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Effects of processing parameters on aluminium–lithium ribbon production

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Abstract

Binary Al–Li alloys containing up to 10 wt.% (approximately 30 at.%) lithium were prepared as ribbons by free chill-block melt spinning using a specially constructed apparatus. The change in ribbon morphology and topography as a function of lithium addition, purity of the protective atmosphere and wheel speed was studied by image analysis, scanning electron microscopy, optical microscopy and X-ray diffraction.

The preparation atmosphere has a marked effect on the wetting of the liquid Al–Li alloy on the chilled casting wheel. The formation of Li_2O and Li_2CO_3 affects the ribbon morphology. The addition of lithium increases the reactivity of Al–Li liquid and results in a change in ribbon topography. A relationship between the ribbon thickness and wheel speed was established. As expected, an increasing wheel velocity decreases the ribbon thickness.

1. Introduction

Aluminium–lithium alloys are light and desirable for aeronautical applications. However, because of processing problems using conventional techniques [1], these alloys have low ductility and fracture resistance.

The production of Al–Li alloys by rapid solidification can solve some of these problems [2, 3]. There are two commercially viable techniques for rapid solidification, atomization and melt spinning. The processing conditions used in these techniques affect the solidification process as well as the morphology and topography of the as-cast products.

In this paper we present some results from a study of the effects of processing parameters, such as purity of the protective atmosphere, lithium addition and wheel velocity, on the topography and morphology of Al–Li ribbons produced by melt spinning. This study may help to control the microstructure of rapidly solidified Al–Li alloys.

2. Experimental procedures

2.1. Ribbon production

In order to control the production conditions of Al–Li ribbons we constructed a special chill-block melt spinning apparatus. The apparatus provides an inert atmosphere for the alloying of pure aluminium with lithium.

Ribbons of binary Al–Li alloys containing up to 10 wt.% (approximately 30 at.%) lithium and weighing about 3 g were prepared from pure aluminium (99.999 wt.%) and pure lithium (99.9 wt.%). The apparatus as well as details of ribbon production are described elsewhere [4].

Three wheel surface velocities 12.5, 22.2 and 35.7 m s^{-1} were tested for ribbons containing 1.6 and 3.2 wt.% lithium. Prior to each experiment, the casting copper wheel surface was polished using SiC paper, grade 600, and cleaned with acetone. The purity of the protective helium atmosphere was varied as shown in Table 1.

2.2. Ribbon characterization

Pieces were cut at different locations from each as-cast ribbon. They were examined by image analysis (Kontron IBAS) or a travelling optical microscope to determine the width and the transverse section of the ribbon and to deduce its average thickness.

Changes in the topography of ribbons were monitored using JEOL 840 and 820 scanning electron microscopes (SEM). Observations were performed on the two side surfaces (the wheel side surface and the atmosphere side surface) of as-cast ribbons.

Phase analysis was done by X-ray diffraction using a Philips PW 1130 diffractometer.

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TABLE 1. Conditions of helium atmosphere preparation

Chamber vacuum (Pa)	Flushing number	Atmosphere quality
132	1	Impure (IM)
66	2	Intermediate (IN)
42–26	3	Pure (PU)

3. Results

The measured thickness t of the ribbons was normalized by the experimental flow rate Q_E to eliminate the influence of small variations in flow. The quality of the atmosphere and lithium additions affected the ribbon thickness as shown in Fig. 1.

The thickness of the ribbons, cast under pure helium atmosphere, did not depend on lithium additions. The average thickness was approximately 50 μm. However, when the protective helium atmosphere was contaminated by air, lithium additions led to a change in ribbon thickness. The ribbons were thicker when the helium atmosphere was contaminated. Their thickness increased at the expense of their width (Fig. 1).

SEM examinations of the surfaces of as-melt-spun ribbons prepared in a helium contaminated atmosphere, showed that the free side surfaces were extensively contaminated. A typical microstructure is shown

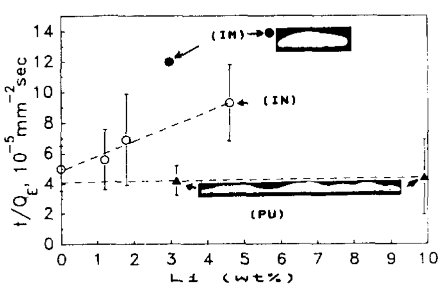

Fig. 1. Effects of lithium additions and atmospheric quality on the Al–Li ribbon thickness.

in Fig. 2(a). The wheel side surfaces of these ribbons presented features which look like craters (Fig. 2(b)).

Debris from contaminated and 9.91 wt.% lithium ribbons was stuck to the wheel surface.

In addition to wheel impressions, the wheel side surfaces of the ribbons exhibited depressions due to gas pockets (Fig. 3(a), (b)). Up to 1.79 wt.% lithium, the gas pockets were distributed heterogeneously (Fig. 3(a)). However, as the lithium content increased above 1.79 wt.%, the gas pockets formed channels in the direction of casting, represented by an arrow in Fig. 3(b).

X-ray diffraction analysis of the free surface layers of ribbons prepared in the most contaminated helium atmosphere showed that Li_2CO_3 is the only contaminant. However, ribbons cast under pure and intermediate helium atmospheres only contained the usual phases of the lithium-richer region of the Al–Li phase diagram [5].

The thickness of the ribbon decreased as the wheel velocity increased (Fig. 4). The established straight line was obtained by linear regression.

4. Discussion

When the melt leaves the orifice of the crucible it reaches the wheel casting surface in a few milliseconds. Thus, internal contamination of the jet could not occur. However, when the liquid impinges on the wheel casting surface it forms a puddle and the melt is subjected to reactions with the atmospheric impurities because of the large surface tension of lithium and the exposed melt surface. In addition, Al–Li alloys are sensitive to oxygen impurities in the protective atmosphere. They also have a great chemical affinity to air constituents such as N_2, CO_2, H_2O etc. [6]. The formation of a layer of contaminants around the puddle prevents wetting of the chilled block by the liquid.

Any change which occurs in the melt puddle affects the thickness as well as the width of the ribbon. The effect of atmospheric quality on the melt puddle and

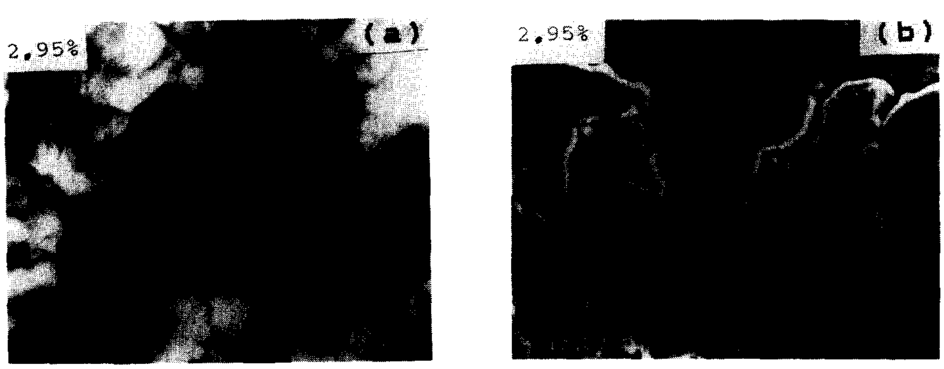

Fig. 2. SEM images of 2.95 wt.% lithium ribbon: (a) free side surface; (b) wheel side surface.

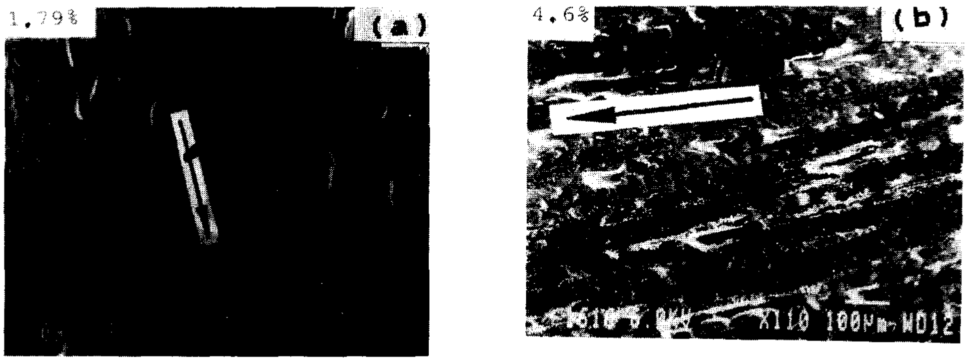

Fig. 3. Wheel side surfaces of (a) 1.79 wt.% lithium ribbon and (b) 4.6 wt.% lithium ribbon.

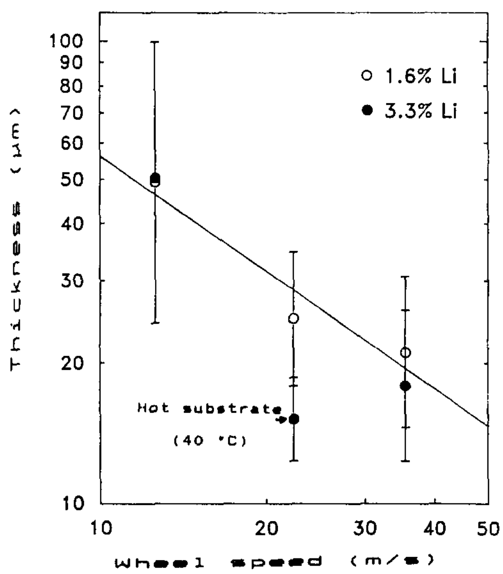

Fig. 4. Effect of wheel velocity on the ribbon thickness.

ribbon dimensions was studied from cross-sections of ribbons.

Examination of ribbon cross-sections showed that the wetting angle of the liquid on the wheel surface changes with atmospheric quality. The wetting is better when the helium atmosphere is relatively pure (Fig. 5(a), (b)). X-ray diffraction analysis was used to determine the type of contaminant which prevented wetting of the casting surface. It showed the existence of Li_2CO_3 which may be formed via the reaction [6]:

$$Li_2O + CO_2 \longrightarrow Li_2CO_3 \quad (1)$$

It is worth mentioning that Li_2O was not detected. In spite of the fact that the carbonate cannot be formed from the reaction of Al–Li liquid with the graphite crucible, as reported by Field and Butler [6], and according to reaction (1), Li_2O disappears as a result of reaction with CO_2 gas present in the contaminated atmosphere. This transformation process can occur even when the ribbon is ejected from the wheel casting surface because of the high temperature of the ribbon. The amount of eventual remaining Li_2O is below the detection threshold of X-ray diffraction.

Under the most contaminated helium atmosphere, the impurities adsorbed on the wheel surface or present in the gas layer boundary, rotating with the wheel, react with the melt to form Li_2O and Li_2CO_3. Because these compounds are friable, they stick to the wheel surface, leading to the formation of craters on the surface of contaminated ribbons.

The surface state of the casting wheel and the nature of the protective atmosphere are the parameters which most affect the wheel side surface of ribbons. The change in wheel side surface topography with increasing lithium content is due to the increase in Al–Li reactivity and the formation of contaminated zones near the orifice. These zones induce depressed regions at the back of the melt puddle which constitute permanent preferential sites for trapping the gas layer boundary rotating with the wheel.

The established relationship between the ribbon thickness and the wheel speed is

$$t = 575 V_s^{-0.9} \quad (2)$$

This empirical relationship is independent of lithium concentration and also of the solidification process. Although the slope of the straight line $\log t = f(\log V_s)$

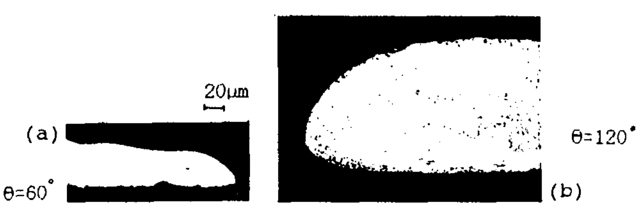

Fig. 5. Wetting angles of Al–Li alloy containing 3.14 wt.% lithium: (a) pure atmosphere; (b) contaminated atmosphere.

has a value of −0.9, which is common for amorphous rapidly solidified alloys [7], the Al–Li alloys solidify in a crystalline structure.

5. Conclusions

The purity of the protective helium atmosphere has a marked effect on the wetting of the chilled wheel by the liquid Al–Li alloy. The formation of Li_2O and Li_2CO_3 around the melt puddle influences the ribbon morphology.

The increase in lithium content induces the formation of contaminants at the crucible orifice level. These affect the wheel side surface of ribbons by creating depressed zones at the melt puddle.

The relationship between the wheel velocity and the ribbon thickness is independent of lithium concentration and does not give any information on the solidification process of Al–Li alloys.

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