



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

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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. According to  $Y$  changing from pure  $X$  to pure  $Y$  ie. The temperature will change from maximum to minimum at Al composition in materials like TiAl. The period one of cooling rate is from 40K/s to 15 K/s in speed of 4860mm/hr at the solidified length to be 150mm. The cooling rate will decrease with increasing solidified length. For engineering use the speed is better when the speed is higher like 4,860mm/h when the cooling rate attains from 15K/s to 40K/s with the secondary arm space increasing with the maximum value. When cooling rate is 4,860mm/hr the biggest one in these three conditions will happen with 40K/s when it is 10 $\mu$ m. When DS is 2.8J/ (mol·K) the DG changes from 800J to -2000J with the temperature increases same in TiAl.

**Keywords:** Modelling; 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 and the error analysis to them 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. Then the error is checked with variance to both of constant. 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. Therefore the establishment equation between temperature and cooling rate in terms of the equilibrium diagram [3-6].

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## Calculation and Discussion

### The relationship between the secondary dendrite space and temperature

It is supposed that

$$T = KL \quad (1)$$

K is constant, L is the second dendrite arm space.

Then  $K = T/L$

Since  $T = aC_{com} + b$  [3] -- (2)

Substitute (2) into (1) it has

$$K = (aC_{com} + b) L \quad (3)$$

And supposed that

$$C_{com} = 0.06, L = 20 \mu\text{m} \quad (4)$$

Because it has

$$K = 44.260 \text{ K}\mu\text{m} \quad (5)$$

$$\text{So } T = 44.260 * L \quad (6)$$

This is the temperature equation with L which is the secondary dendrite arm space.

### Discussion

As seen in Figure 1 the relationship between temperature and secondary dendrite space is exhibited according to the equation above. When the secondary dendrite arm space L increases from 10 $\mu\text{m}$  to 130 $\mu\text{m}$  the temperature will increase from 300 $^{\circ}\text{C}$  to 5,600 $^{\circ}\text{C}$  in TiAl. The bigger space expresses that the higher temperature. So the whole dendrite may be expressed in terms of the whole space changing. Because it is supposed that  $C_{com} = 0.06$  and  $L = 20 \mu\text{m}$  the whole space and temperature will change a certain with the two parameter changing. At the tip of dendrite the temperature attains high value and then temperature will become low. It fits to the principle well (Figure 1).

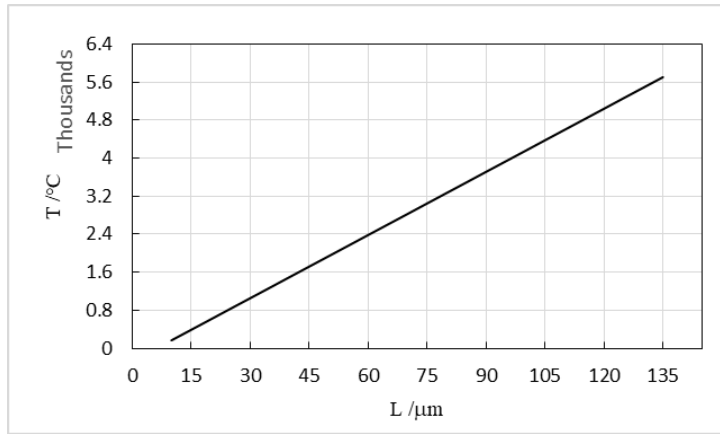
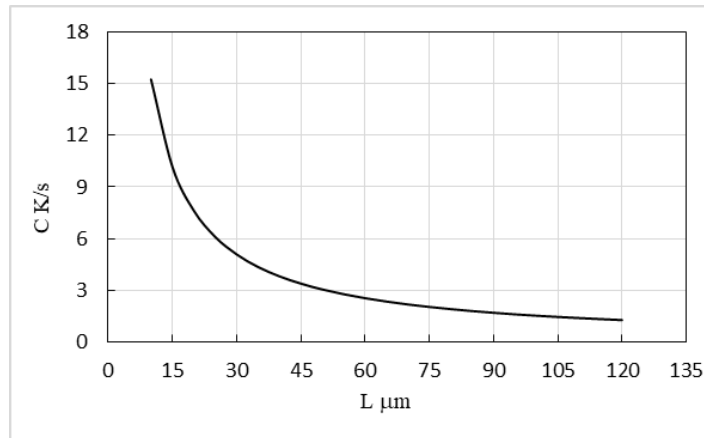
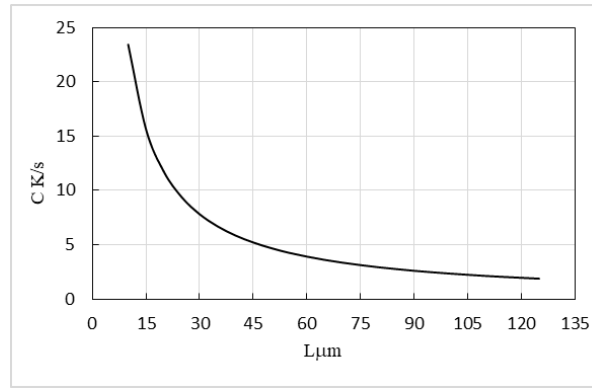


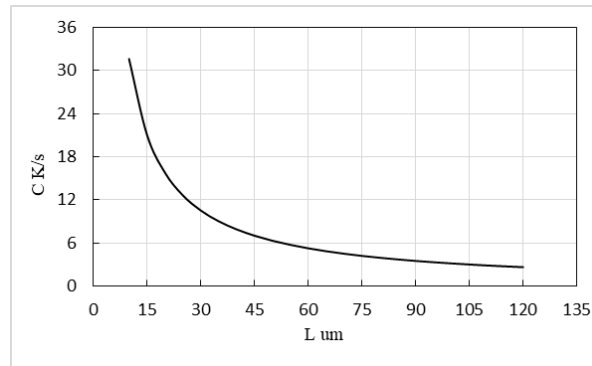
Figure 1: The relationship between temperature and dendrite second space in TiAl.



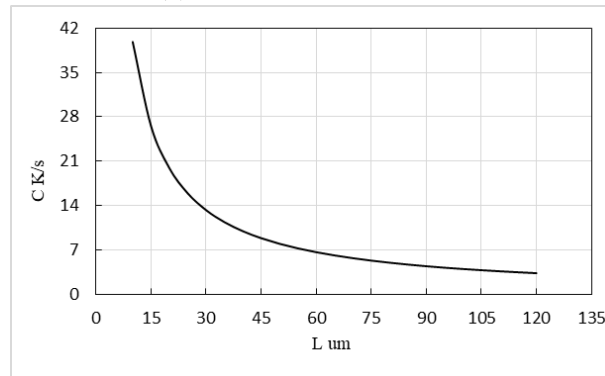
(a)  $v = 1860 \text{ mm/hr}$ ;  $l_s = 150 \text{ mm}$



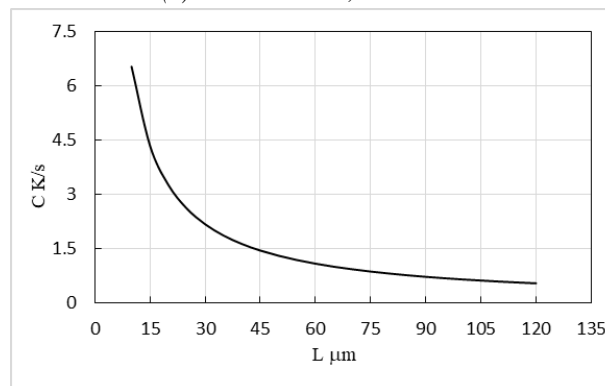
(b)  $v=2860\text{mm/hr}; l_s=150\text{mm}$



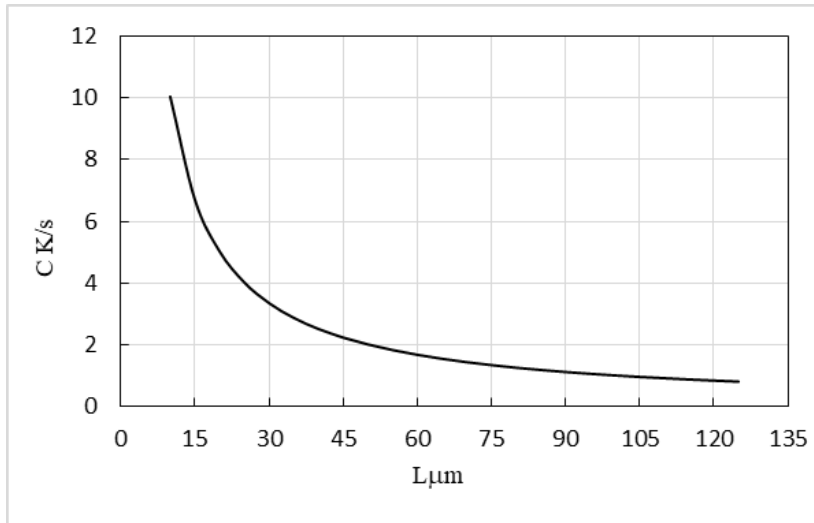
(c)  $v=3860\text{mm/hr}; l_s=150\text{mm}$



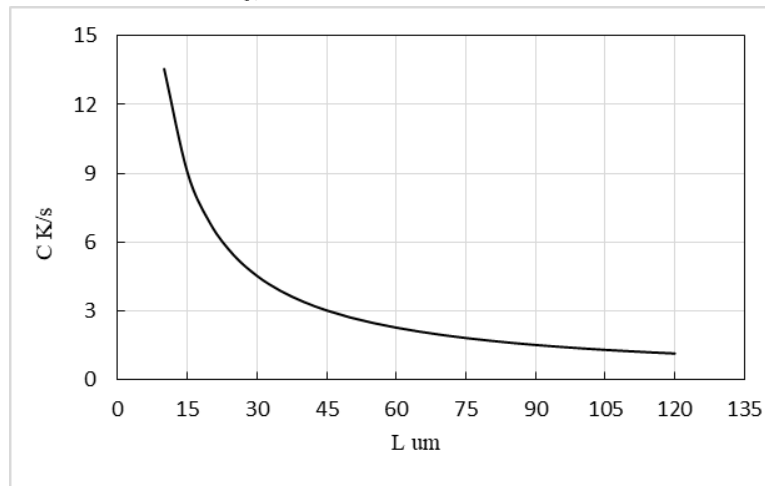
(d)  $v=4860\text{mm/hr}; l_s=150\text{mm}$



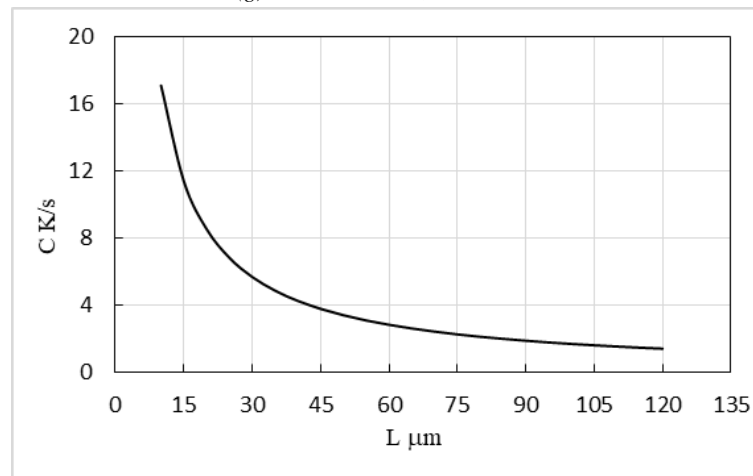
(e)  $v=1860\text{mm/hr}; l_s=350\text{mm}$



(f)  $v=2860\text{mm/hr}; l_s=350\text{mm}$

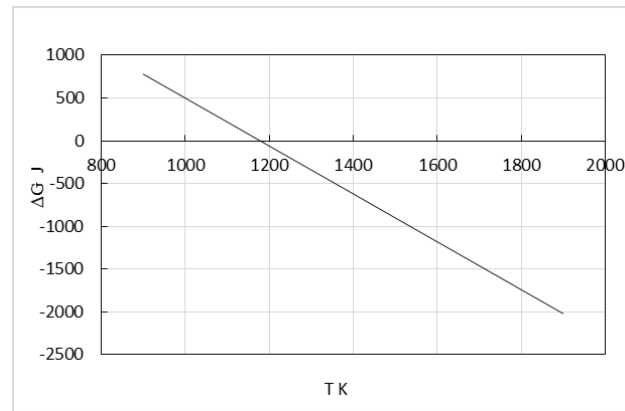


(g)  $v=3860\text{mm/hr}; l_s=350\text{mm}$



(h)  $v=4860\text{mm/hr}; l_s=350\text{mm}$

**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 linear relationship between Gibbs free energy difference and temperature in TiAl.

As seen in Figure 2(a~h) when the drawing speed increases from 1860~4860mm/hr with the solidified length of 150mm and 350 mm the cooling rate will increase from 15K/s, 24K/s, 32K/s & 40K/s and 7K/s, 10K/s, 13K/s & 18K/s at the place of 10 $\mu$ m to 1.5K/s, 2K/s, 3K/s & 4K/s and 0.5K/s, 1K/s, 1.5K/s & 2K/s at the same one of 120 $\mu$ m in TiAl respectively. At the solidified length to be 350mm it has maximum value of cooling rate with 40K/s under the condition of 4860mm/hr. Meantime the minimum cooling rate is 0.5K/s under 1860mm/hr and solidified length of 150mm. It expresses that the cooling rate decreases with the drawing speed becomes bigger (Figure 2,3).

### Gibbs free energy is defined as below

From Figure 3 DG decreases with temperature increasing. It decreases with entropy DS maintaining 2.8J/mol/K. This is the result of concentration of liquid and solid in terms of composition. When DS is 2.8J/ (mol·K) the DG changes from 800J to -2000J with the temperature increases from 850K to 1900K respectively. G is Gibbs free energy and DH is enthalpy [3-4]. It is supposed that enthalpy is constant in this study. It means that when DS becomes big the Gibbs free energy DG will decrease.

$$\Delta G = \Delta H - T\Delta S \quad (7)$$

In Ti-Al  $\Delta H$  and  $\Delta S$  are to be

$$\Delta H = 3.3 \text{ KJ/mol}, \quad \Delta S = 2.8 \text{ J/mol/K at } 1492^\circ\text{C}$$

### Conclusions

- At solid and liquid interface in solidification the line model of temperature and dendrite secondary arm space in solidified course has been established. 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 analysed according to dendrite therefore the dendrite secondary arm space can determine temperature. When the secondary arm space in dendrite is from 10 to 130 $\mu$ m the temperature

changes from 300 $^\circ$ C to 5,600 $^\circ$ C. Y changes from pure X to pure Y the temperature will change from maximum to minimum with increasing secondary arm space in materials like TiAl.

- The period one of cooling rate is from 25K/s to 145 K/s in speed of 8,860mm/hr. For engineering use the speed is better when the speed is higher like 7,860mm/h when the cooling rate attains from 20K/s to 77K/s with the secondary arm space increasing to minimum value 4860mm/hr. When cooling rate is 8860mm/hr the biggest one in these three conditions will happen with 145K/s mentioned above.
- When DS is 2.8J/ (mol·K) the DG changes from 800J to -2000J with the temperature increases from 850K to 1900K. From diagram the concentration of Al is measured to be 1.6at% in 46Al at%. The calculation value is thought to be phase forming element due to the minus. That has been the low concentration with solid solution in TiAl.

### Foundation

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