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The effects of thermo-mechanical parameters on the microstructure of Thixocast A356 aluminum alloy

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Abstract

In general, semi solid Thixocast (A356) alloys are consisted of extensive globular α-Al regions, which are surrounded by eutectic (β) phase. The better formability, higher toughness and structure free porosities, gas cavities and shrinkages are the important advantages of this globular structure. In addition the thermo-mechanical processing is known as one of the most effective processing techniques to control the final mechanical properties. Accordingly, in present work the effects of strain rate and the deformation temperature on the microstructure (morphology of Si phase) of Thixocast aluminum (A356) alloy have been studied. In this regard, hot compression tests at 450, 500 and 540 °C with strain rate of 0.0001, 0.0005, 0.001 and 0.01 s^{-1} have been performed. The results showed an extensive change in the morphology of eutectic Si fibers through breaking and spheroidization processes.

Keywords: Thixocast A356; Thermo-mechanical processing; Spherodized Si; Spheroidization

1. Introduction

During last two decades different valuable research works have been conducted on semi-solid metal processing as a unique manufacturing method to form near net shape products for various applications in particular automotive and electronic industries [1]. In this way Reginaldo et al. [2] reported better properties in products made by Thixocasting process than that of made by permanent casting methods.

Al–Si and Al–Si–Mg alloys, due to their casting properties, have been used widely for Thixocasting processes. A356 and A357 are the most common alloys used to obtain near net shape products because of the related high volume of Al–Si eutectic which provides fluidity and good cast-ability [3–5]. The microstructure of semi-solid processed Al–Si alloys usually consists of an Al region (with α-Al globular structure) and eutectic region (with Al/Si eutectic phases) (Fig. 1). The eutectic region contains of Si, Mg_2Si as well as other possible inter-metallic particles embedded in Al. Due to the eutectic reaction principles, the Si particles appear in the form of coarse sharp fibers. As is well known the mechanical properties of any Al–Si alloys are controlled by the morphology and distribution of the eutectic Si fibers [6]. The brittleness of coarse Si fibers is the main reason for the poor mechanical properties such as tensile strength, ductility and impact strength [7]. On the other hand, the fine dispersed globular Si particles may result in excellent mechanical properties [8]. Therefore, to improve the mechanical properties of these alloys, modifying the morphology and distribution of silicon particles is necessitated. This may be addressed through chemical modification [9,10] or by the long-term solutionizing heat treatment [11,12]. As is well-established the Si particles may undergo significant changes in size and shape during solutionizing treatment. The coral like network of the Si phase is first fragmented and this is followed by coarsening of individual particles and their subsequent globulization with time. As Ogrish et al. reported all eutectic Si fibers in a Sr-modified alloy were globulized through 3 min holding at 540 °C [13,14]. The globular Si particles were coarsened by increasing the holding time (Fig. 2).

Cast A356 alloys are known as in situ metal matrix composites (MMC), with Si particles reinforcing the aluminum matrix. The deformation behavior of these alloys is also affected by the size, distribution and aspect ratio of Si particles by which the initiation and the evolution of damage to these particles are determined [15,16]. The Si particles are very brittle thereby cannot accommodate the plastic deformation of the surrounding matrix

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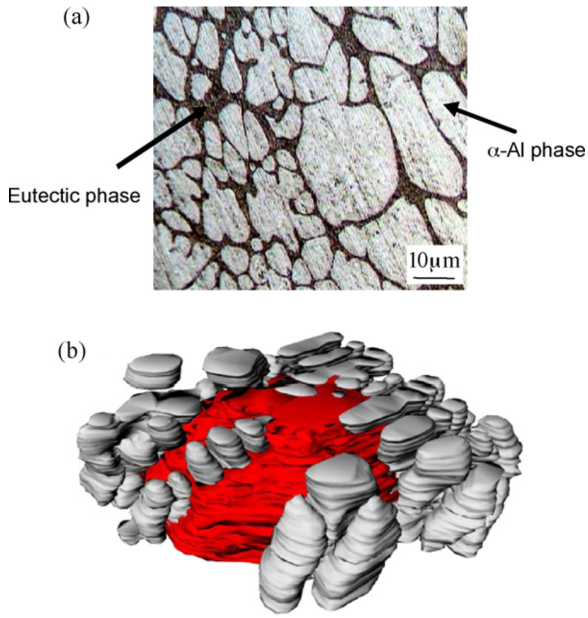

Fig. 1. The initial microstructure: (a) 2D and (b) 3D schematic [7].

due to the incompatibility stresses develop in both the particles and the matrix [17]. In other word, the region of interest in the deformation process of these alloys is the eutectic region.

Appreciating all the economic drawbacks of alloying and/or heat treatment methods, the possibility of applying any other technique to globulized Si fibers in aforementioned alloy is highly demanded. In this respect thermo-mechanical processing (TMP) as the most effective microstructural modification method may be considered to control the state of Si fibers (the shape and morphology). In addition thermo-mechanical processes are important methods which are used to improve the mechanical properties of MMCs and produce products having stable properties [19,20]. It is worth mentioning that the discontinuous reinforced Al alloys are more sensitive to TMP parameters such as temperature and strain rate than unreinforced alloys [18].

To reveal the effects of strain and strain rate on the macroscopic behavior of semi-solid aluminum alloys under compression forming in liquid–solid two-phase region are extensively studied by Kang et al. [21]. However, few investigations have been dealt with the effects of thermo-mechanical processing parameters in solid state region on the morphology of Si particles in Thixocast (A356) alloys [22–24]. In better word, few studies have been conducted on the compression behavior of discontinuously reinforced aluminum alloy, A356, at a high temperature range, which seems more important in application of high temperature plastic deformation. Consequently, the purpose of this study is to properly address the mechanism of Si fibers globulization through applying TMP, hot compression, in solid state region.

Table 1
The chemical composition of experimental alloy (in wt%)

Al	Si	Mg	Fe	Cu	Mn	Ti	Sr	Ni
Bal.	7.50	0.40	0.15	0.03	0.03	0.20	0.05	0.03

2. Experimental procedures

A semi solid aluminum casting alloy (A356 Al) has been examined in this research. The chemical composition of the experimental alloy has been mentioned in Table 1. The hot compression cylindrical specimens were machined in accordance with ASTM F136-84 standard (with height-to-diameter ratio of 1.5 and height of 11 mm). The schematic representation of the applied TMP cycle is shown in Fig. 3. This was carried out utilizing an INSTRON computerized universal testing machine (model 4208 with maximum load of 30 tonnes) equipped with a proper controllable furnace. The specimens were first coated with Teflon tape, heated to the experimental temperature (450, 500 and 540 °C), held for 10 min to homogenize the temperature. This was followed by straining the specimens at a given constant strain rate (0.0001, 0.0005, 0.001, 0.01 s^{-1}). Then, the samples were immediately water quenched to study the microstructural changes at a given thermo-mechanical condition. The specimens were sectioned parallel to deformation direction, grinded, polished and etched by Keller solution for further microstructural studies. The SEM and optical microcopies equipped with image analyzer were employed for microstructure examination.

The silicon particle characteristics were measured using a BUEHLER OMNIMET ENTERPRISE (861000) quantitative image analyzer. From these, the following parameters were determined:

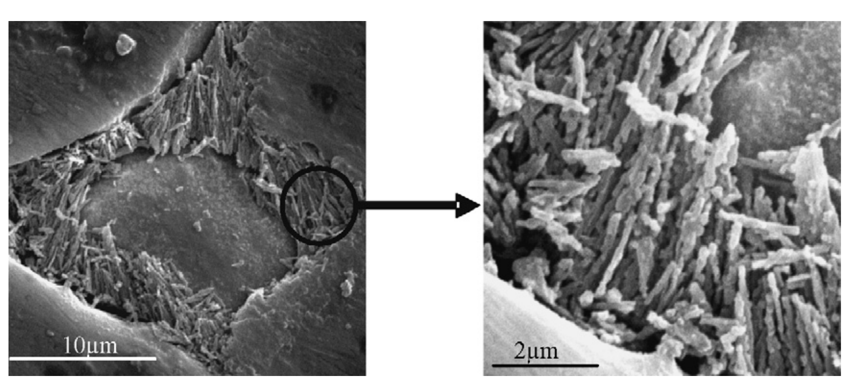

Fig. 2. The eutectic Si particles modified by Sr in an Al–Si alloy.