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Thermal evolution of nanoquasicrystalline $Al_{93}Fe_3Cr_2Ti_2$ alloy

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Abstract

In this work, thermal evolution of bulk nanoquasicrystalline $Al_{93}Fe_3Cr_2Ti_2$ material, obtained by consolidation of nanoquasicrystalline powder particles, is studied. The powder particles were obtained by gas atomization and the consolidation of the powders was achieved via warm extrusion [1,2]. The evolution of the microstructure during processing as well as with further thermal treatments was investigated. The consolidated material contains spherical particles of an icosahedral i-phase of around 200 nm in diameter. The quasicrystalline phase is detected even after 1 h at 500 °C, and afterwards, it evolves through a metastable Al_6Fe phase to the equilibrium phases.

Keywords: Nanostructured materials; Quasicrystals; Powder metallurgy; Microstructure; X-ray diffraction

1. Introduction

Since the first synthesis of a quasicrystalline (QC) phase in a rapidly solidified AlMn alloy in 1984 and its subsequent interpretation, great efforts have been devoted to the synthesis, structure, physical and chemical properties of QC alloys. The quasicrystalline alloys are characterised by high hardness and brittleness owing to the difficulty of dislocations movement in the quasiperodic lattice without long-range-periodicity. However, if nanoscale QC particles are dispersed homogenously in a ductile matrix, the mixed phase alloy is expected to exhibit high strength combined with good ductility. Kimura et al. [3] observed that an icosahedral phase is formed in rapidly solidified Al–Fe–Cr–Ti alloys, which is promising for aerospace and automotive applications.

The aim of the present work is to study the thermal evolution of a nanoquasicrystalline Al alloy with nominal composition of $Al_{93}Fe_3Cr_2Ti_2$ (at.%).

2. Experimental procedure

The $Al_{93}Fe_3Cr_2Ti_2$ at.% powder was produced by helium atomization of pure Al and Ti, and master Al–Fe and Al–Cr alloys. The powder was sieved into four powder particle size fractions, <25, 25–50, 50–100, and 100–200 μm. The chemical composition of the powder was confirmed by means of wet chemical analysis, as shown in Table 1.

Cylindrical bars were prepared by extrusion of the sieved powder particles with a horizontal extrusion press with a container diameter of 42 mm and maximum available pressure of about 1300 MPa. The extrusion temperature was 400 °C, the extrusion ratio was 10:1, and the ram speed was 0.3 mm/s. Prior to the extrusion, the encapsulated powder batches were submitted to heating at 400 °C for 15 min. The resulting bars were examined by means of X-ray diffraction using Cu Kα radiation (XRD), and transmission electron microscopy (TEM). To study the thermal evolution, the bars were heat treated in air for 1 h at 400, 500 and 550 °C.

3. Results and discussion

Fig. 1 collects the XRD patterns, in the most representative range of 2θ between 35° and 50°, of the as-extruded and the heat treated bar processed with the 50–100 μm powder particle size fraction. In the as-extruded state, signals of α-Al and Al_3Ti are seen, together with peaks in 2θ: 22.9, 41.3, 43.5, 61.6 and 73.7, which can be indexed as an icosahedral phase (i-phase) using the indexation scheme for icosahedral quasiperiodic crystals [4]. The presence of the icosahedral i-phase in the $Al_{93}Fe_3Cr_2Ti_2$ as-extruded bar was confirmed by TEM. Selected area diffraction patterns revealed the two-, three- and five-fold reflection spots as can be seen in Fig. 2. Quasicrystals in this alloy have the clear and characteristic spherical shape shown in Fig. 2, with a diameter of around 200 nm.

The XRD patterns of the bar treated for 1 h at 400 °C are very similar to those of the as-extruded bar, with α- Al, QC and Al_3Ti signals. After annealing at 500 °C, the XRD patterns show α- Al, a clear decrease of the amount of quasicrystalline phase, the presence of the Al_6Fe phase, Al_3Ti and small signals

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Table 1
Chemical composition of the powder fractions studied

	Al (at.%)	Fe (at.%)	Ti (at.%)	Cr (at.%)
Nominal	93	3	2	2
<25 μm	92.5	3.2	2.3	2.0
25–50 μm	92.4	3.3	2.3	2.0
50–100 μm	92.4	3.3	2.3	2.0

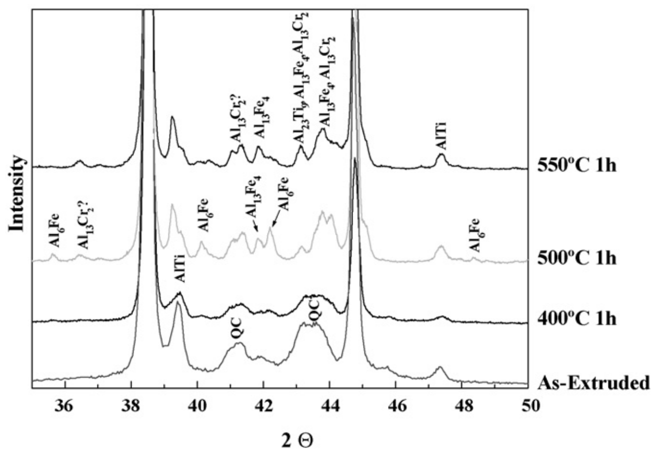

Fig. 1. XRD patterns of as-extruded and heat treated bars.

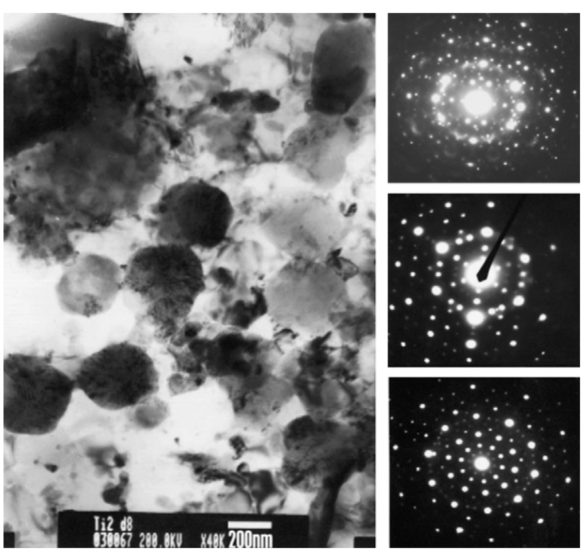

Fig. 2. As-extruded $Al_{93}Fe_3Cr_2Ti_2$ bar: quasicrystals and selected area diffraction patterns. TEM.

of the equilibrium $Al_{13}Fe_4$ and $Al_{13}Cr_3$ phases. After the 550 °C annealing, neither the icosahedral phase nor the Al_6Fe phase are detected any more and, instead, only clear signals of equilibrium phases are recognized: α- Al, $Al_{13}Cr_2$, $Al_{13}Fe_4$ and Al_3Ti.

Other authors working on materials of same composition obtained by melt spinning [5] reported data from the as-spun ribbons and after a heat treatment for 30 min at 550 °C. The as-spun ribbon consisted of icosahedral particles embedded in a α-Al matrix, and a small fraction of metastable distorted $Al_{13}(Cr, Fe)_{2–4}$ phase. After 30 min at 500 °C, they observed the equilibrium α-Al, $Al_{13}Cr_2$, $Al_{13}Fe_4$ and Al_3Ti phases. In this work, the extruded bars from gas atomised powder presented slightly differences: in the as-extruded state α-Al, i-phase and Al_3Ti are observed, and after 1 h at 500 °C the i-phase is still detected, indicating the high stability of this QC phase, and a metastable Al_6Fe phase appears. After 1 h at 550 °C, the melt-spun ribbons and the extruded bars presented similar phases.

4. Conclusions

Extruded bars obtained from nanoquasicrystalline $Al_{93}Fe_3Cr_2Ti_2$ gas atomized alloy, in the powder particle size range of 50–100 μm retain the nanoquasicrystalline phase, even after a thermal treatment of 1 h at 500 °C. Above this temperature the quasicrystals decompose to form more stable phases. The microstructure evolves through a metastable Al_6Fe phase towards the equilibrium α- Al, $Al_{13}Cr_2$, $Al_{13}Fe_4$ and Al_3Ti phases in the range 400–550 °C.

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References

[1] I. Todd, Z. Chlup, J.G. O’Dwyer, M. Lieblich y, A. García Escorial, Mater. Sci. Eng. A 375 (2004) 1235.
[2] Z. Chlup, I. Todd, A. García Escorial, M. Lieblich, A. Chlupova y, J. O’Dwyer, Mater. Sci. Forum 427 (2003) 2417.
[3] H.M. Kimura, K. Sasamori, A. Inoue, J. Mater. Res. 15 (12) (2000) 2737.
[4] P.A. Bancel, P.A. Heney, P.W. Stephens, A.I. Goldman, P.M. Horn, Phys. Rev. Lett. 54 (1985) 2422.
[5] M. Galano, F. Audebert, B. Cantor, I. Stone, Mater. Sci. Eng. A 377 (2004) 1206.