Use of strontium ferrite powders in the production of hybrid rare-earth bonded magnets

Bruno Ferreira Antunes da Silva[1,a], Suzilene Real Janasi[2,b], Patrícia Brissi Santos[1,c], Daniel Rodrigues[2,d], Hidetoshi Takiishi[1,e]

[1]Instituto de Pesquisas Energéticas Nucleares, São Paulo, SP, Brazil

[2]Brats Indústria e Comércio de Produtos Metálicos Especiais, Cajamar, SP, Brazil

[a]brunoferansi@gmail.com, [b]suzilene.janasi@gmail.com, [c]pbsantos@ipen.br, [d]daniel@brats.com.br, [e]takiishi@ipen.br

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Abstract. This paper discusses the preparation of hybrid magnets produced from a mixture of commercial NdFeB ready to press powder (MQEP Magnequench - obtained by melt spinning), strontium ferrite, iron powder and reprocessed (by HDDR) NdFeB powders. The analyzed pieces were produced with different amounts of recycled and commercial powders by using uniaxial compaction at room temperature. A relationship between magnetic properties and microstructure was carried out based on the results obtained in a hysteresigraph, optical microscope and X-ray diffraction.

1. Introduction

Due to their excellent properties, rare-earth bonded magnets, particularly NdFeB, has been used in different applications as sensors and high performance electric motors. The computers market is nowadays the largest consumer of magnets based on NdFeB, followed by automotive market that has been growing up in recent years.

Even if magnets produced based on rare earth have excellent properties, the ferrite magnets, which have low magnetic properties, have lower production costs and are still widely used. Furthermore, ferrite magnets have better thermal properties compared to NdFeB as temperature coefficient of coercivity (TK K_{cJ}) [1]. Ferrite bonded magnets are ideal for low cost applications combined with precise and complex shapes. However, the magnetic properties of these magnets are the smallest between the commercial magnets. The bonded magnets of NdFeB are more costly but can offer excellent magnetic properties and cost-effective for many applications [2,3].

The thermal properties are the weakness of NdFeB, this means that these magnets cannot work at elevated temperatures [4]. Magnets produced by mixing of NdFeB and ferrite powders, called hybrids magnets, have better thermal properties than magnets produced purely with powders of NdFeB and can work at higher temperatures [5].

These hybrid magnets can fill the gap of magnetic properties between sintered strontium ferrite magnets and NdFeB sintered magnets [6]. The simultaneous use of different magnetic materials would enable the creation of a range of polymeric magnets. The mixture of NdFeB, ferrite, iron and recycled NdFeB can provide advantages such as producing magnets to meet different special requirements forming a new network of magnets with excellent dimensional tolerances, better mechanical and magnetic properties, and also relatively low cost, features that are not easily obtained with sintered magnets.

Due to these advantages, the applications of NdFeB and powder mixtures are still growing up. Applications of this kind of magnets in electric motors can promote miniaturization of the motors and also miniaturization of the devices drove by these motors [7].

The purpose of this work is to discuss the effect of the mixture of magnetic powders with different characteristics (iron, strontium ferrite and recycled NdFeB) in the magnetic properties of the resulting hybrid NdFeB bonded magnets.

2. Experimental Procedure

The samples investigated in this work were prepared from mixtures based on the isotropic commercial powder (Magnequench MQEP) with additives: iron powder, strontium ferrite powder and recycled NdFeB powder. The powders of NdFeB MQEP Magnequench and strontium ferrite have a mean particle size between 50 µm and 70 µm, both were received from the BRATS. The recycled powder was obtained by HDDR process, from commercial NdFeB sintered magnets. The mixtures of powders were made proportionately and pressed uniaxially without magnetic field orientation in a tool with 700 MPa. The samples had cylindrical shape with 1 cm^2 of area and are approximately 6 mm high. Finally the compressed magnets were cured in a tubular furnace for 9 hours at 190 °C under air.

Determination of structures and phase compositions were performed by X ray diffraction using Co Kα radiation. The hysteresis loops were measured in a Hysteresigraph KJS HG 500 with maximum field of 3 T at room temperature. Measurements were made in samples previously magnetized in a pulsed field of 3 T. During measurements, the magnetic field was applied parallel to the magnetization of the samples. The images of microstructures were obtained by optical microscopy (OM).

3. Results and Discussion

Recycled NdFeB powder used in these experiments was obtained via HDDR process from sintered commercial magnets with recombination temperature of 860 °C. The X ray diffraction pattern presented in Fig. 1 shows the presence of the phase $Nd_2Fe_{14}B$. Also it was observed the presence of another crystalline phase not yet identified, probably it is a neodymium-rich phase. Janasi et al. [8] obtained a similar result for recycled NdFeB obtained from sintered commercial magnets via HDDR process in lower recombination temperatures.

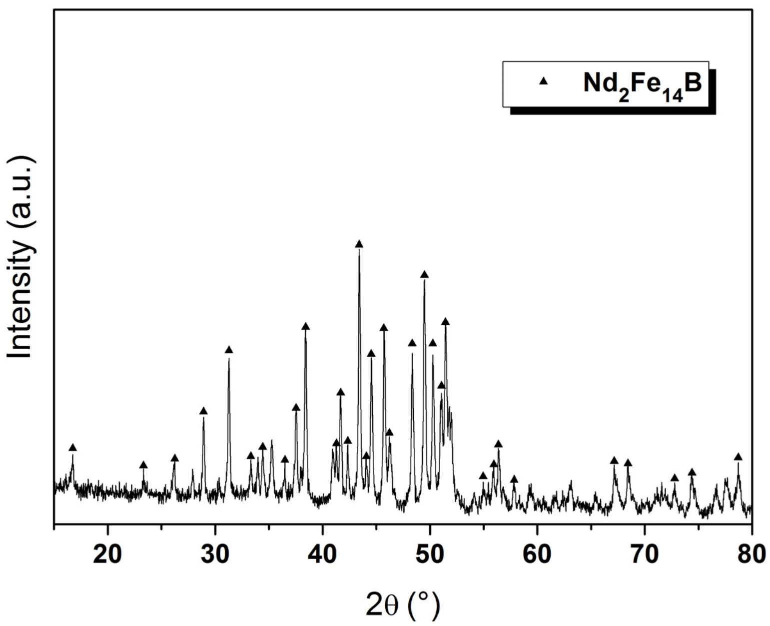


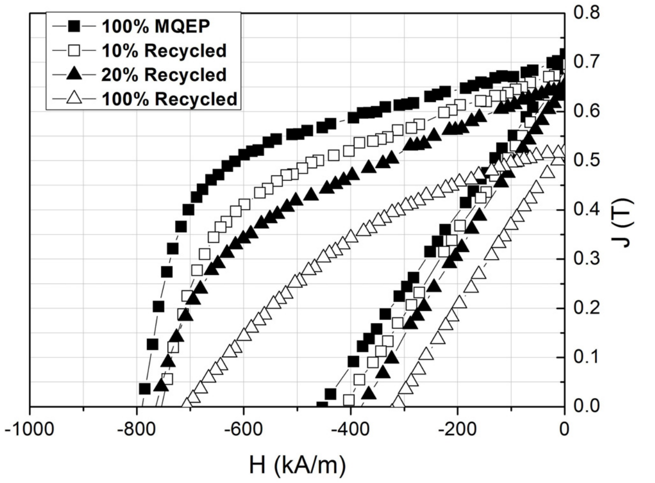
Fig. 1: X ray diffraction pattern of NdFeB recycled powders produced by HDDR.

Table 1 shows values of the magnetic properties and density obtained for the hybrid magnets prepared with different additives in different contents. As expected the density of the bonded hybrid magnets changed with the increasing of Sr ferrite and Fe contents, while for recycled NdFeB powder there were not significant changes on the density of the hybrid magnets.

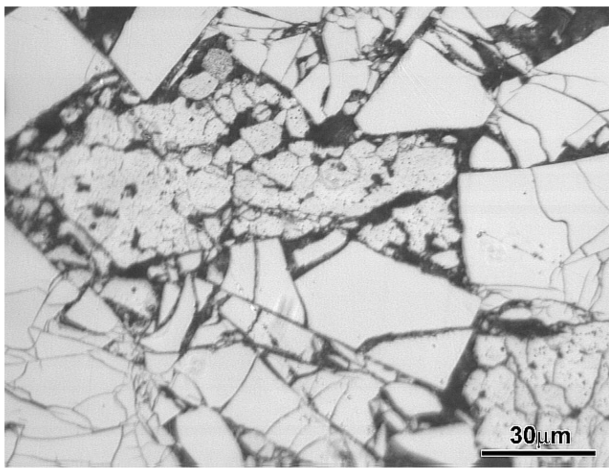
Table 1: Magnetic characteristics and density of hybrid magnets of NdFeB mixed with different additives

Additives % wt	J_r (T)	H_{cJ} (kA/m)	BH_{max} (kJ/m^3)	ρ (g/cm^3)
100% MQEP	0.71	789.4	79.8	5.75
100% Ferrite	0.19	147.2	5.0	3.59
100% Recycled	0.52	707.4	43.1	5.34
10% Fe	0.72	712.2	62.1	5.95
10% Ferrite	0.64	763.1	63.5	5.57
10% Recycled	0.68	749.6	71.4	5.81
20% Fe	0.74	588.9	46.1	6.04
20% Ferrite	0.58	755.2	49.9	5.35
20% Recycled	0.65	764.7	63.4	5.75

The demagnetizing curves obtained for the hybrid magnets using the recycled NdFeB powder produced by HDDR (Fig. 1) are presented in Fig. 2 (a). It is possible to observe that the addition of this recycled powder to the commercial NdFeB powder MQEP have a small effect in H_{cJ} and J_r. For the hybrid magnet containing 20 wt% of recycled material, occurs a small reduction in J_r (4%) and an increase in H_{cJ} (2%) in relation to the magnet prepared with 10 wt% of recycled NdFeB, whose microstructure is shown in Fig. 2 (b). This microstructure shows that the particles of recycled powder are smaller than the commercial MQEP NdFeB powder and are not homogeneously distributed into de MQEP NdFeB matrix.



(a)

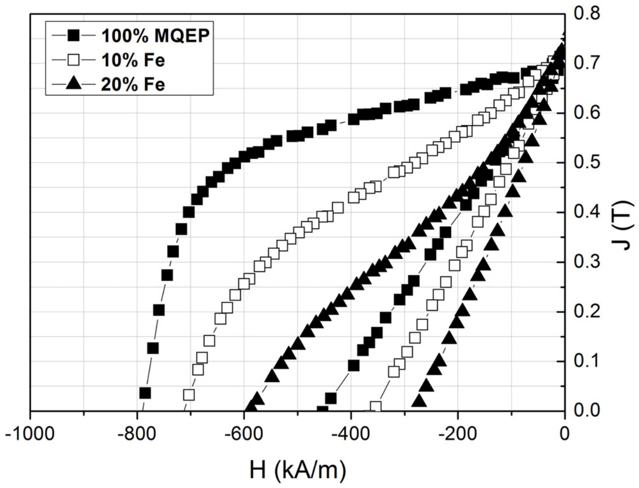


(b)

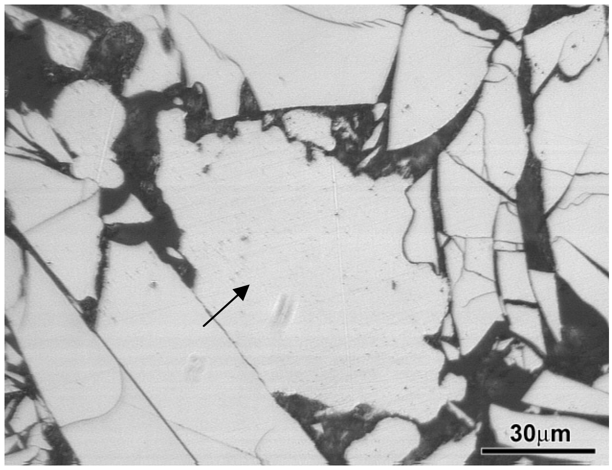
Fig. 2: (a) Demagnetizing curves of MQEP blended with recycled NdFeB powder and (b) the microstructure of the hybrid magnet with 10 wt% of recycled NdFeB powder.

There was an enhancement of J_r for MQEP NdFeB hybrid magnets containing MQEP NdFeB powders blended with Fe powder, as observed by the demagnetizing curves of Fig. 3 (a). The sample with 20 wt% of Fe powder has J_r 4% higher than the initial value of the 100 wt% MQEP magnet. Schneider et al. [1] obtained similar results for carbonyl-Fe additions. According to them, the enhancement in J_r is attributed to large interaction (exchange coupling) between the grains of the present two magnetic phases, a hard magnetic phase (NdFeB) and a soft magnetic one (iron). Increasing contents of Fe powder results in magnets with low values of H_{cJ}, due probably to the low H_{cJ} value presented by this soft magnetic phase [9].

The microstructure of the hybrid magnet prepared with 10 wt% of iron powder, presented in Fig. 3 (b), shows the presence of a large particle of iron powder at the center of the picture (indicated in the figure by the arrow).



(a)

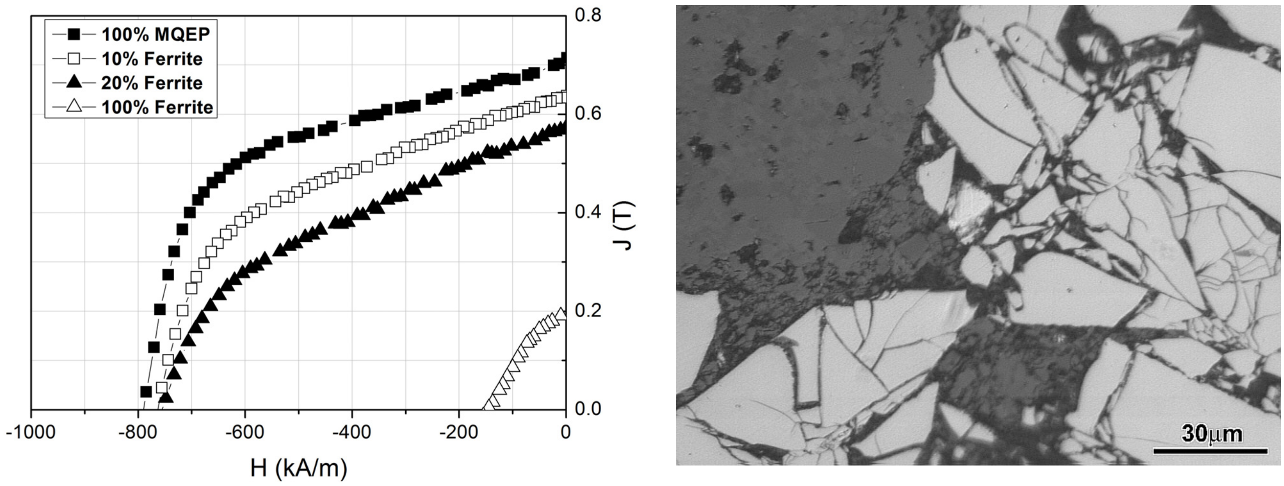


(b)

Fig. 3: (a) Demagnetizing curves of MQEP blended with iron and (b) the microstructure of the hybrid magnet with 10 wt% of iron powder.

Fig. 4 (a) shows the demagnetization curves of NdFeB hybrid bonded magnets prepared with additions of different amounts of strontium ferrite. In this case, the increase of strontium ferrite content decreases both J_r and H_{cJ}. This decrease is more pronounced for J_r (18%) than for H_{cJ} (3%) for the samples obtained with the addition of 20wt% of ferrite powder. Similar results for the hybrid magnet with 20 wt% of Sr ferrite were obtained by Schneider et al. [1], with values around 580 mT for J_r and 9 kOe (716 kA/m) for H_{cJ}.

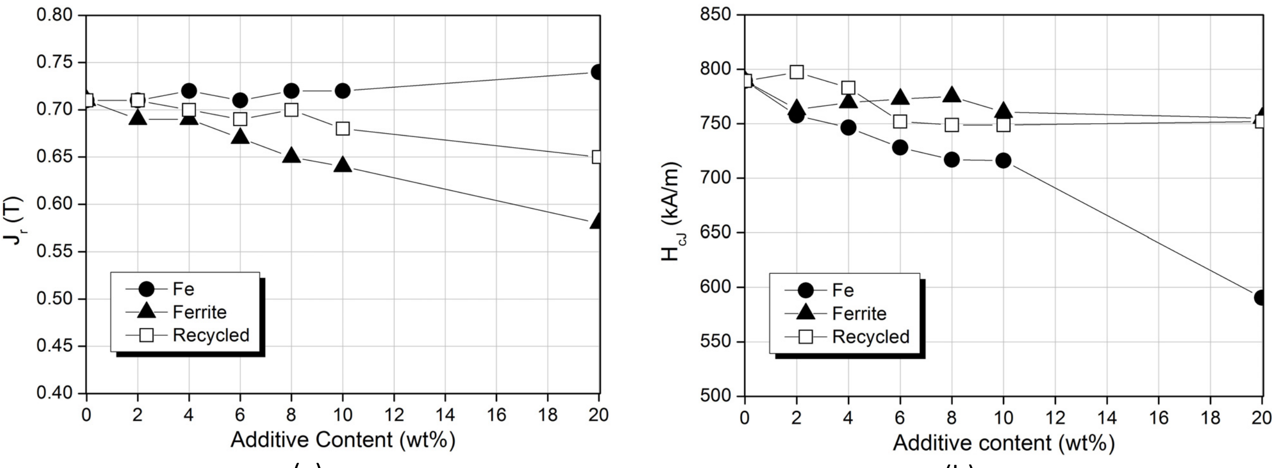
The microstructure of the NdFeB hybrid magnetic with 10 wt% of Sr ferrite, presented in Fig. 4 (b) is similar to that presented in Fig. 2 (b) for recycled NdFeB powder addition and shows clearly the presence of Sr ferrite powder (large darker regions). Although Sr ferrite powder is in small proportion in relation to NdFeB powder (matrix) in this hybrid magnet, and both powders present similar granulometric range, Sr ferrite powder is not homogeneously distributed in the NdFeB matrix, probably due to the ceramic characteristic of this powder (ferrite) or to a non homogeneous mixture of the powders.



(a) (b)

Fig. 4: (a) Demagnetizing curves for MQEP blended with strontium ferrite powder and (b) the microstructure of the hybrid magnet with 10 wt% of strontium ferrite powder.

Fig. 5 (a) and (b), compares the effect of the different additives and their contents on the magnetic properties of the resulting hybrid magnets based on MQEP NdFeB. It can be observed that the increase of Sr ferrite and recycled NdFeB powders contents reduces J_r, but for Fe additions this effect is inverse, i.e. J_r increases with the increase of iron content. While mixing with Sr ferrite and recycled NdFeB gives only a little reduction in H_{cJ}, increasing contents of iron reduces drastically the H_{cJ} values of the hybrid magnets. It seems that for iron additions the enhancement in J_r is correlated with a lowering in H_{cJ} and vice versa. This behavior was also observed by Schneider et al. [1].



(a) (b)

Fig. 5: Dependence of remanence, J_r (a) and coercivity, H_{cJ} (b) with the additives (ferrite, iron and recycled NdFeB powders) contents for hybrid bonded magnets based on MQEP NdFeB.

The changes observed with additions of strontium ferrite and recycled NdFeB powders to the NdFeB MQEP were more effective for Jr, with reduction ranging from 4% to 18%, while the results of H_{cJ} were little changed, with reductions between 3% and 5%.

Among the three additives investigated in these experiments, recycled NdFeB powder seems to be the more interesting, taking in account that there was only a small reduction in the magnetic properties of the hybrid bonded NdFeB magnet when this recycled powder was added to the commercial isotropic MQEP NdFeB.

4. Conclusions

It was observed especially in samples with iron contents that Jr improvements are correlated with the reduction of H_{cJ} and vice versa.

The magnetic properties displayed by the magnets produced with addition of recycled powders obtained via HDDR were interesting, indicating a possible future application for this type of material.

Adding powders with lower magnetic properties compared to NdFeB on the mixture, we obtain magnets with lower performance, but with adequate possibilities for several applications, and reduced production cost. Intermediate results for magnetic properties can be obtained with the preparation of these hybrid magnets.

A wide range of special values of J_r and H_{cJ} can be obtained with the production of bonded hybrid magnets tailored with mixtures of this type.

References

[1] J. Schneider, R. Knehans-Schmidt: Journal of Magnetism and Magnetic Materials 157 (1996). p. 27.

[2] X.F. Wang, D. Lee and Z.L. Jiang: Journal of Applied Physics 99, 08B513-1 (2006).

[3] D. Bueno-Báques, E. Padrón Hernandez, J. Matutes-Aquino, S.M Rezende and D.R. Cornejo: Journal of Alloys and Compounds 369 (2004), p. 158.

[4] Hua Zhenghe et al. Journal of Rare Earths 25 (2007), p. 336.

[5] D. Plusa, M. Dospial, B. Slusarek, U. Kotlarczyk and T. Mydlarz: Rev. Adv. Mater. Sci. 18 (2008), p. 541.

[6] D. Plusa, M. Dospial, B. Slusarek and U. Kotlarczyk: Journal of Magnetism and Magnetic Materials 306 (2006), p. 302.

[7] B. Slusarek, I. Dudzikowski: Journal of Magnetism and Magnetic Materials 239 (2002), p. 597.

[8] S.R. Janasi, B.F.A. da Silva, D. Rodrigues, F.J.G. Landgraf, H. Takiishi, M.F. de Campos: Proceedings of 19º Congresso Brasileiro de Engenharia e Ciências dos Materiais – CBECiMat (2010), Campos do Jordão, SP, p. 6261.

[9] B. D. Cullity, C.D. Graham: Introduction to Magnetic Materials, Second Edition, John Wiley & Sons, Inc., USA (2009)