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Influence of Cu content on microstructure and mechanical properties of thixoformed Al−Si−Cu−Mg alloys

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Abstract: The effects of Cu content on the microstructure and mechanical properties of thixoformed Al−6Si−*x*Cu−0.3Mg (*x*= 3, 4, 5 and 6, mass fraction, %) alloys were studied. The samples were thixoformed at 50% liquid content and several of the samples were treated with the T6 heat treatment. The samples were then examined by optical microscopy (OM), scanning electron microscopy (SEM), energy dispersive X-ray (EDX) spectroscopy and X-ray diffraction (XRD) analysis, as well as hardness and tensile tests. The results show that the cooling slope casting and thixoforming process promote the formation of very fine and well distributed intermetallic compounds in the aluminium matrix and the mechanical properties of the alloys increase considerably compared with the permanent mould casting. The results also reveal that as the Cu content in the alloy increases, the hardness and tensile strength of the thixoformed alloys also increase. The ultimate tensile strength, yield strength and elongation to fracture of the thixoformed heat-treated Al−6Si−3Cu−0.3Mg alloy are 298 MPa, 201 MPa and 4.5%, respectively, whereas the values of the thixoformed heat-treated alloy with high Cu content (6%) are 361 MPa, 274 MPa and 1.1%, respectively. The fracture of the thixoformed Al−6Si−3Cu−0.3Mg alloy shows a dimple rupture, whereas in the alloy that contains the highest Cu content (6%), a cleavage fracture is observed.

Key words: Al−Si−Cu−Mg alloy; Cu content; thixoforming; T6 heat treatment; mechanical properties

1 Introduction

Thixoforming is a type of semisolid metal (SSM) processing for forming alloys in the semisolid state to near net-shaped products. Today, thixoforming has become one of the important processing techniques accepted by many manufacturers, replacing conventional casting and forging processing routes. In recent years, the need to produce a product, that is superior in mechanical properties to those using conventional casting (e.g, permanent mould casting), has drawn the attention toward SSM processing [1]. According to CAMACHO et al [2] and LIU et al [3], SSM processing for aluminium alloys is normally performed between the solidus and liquidus temperatures at 30% and 50% liquid content. For the alloy to be suitable for thixoforming, it must have a wide processing window and low sensitivity of the liquid fraction, as described by CHEN et al [4] and SALLEH et al [5]. In contrast, aluminium alloys that have a very high sensitivity to temperature are not suitable for thixoforming [6].

Some works had been performed to investigate the thixoformability of modified commercial alloys for SSM processing. LIU et al [3] had examined the thixoformability of Al−Si−Cu and Al−Si−Cu−Mg alloys using the MTDATA thermodynamic and phase equilibrium commercial software that was combined with the MTAL database. Three criteria for thixoformability were identified and a range of alloy compositions, based on Al−Si−Cu and Al−Si−Cu−Mg, were evaluated in relation to these criteria. It was observed that the addition of up to 10% Cu in the A356 aluminium alloy resulted in an enlarged working window, as well as reduced temperature sensitivity of the liquid fraction. WU et al [7] studied the effects of Cu content on microstructure and mechanical properties of cast Al−14.5Si−0.5Mg alloys. They observed that low Cu

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content (0.52%) alloy had higher ultimate tensile strength (UTS) and elongation than the high Cu (4.65%) content alloy. Nevertheless, the hardness of the low Cu alloy was lower than high Cu alloy with the values of HRB 68 and HRB 80, respectively. ZEREN et al [8] investigated the Cu addition on microstructure and hardness of near-eutectic Al−Si cast alloys. The hardness of the as-cast samples in T6 condition increased from HB 55 to HB 118, as the Cu content increased to a maximum of 5%.

According to RINCON et al [9], Al−Si−Cu−Mg aluminium alloy is commonly used in the automotive industry due to its excellent castability and corrosion resistance. This age-hardenable alloy has shown an increase in automotive uses within recent years, especially because there is a demand for lighter vehicles, as one of the important goals to improve fuel efficiency and reduce vehicle emissions, as explained by MAHMUDI et al [10]. Copper and magnesium are usually added to increase the mechanical properties of cast Al−Si alloy. During solidification, alloying elements and impurities partially form various constituent particles, including Al_2Cu, $Al_5Cu_2Mg_8Si_6$, Al_5FeSi, Mg_2Si and $Al_8Mg_3FeSi_6$ under different conditions, as discussed by CÁCERES et al [11] and IBRAHIM et al [12]. According to ALKAHTANI [13] and ELSEBAIE et al [14], T6 heat treatment was one of the main methods used to improve the mechanical properties of alloys that contain Cu and/or Mg elements. The effect of precipitation strengthening on the mechanical properties of these alloys is strongly dependent on the number of Cu and Mg solute atoms in the Al matrix [7].

Although the effects of Cu on the microstructure of conventional cast Al−Si−Cu−Mg alloys have been reported frequently in the literature, the work here is significant since there is yet rare report on the effects of Cu on the microstructure and mechanical properties of Al−Si−Cu−Mg subjected to thixoforming process. Therefore, in this work, an experimental work was performed to investigate the microstructural features and mechanical properties of thixoformed Al−6Si−Cu−0.3Mg alloy with different Cu contents (3%−6%). The alloys were produced using a cooling slope casting method, before they were thixoformed in a press. The effects of T6 heat treatment on the mechanical properties and fracture behaviour of the thixoformed alloys were then investigated.

2 Experimental

The Al−6Si−*x*Cu−0.3Mg (x=3, 4, 5 and 6, mass fraction, %) alloys used in this work were fabricated using a conventional casting process. The chemical compositions of the alloys were determined by X-ray fluorescence (XRF) technique, as depicted in Table 1. Differential scanning calorimetry (DSC) was performed primarily to estimate the liquidus temperature and liquid fraction profile within the semisolid range of the as-cast material. The alloys were cut into small pieces (less than 25 mg) for testing using a Netzsch-STA (TG-DSC) 449 F3 simultaneous thermogravimeter. The heating rate employed was 10 °C/min in nitrogen to prevent oxidation. The experimental flow process for this work is shown in Fig. 1. Determinations of the liquid fraction with temperature for the alloys were obtained from the heat flow versus temperature curves, as shown in Fig. 2.

The alloys were subjected to the cooling slope (CS) casting processing route to obtain the thixotropic behaviour of the feedstock for thixoforming. The cooling slope casting apparatus consists of resistance furnace, 90 mm wide incline plate and stainless steel mould. The parameters (i.e, pouring temperature of 630 °C and cooling length of 400 mm) used in this work were selected based on the previous investigation with A319 aluminium alloy [15]. 1 kg of each of the respective alloys (refer to Table 1) were melted and superheated using a resistance furnace to 700 °C in an argon atmosphere and then brought down to the selected pouring temperature (630 °C) before being poured onto the surface of the plate. The tilt angle of 60° of the slope plate was selected with respect to the horizontal plane and was additionally water-cooled to increase the nucleation rate of the solid particles, to produce a globular microstructure. Its surface was coated with a thin layer of boron nitride in order to reduce sticking of the molten alloy. Subsequently, the semisolid melt was collected in a 160 °C preheated cylindrical stainless steel mould, before it was cooled down to room temperature.

A high frequency induction coil (80 kHz, 35 kW) was used to heat the cooling slope cast ingots to the semisolid temperature range as listed in Table 2. These

Table 1 Chemical compositions of studied alloys (mass fraction, %)

Alloy	Si	Cu	Mg	Mn	Zn	Ni	Fe	Cr	Ti	Al
Al−6Si−3Cu−0.3Mg	6.26	2.91	0.30	0.10	0.71	0.06	0.23	0.03	0.03	Bal.
Al−6Si−4Cu−0.3Mg	6.24	3.89	0.27	0.10	0.66	0.03	0.18	0.03	0.05	Bal.
Al−6Si−5Cu−0.3Mg	6.21	5.03	0.24	0.11	0.68	0.09	0.21	0.01	0.03	Bal.
Al−6Si−6Cu−0.3Mg	6.20	5.91	0.21	0.10	0.51	0.05	0.22	0.01	0.07	Bal.