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Microstructure of Ni_2MnGa Alloys Solidified by Suction Casting

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Ni-Mn-Ga alloys are a new type of active and multifunctional materials, which combine the properties of ferromagnetism with those of a reversible martensitic transformation. On cooling, they undergo a martensitic transformation from a ferromagnetic high-temperature cubic $L2_1$ phase to a low symmetry martensitic phase. Recoverable strains induced by magnetic fields, of up to 10%, have been reported for single crystals close to the stoichiometric composition, due to the rearrangement of martensite variants by twin boundary migration in the ferromagnetic martensitic phase [1,2]. Magnetic-field-induced-strains (MFIS) found in polycrystalline alloys are remarkably smaller than for single crystals because of the randomly oriented grains and twin variants [3,4]. Larger MFIS can be generated in coarse-grained, highly-textured, polycrystalline samples. In this sense, the suction casting rapid solidification technique is used in this investigation to produce Ni_2MnGa bulk polycrystalline alloys in the form of cylinders of 1 mm and 2 mm in diameter (named C1 and C2, respectively), and tubes of 2 mm and 3 mm outer diameters (T2 and T3) and wall thickness of about 250 µm. A detailed study of the microstructure and crystallographic texture of the as-cast samples is presented.

Rods and tubes were characterized by X-ray diffraction (XRD), confocal microscopy (CLSM), electron backscattered diffraction (EBSD) and transmission electron microscopy (TEM). Room temperature XRD profiles were recorded in a PANalytical Empyrean diffractometer. An Olympus LEXT OLS4000 confocal microscope was used to image the rods and tubes fracture surfaces. Texture studies were performed by means of the electron backscattered diffraction technique in a FE-SEM Σigma (Carl Zeiss) scanning electron microscope, equipped with an Oxford Nordlys Nano electron backscatter detector. Crystallographic data given by ICSD card #103803 (Ni_2MnGa, space group *F m -3 m*) was considered to identify the crystal orientations in EBSD patterns. TEM observations and selected area diffraction patterns were performed in a Philips CM200 UT and a FEI TECNAI F20 G2 microscopes, operating at 200 kV and equipped with an energy-dispersive X-ray spectroscopy (XEDS) facility.

At room temperature all samples are in cubic $L2_1$ ordered austenitic phase. XEDS analyses confirm the stoichiometric composition Ni_2MnGa in the rods and tubes investigated, with a quite narrow dispersion (less than 1 at.%) around the nominal composition. EBSD maps of rods' cross sections show small and equiaxed grains on the outer surface close to the mold, and toward the center, larger columnar grains grown in the radial direction. Most grains have their [100] direction parallel to the radial direction. For the tubes, columnar grains are mainly observed (Figure 1). A larger population of small and equiaxed grains is found at the outer surface and for sample T2. A strong texture with the [100] direction parallel to the radial direction is observed, in complete agreement with X-ray diffraction results. Precipitates with mean diameters ranging from 100 nm to 270 nm, associated to S, Se and P traces in the precursor manganese, are found in all the samples. They are identified as α-Mn(S,Se), with a NaCl-type structure, and P_4S_5, a phosphorus sulfide with monoclinic structure. Additionally, different dislocation configurations are observed, distributed within the matrix (see Figure 2b) and around precipitates.

As a consequence of the large crystalline texture resulting from the solidification method applied, the massive samples obtained undergo magnetic field-induced twin boundaries reorientation as the main magnetization mechanism.

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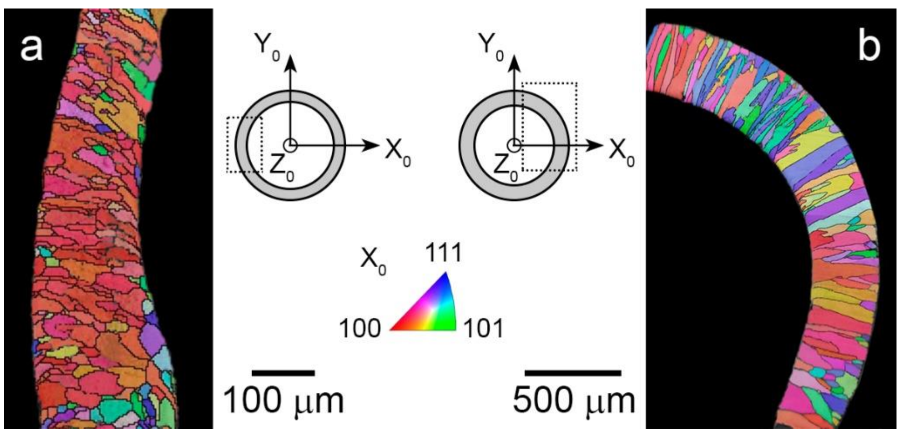

Figure 1: EBSD maps for samples (a) T2 and (b) T3, colored according to the inverse pole figure in the X_0 direction. The areas where maps were acquired are shown schematically in the central figures.

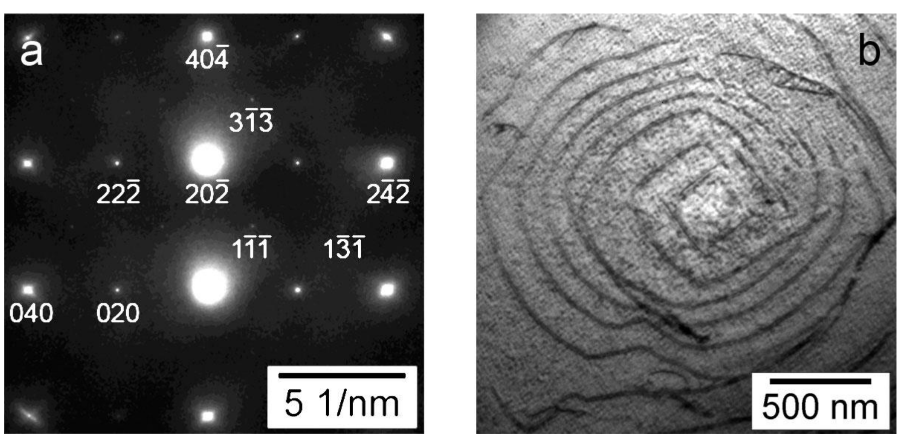

Figure 2: (a) Electron diffraction [101] zone axis pattern corresponding to the $L2_1$ structure. (b) TEM bright field micrograph showing typical helical dislocation configurations found in the samples.

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