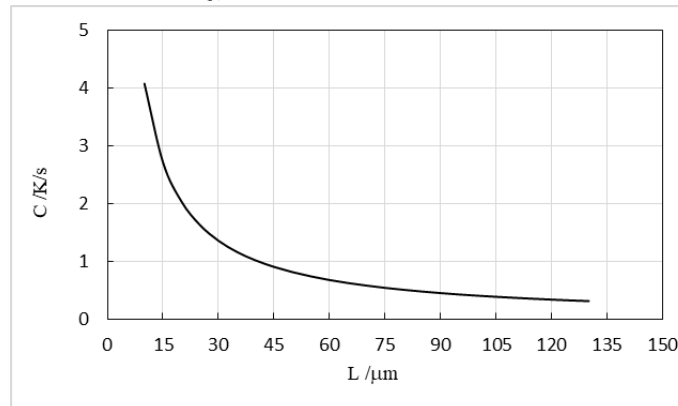
(d)  $v=1360\text{mm/hr}; l_s=210\text{mm}$



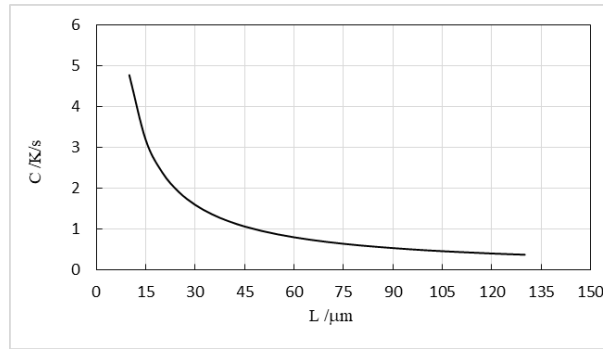
(e)  $v=760\text{mm/hr}; l_s=350\text{mm}$



(f)  $v=960\text{mm/hr}; l_s=350\text{mm}$



(g)  $v=1160\text{mm/hr}; l_s=350\text{mm}$



(h)  $v=1360\text{mm/hr}; l_s=350\text{mm}$

Figure 2: The relationship between cooling rate and dendrite secondary arm space with various solidified speed  $v$  at the two solidified length  $L_s$  in TiAl.

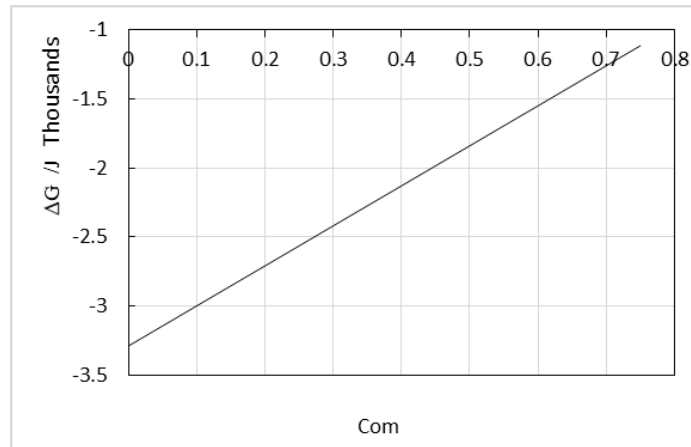


Figure 3: The relationship between  $\Delta G$  and composition difference in TiAl.

### Discussion

According to mathematic equation to model intrinsic relation between the dendritic secondary arm space and composition it has Since

$$T = -1000\text{Com} + 2273 \quad [3] \quad \text{--- (1)}$$

$$\text{And } T = 44,260/L \quad [6] \quad \text{--- (2)}$$

So it has

$$L = 442,60 / (-1000\text{Com} + 2273)$$

$$\text{Since } \text{Crate} = 9680/44 * L$$

From above equations it has

$$\text{Crate} = 9680 / (-1000\text{Com} + 2273) \quad \text{--- (3)}$$

The (3) is the equation of cooling rate and composition.

Here  $T$  is temperature  $K$ ;  $\text{Com}$  is composition;  $L$  is dendritic secondary arm space  $\text{mm}$ .  $\text{Crate}$  is cooling rate  $\text{mm}$ .

Since Gibbs free energy is  $\Delta G = \Delta H - T\Delta S$  --- (4)

Substitute (1) to above equation it has

$$\Delta G = \Delta H + (1000\text{Com} - 2273)\Delta S \quad \text{--- (5)}$$

Here  $\Delta G$  is Gibbs free energy;  $\Delta H$  is enthalpy  $\text{KJ/mol}$ ;  $\text{Com}$  is composition  $\text{Al}$ ;  $\Delta S$  is entropy  $\text{J/mol/K}$ .

In Figure 1 the crate will increase from 4.3K/s to 7.7 K/s when the composition of Al increases from 0~1. From it it is observed that the cooling rate is 4.7K/s in Ti3Al meanwhile it becomes 5.5K/s in TiAl. In addition the cooling rate is 6.4K/s in TiAl3, so the directional solidification will be easy in Al rich alloy since they are big cooling rate. As seen in Figure 2(a-h) when the drawing speed increases from 760~1360mm/hr with the solidified length of 210mm and 350 mm the cooling rate will increase from 4.5K/s, 5.7K/s, 6.2K/s & 8K/s and 0.2K/s, 0.5K/s, 0.6K/s & 0.7K/s at the place of 10 $\mu\text{m}$  to 2.7K/s, 3.3K/s, 4.1K/s & 4.8K/s and 0.2K/s, 0.3K/s, 0.35K/s & 0.4K/s at the same one of 135 $\mu\text{m}$  in TiAl respectively. At the solidified length to be 350mm it has maximum value of cooling rate with 8K/s under the condition of 1,360mm/hr. Meantime the minimum cooling rate is 0.2K/s under 760mm/hr and dendrite secondary arm space  $L=135\mu\text{m}$  with solidified length of 350mm. It expresses that the cooling rate increases when the drawing speed becomes bigger (Figure 2,3).

As seen in Figure 3 the free energy difference will increase if composition of Al increases. The energy difference will be from -3,300J to 1,200J when composition Al is from 0 to 0.75 in TiAl. It expresses that the Al content is bigger the consumed eneger is smaller. That says that TiAl3 is easier to form than TiAl which is

easier than Ti<sub>3</sub>Al too in general. The easy degree turn is TiAl<sub>3</sub>...>TiAl >Ti<sub>3</sub>Al in Ti-Al intermetallic compounds. In short it known that the directional solidification will be easy in Al rich alloy since they are big cooling rate. The cooling rate increases when the drawing speed becomes bigger. Meanwhile the temperature difference will decrease if composition difference of Al increases. It is known that free energy will decrease when the temperature increases therefore the relation between free energy and composition of Al exists in. It is seen that the bigger composition difference will create the lower temperature difference.

## Conclusions

- At solid and liquid interface in solidification the curve model of temperature and dendrite secondary arm space in solidified course has been established within 760mm/hr and 1360mm/hr with 210mm and 350mm of solidified length. Meantime the cooling rate and secondary arm space L has been discussed. In the intersection the cooling rate of solid and liquid  $\Delta T$  is gained. Composition difference has been deduced and analyzed according to dendrite therefore the dendrite secondary arm space can determine temperature. When the secondary arm space in dendrite is from 10 to 135 $\mu$ m the temperature changes from 4,200°C (4473K) to 300°C (573K). It is known that TiAl<sub>3</sub> is easier to form than TiAl which is easier than Ti<sub>3</sub>Al too in general. The easy degree turn is TiAl<sub>3</sub>...>TiAl >Ti<sub>3</sub>Al in Ti-Al intermetallic compounds.
- The period one of cooling rate is from 8K/s to 0.7 K/s in speed of 1,360mm/hr. When the cooling rate attains from 4.5K/s to 0.2K/s with the secondary arm space increasing to minimum value 760mm/hr. When cooling rate is 1360mm/hr the biggest one in these three conditions will happen with 8K/s mentioned again.
- The crate will increase from 4.3K/s to 7.7 K/s when the composition of Al increases from 0~1. From it is observed that the cooling rate is 4.7K/s in Ti<sub>3</sub>Al meanwhile it becomes 5.5K/s in TiAl. In addition the cooling rate is 6.4K/s in TiAl<sub>3</sub>, so the directional solidification will be easy in Al rich alloy since they are big cooling rate. When the composition increases from 0 to 100% the dendritic secondary arm space will increase from 19 $\mu$ m to 35 $\mu$ m. It explains that the more composition create higher dendritic secondary space.

## Foundation

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