

Development of Rare Earth-saving Magnet Using Localized Diffusion Method

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ABSTRACT

$\text{Nd}_2\text{Fe}_{14}\text{B}$ sintered magnets are used in the drive motors of hybrid, electric and other vehicles. A magnet in which rare earth content is reduced by means of a localized diffusion method has been developed in order to reduce the volume of dysprosium.

The distribution of the demagnetization fields in a motor is not uniform, so the necessary coercivity distribution for the magnets was quantified using Computer Aided Engineering (CAE). Then material specifications of the localized Dysprosium diffusion satisfied with this coercivity distribution was determined, and optimal manufacturing conditions including the position of Dysprosium diffusion were set. The coercivity distribution in the every position of the magnet using localized diffusion method was inspected. As a result, the magnet was satisfied with coercivity distribution demanded by CAE.

Furthermore, evaluation of motor characteristics, especially the demagnetizing characteristic concerned with Dysprosium reduction, showed this developed magnet to possess identical characteristics to a conventional magnet.

Dysprosium resources represent a particular issue among the rare earths more generally, and the technology developed in this project is able to reduce Dysprosium use in magnets by approximately 30% without compromising motor performance.

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INTRODUCTION

Electric automobiles are on the rise because they eliminate CO_2 emissions. More electric cars will mean an increased demand for magnets used in hybrid car motors⁽¹⁾. Figure 1 shows a motor of Honda Integrated Motor Assist (IMA) system. The motor uses $\text{Nd}_2\text{Fe}_{14}\text{B}$ sintered magnets with high magnetic flux density, contributing to increased torque and downsizing. When used at a high temperature, however, the magnetic flux density of these magnets lowers, which in turn reduces motor torque. This demagnetization characteristic is supplemented by $\text{Nd}_2\text{Fe}_{14}\text{B}$ sintered magnets containing Dysprosium (Dy), to replace part of the Neodymium (Nd). High anisotropy fields of $(\text{Nd, Dy})_2\text{Fe}_{14}\text{B}$ make it possible to use magnets at high temperatures.

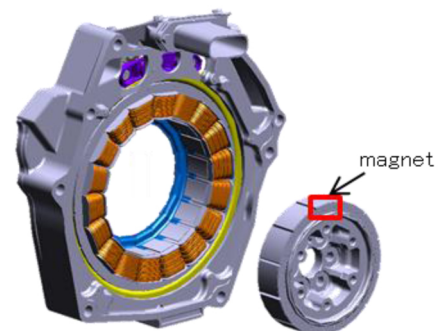


Figure 1. Motor of Honda IMA system

Rare earth metals including Dy are produced in only a few areas, with China currently accounting for more than 90% of the world production. Increase in demand and limited

production have caused a dramatic increase in Dy price 2011. Trends in rare earth prices are shown in Figure 2(2). Although the prices are currently on a downward trend, they are still just over 20 times higher than 5 years ago. Since it is predicted that Dy will dry up while demand continues(3), there is an urgent need to reduce Dy use without lowering demagnetization characteristics of magnets used in motors.

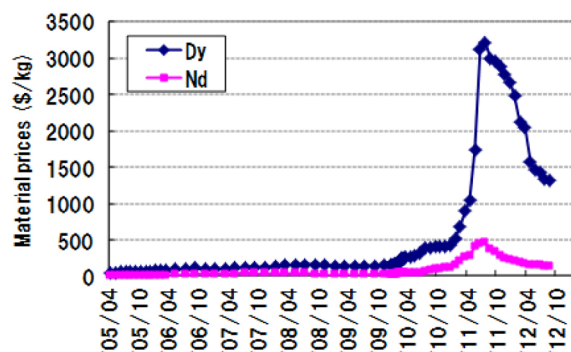


Figure 2. Material prices of Nd and Dy

ISSUES OF REDUCING DY USE

When the demagnetization fields that magnets in a motor receive exceed coercivity, the magnetic flux emitted decreases, and is not recovered even after demagnetization fields lower, causing motor induced torque to decrease. This phenomenon is called “demagnetization.” Because the coercivity of a $\text{Nd}_2\text{Fe}_{14}\text{B}$ sintered magnet decreases at a high temperature (Figure 3), demagnetization will occur when a certain temperature limit is exceeded. $\text{Dy}_2\text{Fe}_{14}\text{B}$ has anisotropy fields that are about two times stronger than those of $\text{Nd}_2\text{Fe}_{14}\text{B}$, and a Dy-added magnet thus has high coercivity and a higher temperature at which demagnetization occurs. Magnet temperature increases when the vehicle is going uphill or running continuously at a high speed. With a directly-reduced amount of Dy, coercivity will decrease and the Dy reduced magnet will not be suitable for a vehicle. It is therefore necessary to develop a technique to reduce Dy while maintaining demagnetization characteristics.

Grain boundary Dy diffusion has been proposed as a technique to reduce the amount of Dy used in an $\text{Nd}_2\text{Fe}_{14}\text{B}$ sintered magnet. Dy diffusion is the technique that thermally diffuses Dy from a magnet surface to inside of it(4) (5). The conventional Dy diffusion technique is that Dy has diffused all over the magnet surface, and a magnet with localized Dy diffusion has never been evaluated for use in a motor.

Our concept was to use a minimal amount of Dy only in areas where it is necessary to reduce the overall amount. That is to say we hypothesized that, by increasing the coercivity only where demagnetization is more likely to occur, we would be able to get the usual level of demagnetization characteristics. Figure 4 illustrates this concept. A technique to reduce Dy use and maintain motor characteristics needs to

be established. We reported the concept of this “Dy partially reduced magnet” using localized diffusion method previously(6). In this paper, our knowledge through the mass production development is mentioned.

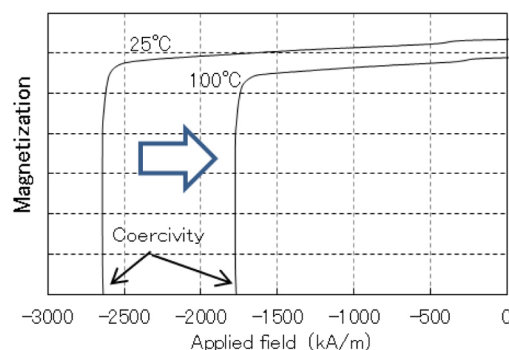


Figure 3. Temperature dependence of $\text{Nd}_2\text{Fe}_{14}\text{B}$ sintered magnet

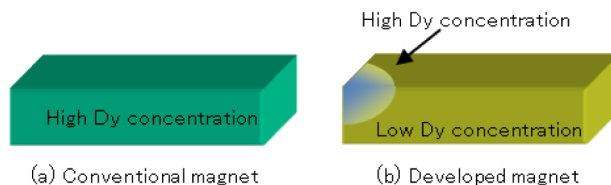


Figure 4. Concept of Dy partially reduced magnet

EXAMINATION OF DY REDUCTION

Using JMAG (by JSOL), electromagnetic field analysis software, we calculated demagnetization behavior of an IPM (Interior Permanent Magnet) motor and quantified the amounts of Dy needed in different areas. The electromagnetic fields of the motor were analyzed under demagnetization conditions to identify demagnetized areas. The results are shown in Figure 5. Demagnetization occurs not uniformly, but starts at the end of the magnetic pole on the circumference side of the rotor. This is due to the demagnetization fields which the magnet receives inside the motor are larger in corners.

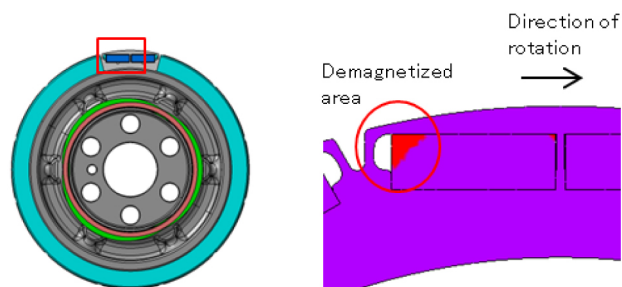


Figure 5. Calculated demagnetization area by electromagnetic fields in IMA motor

Coercivity needed in different areas, as quantified in electromagnetic field analysis, is shown in Figure 6.

Coercivity distribution needed in the motor is asymmetrical, as shown in Figure 6 (a). We aimed for symmetrical magnets [Figure 6 (b)] for easier motor assembly.

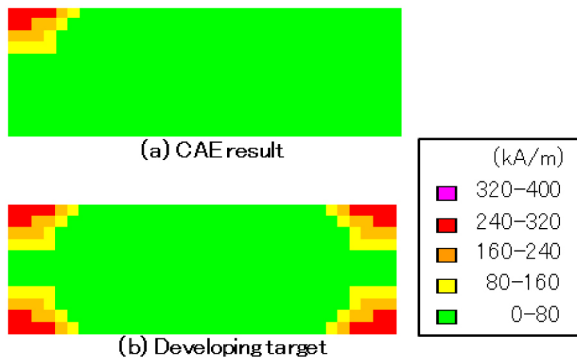


Figure 6. Increment of necessary coercivity distribution from lowest part in the magnet

MANUFACTURING PROCESS AND SETTING OPTIMUM CONDITIONS FOR MAGNETS USING LOCALIZED DY DIFFUSION

Manufacturing Process for Magnets using Localized Dy Diffusion

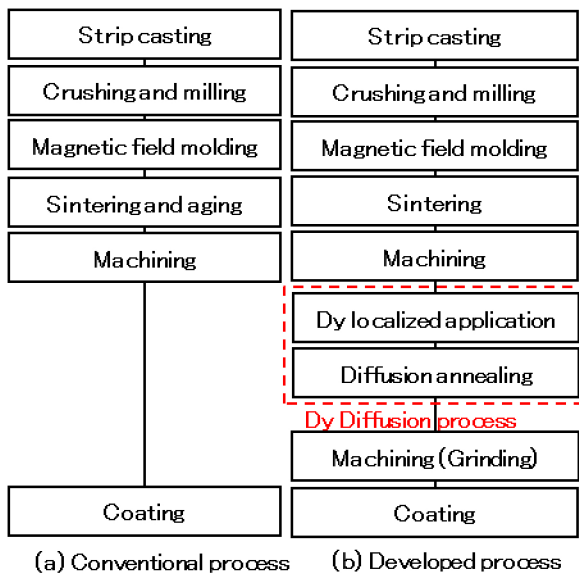


Figure 7. Difference of conventional process and developed Dy localized diffusion process

We examined a manufacturing process that diffuses Dy locally in areas where increment of coercivity is necessary. Figure 7 shows the differences between this process and the conventional magnet manufacturing process. We produced magnets that contained less Dy at the center, as shown in Figure 6 (b), then applied Dy only where it is necessary, and

thermally diffused it [Figure 7 (b)]. Figure 8 is an appearance image of magnet after Dy localized application. To apply Dy, we used the method that allows precise control of amounts and locations.

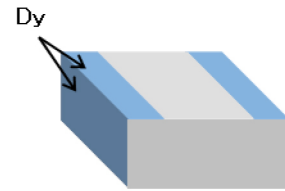


Figure 8. Appearance image of magnet after Dy localized application

Setting Optimal Conditions for Localized Dy Diffusion

Amount of applied Dy

Figure 9 shows the relationship between the amount of Dy applied to the magnet per unit area and increased coercivity. As the amount of Dy applied increased, the coercivity at corner areas also increased. This is believed to be due to Fick's Law, where diffusion speed in a substance depends on concentration.

Width of applied Dy

Figure 10 shows the relationship between the application width and increased coercivity. The increase of coercivity at corners (a) little influenced by application width (Figure 10 (a)), while the increase at the center (b) showed dependency [Figure 10 (b)]. These results indicate that, by changing the width of applied Dy, the range of coercivity increase can be controlled.

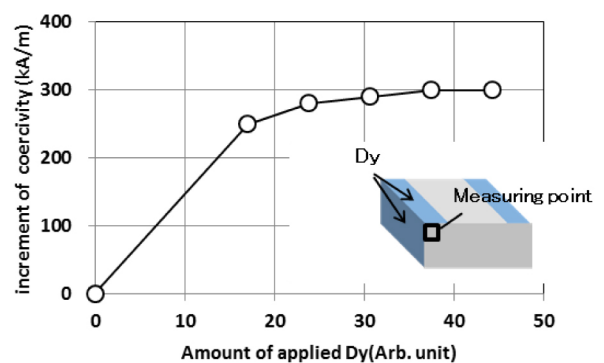


Figure 9. Relationship between Dy density and increment of coercivity