Microstructure of Al–Mn–Be melt-spun ribbons

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ABSTRACT

Microstructures of two alloys with the nominal compositions of $Al_{92}Mn_3Be_5$ and $Al_{89}Mn_6Be_5$ were characterized in the initial as-cast condition (after vacuum induction melting and casting) and after melt spinning. In the initial conditions, both alloys consisted of an aluminum-rich solid solution and two metastable intermetallic phases: Be_4AlMn and $Al_{10}Mn_3$(Be). Both alloys melted over a rather large temperature range (between 230 °C and 310 °C). This was the main reason for the presence of unmelted particles in the melt-spun ribbons. Nonetheless, with the use of optimized melt-spinning parameters a microstructure composed of the Al-rich solid solution and finely dispersed quasicrystalline particles in ribbons with thicknesses ranging from 30–200 μm was achieved. The dispersion of quasicrystalline particles was finest on the wheel side of the thinnest ribbons, attaining microhardness values between 250 HV and 300 HV.

1. Introduction

Quasicrystals represent an additional state of matter, between the crystalline and glassy states. The positions of atoms are ordered, but with non-crystallographic rotational symmetry and without three-dimensional periodicity [1]. They were discovered in melt spun $Al_{86}Mn_{14}$ alloy in 1984 [2]. Since that time, dozens of others have been found [3,4], and some of them have already found application [5].

One of the very interesting potential applications is the use of quasicrystals as a strengthening phase in lightweight aluminum alloys. As early as 1992 Inoue [6] reported on Al–Mn–Ce melt-spun ribbons attaining tensile strengths above 1 GPa. These alloys were characterized by a microstructure consisting of a fine dispersion of spherical quasicrystalline particles in an Al-rich solid solution matrix. This concept was then further extended into many different alloy systems [7] and confirmed also by other researchers [8].

It has recently been discovered that Be strongly enhances the quasicrystal forming ability in the Al–Mn system [9]. Be additions shift the minimum amount of Mn for the formation of quasicrystals by melt-spinning to as little as 2.5 at.% Mn, in contrast to 6 at.% Mn in the Al–Mn system alone. In addition, Be additions also lowered the critical cooling rate for the formation of quasicrystals; quasicrystals were present in the microstructure of conventionally cast Al–Mn–Be alloys (mould casting, injection molding). However, in these alloys a hexagonal approximant phase was also present in the Al-rich solid solution, in addition to the quasicrystalline particles [10].

In the above mentioned literature only limited information exists regarding the microstructure of melt-spun Al–Mn–Be

Table 1 – Chemical compositions of investigated alloys (ICP-AES)

Alloy	Al		Mn		Be	
	wt.%	at.%	wt.%	at.%	wt.%	at.%
$Al_{92}Mn_3Be_5$	92.5	92.5	6.0	3.0	1.5	4.5
$Al_{89}Mn_6Be_5$	86.9	88.6	11.1	5.6	1.9	5.8

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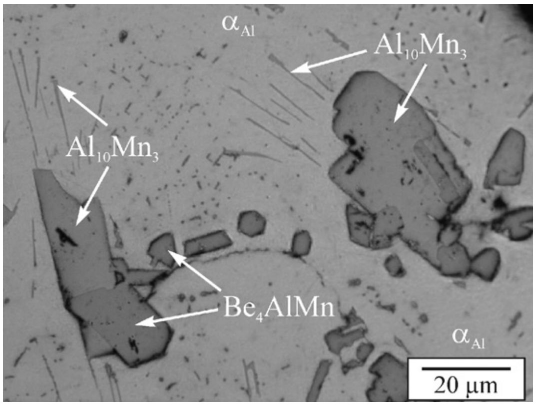

Fig. 1 – Microstructure of alloy $Al_{92}Mn_3Be_5$ after vacuum induction melting and casting. (LM).

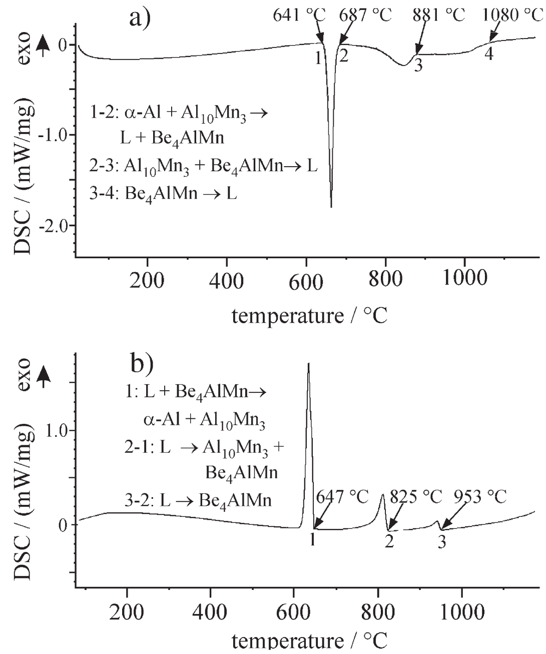

Fig. 3 – DSC traces of alloy $Al_{89}Mn_6Be_5$ a) heating, b) cooling. Heating and cooling rates were 10 °C/min.

alloys, and there is little information about the influence of casting conditions during melt spinning on the microstructural evolution and the distribution of quasicrystalline particles in the melt-spun ribbons. Therefore, it was our main goal to examine this relationship. In addition, we wanted to determine whether additional phases formed in thicker melt-spun ribbons, and to determine the influence of the size and distribution of quasicrystalline, and possibly other, phases on mechanical properties, especially hardness.

2. Experimental

For the investigation, two Al–Mn–Be alloys were selected having approximately the same Be content (~5 at.% Be), but different Mn content. The content of Mn in the first alloy ($Al_{92}Mn_3Be_5$) was close to the lowest limit of the quasicrystalline formation range (around 3 at.% Mn), but in the second it was approximately twice as high, in order to appropriately increase the fraction of the quasicrystalline phase (Table 1).

For the preparation of the alloys, pure Al (99.99 wt.% Al) and two master alloys Al–Mn (30 wt.% Mn) and Al–Be (5.5 wt.% Be) were used. The alloys were vacuum induction melted (VIM) at $\approx 10^{-2}$ mbar. The melt was homogenized at ≈1100 °C, and then cast from 1000 °C into 50-mm diameter cylindrical copper molds. The rods were sectioned to appropriate lengths to fit into the crucible of a melt spinner.

The melt spinning experiments were carried out in a Melt Spinner 30 M, Marko Materials Inc, North Billerica, MA, USA. The graphite crucibles were protected with BN on their inner surfaces to avoid contamination of the melt. Some crucibles had orifices with 1.8 mm diameter, while others had orifices of 1.0 mm diameter. The crucible had a cover, and the space above the melt was filled with Ar (flow rate approximately 4 l/min) to obtain an overpressure in relation to the pressure of the chamber, where nitrogen was used as a protective gas (flow rate approximately 25 l/min). The specimens were inductively melted. As the melt viscosity fell below a critical level, the melt started to flow through the orifice onto a copper wheel where it solidified. The casting speed varied between 19.6 and 25.2 m/s.

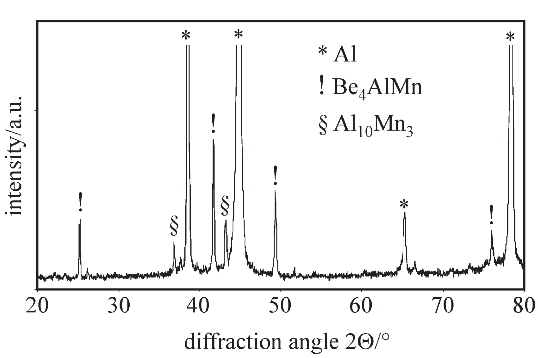

Fig. 2 – Diffractogram of alloy $Al_{92}Mn_3Be_5$ after vacuum induction melting and casting.

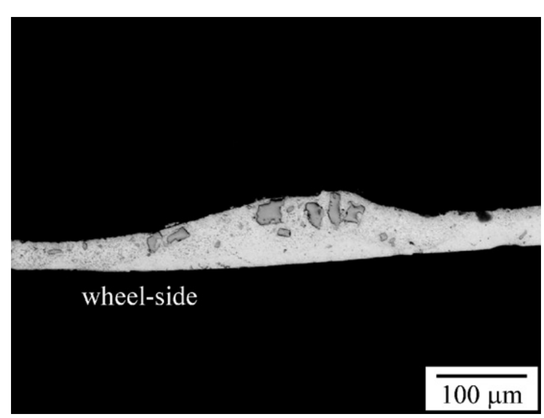

Fig. 4 – Microstructure of a melt-spun ribbon (orifice diameter 1.8 mm) with numerous unmelted particles. (LM, alloy $Al_{92}Mn_3Be_5$).