STRUCTURE AND MAGNETIC PROPERTIES OF PERMALLOY PREPARED BY THE COMPACTION OF POWDER

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Abstract

The aim of this work was to investigate the structure and magnetic properties of powdered and compacted microcrystalline NiFe (81 wt.% of Ni) permalloy.

Keywords: permalloy, soft magnetic materials, coercivity

INTRODUCTION

Permalloy is the name which has been given to a series of nickel–iron alloys so heat-treated to have an initial permeability much larger than that of pure iron and are produced usually in the form of thin sheet [1]. Therefore it is logical to attempt to prepare such material direct in required form (more “bulk” form), for example in the form of a cylinder or a ring, which would be more convenient for some industrial applications. The Ni-Fe based alloy (permalloy) system shows excellent soft magnetic properties and these alloys have been widely applied in the field of electronic devices and industry.

Over the past several years the method of mechanical milling and mechanical alloying was widely spread in order to exploit it to produce a variety of equilibrium and non-equilibrium alloy phases and posses further possibility for research work and application of permalloy. The Ni-Fe based alloy (permalloy) system shows excellent soft magnetic properties and these alloys have been widely applied in the field of electronic devices and industry.

We believed that permalloy of the composition 81 wt% of Ni and 19 wt% of Fe, which is nonmagnetostrictive material, remains after milling single-phased material full fitting above mentioned conditions.

EXPERIMENTAL METHODS

The powder sample was prepared by mechanical milling of NiFe (81 wt.% of Ni) microcrystalline ribbon obtained by melt spinning. The ribbon was thin (20 μm), brittle enough and thus suitable for milling. The milling process was performed in Ar-protective atmosphere in a high-energy planetary ball mill (RETSCH PM4000 with hardened steel vials and balls) with ball-to-powder-ratio of 6:1 and with a speed of 180 rpm up to 30 h.

The bulk samples were prepared by uniaxial compaction of small pieces of broken ribbon with area of several mm² respectively of powders in the form of cylinders (diameter 10 mm, height 2.5 mm, weight approx. 2 g). The compaction was performed at a pressure of 800 MPa for 5 min at 600 °C in vacuum (in order to prevent oxidation and to remove free gases from powder before the compaction). The cylinders were annealed at temperatures between 500 °C and 1200 °C for 1 h. All handling with the bulk sample preparation was done in glove box [3].

High-energy X-ray diffraction (XRD) measurements were performed on the wiggler beamline BW5 at the DORIS III positron storage ring (HASYLAB Hamburg, Germany) using monochromatic photon beam with energy of 99 keV (λ = 0.01252 nm). The diffraction experiments were carried out in Debye-Scherrer geometry. Quartz capillaries with a diameter of 2 mm and 20 μm wall thickness were filled with powder samples. The samples measured at room temperature were illuminated for 10 s by a well-collimated incident beam with a cross-section of 1mm×1mm. XRD patterns were collected using a MAR345 imaging plate detector mounted orthogonal to the X-ray beam. Two dimensional diffraction patterns were radially integrated into Q-space (Q=4π sin(θ)/λ) using Fit2D [4].

The morphology of the samples was investigated by SEM (Vega 5135MM Tescan scanning electron microscope at 20 kV accelerating voltage).

The DC coercivity of powder was measured by a Förster Koerzimat at room temperature.
STRUCTURE

Fig. 1 shows XRD pattern of 25 h milled FeNi ribbon and verifies our assumption of stability of the FeNi alloy during milling. There are present only peaks of FeNi3 and FeO phases in the figure. It means that no additional ferromagnetic FeNi phase is created during milling. XRD pattern consists of FeO peaks too, because the powder sample was partial oxidized before X-ray investigation during exposition of oxygen (of air) for a relatively long time.

The XRD analysis revealed that the milling of the NiFe microcrystalline ribbon and the compaction of this powder have no significant influence on the structure of the material. The phase was identified as a NiFe solid solution [3].

MAGNETIC PROPERTIES

The absolute value of magnetostriction of the bulk samples was checked by the strain gauge method to be below 2 ppm [3].

The coercivity of bulk samples decreases up to 10 times in comparison to powder samples due to renew of the “magnetic contact” between the powder particles. The compact is magnetized dominantly by domain wall displacement in contrast with powder samples in which magnetization vector rotation is dominant magnetization process [6].

The coercivity of hot compacted powder ranges from 100 to 2000 A/m, with lowest value for sample compacted at 600 °C (it was the highest applied value), Fig. 3a.

The samples prepared by the compaction of powder at 600 °C we further annealed at the range from 500 °C to 1200 °C. This annealing is displayed in Fig. 3b. The annealing at higher temperatures causes relaxation of residual stresses introduced during milling and compaction and
improves contact between powder particles, causing lowering of the coercivity, Fig. 3b. The lowest value of coercivity (11 A/m) was achieved for the sample prepared by compaction of broken ribbon, annealed at 1200 °C, and is comparable with that for material prepared by convention way in the form of thin sheet (Hc = 4 A/m) [3].

![Fig. 4 The coercivity of bulk samples compacted at 600 °C and then annealed at different temperatures as a function of milling time.](image)

CONCLUSION

We have prepared bulk samples of the chemical compositions NiFe (81wt% of Ni) in the form of cylinders from the powder prepared by milling in the planetary mill. The powder remains single phase after milling for 30 h. The lowest value of the coercivity of the small cylinders is 11 A/m what is comparable with the value of coercivity of conventional permalloy [7, 8].

It was found by the investigating of the influence of mechanical milling on the magnetic properties of powder samples prepared by the milling of the ribbon that the alloy remains a solid solution with stable structure during the whole milling process. With the decreasing of the particle size the rotation of magnetization vector gradually becomes dominant magnetization process and thus coercivity increases. After compaction of the powder by uniaxial hot pressing the magnetic contact between powder particles is recreated and for resulting bulk the displacement of the domain walls becomes dominant magnetization process.

References


This work was supported by the Scientific Grant Agency of the Ministry of Education of Slovak Republic and the Slovak Academy of Science VEGA 1/0862/12 and KEQA 072TUKE-4/2014.