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Atomization of Al-rich alloys: Three paradigmatic case studies

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ABSTRACT

In this work we present our results on three aluminum rich alloys processed by atomization: $Al_{90}Fe_5Nd_5$, $Al_{93}Fe_3Cr_2Ti_2$, and $Al_{68.5}$ $Ni_{31.5}$, for structural and functional applications. Amorphous and a nanocomposite microstructure, formed by nanocrystals of α-Al embedded in a remaining amorphous matrix, are obtained in the atomized $Al_{90}Fe_5Nd_5$ powder particles. Bars produced by extrusion of this powder present yield strength above 700 MPa. Atomized $Al_{93}Fe_3Cr_2Ti_2$ powder particles contain a high proportion of quasicrystalline precipitates, stable up to 500 °C. At 300 °C, $Al_{93}Fe_3Cr_2Ti_2$ extruded bars present ultimate tensile strength as high as 280 MPa. Raney alloy, $Al_{68.5}$ $Ni_{31.5}$, is of high interest as a catalyst. When it is atomized, the particles present a fine dendrite microstructure, which is very suitable for catalyst reactions once the Al rich phases have been leached away.

1. Introduction

Aluminum alloys are the most industrially used metallic materials along with steels. Thanks to the development of new techniques of non equilibrium processing, especially of rapid solidification, RS, in the 1980s new Al alloys were obtained. Rapid solidification permits the introduction of more alloying elements in solid solution in the Al crystals and the refinement of grain size, thus improving the alloy thermal stability and tensile strength. In addition, new metastable phases and alloys appear, such as amorphous Al alloys, with ultimate tensile stress (UTS) up to 1200 MPa, and nanocomposites, formed by nanocrystals embedded in an amorphous matrix, with UTS up to 1550 MPa [1]. In 1984, Shechtman observed, for the first time, the presence of quasicrystals, QC, in RS Al alloys. These new quasicrystals are hard and brittle due to the difficulty the dislocations have in moving in the quasiperiodic lattice, without long range periodicity [2]. In spite of their brittleness, the use of QC as reinforcement of a ductile Al matrix could improve its mechanical properties and enhance its thermal stability [3].

Gas atomization is an industrial RS process, which makes it possible to produce large amounts of powder particles. In the gas atomization method a liquid stream of a molten alloy is disintegrated by high velocity gas, giving rise to spherical particles less than 200 μm in diameter that solidify in a containerless way. Containerless processing promotes non-equilibrium solidification by avoiding the contact of the liquid with any surface, which permits large undercooling of the melt by preventing heterogeneous nucleation. This gives rise to a variety of metastable solid states. Moreover, the solidification path may become rather complex, and frequently the microstructure appears as a mixture of stable crystalline phases and metastable phases and/or amorphous phases.

The importance of atomization is also evident in the current fast development of additive manufacturing processes, which are demanding powders with constant properties: chemical composition, shape, flow and filling capacity.

In this work we present the results on two structural Al alloys, $Al_{90}Fe_5Nd_5$ and $Al_{93}Fe_3Cr_2Ti_2$, and a functional intermetallic alloy $Al_{68.5}Ni_{31.5}$, Raney, all obtained by atomization.

$Al_{90}Fe_5Nd_5$ is a good candidate to be obtained as a metallic glass [1] and its mechanical properties can be improved by partial crystallization, with the formation of Al crystals embedded in a remaining amorphous matrix. The second alloy, $Al_{93}Fe_3Cr_2Ti_2$, is interesting because it forms hard quasicrystals that strengthen the alloy [1–3]. This alloy was also studied in melt spun ribbons [4,5] in the same project. Considering the small size of atomized particles, the preparation of bulk materials for structural applications, in the case of $Al_{90}Fe_5Nd_5$ and $Al_{93}Fe_3Cr_2Ti_2$ alloys, require a further consolidation that preserves the as-solidified microstructure as much as possible, which is a perpetual issue in powder metallurgy.

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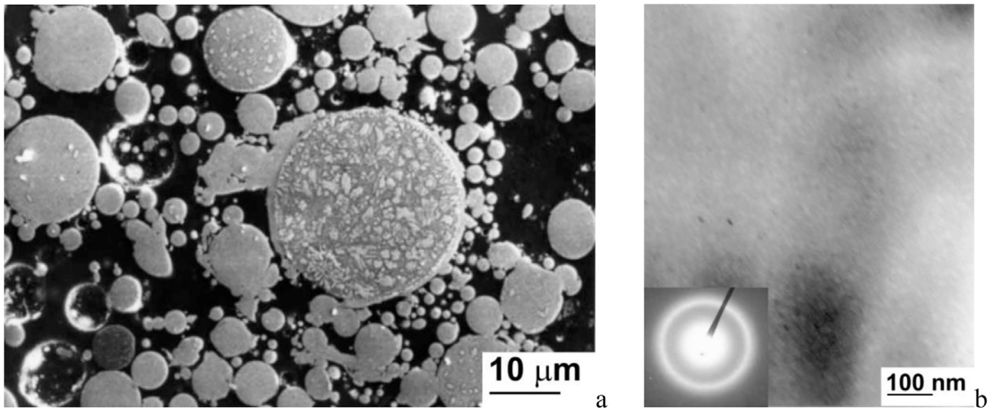

Fig. 1. a) SEM micrograph of cross-sections of atomized $Al_{90}Fe_5Nd_5$ powder −25 μm b) TEM bright field and selected area diffraction pattern of an atomized $Al_{90}Fe_5Nd_5$ powder −25 μm.

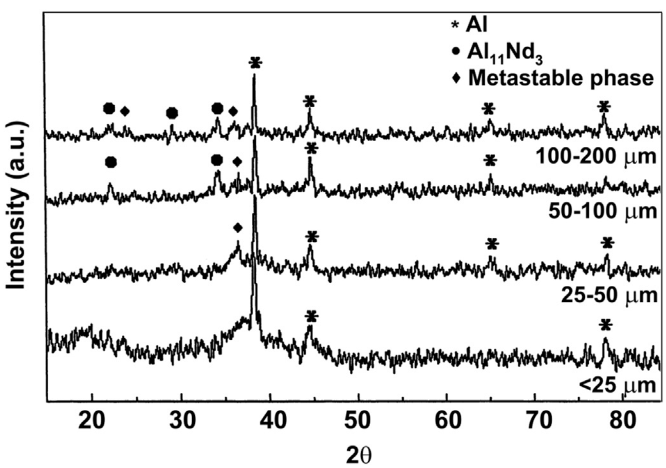

Fig. 2. X-ray diffraction patterns of atomized $Al_{90}Fe_5Nd_5$ powder.

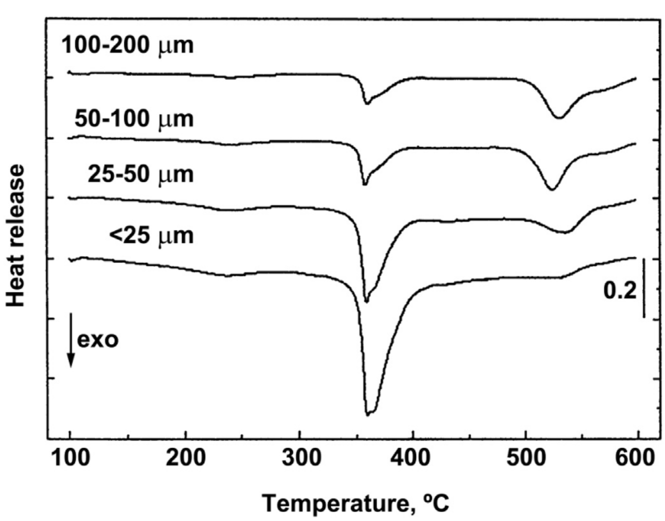

Fig. 3. DSC traces of atomized $Al_{90}Fe_5Nd_5$ powder.

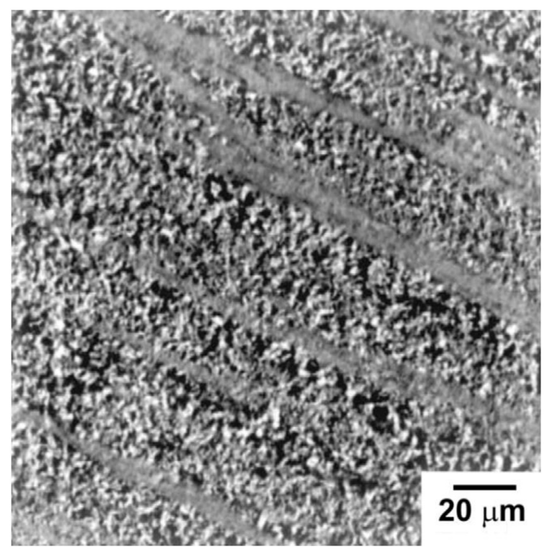

Fig. 4. SEM micrograph of a longitudinal section of the bar extruded at 450 °C, powder size fraction 50–100 μm.

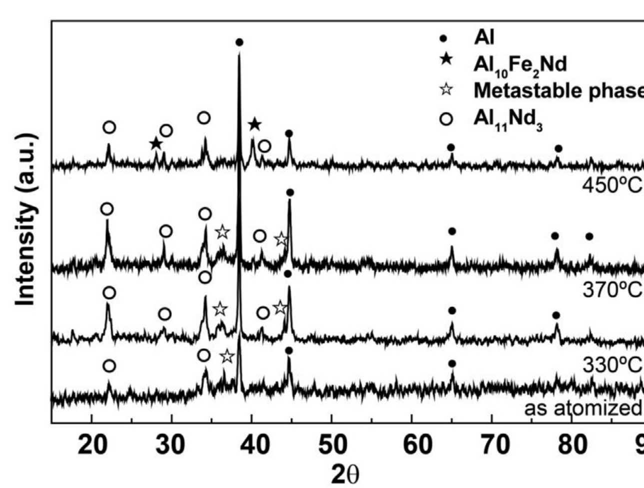

Fig. 5. XRD patterns of 50–100 μm powder size fraction extruded bars at 330, 370 and 450 °C.