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Effect of high magnetic field on the crystallization of $Nd_2Fe_{14}B/\alpha$-Fe nanocomposite magnets

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Abstract: $Nd_{8.1}Dy_{0.9}Fe_{76.95}Co_{8.55}B_{5.5}$ nanocomposite magnets annealed with and without a 10 T magnetic field were investigated in this article. The ribbons with coexisting amorphous and crystalline phases were selected to do this study. The results of Mössbauer spectroscopy revealed that the content of α-Fe increased when annealed in high strength magnetic field. The size of the grains also increased considerably after the application of magnetic annealing. All these led to the decrease of the magnetic properties, especially the coercivity of the ribbons.

Key words: magnetic materials; nanocomposite magnet; crystallization; magnetic field; melt spinning

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1. Introduction

Melt spinning nanocomposite magnets were investigated widely during the last two decades, and different annealing methods have been introduced to crystallize the amorphous alloy into nanocomposite [1-6]. Yang *et al.* researched the effect of magnetic field on the crystallization of $Nd_2Fe_{14}B/Fe_3B$ magnets, which revealed that the externally applied magnetic field could induce a uniform distribution of fine grains and change the content of each phase [7-11]. The heat treatment in magnetic field was applied to alloys with indium addition [12-13]. As to the alloys treated with this method, a slight anisotropy in the different direction of ribbons was found. Cui *et al.* also found weak anisotropy in the ribbons annealed in a 1.2 T magnetic field [14]. Although all these results have revealed the anisotropy in the ribbons, the magnetic properties have not been enhanced obviously. The magnetic field applied by them was in the range from 0.2 T to 1.2 T. But the high strength magnetic field up to 10 T has not been applied to anneal this material.

The high strength static magnetic field larger than 10 T can be easily obtained with the emergence of a superconducting magnet. The texture has been found for the superconducting materials YbaCuO [15], the rolled zinc alloy sheet [16], Fe-C alloy [17-18], SmCo [19] and NdFeB [20] alloys prepared or heat treated under high strength magnetic field. The difference of the magnetic susceptibility in different crystallographic directions was considered as the main factor to format these textures. Recently, the crystallization behavior of the bulk amorphous alloy $Zr_{62}Al_8Ni_{13}Cu_{17}$ under a 10 T magnetic field has also been researched [21]. The stability of the bulk amorphous alloy $Zr_{62}Al_8Ni_{13}Cu_{17}$ can be promoted by an external high strength magnetic field.

According to the above results, it is very important to investigate the crystallization of NdFeB

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amorphous ribbons in the high strength magnetic field of 10 T.

2. Experimental

The $Nd_{8.1}Dy_{0.9}Fe_{76.95}Co_{8.55}B_{5.5}$ (at.%) alloy ingot was prepared by induction melting under purified argon, and then it was crushed into 5-10 mm particles. The particles were arc-melted under purified argon. The molten liquid overflowed onto the copper roll with a wheel speed of 12 m/s, as this helped to achieve better properties. The melt-spun ribbons were annealed in vacuum at 690°C for 5 min with and without magnetic field. The as-spun and annealed ribbons were spread on the adhesive paper and then put on the sample holder to identify their structures by D/max-rC X-ray diffractometer (XRD with Cu K_α radiation). The as-spun ribbons were crushed into powders with a size of 70-100 μm and SDTQ1600 differential thermo analysis (DTA) with a heating speed of 20°C/min was applied to research their crystallization sequence. The magnetic properties of the ribbons were measured along the spun direction by vibrating sample magnetometer (VSM) with the maximum applied magnetic field of 1.8 T. The microstructure was viewed with JEM-200CX transmission electron microscope (TEM). The samples for TEM investigation were prepared as follows: The ribbons were crushed in a mortar and the resulting powder was mixed with aluminum powder in a mass ratio of 3:7. The mixture of 1 g was then placed in a die with a diameter of 10 mm, pressed at a pressure of 7 MPa for few seconds. The resulting sheet was then rolled into a pellet of 0.1 mm in diameter gradually. The pellet was ground and ion-etched. The duration for ion-erosion should be long enough to get a large thin area. The hyperfine structures of the ribbons were measured with ^{57}Co Mössbauer spectroscopy at room temperature.

3. Results and discussion

Fig.1 shows the X-ray diffraction patterns of the as-spun ribbon. The ribbon consists of amorphous phase, the hard magnetic phase $Nd_2Fe_{14}B$, and soft magnetic phase α-Fe. Fig. 2 shows its thermal analysis curve, which shows two exothermic peaks at 588°C and 661°C corresponding with two crystallization stages.

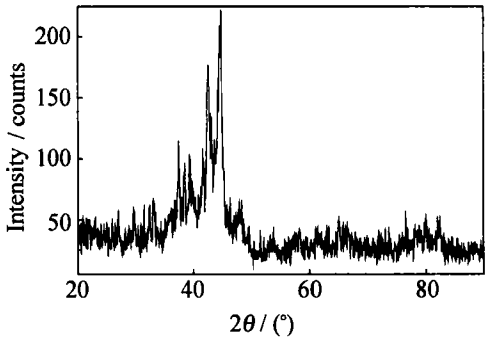

Fig. 1. X-ray diffraction pattern of the as-spun ribbon.

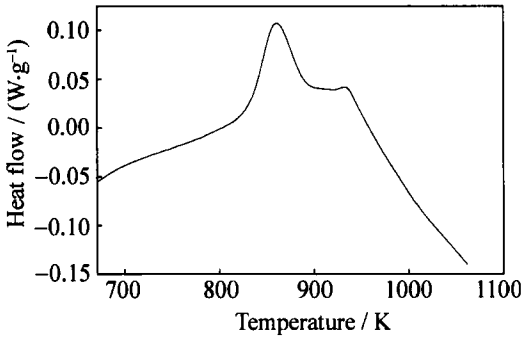

Fig. 2. DTA curve of the as-spun ribbon.

The ribbons were sealed in vacuum quartz capsules, and then annealed with and without a magnetic field at 690°C for 5 min. The applied magnetic field intensity was 10 T. Fig. 3 shows the X-ray diffraction patterns of these ribbons. All of these ribbons consist of hard magnetic phase $Nd_2Fe_{14}B$ and

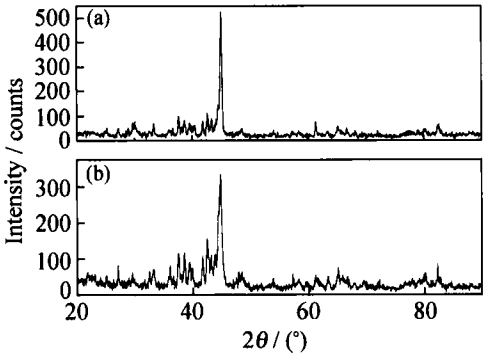

Fig. 3. XRD patterns of ribbons annealed without (a) and with (b) the magnetic field of 10 T.