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Investigating the magnetic entropy change in single-phase Y_2Fe_{17} melt-spun ribbons

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The inspection of simplified fabrication and/or processing routes in order to produce materials with attractive magnetocaloric properties is of paramount importance for the development of environmentally friendly magnetic cooling technology. In this work, we have made use of the melt-spinning technique to obtain directly single-phase Y_2Fe_{17} polycrystalline ribbons avoiding any high-temperature annealing for phase consolidation and homogenization. The melt-spun ribbons, with hexagonal Th_2Ni_{17}-type crystal structure, exhibit a moderate maximum value of the magnetic entropy change, $|\Delta S_M^{peak}| = 2.4(4.4)$ J kg^{-1} K^{-1} under an applied magnetic field change of 2(5) T. Although these values are similar to those for the bulk alloy, the $\Delta S_M(T)$ curves are manifestly broader, thus giving rise to an expansion of the working temperature range and the enhancement of about 15% in the refrigerant capacity. We also show that the magnetic field dependence of $|\Delta S_M{}^{peak}|$ at $T = T_C$ follows a $H^{2/3}$ power-law.

1. Introduction

An important challenge of modern society consists in reducing energy consumption through the development of more energy efficient technologies of massive use [1]. Consequently, national and international funding agencies are promoting research and development focused on this target. Commercial refrigeration is a typical example in which the search for a more proficient and clean technology is needed [2]. Therefore, magnetic refrigeration, a solid-state technology based in the magnetocaloric (MC) effect, attracts great interest because it is considered a feasible alternative for the conventional air-compressed refrigerant systems due to, among other advantages, its higher efficiency (of up to 60% of Carnot's cycle) [3–5]. One of the most active fronts in the field is the development of MC materials with enhanced refrigerant properties [2,6].

Materials with second-order magnetic phase transition (SOMPT) exhibit appealing characteristics for magnetic refrigeration such as the absence of thermal hysteresis and the smoothness of the transition [7–9]. Moreover, SOMPT materials provide a broader temperature interval for the MC effect thus favouring remarkable values of the refrigerant capacity (*RC*), a magnitude which permits an estimation of how much heat can be absorbed at the cold end of the thermodynamic cycle and expelled through the hot end [10]. Amongst these SOMPT materials, Fe-rich R_2Fe_{17} binary intermetallic compounds with R = Y, Pr or Nd are certainly interesting due to a combination of rather high saturation magnetization and near room temperature Curie point (T_C = 303, 335, and 285 K, respectively), together with a low amount of rare-earth content [11,12]. Recent works on the MC behaviour of these Fe-rich alloys in bulk form confirm the moderate values for the maximum magnetic entropy change, $|\Delta S_M^{peak}| \approx 6$ J kg^{-1} K^{-1} and refrigerant capacity $RC \approx 500$ J kg^{-1} under a magnetic field change $\mu_0\Delta H = 5$ T [11–14].

Cooling (or heating) devices based on magnetic refrigeration technology require fast heat exchange in the cold and hot ends of the thermodynamic cycle between the MC material and the fluid

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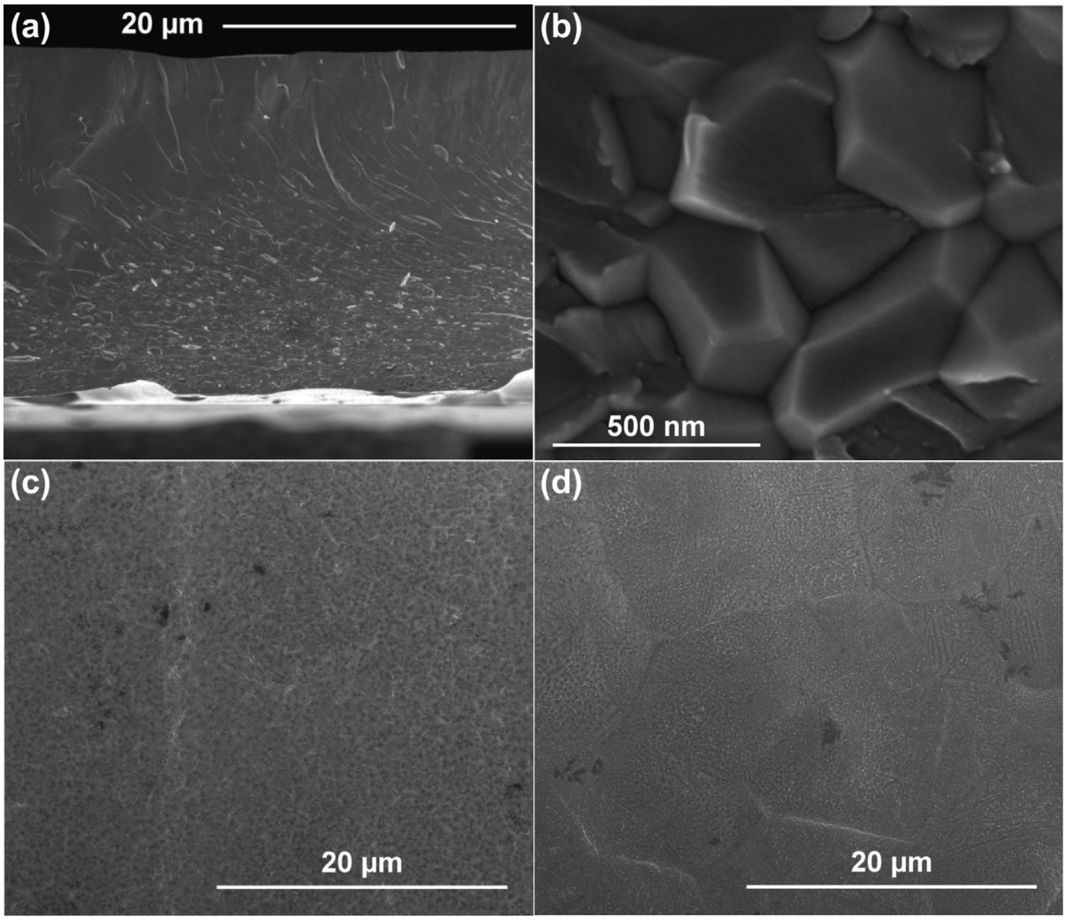

Fig. 1. SEM micrographs of the typical microstructure of as-solidified Y_2Fe_{17} ribbons: (a) fracture cross-section; (b) higher magnification image showing several crystalline grains; (c) ribbon wheel-side surface, and; (d) ribbon free surface.

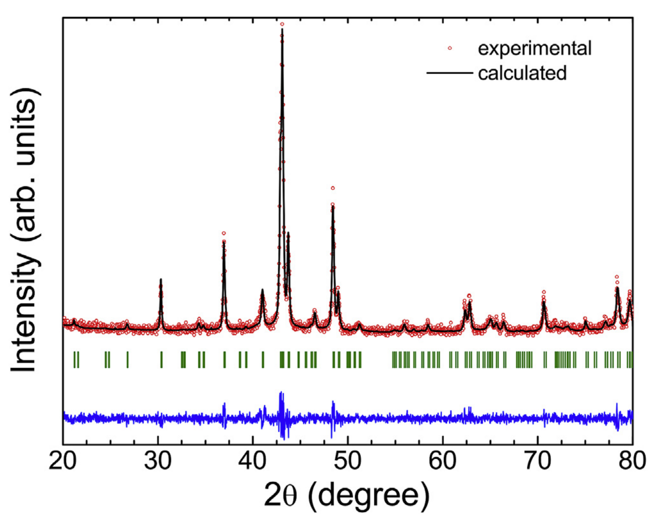

Fig. 2. Room temperature experimental and calculated XRD patterns for as-quenched Y_2Fe_{17} melt-spun ribbons. The difference between both patterns is depicted at the bottom of the figure. The vertical green bars correspond to the positions of the Bragg reflections for the $P6_3/mmc$ hexagonal crystal structure. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

heat exchanger [2]; MC materials with large surface to volume ratios, and more precisely melt-spun ribbons, may satisfy such condition [15]. Moreover, the melt-spinning method is a one-step and low-cost fabrication process for R_2Fe_{17} ribbons, which avoids the high-temperature long-time processing needed for the phase homogenization in conventional bulk alloys. In addition, the integration of melt-spun Y_2Fe_{17} ribbons into heat exchangers for magnetic refrigerators and the magnetocaloric performance of parallel-staked ribbons with micro- and nanocrystalline microstructure is currently being considered [16]. However, the MC effect in melt-spun R_2Fe_{17} ribbons remains almost unexplored except for the pseudo-binary $NdPrFe_{17}$ alloy [17], and a preliminary study performed under a low applied magnetic field (i.e., 1 T) on Y_2Fe_{17} [18].

The aim of this work is to provide a detailed investigation on the magnetic and magnetocaloric properties of single-phase Y_2Fe_{17} melt-spun ribbons. Our results are compared with those obtained for a synthesized bulk alloy and also with data reported in the preliminary study carried out by Fang et al. [18].

2. Experimental procedure

Polycrystalline ribbons with nominal composition Y_2Fe_{17} were produced by rapid solidification using a homemade melt spinning set-up at a linear speed of the copper wheel of 20 m^{-1} from bulk pellets previously obtained by arc melting. Pure metallic elements were used as raw materials (≥99.9%). Both the arc-melted starting alloys and the melt-spun ribbons were fabricated under a highly pure Ar atmosphere. For comparison purposes, one of these arc-melted pellets was annealed at 1373 K in a vacuumed quartz