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Magnetic Viscosity of Sr-Na-Zn W-Type Hexagonal Ferrite Magnets

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Abstract. The temperature dependence of the magnetic viscosity coefficient (Sv), the activation volume (v), and the anisotropy field (H_A) were examined for Sr-Na-Zn W-type hexagonal ferrite magnet from 77 to 623 K. Samples with different coercive forces (H_cJ) were prepared, and the dependence of Sv and v on H_cJ was studied at 300 K. The results show that the temperature dependence of Sv is the same as that of H_cJ. The value of v is inversely proportional to H_A. The logarithm of Sv is proportional to log H_cJ and H_cJ is proportional to v^-1, as in the case of SmFe_11N_8 and SrM particles used in magnets and BaM fine particles used for high density recording media. They are considered to have a similar coercive force mechanism.

1. INTRODUCTION

In recent years, there has been a growing interest in W-type hexagonal ferrite which has a saturation magnetization (J_s) about 10% greater than that of M-type hexagonal ferrite. Many reports on the magnetism of W-type Hexagonal ferrites have been published [1,2], though studies on their magnetic viscosity are particularly few. The magnetic viscosity in permanent magnets belongs to the Jordan-type aftereffect phenomenon and is caused by thermal fluctuations [3,4]. It is known to depend on the magnetic viscosity coefficient (Sv), the irreversible susceptibility (Xirr) and the logarithmic time (ln t) [3-5]. When the change in magnetization from time t_1 to t_2 (∆J) is considered, Sv can be expressed using the following equation [3-5]:

\[ Sv = \Delta J / Xirr (ln t_2 - ln t_1) = k T / (\partial E/\partial H) = k T / v J_s \]  \hspace{1cm} (1)

where k is the Boltzmann constant, E is the activation energy, v is the activation volume and H is the magnetic field. This paper reports on studies of the temperature dependence of Sv and the anisotropy field (H_A) for a Sr-Na-Zn W-type hexagonal ferrite in the temperature range from 77 to 623 K. Also, the relationships between the coercive force (H_cJ) and both Sv and v were investigated at 300 K.

2. EXPERIMENTAL

Sr-Zn W-type hexagonal ferrite was investigated with 1.33 wt% Na_2O and 0.67 wt% SrO, which were added after semisintering treatment. Table 1 shows sintering conditions, grain size (D) and the magnetic properties of Sr-Na-Zn W-type hexagonal ferrite magnets. These samples were spherical with diameters of 4 mm. After the application of 1.6 MA/m, the samples were subjected to a constant external field (Hex) for 1000 s and ∆J was measured using a vibrating sample magnetometer (VSM). The apparent reversible susceptibility (Xrev) and the total differential susceptibility (X'tot), obtained by differentiating the demagnetizing curve with respect to Hex, were also measured using a VSM. Xirr can be expressed as X'tot - X'rev, where the prime indicates the values before correcting for the demagnetizing field. Corrections were made for the demagnetizing field using a demagnetizing factor of N=1/3. The uniaxial anisotropy constant (K_u) is obtained from unsaturated torque curves. For the torque magnetometer used, fields were available in the range of 0.8 to 2 MA/m. The coefficient of the sin^2 θ term was extrapolated to infinite H by plotting against 1/H. The uniaxial anisotropy constants and the anisotropy fields are related by H_cJ=2K_u/J_s.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Sintering conditions</th>
<th>D (μm)</th>
<th>J_s (T)</th>
<th>B_r (T)</th>
<th>H_cJ (kA/m)</th>
<th>(BH)_{max} (kJ/m^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>125°C x 0.5 h</td>
<td>0.5 - 1.5</td>
<td>0.407</td>
<td>0.335</td>
<td>138</td>
<td>19.3</td>
</tr>
<tr>
<td>B</td>
<td>1275°C x 1.0 h</td>
<td>1.1 - 2.0</td>
<td>0.407</td>
<td>0.349</td>
<td>82</td>
<td>15.3</td>
</tr>
<tr>
<td>C</td>
<td>1300°C x 0.5 h</td>
<td>1.8 - 4.0</td>
<td>0.456</td>
<td>0.355</td>
<td>36</td>
<td>5.4</td>
</tr>
<tr>
<td>D</td>
<td>1300°C x 1.0 h</td>
<td>3 - 40</td>
<td>0.456</td>
<td>0.414</td>
<td>18</td>
<td>2.4</td>
</tr>
<tr>
<td>E</td>
<td>1300°C x 2.0 h</td>
<td>3 - 60</td>
<td>0.456</td>
<td>0.417</td>
<td>14</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Table 1. Sintering conditions, grain size D and the magnetic properties of Sr-Na-Zn W-type hexagonal ferrites

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3. RESULTS AND DISCUSSION

Similar curvatures of the magnetic field dependencies of $\Delta J/ln(t_1 - ln t_2)$ and $X_{irr}$ were observed for Sample A and these had maximum values around the $H_{cj}$ point for each temperature. Figure 1 shows the magnetic field dependence of $S_v$ for Sample A obtained from Eq.(1), using the values of $\Delta J/ln(t_1 - ln t_2)$ and $X_{irr}$. The range in which $S_v$ stays constant with $H_{ex}$ is very wide at each temperature. For Sample A, $J_s$ and $K_a$ both decreased as temperature increased. The temperature dependence of $S_v$ and $H_{cj}$ is shown in Figure 2 for Sample A. The temperature dependence of $S_v$ is the same as that of $H_{cj}$, $S_v$ and $H_{cj}$ increase with the increase in the temperature between 77 K and 500 K, as in the case of SrM and BaM magnets[6]. The values of $S_v$ and $H_{cj}$ are maximized near 520 K and decrease suddenly after that. The temperature dependence of the anisotropy field ($H_{A}$) obtained using the values of $K_a$ is shown in Figure 3 along with the activation volume ($v$) calculated from $S_v$. The value of $v$ is inversely proportional to $H_{A}$ in the temperature range from 77 K to 623 K. Figure 4 shows the dependence of $S_v$ and $v$ on $H_{cj}$ at 300 K for Sr-Na-Zn W-type hexagonal ferrite samples A, B, C, D and E. The logarithm of $S_v$ is proportional to the logarithm of $H_{cj}$ and is proportional to $v^{-1}$, as in the case of Sm$_2$Fe$_{17}$N$_x$ and SrM particles used in permanent magnets and BaM fine particles used for high density magnetic recording media[7-9]. It is believed that they have a similar coercive force mechanism.

Figure 1. External field dependence of the magnetic viscosity coefficient $S_v$ for Sample A at various temperature.

Figure 2. Temperature dependence of coercive force $H_{cj}$ and the magnetic viscosity coefficient $S_v$ for Sample A in the temperature range between 77 and 623 K.

Figure 3. Temperature dependence of the anisotropy field $H_{A}$ and the activation volume $v$ for Sample A in the temperature range between 77 and 623 K.

Figure 4. Plots of the magnetic viscosity coefficient $S_v$ and the activation volume $v$ against coercive force $H_{cj}$ for Sr-Na-Zn W-type hexagonal ferrites.

References