Influence of Dy$_2$O$_3$ and Sn on the Structure and Magnetic Properties of NdFeNb Magnets

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Abstract

Addition of 2.0wt% Dy$_2$O$_3$ or 0.3wt% Sn proved to be very effective in improving the permanent magnetic properties of NdFeNbB magnets. Dy$_2$O$_3$ additions result in the increase in the $H_{ci}$ and temperature dependence due to formation of (NdDy)$_3$-rich phase and grain refinement of $\Phi$ phase. This improvement of the coercivity stability of the magnets from the addition of Sn is attributed to the smoothing effect of the Sn addition at the grain boundaries. The magnetic properties, the temperature dependence and Curie temperature of NdFeNbB with Dy$_2$O$_3$ and Sn combined addition were found to be considerably improved.

Keywords: NdFeNbB permanent magnets, magnetic properties, Dy$_2$O$_3$, Sn

1. Introduction

NdFeB permanent magnetic materials have enjoyed considerable attention because of their high magnetic properties. The NdFeNbB alloy was melted in vacuum induce furnace. The alloy ingot was broken and Dy$_2$O$_3$ and Sn was added before ball milling with gasoline to particle size of 3-5 µm. The powders were pressed in the 1.8T magnetic field. After isotropic pressing, the green compacts were then sintered at 1115°C for 1 hour in vacuum and subsequently heat treated at 580°C for 1h.

From Fig.1(a) we can see that the additions of Dy$_2$O$_3$ can be seen to result in a considerable increase of $H_{ci}$ and $H_{cb}$. On the other hand, $B_r$ slightly decreases with the addition of Dy$_2$O$_3$. The $(BH)_{max}$ slightly increases up to $x=1.5$wt% and then decreases with subsequent addition of Dy$_2$O$_3$ content. The alloys of NdFeNbB+$x$Sn in the range $x=0-0.6$ have been investigated and their magnetic properties are shown in Fig. 1(b). The addition of Sn up to 0.3wt% causes the value of $H_{ci}$ to increase, and further addition of Sn results in the decrease of said value. On the other hand, $B_r$ and $(BH)_{max}$ slightly decrease with the addition of Sn. The simultaneous addition of Dy$_2$O$_3$ and Sn to NdFeNbB shows the best temperature dependence, as shown in Table1. The temperature dependence of NdFeNbB with only Dy$_2$O$_3$ additions is greater than that of with Sn additions. According to the additions of Dy$_2$O$_3$ and Sn, the coercivity and the temperature dependence are greatly improved, as shown in Fig. 2(b).

It can be inferred that sintered NdFeNdB magnet is a multi-phase material consisting of $\Phi$ phase as matrix and NdFe$_2$B$_4$(\H phase), Nd-rich constituents, $\alpha$-Fe as minor phases as shown in Fig. 3. There are many small deposits distributed at the grain junctions and at the grain boundaries. From the EDAX analysis, we can deduce that Dy largely partitions to the Nd-rich phase, and less to the $\Phi$ phase. Sn mainly goes into the grain boundaries.

![Fig. 1. Variations in $B_r$, $H_{cb}$ and $(BH)_{max}$ of NdFeNbB+ $x$Dy$_2$O$_3$ and NdFeNbB+$x$Sn as a function of Dy$_2$O$_3$-concentration(a) and Sn-concentration(b)](image)

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Table 1. The magnetic properties of the magnets at room temperature

<table>
<thead>
<tr>
<th>Samples</th>
<th>$B_r / T$</th>
<th>$H_{ci} / \text{kA.m}^{-1}$</th>
<th>$(BH)_{\text{max}} / \text{kJ.m}^{-3}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>NdFeNbB (A)</td>
<td>1.13</td>
<td>656.0</td>
<td>230.5</td>
</tr>
<tr>
<td>NdFeNbB+2%Dy$_2$O$_3$ (B)</td>
<td>1.11</td>
<td>824.0</td>
<td>221.8</td>
</tr>
<tr>
<td>NdFeNbB+0.3%Sn (C)</td>
<td>0.94</td>
<td>1016.0</td>
<td>165.1</td>
</tr>
<tr>
<td>NdFeNbB+2%Dy$_2$O$_3$+0.3%Sn (D)</td>
<td>1.09</td>
<td>1024.0</td>
<td>214.4</td>
</tr>
</tbody>
</table>

Fig. 2. The hirr and temperature dependence of coercive field of the magnets.

Fig. 3. MFM images of NdFeNbB+2%Dy$_2$O$_3$+0.3%Sn.

References