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ON THE MAGNETIC PROPERTIES OF BONDED MAGNETS MADE FROM A MIXTURE OF Nd(Fe,Co)B AND STRONTIUM FERRITE OR ALNICO POWDER

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Abstract. Isotropic epoxy-resin bonded magnets composed of a mixture of Magnequench MQP-B and strontium ferrite or alnico powders have been prepared using a compression moulding technique. The magnetic measurements have been performed using the vibrating sample magnetometer in a magnetic field up to 14 T. From the analysis of the differential susceptibility versus an internal field it was deduced that the main mechanism of magnetization reversal process in MQP-B and MQP-B with strontium ferrite magnets is the pinning of domain walls at the grain's boundaries of the MQP-B component. For MQP-B magnet with alnico, the rotation of the magnetization vector in alnico grains plays an important role in magnetization reversal process. The interaction between the magnets particles was examined by use of the so-called $\delta M(H_i)$ plot. The negative values of δM in all range of applied fields prove that the interaction between the magnet particles is the long-range magnetostatic one, except for the sample with ferrite for which the δM remains positive for an applied field less than 1.1 T.

1. INTRODUCTION

Bonded magnets play an important and still growing role among the commercially available permanent magnets. They are produced from a wide variety of hard magnetic powders mixed with several polymers as a binder and by several manufacturing technologies. For this reason, the bonded magnets provide almost innumerable possibilities of combinations of magnetic, mechanical, thermal and electrical properties desired in a specific application. Additionally, the bonded magnets can be formed into complex, net shape to be applied for example in computer storage devices or automotive products. The most frequently used material for manufacturing bonded magnets is strontium or barium ferrite powder and neodymium-iron-boron or samarium-cobalt one. The magnets based on rare-earth-transition metal alloys have excellent magnetic properties but ferrite magnets, while providing the worse magnetic properties, cost significantly less and are still widely used. In contrast to magnets produced from NdFeB alloys the ferrite magnets have positive temperature coefficient of coercivity H_c as which means that the coercivity increases with increasing temperature. Thus the bonded magnets produced from a mixture of ferrite and NdFeB powders (hybrid magnets) have lower temperature coefficient of coercivity than that made of pure NdFeB powder and can work in higher temperature.

The magnetic properties are among others influenced by the interaction occurring between dif-

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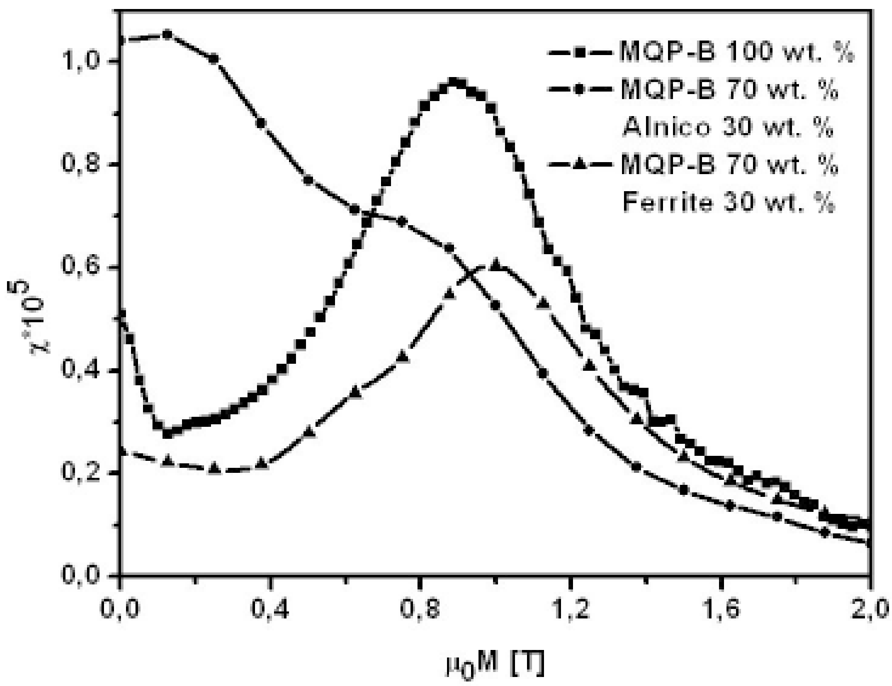

Fig. 1. Differential susceptibility curves of the samples made from 100 wt.% of MQP-B powder, 70 wt.% of MQP-B and 30 wt.% of alnico powders, 70 wt.% of MQP-B and 30 wt.% of strontium ferrite powders.

ferent magnet components. In this paper δ*M*(*H*) plot have been used to study these interactions and the magnetization reversal mechanisms in hybrid magnets made from a mixture of NdFeB with strontium ferrite or alnico powders.

2. EXPERIMENTAL DETAILS

The samples investigated in this study were produced from a mixture of an isotropic Magnequench MQP-B powder and strontium ferrite or alnico powder using a compression-moulding technique at a pressure of 900 MPa. The samples were cured at 180 °C for 2 hours. The hard magnetic fractions of hybrid magnets investigated were as follows: a) 100 wt.% of MQP-B, b) 70 wt.% of MQP-B and 30 wt.% of ferrite, c) 70 wt.% of MQP-B and 30 wt.% of alnico. 2.5 wt.% of an epoxy resin was used as a binder. MQP-B is based on rapidly quenched nanocrystalline ribbons from Nd-Fe-Co-B alloy consisting of 81.7 Fe, 4.5 Co, 9.5 Nd, 4.3 B in at.% [1]. The ribbons were ground into particles with average size ~200 μm. For alnico and ferrite powders these sizes are 250 μm and 50 μm, respectively.

The magnetic measurements were carried out at room temperature. The initial magnetization curves, the major hysteresis loops, the sets of recoil curves from different points on the initial magnetization and demagnetization curves were performed by the Bitter vibrating sample magnetometer with a maximum applied magnetic field of 14 T. From the initial magnetization curves the differential susceptibility curves were derived.

The interaction between the magnet particles was examined by use of the so-called $\delta M(H_i)$ plot. δM is defined as [2,3]:

$$\delta M(H_i) = M_{irr}^{d}(H_i)/M_R - \left(1 - 2M_{irr}^{r}(H_i)/M_R\right). \quad (1)$$

The demagnetizing remanence $M_{irr}^{d}(H_i)$ and magnetizing remanence $M_{irr}^{d}(H_i)$ were determined from the recoil curves as the value of magnetization when the demagnetizing (magnetizing) field is changed from $|\mu_0 H_i|$ to 0. M_R is the remanence determined from the major hysteresis loop measured at a field of 14 T.

3. RESULTS AND DISCUSSION

Fig. 1 presents the differential susceptibility derived from the initial magnetization curves as a function of an internal magnetic field for all samples inves-

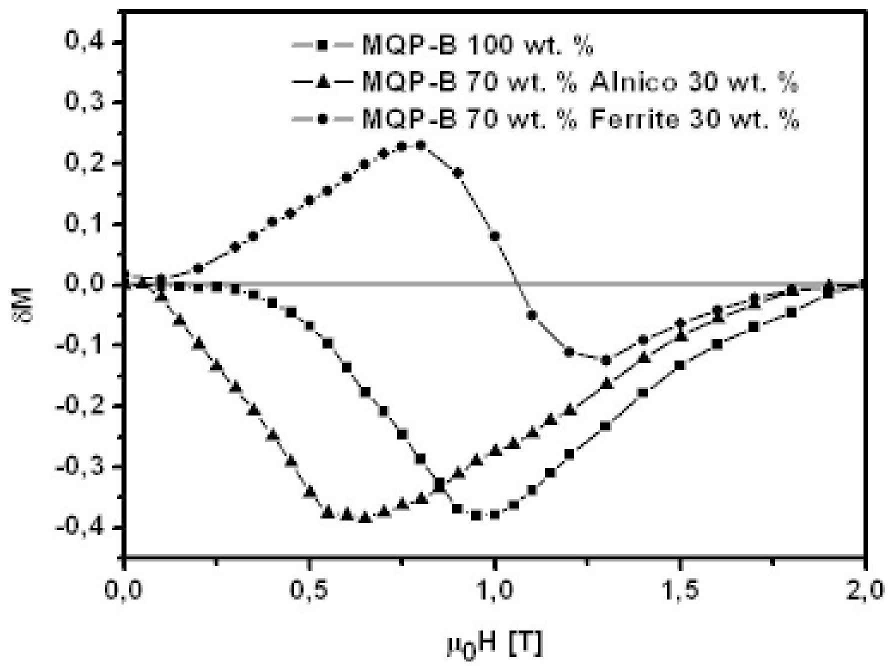

Fig. 2. $\delta M(H_i)$ relationship for the samples made from 100 wt.% of MQP-B, 70 wt.% MQP-B and 30 wt.% of alnico powders, 70 wt.% of MQP-B and 30 wt.% of strontium ferrite powders.

tigated. The low value of susceptibility for low internal magnetic fields and the maksimum corresponding almost to the sample coercivity are the characteristic features for materials in which the main magnetization reversal process is the pinning of domain walls. The lower value of initial susceptibility for the sample made from a mixture of MQP-B and ferrite powders in comparison with the sample made from the pure of MQP-B powder suggests that in low internal magnetic fields the rotation of magnetization vector occurs in single domain grains of MQP-B particles. The dependence of susceptibility versus an applied field for hybrid magnet produced from a mixture of MQP-B and alnico powders is the combination of different types of magnetization processes. For this sample, apart from the pinning of domain walls in MQP-B grains, the rotation of the magnetization vector in alnico grains plays the dominant role in magnetization reversal process.

Fig. 2 shows the δM plots for all samples investigated. According to Wohlfarth's theory [3] δM given by (1) is equal to zero for a magnet composed of non-interacting single-domain particles which means that the fraction of irreversible processes occurring during magnetization (M_{irr}^{r} / M_R) is equal to those occurring in demagnetization [1/2(1-M_{irr}^{d} / M_R)] at the same value of the magnetic field. As it can be seen in Fig. 2, the relation (1) is not valid for all three samples investigated. The negative values of δM for the two magnets (made from pure MQP-B powder and a mixture with alnico) suggest that the interactions between the magnet particles and grains have the dipolar (long-range magnetostatic) character and promote the demagnetized state. The magnetostatic interactions cause the fraction of irreversible processes to be lower during magnetizetization process in comparison with those occurring during demagnetization. In the case of magnet with strontium ferrite, the δM plot has a positive value between zero applied magnetic field and 1,1 T which certifies that in this range of fields the interparticle interactions support the magnetization process and the mean field effects are dominant. It is interesting to note that the |δM| have the highest value at the field near to the sample coercivity equal to 0,93 T, 0,80 T, and 0,52 T for MQP-B magnet, MQP-B with ferrite and MQP-B with alnico ones, respectively.

4. CONCLUSIONS

It has been shown that the main mechanism of magnetization reversal process in MQP-B and MQP-B with strontium ferrite magnets is the pinning of domain walls at the grain's boundaries of the MQP-B component. For MQP-B magnet with alnico, apart from the pinning of domain walls in MQP-B grains, the rotation of the magnetization vector in alnico grains plays an important role in magnetization reversal process. From the δM plots as a function of an applied field results that the magnetostatic interparticle interactions are dominant in MQP-B and MQP-B with alnico magnets while in MQP-B with strontium ferrite magnet the mean field effects contribute mainly to the interaction in the range of fields from zero to 1,1 T.

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