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Microstructural coarsening of 7005 aluminum alloy semisolid billets with high solid fraction

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ABSTRACT

In the present study, 7005 aluminum alloy billets were supplied in the warm extruded and T6 heat treated state. They were then reheated to the semisolid state and the microstructural evolution and coarsening investigated. This is necessary groundwork if the billets are to be formed to shape by semisolid processing, an innovative manufacturing route which has recently gained wide use for a range of aluminum alloys but which has not yet been applied to 7005. The results showed that the average spheroid size, liquid film thickness and liquid fraction of 7005 aluminum alloy increased with increase in soaking time. Intragranular liquid droplets were present in solid grains, and coarsened with increase in soaking time and isothermal temperature. The roundness of globules of solid in the semisolid state at 600 °C–615 °C was in the range of 1.5 to 2.0 after soaking for periods up to 12 min at 620 °C, but for times greater than 15 min was more than 2, which is unlikely to be suitable for the semi-solid forming process, where smooth flow is required and therefore relatively round globules. When the isothermal temperatures were 600 °C, 610 °C, 615 °C and 620 °C, the coarsening rates were 542 $\mu m^3\ s^{-1}$, 606 $\mu m^3\ s^{-1}$, 683 $\mu m^3\ s^{-1}$ and 688 $\mu m^3\ s^{-1}$, respectively. The coarsening rate *K* increased with the increase of isothermal temperature. These values place this alloy on the dividing line between typical coarsening rates for normally cast alloys and typical coarsening rates for normally wrought alloys. This is attributed to the fact that the alloy has a relatively simple precipitation hardening system in comparison with other 7xxx alloys and the hardening precipitate ($MgZn_2$) melts below the temperature the experiments have been carried out at, hence preventing the precipitates inhibiting liquid film migration and diffusion along narrow liquid films at spheroid boundaries. Coarsening tends to occur via Ostwald ripening and coalescence, but Ostwald ripening plays an increasing role with the increase of isothermal temperature.

1. Introduction

Semisolid processing (SSP), developed at MIT during the 1970s, is a near-net-shape forming technology for metals, alloys and composites [1–3]. The semisolid billet with a suitable spheroidal microstructure for thixotropic behavior is formed to near-net-shape components at temperatures between the solidus and the liquidus. The components produced by SSP have higher mechanical properties and reduced casting defects such as porosity in comparison to conventional casting. The near-net-shape production of complex parts can be achieved with lower pressure in SSP than with conventional forging. Therefore, SSP has received considerable attention in recent years [4–7].

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Thixoforming, as a typical technological route of SSP, involves three procedures, fabricating semisolid billet, reheating (remelting) and forming. To behave thixotropically in the semisolid state, the microstructure must be non-dendritic. The required spheroidal microstructure can be produced by either a liquid state route or a solid state route [8]. Liquid routes include those in which liquid metal is cooled down to a semisolid temperature and stirred with a mechanical stirrer [e.g. 9,10] and those based on electromagnetic stirring with the Lorentz force created by a changing magnetic field [e.g. 11,12]. Solid state routes generally involve thermomechanical processes. The two main solid state routes are strain induced melt activation (SIMA) processing [13–15], and recrystallization and partial remelting (RAP) processing [16]. SIMA involves the hot deformation of the starting material, i.e. the starting material is deformed above the recrystallization temperature. It is then cold deformed before reheating. RAP is based on the process of warm deformation of the starting material below the recrystallization temperature and no subsequent cold deformation step is required before reheating. It is often quite difficult to identify whether it is the SIMA route or the RAP route which is being utilized because this depends on examining the microstructure before it is reheated and checking whether it is in a state of cold deformation after hot extrusion or in the warm deformed state (in both cases the grains are likely to be elongated). The crucial test is whether there is sub-grain structure within the elongated grains. If sub-grains exist the route is likely to be SIMA. If the elongated grains appear relatively featureless in terms of sub-grain structure and there are contrast variations within the grains, indicating strain, the route is likely to be RAP (e.g. [17]).

The advantages of the SIMA and RAP processes are that some normally wrought aluminum alloys are supplied in the deformed state in any case (e.g. by extrusion) and the spheroids are more fully rounded than those from electromagnetic stirring e.g. by the magnetohydrodynamic stirring (MHD) route [8]. Atkinson and Liu [18] compared coarsening rates in the semisolid state across a range of aluminum alloys, including both cast compositions and those compositions which are normally wrought. They found rates which were significantly lower for wrought compositions (including 7034 and 7075) and concluded that this was likely to be due to precipitating phases, or dispersoids which are resistant to dissolution, which are pinning the liquid boundary migration.

Wrought aluminum alloys of the 7xxx series are widely used in industry due to their higher mechanical properties compared with other aluminum alloys. 7005 has a composition based on Al, Zn, Mg, Mn and Si, and $MgZn_2$ is the strengthening precipitate. It is used extensively for bicycle components. In comparison with 7xxx alloys such as 7075 it is less resistant to recrystallization because the precipitate structure is less complex [17]. Semisolid processing is a potential near-net-shape technology for forming 7005 aluminum alloy but there has been little work reported in the literature to date. The present work is aiming to examine microstructural coarsening in the semisolid state in billet of 7005 aluminum alloy supplied in the extruded and T6 heat treated condition. This is necessary groundwork for semisolid processing given that the size of the spheroids in the formed component has a strong influence on the mechanical properties of the component produced and their shape (in terms of the degree of roundness) affects the smoothness of flow into the die.

2. Experimental Procedure

The 7005 aluminum alloy was supplied in the extruded and T6 heat treated state by Guangdong Jialong Metal Materials Co. Ltd of China. The extrusion was carried out between 300 and 400 °C i.e. at temperatures likely to be below or around the recrystallization temperature. The subsequent T6 heat treatment may also have taken the material into the recrystallizing regime. The chemical composition was analyzed with an Axios pw4400 X-ray fluorescence spectrometer and found to be 5.1 wt.% Zn, 1.1 wt.% Mg, 0.49 wt.% Mn, 0.34 wt.% Si, 0.31 wt.% Fe, 0.1 wt.% Cr, and 0.04 wt.% Ti. The extrusion ratio was 16:1. The as-received billets were machined into cylindrical samples with diameter of 10 mm and height of 10 mm. A "Mettler TGA/SDTA851e" Differential Thermal Analyzer (DTA) was employed to determine the solidus and liquidus temperatures. The samples were heated to 710 °C at 10 °C/min and cooled to room temperature at the same rate. Fig. 1(a) shows the differential scanning calorimetry (DSC) curve. As indicated in Fig. 1(a), the solidus and liquidus temperatures were 588 °C and 647 °C, respectively. The solid fraction versus temperature curve was obtained by integrating under the DSC curve (Fig. 1(b)). When the temperature was below 620 °C, the solid fraction decreased slowly, but faster with further increase of temperature. For temperatures of 600 °C, 610 °C, 615 °C and 620 °C, the corresponding solid fractions were 0.9,

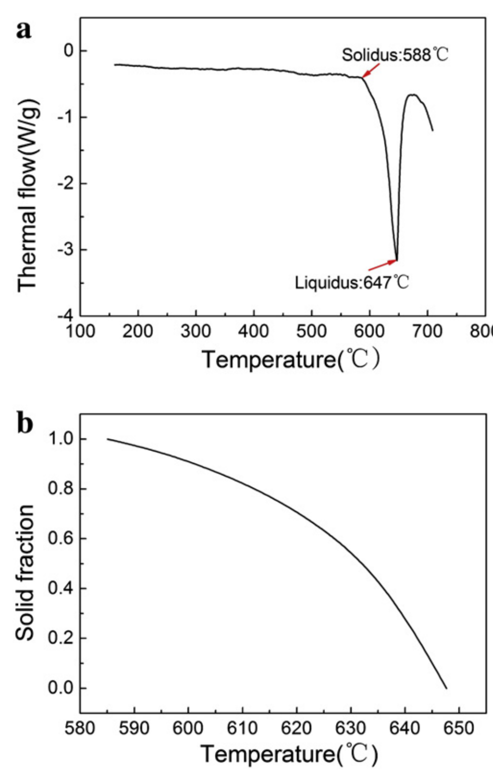

Fig. 1 – (a) DSC curve (10 °C/min) of the as-extruded 7005 aluminum alloy and (b) solid fraction versus temperature derived from the DSC curve.