Solidification path simulation of die casting alloy for phase evolution prediction

Mohamad Rusydi Mohamad Yasin[1,*], Qingyou Han[2], Dongke Sun[2]

[1]Faculty of Manufacturing and Mechatronic Engineering Technology, Universiti Malaysia Pahang, 26600 Pekan, Pahang

[2]Purdue Polytechnic, Purdue University, West Lafayette, IN 47907, United States

[*]Corresponding e-mail: rusydi@ump.edu.my

Keywords: Alloy, Solidification, Die Casting, Simulation

ABSTRACT – The study focuses on thermodynamic simulation of solidification path for phase evolution prediction of aluminum die-casting alloys. The simulation allows important issues to be studied, such as the control of morphology and optimization of the solidification range in the alloy design. The simulation are primarily based on the solidification profiles and the alloys quaternary phase diagram. The results of the simulations are comparable with the available experimental data. Based on the overall developments, the proposed approach is a viable basis for the development of an effective computational tool to be used in the simulation of solidification of die-casting aluminum alloy.

1. INTRODUCTION

Iron (Fe) is always present in the aluminum silicon alloys to prevent "sticking" of the alloy to the steel casting molds [1]. However, Fe is one of the detrimental elements in aluminum alloy, mainly because it is the main cause of the impurities formation [2]. Fe regularly forms AlFe and AlFeSi intermetallics in the aluminum alloys due to the low solubility limit of Fe in Al (<0.05%). The mechanical properties of the alloy will be impaired by the high Fe content, and the ductility will severely decrease once the Fe content is over a critical percent [3]. A previous study outlined a meticulous method for the thermal analysis on solidification of aluminum alloys [4]. The experimental investigation is idealistic in laboratory setup, however may be time consuming and not economical for the industry. The phase formation sequence during the solidification can easily be forecasted for ternary alloys when the liquidus projection of the ternary system is known. In actual industrial setup, higher order alloys with more than three elements are more widely used in the industry due to the more superior mechanical properties of the alloys. However, the reliable liquidus projection for these alloys are rarely available. This paper attempts to model the solidification path of quartenary system of alloy for predicting the phase formation. The analysis of solidification path by the thermodynamic simulation can be utilized to minimize the formation of beta-phase in designing the die-casting aluminum alloys.

2. METHODOLOGY

Pandat software was used to compute the equilibrium phase diagram of die casting alloys with the Pan Aluminum database. The database is designed specifically for the multi-component Aluminum-rich casting alloys. The Al-Fe-Mn-Si system was particularly analyzed in this study. In each standardized die-casting alloy with given silicon content, the amounts of iron and manganese present play important roles in establishing mechanical properties of the material being produced. It is therefore of special interest to investigate the precipitation of Fe- and Mn- containing phases. The compositions of the alloys being analyzed are listed in Table 1.

Table 1 Composition of A360 and B360 alloy

Alloy	Composition (wt%)							
	Si	Fe	Mn	Cu	Mg	Zn	Ni	Al
A360	9.5	1.3	0.3	0.6	0.5	0.5	0.5	Bal
B360	9.5	0.4	0.3	0.6	0.5	0.2	0.1	Bal

The Scheil Rule was adopted in the modelling of the solidification model. The assumptions are that no diffusion occurs after solidification process completes ($D_S = 0$). Scheil Rule is also valid due to another assumption of equilibrium condition at the solid-liquid interface. In modelling the solidification profile, the pressure is assumed to be at atmospheric pressure and constant throughout the solidification. Phase diagram information for multicomponent die casting aluminum alloys are coupled to solidification model to predict the solidification path. The Al-Fe-Si ternary phase diagrams and Al-Fe-Si-Mn quaternary liquid projections were calculated using Pandat software. The solidification paths of the selected die-casting alloys are plotted on the quaternary phase diagram. The sequence of reactions during solidification process is then matched with the solidification path to determine the phase formation on the solidification path.

3. RESULTS AND DISCUSSION

Figure 2 represents the composition of A360, and its solidification path. The solidification path starts within the β-AlFeSi region, therefore the formation of β-AlFeSi occur at the beginning of the solidification process. Line (i) indicates the formation of β-AlFeSi, which occurs until the through between the α-AlFeSi and β-AlFeSi phases is reached. During this phase, the Fe fraction is reduced to form the β-AlFeSi, while Si content maintains its fraction. The reaction continues

with the formation of secondary α-AlFeSi and β-AlFeSi along the boundary line (ii) until the ternary eutectic composition is reached. Fe, Mn and Si fraction are consumed within this phase. The solidification continues with the formation of Al, Si and α-AlFeSi in the ternary eutectic at point (iii). The complete nucleation sequence of A360 is shown in the Table 2. The sequence of formation starts with the formation of α-AlFeSi and β-AlFeSi, followed by Al and finally Si.

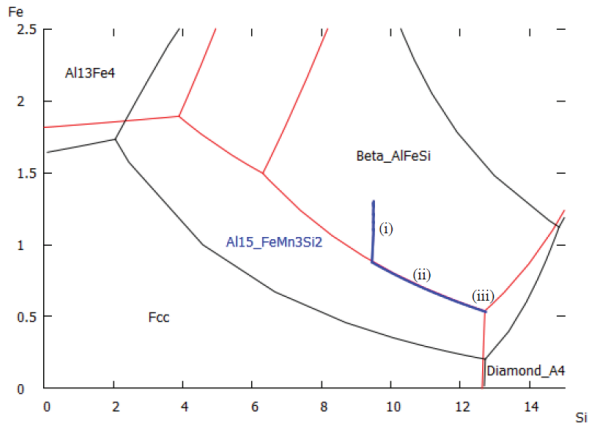

Figure 1 The solidification path of A360 alloy

Table 2 Reaction during solidification of A360 alloy

Temp (K)	Reactions during Solidification
906.79	Liq → $Al_{15}FeMn_3Si_2$ (α)
880.92	Liq → $Al_{15}FeMn_3Si_2$ (α) + AlFeSi (β)
871.36	Liq → $Al_{15}FeMn_3Si_2$ (α) + AlFeSi (β) + Al
848.56	Liq → $Al_{15}FeMn_3Si_2$ (α) + AlFeSi (β) + Al + Si

Meanwhile, Figure 2 represents the composition of B360 and its solidification path. B360 has the same composition as A360, except having lower Fe content. The solidification path starts within the α-AlFeSi region, hence the α-AlFeSi phase is a more dominant phase formation. Line (iv) illustrates the formation of α-AlFeSi and Al until the through between the α-AlFeSi and Si is reached. During this phase, the Si fraction is reduced to form the α-AlFeSi, while Fe content maintains its fraction. The reaction continues with the formation of secondary α-AlFeSi, Al and Si along the boundary line (v) until the ternary eutectic composition is reached. During this phase, the Al and Mn fraction is consumed while Si fraction is constant, therefore the Fe fraction is increased. The solidification continues with the formation of β-AlFeSi in the ternary eutectic at point (vi). The nucleation sequence of B360 alloy is shown in Table 3. The sequence of formation starts with the formation of α-AlFeSi and Al, followed by Si and finally β-AlFeSi.

Both simulations confirm the experimental results in previous study [4]. The reduction of Fe can shift β-AlFeSi to α-AlFeSi phase. Fe addition above the α-AlFeSi and β-AlFeSi boundary line introduces the β-AlFeSi at the start of solidification process, hence become a large phase within the solidified aluminum alloy. In contrary, the β-AlFeSi forms last at the end of solidification, therefore the formation is minimal.

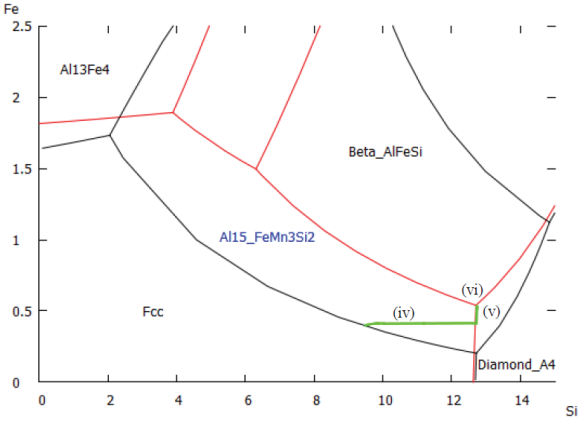

Figure 2 The solidification path of A360 alloy

Table 3: Reaction during solidification of A360 alloy

Temp (K)	Reactions during Solidification
872.21	Liq → $Al_{15}FeMn_3Si_2$ (α)
871.80	Liq → $Al_{15}FeMn_3Si_2$ (α) + Al
848.77	Liq → $Al_{15}FeMn_3Si_2$ (α) + Al + Si
848.56	Liq → $Al_{15}FeMn_3Si_2$ (α) + Al + Si + AlFeSi (β)

By comparison, the result of the simulation shows that for A360, the β-AlFeSi fraction formed is 0.02954, while for B360 which has less Fe content, the β-AlFeSi fraction is reduced to 0.00526.

4. CONCLUSIONS

The method of thermal dynamic simulation to predict the α-AlFeSi and β-AlFeSi phase formation of the aluminum die-casting alloy is studied. The study indicates that the addition of Fe in the composition of the alloy favors the formation of the β-AlFeSi phase. The fraction of β-AlFeSi formation is dictated by whether the composition is above or below the α-AlFeSi and β-AlFeSi boundary line. If the Fe level is above the boundary line, the β-AlFeSi phase is larger due to it being formed at the starting of the solidification.

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