Degree of Preferred Growth of Single Stage Hot Deformed NdFeB Magnets

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Abstract

The magnetic anisotropy is an important property for anisotropic NdFeB magnets. This paper introduced a simple and efficiency method to evaluate quantitatively the degree of alignment from X-ray different patterns. The magnetic anisotropy of single stage hot deformed NdFeB magnets was investigated with this method. The results of the orientation factors had a good identity with the remanence and maximum energy product.

Key Words: NdFeB magnet, SSHD, orientation factor
1. Introduction

Permanent magnets have much applications in modern life, such as in home appliances, speakers, office automation equipment, medical laboratory diagnostic test equipment, and so on. As a hardest permanent magnet, NdFeB magnet has been of great interest to manufacturers and researchers since its invention in 1983. To get high coercivity ($H_c$), remanence ($B_r$) and magnetic energy product ($\langle BH \rangle_{max}$) is the anticipate of the modern hard magnetic materials.

NdFeB powders for bonded magnet could be fabricated by two methods: melt-spinning and powder metallurgy techniques. The melt-spun ribbon of NdFeB alloy has equiaxed and randomly oriented Nd$_2$Fe$_{14}$B grains. And it has the smaller grain and better magnetic properties than the powders made from other method. In order to get higher performance NdFeB magnets, it is necessary to fabricate such material into anisotropy. One of highly effective methods of imparting anisotropic properties to isotropic powders is hot deformation. General hot deformation method includes two processes: hot press and die-upset step by step. A new and simple hot deformation method for fabricating anisotropic NdFeB magnet introduced by our laboratory in the recent years is named as the single stage hot deformation(SSHD) [1–5]. This method
simplifies the traditional hot deformation processing with one-step hot pressing and replacing sample die with Cu tube.

Many research results about single stage hot deformed NdFeB magnets have been reported [1~5]. In this study, a quantitative analysis for the magnetic anisotropy from X-ray diffraction patterns of such magnets will be discussed.

Magnetic anisotropy of hot deformed NdFeB magnets was regarded as the formation of texture along with the press direction. The degree of the orientation of the SSHD anisotropic NdFeB magnets was considered as to have the relationship with the intensity of the XRD patterns in (00L) directions. Based on Lotgering’s theory [6], the orientation factor that was used to express the degree of the orientation was calculated by the formula as follows:

\[
F = \frac{P - P_0}{1 - P_0} \quad (1)
\]

Here, \( F \): orientation factor;

\( P \): Lotgering factor:

\[
P = \sum I_{HKL} \cos \Phi / \sum I_{HKL}; \quad (2)
\]

\( P \): Lotgering factor for anisotropic magnet;

\( P_0 \): Lotgering factor for isotropic magnet;

\( \Phi \): Angle between HKL and 00L.
P denotes the total relative intensity of the anisotropy sample at (00L) orientation. P₀ denote the total relative intensity of the isotropy sample at (00L) orientation. P₀ is 0.56 that was calculated from the X-ray diffraction intensities of the perfectly isotropic NdFeB magnet, i.e. the data in JCPDS card. The value of the orientation factor is in the range of 0 and 1. As expected, large orientation factor F implies high alignment and good anisotropic magnetic properties.

2. Experimental

The start materials used were commercial isotropy MQPA, MQPB and MQPB+ ribbon powder (Made by magnequench Co.). Al, Zn powders with the particle size of 2 µm, and the purity of 99.9 % were added as lubricants. They were mixed with the MQ powders mechanically with the amount range from 0.2 to 1.0 wt%. The mix-powders were poured into copper tube and then pressed at $20.67 \times 10^6$ Pa and 700 °C. The magnetic properties were measured by a hysteresis graph system with a maximum field of 1600KA/m(20KOe) after premagnetization at 7200 KA/m(90 KOe). X-ray diffraction patterns were obtained with a RIGAKU X-ray analyzer with Cuk α radiation, wavelength of 1.54 Å, and the diffraction angle 2θ in the range form 20 to 70 degree.
3. Result and discussion

Fig. 1 shows the X-ray diffraction patterns of various SSHD samples which composition and magnetic properties are listed in Table 1. It is observed that there are two main peaks of (105) and (006) for Sample 1-4, and these samples are all from MQPA powder. It indicates that the texture in (105) and (006) directions are formed in these samples. Therefore, for the samples 5-6 made from MQPB and MQPB+ powders, there are several main peaks with nearly same intensities. That means random orientation of the crystallites and isotropic properties. Furthermore, the improvement of the magnetic properties after SSHD process is also not observed. It means that no magnetic anisotropy is formed in the case of these two kinds magnets. The reason for that is the amount of Nd in the magnets[7]. Nd content in MQPA powders is much more than that in the stoichiometric Nd$_2$Fe$_{14}$B alloy powder. When hot deformation process is carried out, liquid Nd-rich phase is formed and promotes grain rotation and alignment. For the MQPB or MQPB+ powder, however, almost little additional Nd is available to form the Nd-rich phase[8].

The results of orientation factors calculated by the formula 1 and 2 are also listed in Table 1. There is much difference of the orientation factors between various samples.
made from MQPA with different additives, or MQPB and MQPB+ ribbon powders. The magnetic properties, especially remanence and maximum energy product had the better identity with that of orientation factor. That is, the higher remanence or energy product is related with the higher orientation factor.

The relationship between remanence, maximum energy product, coercivity and the orientation factors are showed in Fig.2 ~ Fig.4, respectively.

From Fig.2 and Fig.3, it could be observed that the values of orientation factor have a good identity with those of remanence and maximum energy. But in Fig.4, the relationship between the orientation factor and coercivity is ruleless. Even though this result could not be explain clearly, the quantities evaluate of magnetic anisotropy by the degree of orientation from XRD patterns also can be thought as an available method for that the typical properties of the magnetic anisotropy, $B_r$ and $(BH)_{max}$ have good agreement with the orientation factors..

4 Conclusion

The magnetic anisotropy of single stage hot deformed NdFeB magnets has been evaluated quantitatively with the orientation factor from X-ray different patterns. The
results of the orientation factors have the good identity with the remanence and
maximum energy product.

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References

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Fig.2 The relationship between orientation factor and remanence

Fig.3 The relationship between orientation factor and maximum energy product

Fig.4 The relationship between orientation factor and coercivity
Table 1 The composition, magnetic properties and orientation factors for some SSHD samples

<table>
<thead>
<tr>
<th>Sample</th>
<th>Composition</th>
<th>$H_c$ (KOe)</th>
<th>$B_r$ (KG)</th>
<th>$(BH)_{max}$ (MGOe)</th>
<th>Orientation factors (F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MQPA+0.2(wt%)Al</td>
<td>8.6</td>
<td>11.6</td>
<td>29.5</td>
<td>0.676</td>
</tr>
<tr>
<td>2</td>
<td>MQPA+0.3(wt%)Al</td>
<td>8.9</td>
<td>12.6</td>
<td>36.9</td>
<td>0.795</td>
</tr>
<tr>
<td>3</td>
<td>MQPA+0.2(wt%)Al, +0.4 (wt%)Zn</td>
<td>13.4</td>
<td>12.3</td>
<td>36.0</td>
<td>0.756</td>
</tr>
<tr>
<td>4</td>
<td>MQPA+0.4(wt%)Zn</td>
<td>13.5</td>
<td>12.0</td>
<td>33.9</td>
<td>0.687</td>
</tr>
<tr>
<td>5</td>
<td>MQPB</td>
<td>10.9</td>
<td>8.9</td>
<td>16.0</td>
<td>0.317</td>
</tr>
<tr>
<td>6</td>
<td>MQPB+</td>
<td>12.4</td>
<td>8.6</td>
<td>16.0</td>
<td>0.297</td>
</tr>
</tbody>
</table>
Fig. 1 X-ray diffraction patterns of the SSHD NdFeB magnets
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