Materials Characterization 118 (2016) 252–262

Contents lists available at ScienceDirect

Materials Characterization

journal homepage: www.elsevier.com/locate/matchar

ECAP: An alternative route for producing AlSiCu for use in SSM processing

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ARTICLE INFO

Article history:
Received 3 March 2016
Received in revised form 30 May 2016
Accepted 2 June 2016
Available online 3 June 2016

Keywords:
Thixoforming
Equal channel angular pressing (ECAP)
Al–Cu–Si alloy
Microstructure
Semisolid material

ABSTRACT

In thixoforming processes control of the solid-to-liquid transition and grain size of the mush metal is essential. If eutectic melting is avoided, subsequent melting of the primary phase should be controllable. To achieve this, the sensitivity of the liquid fraction, df_L/dT, at the desired liquid fraction, f_L, exclusively for the primary phase should be as low as possible ($<0.03\ ^{\circ}C^{-1}$). In addition, the smaller the grain size, the better the rheological behaviour. However, for aluminium alloys with a high silicon content, current commercial processes such as continuous casting result in materials with a large grain size. This paper therefore proposes a new method based on equal channel angular pressing (ECAP) for producing aluminium-copper alloys with a low silicon content. The alloys investigated were Al5Si2.8Cu, Al6Si2.8Cu and Al7Si2.8Cu. To evaluate the semisolid behaviour of these alloys after ECAP processing as well as the effect of heat treatment on globularization of the alloys, they were heated up to 590, 580 and 575 °C, respectively, to achieve a solid fraction of 40% and subsequently soaked for 0, 30, 90 and 210 s and cooled rapidly. The structures of the three alloys had an excellent response to the recovery and recrystallization mechanisms, and refined microstructures ideal for thixoforming were produced. Grain and globule sizes of less than 80 μm and a circularity shape factor of more than 0.60 were obtained. All the alloys exhibited good morphological stability in the semisolid state without significant changes in size or shape, indicating homogeneous apparent viscosity and, consequently, homogeneous die filling. The findings of this study suggest that ECAP is a promising route for the production of semisolid raw material for use in thixoforming.

1. Introduction

Semisolid materials (SSM) processing, such as thixoforming, involves the forming of metallic materials in the semisolid temperature range [1,2]. Although the behaviour of semisolid materials has been well understood since 1976, there are few raw-material suppliers and few suitable alloys [3,4]. The design of appropriate raw materials usually involves three main steps: a) thermodynamic evaluation of the solid-to-liquid transition to determine whether a particular alloy can be used as raw material for SSM processing; b) evaluation of the morphology, size and distribution of the remaining solid at the semisolid temperature; and c) evaluation of the effect of both these factors on the rheological behaviour of the mush metal. Only then can the final mechanical properties of the thixoformed part be determined [5].

Aluminium-silicon alloys A356 and A357 are the most commonly used materials in SSM processing, but A355 and A319, which contain 1 to 1.5 wt% Cu and 3 to 4 wt% Cu, respectively, are also recommended because of the improved mechanical properties after T5 and T6 heat treatment that their higher copper content confers. T5-heat-treated A356 and A357 have yield strengths of 180 and 200 MPa, respectively, while the corresponding figure for T5-heat-treated A355 is 230 MPa and for T6-heat-treated A319S (which has a lower iron and higher magnesium content) the impressive value of 320 MPa [4]. A recent paper [6] reported a thermodynamic assessment of the thixoformability of conventional A319 using the commonly accepted criteria proposed by Liu and Atkinson in 2005 [7], who investigated the mechanical properties of conventional T6-heat-treated A319, which had a yield strength of 200 MPa following heat treatment [8]. Although aluminium–silicon alloys potentially have good properties, their corrosion resistance decreases as their copper content increases, and a maximum copper content of 3 wt% Cu has been suggested [9]. When designing alloys it is essential to consider the expected final mechanical properties as well as the use to which the alloy will be put.

This paper analyses the thixoformability of AlSiCu alloys produced from traditional A319 and focuses on the first two steps in the design of raw materials for SSM processing mentioned at the beginning of

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http://dx.doi.org/10.1016/j.matchar.2016.06.002
1044-5803/

Table 1
Chemical composition of all the alloys tested (in wt%).

Alloy	Si	Cu	Fe	Mg	Mn	Ni	Cr	Ti	Al
Al5Si2·8Cu	4.94	2.91	0.58	0.18	0.09	0.01	0.01	0.07	Bal.
Al6Si2·8Cu[a]	6.04	2.70	0.33	0.21	0.10	0.01	0.01	0.08	Bal.
Al7Si2·8Cu	7.13	2.85	1.05	0.26	0.13	0.01	0.01	0.09	Bal.

[a] Chemical composition close to that of A319 [4].

this section. To study the semisolid thermodynamic transition of Al–5.0 wt% Si–2.8 wt% Cu, Al–6.0 wt% Si–2.8 wt% Cu (close to A319) and Al–7.0 wt% Si–2.8 wt% Cu (referred to in the rest of this paper as Al5Si2.8Cu, Al6Si2.8Cu and Al7Si2.8Cu), CALPHAD simulation software was used with the following simplification of the Liu and Atkinson criteria [7]: "the sensitivity of the liquid fraction, df_L/dT, at the desired liquid fraction, f_L, exclusively for the primary phase must be as low as possible". Thixoforming must be avoided at temperatures at which the secondary, eutectic, phase undergoes transformation, as this transformation is more complex and less stable than the corresponding one for the primary phase [10]. To ensure the raw material had a small grain size (GS), equal channel angular pressing (ECAP) was selected as the production route. With traditional grain-refining methods, such as the use of Al–Ti–B master alloys, the effect of the grain refiner is limited because of the high silicon content [11]. Controlling GS is essential in SSM processing as the smaller the GS, the better the rheological behaviour during processing [1,2].

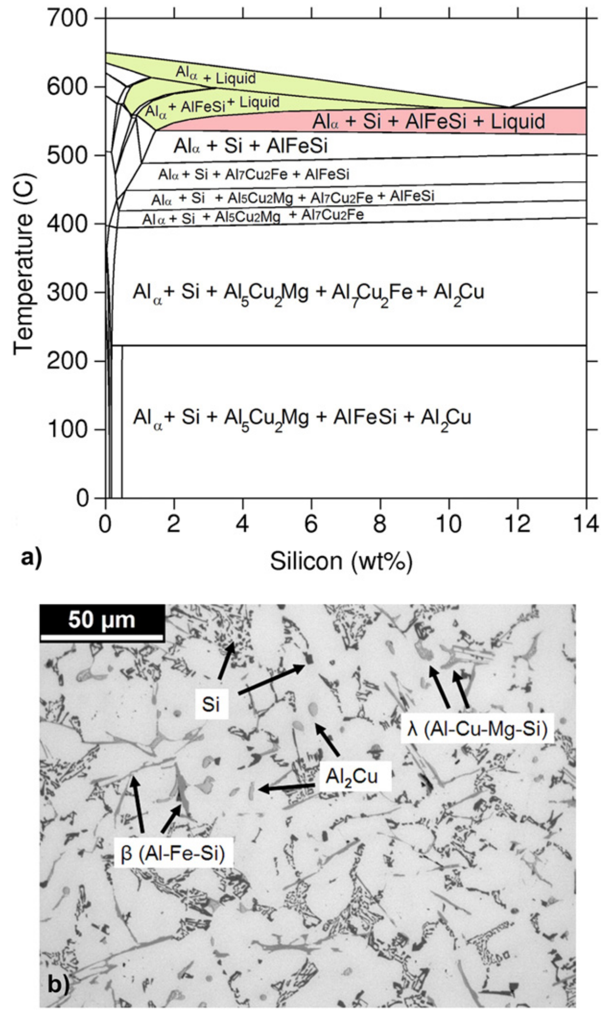

Fig. 2. (a) Expected phase diagram for the AlSiCu alloys taking into account the copper, iron and magnesium content. The region suitable for thixoforming is highlighted in light green, while the temperatures to be avoided are shown in light red; (b) micrograph of Al7Si2·8Cu showing the characteristic microprecipitates.

2. Experimental procedure

The three alloys in the study, Al5Si2.8Cu, Al6Si2.8Cu and Al7Si2.8Cu, were produced using a mix of base alloys, including A356, commercially pure aluminium (Al-CP) and commercially pure copper (Cu-CP). Ingots were prepared using standard stoichiometric ratios. The A356 alloy was heated to 750 °C in a SiC crucible in an electric furnace, and the Al-CP and Cu-CP were added and mixed properly. The mixture was held at 750 °C for about 10 min and stirred periodically to ensure that it dissolved and homogenized. Then each molten alloy was poured at a temperature about 50 °C above its expected melting temperature into a copper refrigerated mould to produce 30 mm-diameter 220 mm-long ingots [12]. The chemical composition of the ingots produced was analysed in an optical emission spectrometer, as shown in Table 1, and the data thus obtained were used in the thermodynamic evaluation of the solid-to-liquid transition in Thermo-Calc®.

Ingots 30 mm in diameter and 150 mm long of all the compositions tested were processed by ECAP in a special H13 die. The die set-up, which is shown in Fig. 1a, consists of a 30 mm diameter punch (1), the ECAP die (2), a die brace (reinforcement) with a heating system (3) and the alignment and support device (4). Fig. 1b shows the schematic details of the ECAP die, which has a 120° outer angle, and Fig. 1c shows the electric element, which is used with a temperature controller (not shown) to allow warm extrusion so that the material can pass under the imposed load conditions. The outlet channel has a diameter slightly larger than the inlet to reduce friction and, consequently, the

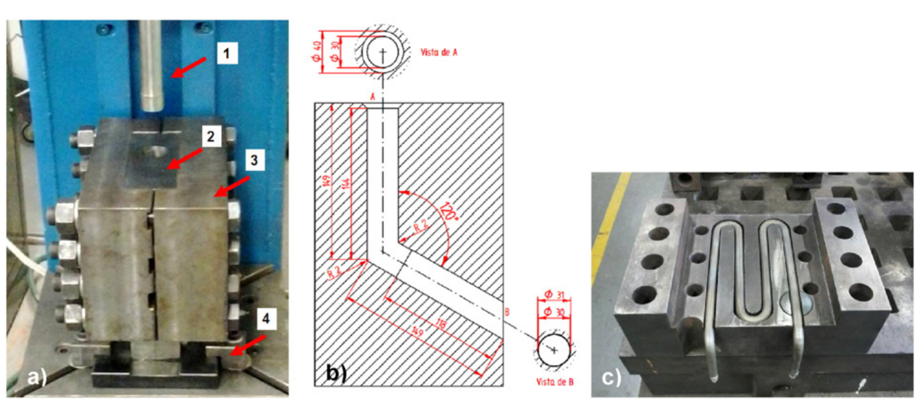

Fig. 1. (a) The ECAP set-up, consisting of (1) a 30 mm-diameter punch, (2) the ECAP die, (3) a die brace (reinforcement) with a heating system and (4) the alignment and support device; (b) schematic details of the ECAP die; (c) electric element with a temperature controller (not shown) for warm extrusion.