

Analyzing the microstructural evolution and hardening response of an Al-Si-Mg casting alloy with Cr addition



Hongyi Zhan*, Bin Hu

General Motors Global Research & Development, China Science Lab, 56 Jinwan Road, Shanghai, China

ARTICLE INFO

Keywords:

Al-Si casting alloy

Intermetallics

Dispersoid

Thermodynamic simulations

ABSTRACT

Chromium is added to Al-Si based casting alloys for the mitigation of die soldering. In the present work, EBSD, EDS and TEM characterizations are combined with thermodynamic simulations to study the microstructural evolution and hardening response of an Al-Si-Mg-Cr casting alloy during heat treatments. It is shown that the Fe-containing intermetallic compounds formed in the inter-dendritic region were acicular π -Al₈(Fe, Cr)Mg₃Si₆ phase and polyhedral Al-(Cr, Fe)-Si phase which is structurally similar to face-centered cubic Al₁₃Cr₄Si₄. The polyhedral Al-(Cr, Fe)-Si intermetallics that crystallized prior to β -Al₅FeSi consumed impurity Fe, suppressing the formation of β phase during gravity die casting process. Also, Cr-addition enables the precipitation of nano-scale Cr-bearing dispersoids in Al dendrite during solution treatment at 813 K. Hardness increment of over 10 HV can be induced by the Cr-bearing dispersoids for as-quenched alloy. Though the dispersoids have a moderate hardening effect on the as-quenched alloy, they may impair the ageing hardening response by acting as heterogeneous nucleation sites for coarse Mg-Si rods and Si particles when quenching into water at 338 K.

1. Introduction

Chromium is not commonly added to Al-Si based casting alloys since it will contribute to the formation of undesirable coarse sludge particles in microstructures, especially when a certain amount of Fe and Mn are already involved in the alloys [1, 2]. Recently, Cr-addition has been identified as an alternative to Fe-addition and Mn-addition for improving the die-soldering resistance of Al-Si based casting alloys [3]. To take this advantage of Cr-addition, it is necessary to clarify how Cr-addition affects microstructures and hardening response of Al-Si based casting alloys.

In the previous studies, it has been reported that Cr has similar influences as Mn on modifying plate-shaped β -Al₅FeSi intermetallics in the inter-dendritic region of Al-Si based casting alloys [4–7]. Gustafsson et al. [4] investigated the influence of Cr as impurity Fe neutralizer in the Al-7 wt%Si-0.3 wt%Mg alloy (all compositions quoted afterwards are in weight percent unless otherwise stated) and reported that body-centered cubic (bcc) structured Al₁₃(Cr, Fe)₄Si₄ with lattice parameter $a = 1.25$ nm formed instead of platelet-shaped β phase in the inter-dendritic region. Li et al. [8] added 0.5% Cr and 0.8% Fe to Al-Si piston alloys and concluded that the newly-formed α -Al-(Cr, Fe)-Si intermetallics was bcc structured as identified by X-ray diffraction (XRD) method. Yang et al. [7] added different levels of Cr to eutectic Al-Si alloys with 0.5% Fe involved and reported that the conversion of Fe-

containing intermetallics from plate-shaped β -Al₅FeSi to fishbone-like α -Al-(Cr, Fe)-Si was beneficial for ductility. The identification of Cr-bearing intermetallic compounds in the previous literatures primarily relied on morphology observations by optical microscopy and composition analysis by energy dispersive X-ray spectrum (EDS). However, morphology observations and EDS results shed no light on crystallography information for the detected intermetallic compounds. Although XRD method can determine crystal structure for intermetallic compounds, it is always challenging to collect relative large volume fraction of specific intermetallic compounds from conventional Al-Si casting alloys for reliable XRD data collection. Due to the limitations of these methods applied in the previous studies, the identity of Al-(Cr, Fe)-Si intermetallic phase in the inter-dendritic region still remains unclear.

In addition, Cr is reported to enable a precipitation of dispersoid in Al wrought [9–11] and casting alloys [12, 13] during heat treatments conducted at elevated temperatures (homogenization and solution heat treatments). Dispersoids, consisting of Al, Si and transition metals like Mn, Fe and Cr, have been commonly applied for grain size control during homogenization or annealing treatment on 6xxx series Al wrought alloys [14, 15]. Cr-bearing dispersoids are generally regarded as incoherent with Al matrix and have no strengthening effects. Recently, Tocci et al. [12] added 0.28% Cr along with 0.12% Mn to an Al-3Si-0.6 Mg casting alloy and reported that hardness increment of ~ 5 HV

* Corresponding author.

E-mail address: h.zhan@uq.edu.au (H. Zhan).

<https://doi.org/10.1016/j.matchar.2018.06.026>

Received 11 May 2018; Received in revised form 10 June 2018; Accepted 22 June 2018

Available online 23 June 2018

1044-5803/ © 2018 Published by Elsevier Inc.

was induced by Cr-bearing dispersoids formed during solution treatment. However, Cr-bearing dispersoids observed in the Al matrix were not identified in their study. As Cr was always added in a combination with Mn [12, 13], its sole effects on dispersoid precipitation and hardening response require further investigations.

An Al-5%Si-0.5%Mg-0.25%Cr alloy has been developed recently for manufacturing automotive components by squeeze casting. In comparison to the most widely used A356 casting alloy (Al-7%Si-0.3%Mg), slightly less Si content in the new alloy is intended to provide a better balance between ductility and castability while more Mg content is for a higher strength. 0.25% Cr is added to the alloy for mitigating die-soldering issue encountered in the squeeze casting process for mold protection. The present research mainly combined thermodynamic simulations with microstructural characterizations by scanning electron microscopy (SEM) and transmission electron microscopy (TEM) on the Al-Si-Mg-Cr alloy for three aims: (i) to understand the effect of Cr addition on suppression of β -Al₅FeSi intermetallics; (ii) to identify Cr-bearing dispersoids formed in Al dendrites and their influence on hardening response of the alloy; (iii) to understand the discrepancy between microstructural characterizations and thermodynamic simulations.

2. Experimental Procedures

2.1. Casting Process and Heat Treatments

The pre-alloyed ingots with a nominal composition of Al-5Si-0.5Mg-0.25Cr were melted in an induction furnace at 1023 K. After the ingots melted completely, modifiers were added in the form of Al-5%Ti-1%B and Al-10%Sr master alloys. Degassing was conducted at 993 K by injecting dry nitrogen gas into the melt and rotation of lance degasser. After two cycles of degassing, the melt was smoothly poured into a permanent mold which was preheated to ~523–573 K to obtain cylindrical castings with diameter of 30 mm. The chemical composition analyzed by optical emission spectrometer (OES) is shown in Table 1. Heat treatments were done in an electrically heated, air-circulating chamber furnace with temperature deviation smaller than ± 5 K. Solution treatment was carried out at 813 K (540 °C) up to 20 h followed by quenching into water at 338 K (65 °C). Ageing treatment was done at 448 K (175 °C) up to 15 h immediately following the solution treatment at 813 K for 8 h.

2.2. Microstructural Characterization and Hardness Testing

Specimens for microstructural observation were all firstly wet ground using silicon carbide papers, then mechanically polished and ultrasonically cleaned. Specimens for optical microscopy (OM) were etched using a solution of 1% hydrofluoric acid, 2.5% nitric acid, 1.5% hydrochloric acid and 95% distilled water. SEM observations including EDS and electron backscatter diffraction (EBSD) were performed on a Zeiss AURIGA instrument equipped with Oxford EDX and EBSD systems. Specimens for TEM and scanning transmission electron microscopy (STEM) were prepared by mechanical grinding and twinjet polishing using a solution of 30% nitric acid and 70% methanol at an applied voltage of 20 V and a temperature of 243 K. TEM bright-field (BF) and STEM high-angle angular dark-field (HAADF) imaging were performed using a JEM-ARM200F microscope equipped with advanced

Table 1
Chemical composition of the Al-Si-Mg-Cr alloy.

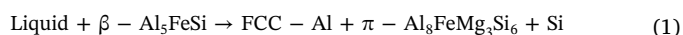
Chemical component (wt%)								
Si	Mg	Cr	Fe	Ti	Mn	Sr	Al	Ni, Sn, Pb, Cu, Zn
4.380	0.480	0.252	0.122	0.085	0.033	0.014	Bal.	< 0.010

Cs corrector and operated at 200 kV.

Hardness testing was conducted on polished specimens using a BUEHLER VH3300 hardness tester with a load of 200 g and loading time of 10s. The average hardness for each conditions were calculated from 8 to 10 measurements. For as-quenched samples, hardness tests were done on them within 10 h after quenching to avoid the interference of natural ageing.

3. Thermodynamic Simulations

Thermodynamic simulations have been proved to be effective in predicting and understanding microstructural evolution of alloys during solidification and heat treatments [14, 16]. In this study, thermodynamic simulations for the Al-4.5%Si-0.5%Mg-0.25%Cr-0.12%Fe system were carried out using PANDAT™ software with the PanAl2017 database. It should be noted that all the intermetallic compounds included in the database are considered as stoichiometric. Fig. 1a shows the comparison between Scheil and equilibrium solidification paths. The Scheil solidification modelling assumes that no diffusion occurs in the solid part while composition of liquid is completely uniform (infinite diffusivity in liquid) [17]. It has been widely applied to simulate as-cast microstructures for casting alloys which experienced non-equilibrium solidification [18]. One of the main differences between the Scheil and equilibrium solidification paths is that a quasi-peritectic reaction:



occurs at 832.8 K in the Scheil simulation and transfers the Fe in β -Al₅FeSi into π -Al₈FeMg₃Si₆. This reaction has been proposed within a similar temperature range by Wang et al. [19] and Backerud et al. [20] in their work on Al-Si-Mg alloys by gravity die casting. In a summary, intermetallics formed in the as-cast microstructures of Al-Si-Mg-Cr alloy are predicted to be π -Al₈FeMg₃Si₆, β -Al₅FeSi, Al₁₃Cr₄Si₄ and Mg₂Si. Analysis was mainly made on Fe- and/or Cr-bearing intermetallics.

The fractions of phases as a function of temperature under equilibrium conditions are shown in Fig. 1b. In contrast to Scheil simulation, equilibrium simulation can be applied for the prediction of heat-treated microstructures. To predict microstructural evolution during heat treatments, the total fractions of main intermetallic compounds after Scheil solidification are compared with those under equilibrium conditions at solution (813 K) and ageing (448 K) temperatures (Table 2). The equilibrium fraction of π phase at 813 K is zero, which implies that π phase formed during non-equilibrium solidification is unstable at 813 K and tend to be decomposed. In contrast, the fraction of β phase at 813 K under equilibrium conditions is comparable to that by Scheil simulation. Table 2 also shows that the fraction of Al₁₃Cr₄Si₄ phase at 813 K under equilibrium conditions is much larger than that by Scheil simulation. It indicates that a large amount of Al₁₃Cr₄Si₄ tend to form in microstructures during solution treatment. To understand this simulation result, Cr concentration in solidified α -Al as a function of temperature by Scheil simulation and equilibrium simulation have been plotted in Fig. 2. Since Scheil simulation assumes no diffusion in solid part during solidification, it predicts the Cr content that trapped in the α -Al solidified at a specific temperature during non-equilibrium solidification. Therefore, the plot based on Scheil simulation (Fig. 2a) indicates that the firstly solidified α -Al will be rich in Cr (~0.25%) while Cr concentration in the subsequently solidified α -Al will decrease gradually with decreasing temperatures. It will result in the segregation of Cr in dendrite cores, which can be explained by the peritectic nature of Al-Cr binary system. While the plot based on equilibrium simulation (Fig. 2b) reveals that the maximal solubility of Cr in Al matrix decreases drastically with decreasing temperatures. For instance, the solubility of Cr in Al matrix at 813 K is only ~0.04%. Based on the above analysis, the predicted increment in the fraction of Al₁₃Cr₄Si₄ at 813 K results from the supersaturation of Cr in the Al dendrites after non-equilibrium solidification. Although the equilibrium fraction of Al₁₃Cr₄Si₄ phase is

Download English Version:

<https://daneshyari.com/en/article/7969150>

Download Persian Version:

<https://daneshyari.com/article/7969150>

[Daneshyari.com](https://daneshyari.com)