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MICROSTRUCTURAL STUDY AND DIFFERENTIAL SCANNING ALORIMETRY ANALYSIS AT ELEVATED TEMPERATURES OF UPERHEATED AS-CAST A357 ALLOY

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ABSTRACT

The microstructure of superheated as-cast A357 alloy has been analysed to study the solidification structures of α-Al dendrites, eutectic Si particles and intermetallic compounds at different sections of the specimen. The primary dendritic arms are broken to globular and spherical shaped of α-Al dendrites due to the thermal effect of superheating thermal treatment. Differential scanning calorimetry showed faster formation of endothermic peaks of superheated as-cast A357 alloy relatively also believed to be attributed by superheating thermal treatment. The solidification sequence of superheated A357 alloy was same as Sr modified Al-7Si-Mg alloy [4] except for the reaction involving Al_5FeSi intermetallic compound which started with Liq. → Al dendrites followed by Liq. → Al + Si and lastly Liq. → Al + Si + Mg_2Si + $Al_8FeMg_3Si_6$.

***Keywords*:** Solidification structures, Superheating, Endothermic peaks.

INTRODUCTION

In the last few decades, Al-Si-Mg alloy is one of the most commercially alloys used in the automotive and aircraft industries which attributed by its excellent combination of good castability and mechanical properties as well as good corrosion resistance and weldability (Shivkumar *et al.,* 1991; Djurdjevic *et al.*, 1999; Yijie Zhang *et al.,* 2005). Solidification process plays a pivotal role in determining the resulted physical and mechanical properties of the alloys. The solidification sequence of alloy Al-Si-Mg alloy consists mainly of three phase transformations by referring to the cooling curves namely the formation of aluminium dendrites, the main binary eutectic reaction and the formation of ternary and/or quaternary eutectic phases such as Mg_2Si and/or Fe-bearing intermetallics (Wang and Davidson, 2001).

Superheating thermal treatment was the alternative non-chemical and thermal treatment that has been practically utilised for grain refinement to the molten metal in aluminium alloys (Chen Zhong-wei *et al.*, 2005; Haque and Ahmad Ismail, 2005). Superheating treatment combined with grain refiner in production of Al-Si alloys has been proven towards improving mechanical properties (Ahmad Ismail, 2005; Jun Wang *et al.,* 2002; Basavakumar *et al.*, 2007). However, the effects of superheating on the formation of phases and solidification sequence have not yet been studied.

Differential scanning calorimetry (DSC) has been used extensively in studying the phase transitions such as melting, glass transitions, or exothermic decompositions. DSC analysis has been used in research of Al-Si alloys in terms of evolution of volume fraction of precipitate (Shahrzad Esmaaeili and David Loyd, 2005), precipitation behavior (Wang and Davidson, 2001; Zhen and Kang, 1998) and phase transition (Jun Wang *et al.,* 2003); Awanoa and Shimizu, 1990).

This present research addresses the comparison of microstructural solidification structure at different sections of the specimen produced via conventional gravity casting technique and formation of phases and solidification sequence using DSC analysis at elevated temperatures.

MATERIALS AND METHODS

The raw material used as a matrix alloy in this research work was primary cast ingot Al-Si-Mg alloy supplied by National Centre for Machinery & Tooling Technology (NCMTT), SIRIM Berhad, Malaysia. The alloy has been cast by continuous casting process and was delivered in the form of bar. The chemical composition of cast alloy was analysed using arc spark spectroscopy (SPECTROMAXx, Germany) and the composition was complied with A357 alloy. The chemical composition (wt.%) of the alloy was 7.24 Si, 0.54 Mg, 0.12 Fe, < 0.10 Mn, 0.10 Ti and the balance was Al.

The primary cast ingot A357 was melted in crucibles by using electric furnace. It was heated up to the superheating temperature of 900°C for 1 hour before poured into the preheated stainless steel mould to produce superheated as-cast A357 alloy via gravity casting technique. Two different specimens of as-cast A357 alloy namely middle section (coded AC-M) and bottom section (coded AC-B) have been prepared for microstructural characterisation. The schematic diagram of the section specimens are shown in Fig. 1.

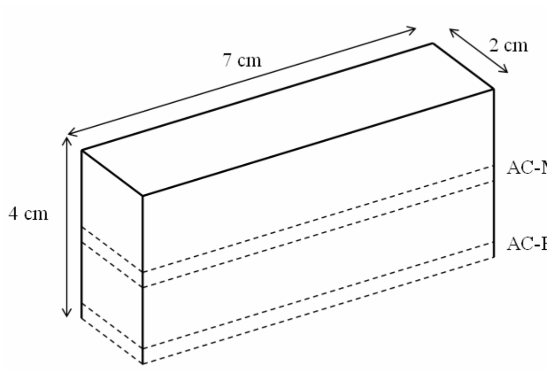

Figure 1: Schematic of the sectioned AC-M and AC-B specimens

The microstructures of all the specimens were characterised by light microscope. Specimens were prepared by the standard metallography methods of cutting and mounting followed by wet grinding on a series of SiC papers. Finally, the specimens were polished with 6 µm, 3 µm and 1 µm diamond suspension using napless cloth. The etchant used was 0.5% HF in order to reveal the grain structures, morphologies of primary aluminium dendrites and eutectic silicon particles in the microstructures. For microstructural analysis, the Image J software (1.41i version) was used to analyse the area fraction and average grain size of α-Al dendrites. Meanwhile, microstructural study of Fe intermetallic compound at higher magnification was done by using scanning electron microscope, SEM (JEOL JSM 6460 LA model, Japan).

DSC studies were carried out on the specimens of superheated as-cast A357 alloy specimens using DSC Q10 TA Instrument model. Parallel slices of 0.5 mm thick were cut from the specimens using

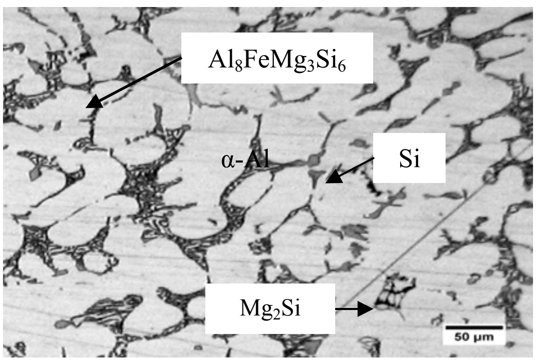

Figure 2: Optical micrographs of superheated as-cast AC-M alloy.

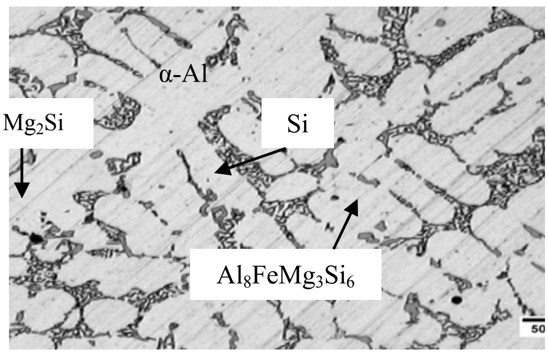

Figure 3: Optical micrographs of superheated as-cast AC-B alloy.

precision diamond blade and discs about 5 mm in diameter were then punched from the slices. The specimens were tested at 10°C/min heating rate from 520ºC to 640ºC.

RESULTS AND DISCUSSION

Microstructure

Figs. 2 and 3 show the as-cast A357 microstructure of middle section specimen (AC-M) and bottom section specimen (AC-B) at low and high magnification respectively. Generally, both as-cast section specimens showed the presence of primary α-Al dendrites and eutectic Si particles alongside minor phases of Mg_2Si and $Al_8FeMg_3Si_6$ intermetallic compounds.

Fig. 2 shows the microstructure of AC-M specimen exhibiting globular growth of α-Al dendrites and exhibiting finer eutectic Si particles. It is seen that Mg_2Si and $Al_8FeMg_3Si_6$ intermetallic compounds

Fig. 3 of AC-B specimen, the microstructure shows elongated globular structure of α-Al dendrites and concentrated coarser eutectic Si particles in between the α-Al dendrites. The eutectic Si particles is spheroidised and associated with Mg_2Si and $Al_8FeMg_3Si_6$ intermetallic compounds at the grain boundaries. From microstructural analysis using Image J software, AC-M specimen has 79.3 % of the area fraction of α-Al dendrites and the average grain size is 35.4 µm. Meanwhile, AC-B specimen having 81.6 % of α-Al dendrites and the average grain size is 31.3 µm.

Finer eutectic Si particles together with spherical globular shaped of α-Al dendrites was clearly observed in AC-M specimen as shown in Fig. 2 was believed to be influenced by the superheating thermal treatment prior to casting. The primary dendritic arms are broken to globular and spherical shaped of α-Al dendrites due to the thermal effect of superheating thermal treatment. The α-Al dendritic structures in AC-M specimen (Fig. 2) also seem to appear alike the spherical solidification structure via refined with C_2Cl_6 followed by superheating thermal treatment as reported by Jun Wang *et al.* (2003). It was found also that superheating thermal treatment tends to spheroidise the needle-like Fe rich phase (Shahrzad Esmaeili and David Loyd, 2005) besides reducing and thus spheroidise the primary α dendrite size (Backerud *et al.*, 1990)

The results indicate that the iron phase crystallises predominantly as $Al_8FeMg_3Si_6$ instead of β-$FeSiAl_5$ platelets in the microstructure of superheated as-cast alloy due to the superheating treatment of the molten aluminium during melting process at 900°C for 1 hour prior to casting. Awanoa and Shimizu (Awanoa and Shimizu, 1990) reported that even in the absence of modifier or trace elements such as Mn, Co, Be and Cr, the morphology of Fe phase can also be modified by superheating the melt appropriately. Their results showed that the Fe phase crystallizes predominantly as Chinese script particles (π-$Al_8FeMg_3Si_6$) instead of Fe platelets (β-$FeSiAl_5$) when the melt was superheated at 850 to 900º for short periods. Moreover, the β-Fe phase may only appear as a primary phase if Fe is higher than 0.8 wt. % (Mondolfo, 1976; 1978).

DSC Analysis

The DSC thermographs in Fig. 4 illustrate the 3 significant endothermic peaks. Peak 2 are associated with the formation of Fe-bearing intermetallic compounds, peak 3 represents the main binary eutectic reaction and peak 4 corresponds to the nucleation and growth of α-Al dendrites. The resulted endothermic peaks are similar as reported by Wang and Davidson (Wang and Davidson, 2001).

The solidification sequence of superheated A357 alloy was same as Sr modified Al-7Si-Mg alloy (Wang and Davidson, 2001) except for the reaction involving Al_5FeSi intermetallic compound which started with Liq. → Al dendrites followed by Liq. → Al + Si and lastly Liq. → Al + Si + Mg_2Si + $Al_8FeMg_3Si_6$ as shown in Table 1.

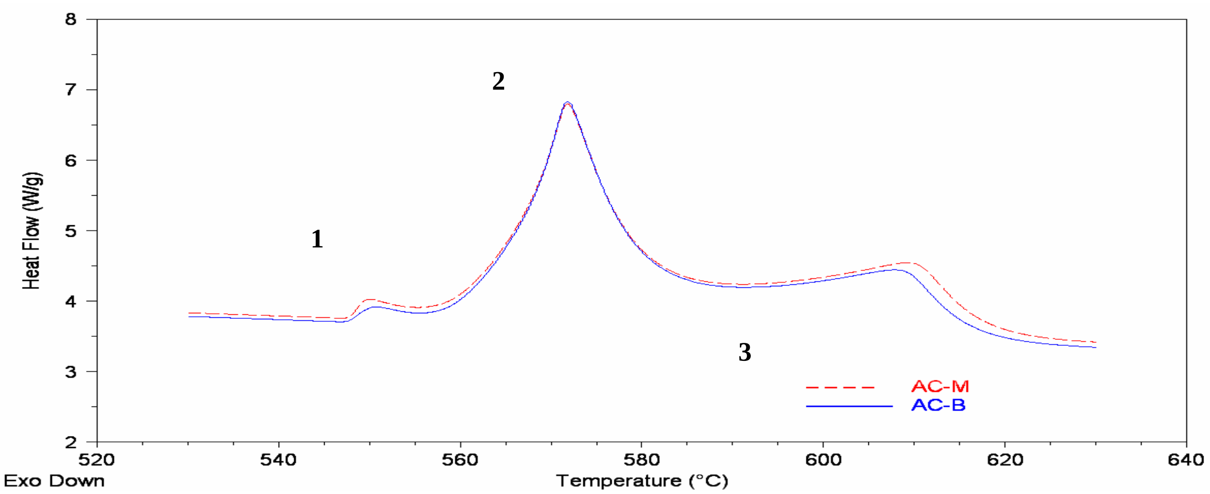

Figure 4: The DSC thermograms of AC-M and AC-B specimens at higher elevated temperatures (530-630ºC).

The significant difference in terms of a faster formation (Wang and Davidson, 2001) and slower formation (Cao and Campbell, 2004) of endothermic peaks as compared to the current research (AC-M specimen) at higher elevated temperatures has been observed and summarised in Table 1. A faster formation of endothermic peaks is believed to be attributed by superheating thermal treatment before pouring. The major reactions 2 and 3 are clearly proven from the microstructures (Figs. 2 and 3).

However, Cao and Campbell Cao and Campbell, 2004) found that the formation temperature of α-Al dendrites and binary eutectic reaction were faster than the current research findings and by Bäckerud *et al.* (1990). This condition might be due to the effect of superheating thermal treatment on the Al with higher Si content and lower Mg content relatively (Al-11.5Si-0.4Mg). In other words, superheating thermal treatment has attributed towards accelerated formation temperature of α-Al dendrites and binary eutectic reaction with the combination of relatively higher Si content and lower Mg content. It was also observed that the Sr addition did not play a crucial role in determining the formation endothermic peaks since the difference between current research and Wang and Davidson (2001) was relatively small. The solidification sequence of superheated A357 alloy was same as Sr modified Al-7Si-Mg alloy (Wang and Davidson, 2001) except for the reaction involving Al_5FeSi intermetallic compound which started with Liq. →Al dendrites followed by Liq. → Al + Si and lastly Liq. → Al + Si + Mg_2Si + $Al_8FeMg_3Si_6$.

Table 1: Solidification reactions

Assignment to DSC peak	Reaction [13]	Suggested start temperature, ºC [13]	Peak temperature, ºC		
			Al-11.6Si-0.4Mg [16]	Al-7.2Si-0.5Mg (AC-M specimen)	Al-6.9Si-0.6Mg [4]
1	Liq. → Al + Si + Mg_2Si + $Al_8FeMg_3Si_6$	550 - 554	-	550	560
2	Liq. → Al + Si	577	569	571	575
3	Liq. → Al dendrites	611 – 615	578	609	610

CONCLUSIONS

The changes in terms of shape and size of α-Al dendrites and eutectic Si particles in AC-M specimen (spherical globular structure of α-Al dendrites, finer eutectic Si particles) and AC-B specimen (elongated globular structure of α-Al dendrites, coarser eutectic Si particles) are believed to be attributed by the superheating thermal treatment. The primary dendritic arms are broken to globular and spherical shaped of α-Al dendrites due to the thermal effect of superheating thermal treatment.

A solidification sequence of superheated as-cast A357 alloy was same as Sr modified Al-7Si-Mg alloy [4] except for the reaction involving Al_5FeSi intermetallic compound. The sequence started with Liq. → Al dendrites followed by Liq. → Al + Si and lastly Liq. → Al + Si + Mg_2Si + $Al_8FeMg_3Si_6$.

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