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The Influence of Pr Concentration on the Magnetic Properties of Pr-Fe-Co-B-Nb HDDR Magnets

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Abstract: Permanent magnets were produced from annealed alloys using the hydrogenation, disproportionation, desorption and recombination (HDDR) process. The influence of Pr concentration on the magnetic properties of these magnets was studied. Under the present processing conditions Pr has a significant influence on the magnetic behaviour of these magnetic materials. Microstructural examinations revealed that free iron was completed eliminated from all studied alloys with annealing and the grain size changed somewhat with praseodymium content. It has also been shown that to obtain bonded magnets with optimum magnetic properties the praseodymium content in these alloys should be around 13.5 at%.

Introduction

In the past, Pr-based magnetic powders have been produced via the HDDR process, but with inferior magnetic properties, compared to Nd-based materials [1]. Ga containing Pr-type HDDR powders with good remanence have also been reported [2] but intrinsic coercivity in these materials was still quite poor. However, it has been shown that anisotropic powders based on the composition $Pr_{13.7}Fe_{bal}Co_{16.7}B_6Nb_{0.1}$, with good remanence and coercivity, can be produced by this process [3-7]. This study was undertaken to optimise the praseodymium content with respect to the magnetic properties of the HDDR permanent magnets. The microstructures of the annealed alloys with various Pr concentrations were observed with a scanning electron microscope (SEM).

Materials and Methods

Commercial alloys in the as-cast state and after annealing in vacuum at 1100°C for 20 h were studied. The details of the preparation of the HDDR magnets, alloy annealing (homogenisation heat treatment) and magnetic measurements have all been described in previous papers [4-7]. Permeameter measurements were performed after saturation in a pulsed field of 6.0 T. Remanence values have been normalized assuming 100% density for the HDDR sample, and by also considering a linear relationship between density and remanence. Microstructural characterization of the alloys was carried out with the aid of a scanning electron microscope (SEM).

Results and Discussion

Back-scattered electron images of the annealed praseodymium-based alloys are shown in Figures 1-5. It can be seen clearly that annealing at 1100°C for 20 h was quite effective in homogenizing all the alloys. Free iron (αFeCo) was completely eliminated from the interior of the matrix phase $Pr_2(FeCo)_{14}B$ grains. Two other phases have been found in the grain boundary of these alloys, namely: $Pr(FeCo)_2$ and $Pr_3(FeCo)$. These phases have been reported previously [6,10]. Small amount of a $Pr_{1+e}(FeCo)_4B_4$ phase has also been found in the annealed $Pr_{12}Fe_{bal}Co_{16}B_6Nb_{0,1}$ alloy. Clearly, the grain size of the matrix phase of these annealed alloys changed with praseodymium content.

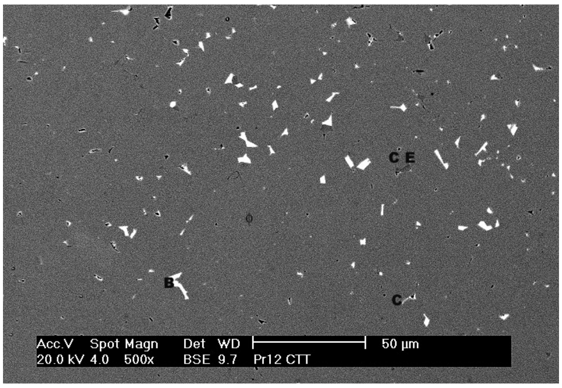

Fig. 1 - Backscattered electron image of the homogenized $Pr_{12}Fe_{bal}Co_{16}B_6Nb_{0,1}$ alloy.

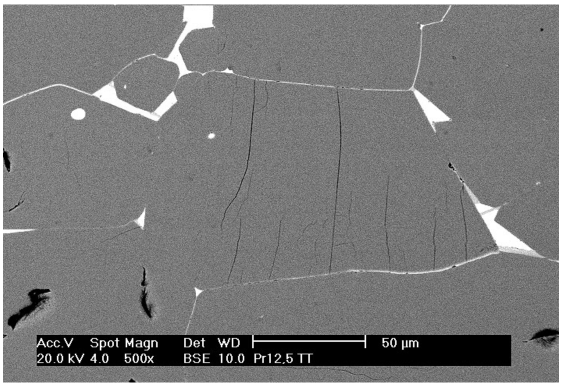

Fig. 2 - Backscattered electron image of the homogenized $Pr_{12.5}Fe_{bal}Co_{16}B_6Nb_{0,1}$ alloy.

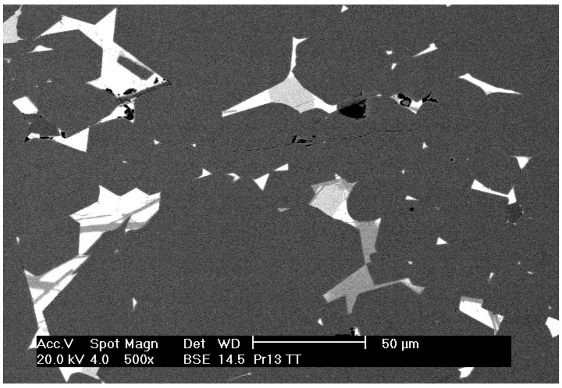

Fig. 3 - Backscattered electron image of the homogenized $Pr_{13}Fe_{bal}Co_{16}B_6Nb_{0,1}$ alloy.

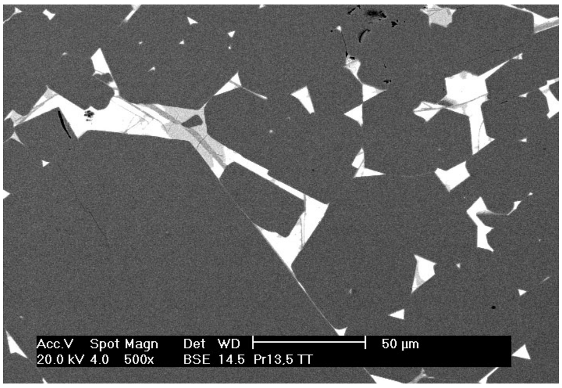

Fig. 4 - Backscattered electron image of the homogenized $Pr_{13.5}Fe_{bal}Co_{16}B_6Nb_{0,1}$ alloy.

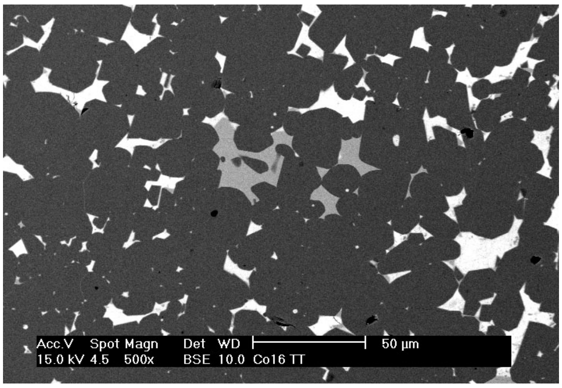

Fig. 5 - Backscattered electron image of the homogenized $Pr_{14}Fe_{bal}Co_{16}B_6Nb_{0,1}$ alloy.

Variation in remanence and intrinsic coercivity of HDDR magnets, produced from annealed Pr-based alloys, as a function of praseodymium content is shown in Figure 6. Good remanence values were achieved in samples prepared from alloys containing more than 12 at% Pr. A peak in remanence has been reached at 13.5 at% with a decrease for higher contents. Reasonable intrinsic coercivity values were achieved in samples prepared using the annealed alloys with more than 12 at% Pr. Thus, overall magnetic properties were achieved in the magnet produced with 13.5 at% Pr. This is best praseodymium content for the present HDDR processing conditions. The grain structure of the HDDR material of this magnet is shown in Figure 7.

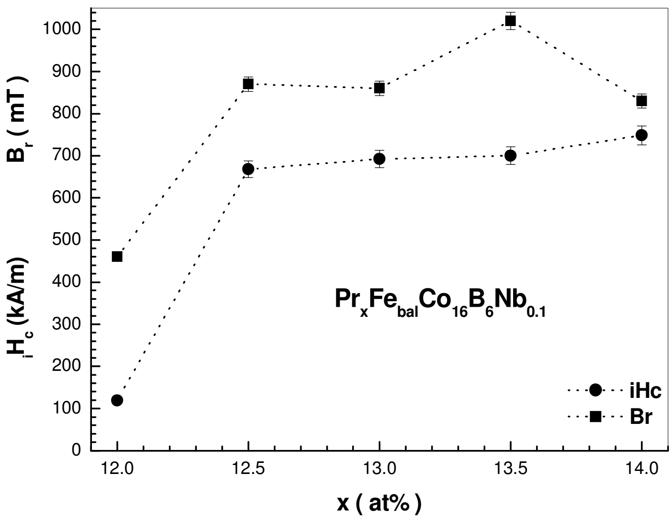

Fig. 6 - Remanence and coercivity versus Pr content for HDDR magnets.

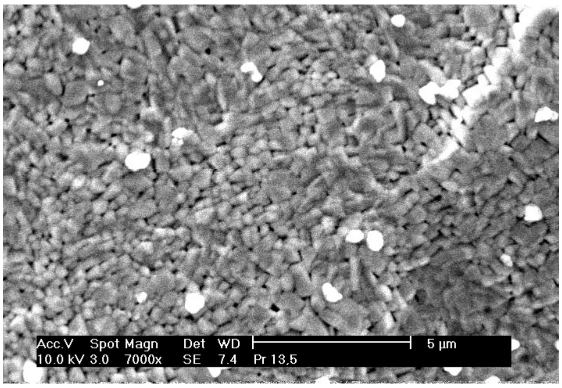

Fig. 7 - Secondary electron image of $Pr_{13.5}Fe_{bal}Co_{16}B_6Nb_{0.1}$ HDDR material.

Conclusions

$Pr_{13.5}Fe_{bal}Co_{16}B_6Nb_{0.1}$ HDDR material produced from annealed alloys yielded magnets with good overall magnetic properties. Therefore, under the present processing conditions the praseodymium content in these alloys should be around 13.5 at%. Grains in the HDDR material produced with the $Pr_{13.5}Fe_{bal}Co_{16}B_6Nb_{0.1}$ alloy were smaller than 1 µm. Annealing was effective to remove free iron in all studied alloys. The grain size of the matrix phase of the annealed alloys changed with praseodymium content.

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