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Microstructure characterization in cryomilled Al 5083

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Abstract

Nanocrystalline metals and alloys processed by severe plastic deformation (SPD) generally have improved mechanical strength compared with conventionally processed materials. In this work, we survey the microstructure of an Al 5083 alloy prepared by ball-milling powders at cryogenic temperatures (cryomilling) then consolidated by hot-isostatic pressing (HIPing) and extrusion into cylindrical billets. After milling, the particles are comprised of nanocrystalline grains, which are maintained following extrusion. We identify MgO, Al_6(FeMnCr), Al(MnFe)Si, AlCrMg, Mg_2Si, and SiO_2 phases as precipitates or dispersoids in the microstructure. This synthesis method results in a yield strength that is approximately twice that of typical wrought Al 5083 alloys. We find that the microhardness is essentially unchanged after annealing at temperatures up to $\sim 0.8T_m$. The influence of the components of the microstructure on the measured mechanical properties is discussed.

Keywords: Al alloy; Oxide; Transmission electron microscopy (TEM); Precipitation; Cryomilling; Dispersoid

1. Introduction

Severe plastic deformation (SPD) is an effective means of producing nanostructured metals and yields substantial improvements in mechanical strength [1,2]. Common methods used to introduce SPD into a material include: rolling, equal channel angular pressing (ECAP), and ball milling. Ball milling performed at cryogenic temperatures (cryomilling) limits dynamic recrystallization by dissipating heat generated during the milling process, thus resulting in a nanocrystalline microstructure [2–6]. In particular, the microstructure and mechanical properties of Al–Mg alloys produced from cryomilled powder compacts have been the subject of several recent studies [7–13]. A unique characteristic found in Al alloys processed at cryogenic temperatures is that a significant fraction of the initial mechanical strength is maintained following heat treatment [2,6,7,10].

In the present work, an Al–Mg alloy (AA 5083) is processed by cryomilling and HIPing followed by extrusion. The presence of Mg (typically <5 wt.%) in Al has the benefit of increasing strength without compromising ductility [14]. Al–Mg alloys are important technologically because they possess good weldability and corrosion resistance. In the 5xxx series Al alloys, small amounts of Mn and Cr (<0.7 wt.%) are added to increase precipitation. The primary effect of such precipitation is to pin grain boundaries and inhibit recrystallization [14]. Thus, a more complex microstructure will evolve as compared to a binary Al–Mg alloy. The phases found in cast 5xxx alloys may include: $MgAl_2$, Mg_2Si, Mg_2Al_3, $Cr_2Mg_3Al_{18}$, $(Fe,Cr)_3SiAl_{12}$, and $MnAl_6$ [14].

The primary purposes of the present study are to: (1) investigate the microstructure (i.e., grain size and morphology) of the cryomilled powder and the microstructure of the bulk nanocrystalline alloy and (2) observe the dispersoid and precipitate phases present in the microstructure and understand their origin. Results from these studies will be used to explain the enhanced strength and unique mechanical behavior of the cryomilled alloy (i.e., retained strength following heat treatment).

2. Experimental

Powder from a commercial Al 5083 alloy was prepared by spray atomization followed by milling at a temperature of −190 °C maintained by liquid nitrogen. The milled powder then was degassed at 425–450 °C in a vacuum (10^{-6} Torr), followed by consolidation by hot-isostatic pressing (HIPing) at 300–325 °C and a pressure of 103 MPa (15,000 psi). After HIPing, the resulting billet was extruded at 200–225 °C with an area

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Table 1
Comparison of the specified concentration range of alloying elements in Al alloy 5083 and the measured concentrations from the cryomilled and extruded Al 5083 alloy in this study

Element	Range (wt.%) [14]	Extrusion (wt.%)
Mg	4.0–4.9	6.2
Mn	0.40–1.0	0.61
Cr	0.05–0.25	0.06
Fe	0.40 maximum	0.30
Si	0.40 maximum	0.095
Cu	0.1 maximum	0.075
O	Not specified	0.8
N	Not specified	0.07–0.09
Al	Balance	Balance

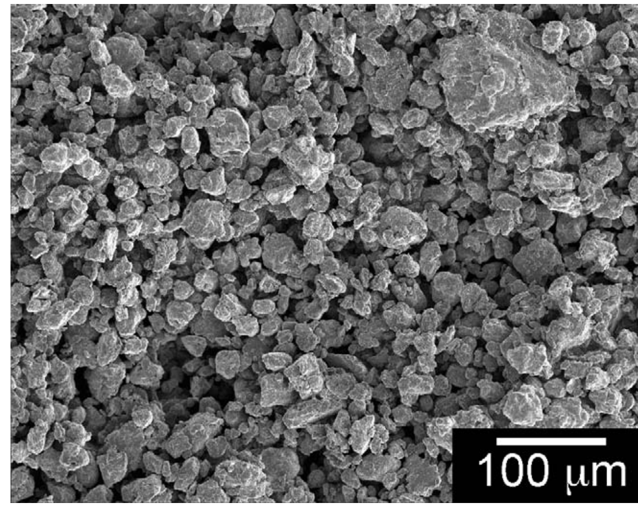

Fig. 1. Scanning electron microscope (SEM) secondary electron image of the cryomilled Al 5083 powder. The particles in this image range in size from 10 to 100 μm.

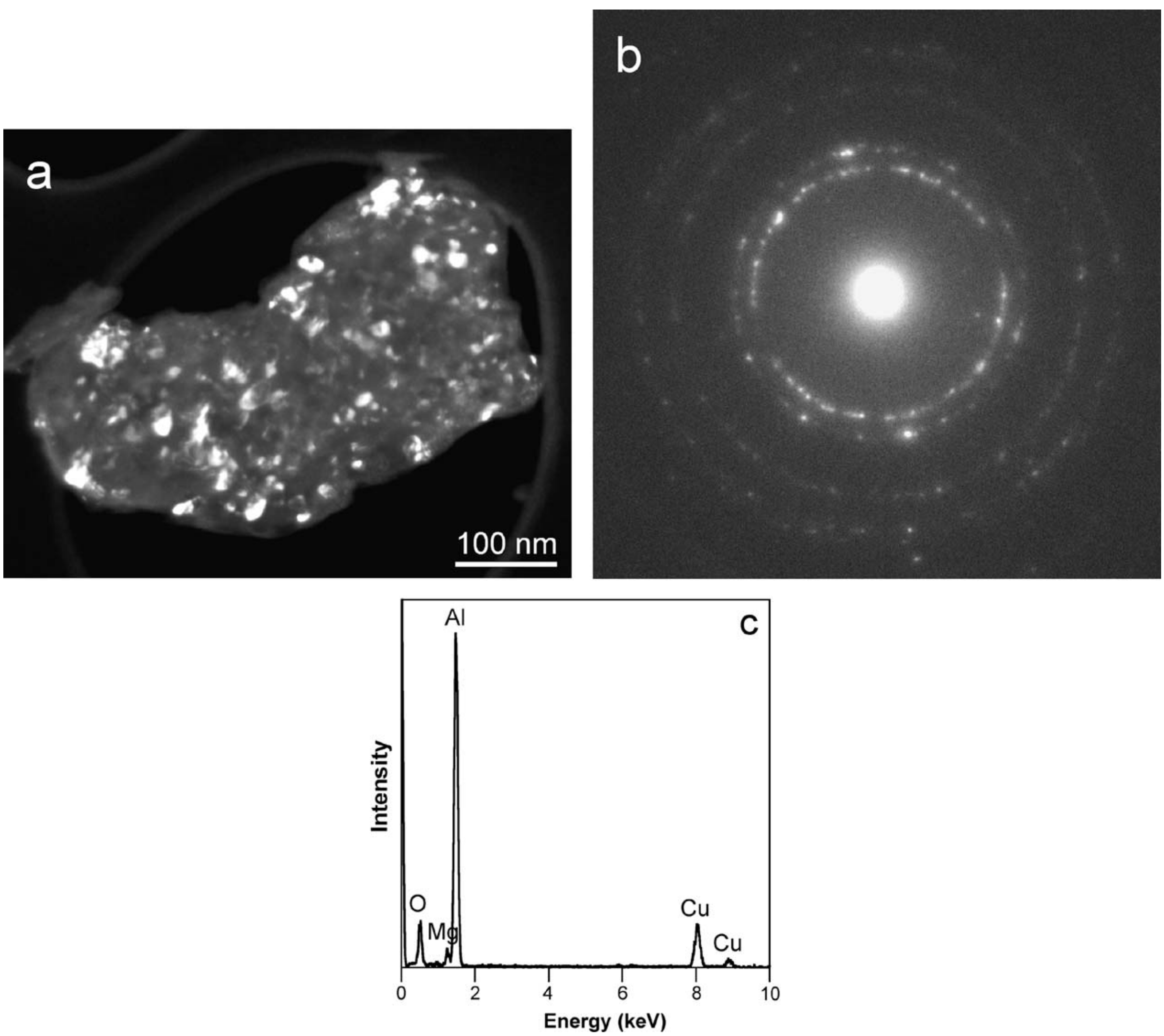

Fig. 2. (a) Dark-field TEM image of a cryomilled Al 5083 particle formed using a portion of the {1 1 1} and {2 0 0} diffraction rings. Individual grains are 10–50 nm. (b) Selected area diffraction pattern from the particle. The rings correspond to Al. (c) EDS spectrum of the particle. O arises from oxides, while Cu is from the support grid.