

## Electrochemical Behavior of Nd-Fe-B Permanent Magnetic Alloys with Co Addition

Satoshi Sunada\*, Yasuhiro Akasofu\*, Yuji Kaneko\*\*  
and Kazuhiko Majima\*

\* Department of Material System Engineering and Life  
Science, Faculty of Engineering, Toyama University  
Gofuku 3190, Toyama, 930-8555, Japan

\*\*Sumitomo Special Metals Co. Ltd., 2-15-17 Egawa,  
Shimamoto-cho, Mishima-gun, Osaka, 618-0013, Japan

It is well known that permanent magnets based on intermetallic compounds composed of rare earth elements and transition metals exhibit exceptionally excellent magnetic properties. Therefore, they have been in practical use for numerous applications such as devices in consumer electronics, computer peripherals, acoustics, magnetic resonance, biomedical and automation. Among these magnets, particularly a commercially available Nd-Fe-B magnet exhibits a maximum energy product,  $(BH)_{\max}$  higher than  $350 \text{ kJ/m}^3$ , and hence, it occupies a leading position today. However, it is at the same time notorious for its poor corrosion resistance. The corrosion causes surface degradation and thereby deteriorates the magnetic properties significantly. Generally, the Nd-Fe-B permanent magnet has been produced by the liquid phase sintering process according to the liquidus line in Nd-Fe-B ternary phase diagram. As a result, this magnet is composed of the matrix phase of  $\text{Nd}_2\text{Fe}_{14}\text{Ba}$  (2-14-1 phase), and the grain boundary phases of non-magnetic  $\text{Nd}_{1.1}\text{Fe}_4\text{B}_4$  (boron-rich phase) and Nd-rich phase. Therefore, it is necessary to investigate the corrosion behavior of these phases individually.

In this study, using neodymium metal (95 % of purity), electrolytic iron (99 % of purity) and boron (99 % of purity), the alloys corresponding to  $\text{Nd}_{11.8}\text{Fe}_{8.2.3-x}\text{Co}_x\text{B}_{5.9}$  (2-14-1 phase with Co) with different  $x$  and the various R(Rare earth metals)-TM(Transition metals) compounds corresponding to boundary phases were prepared by using a high-frequency induction furnace. The  $\text{Nd}_{11.8}\text{Fe}_{8.2.3-x}\text{Co}_x\text{B}_{5.9}$  alloys were homogenized at 1353 K for 21.6 ks. The constituent phases were identified by X-ray diffraction and EPMA. Electrochemical methods were performed as follows. The specimen with the dimension of 50 mm in length, 15 mm in width and 2 mm

in thickness was polished with No.2000 grit water-proofed abrasive paper followed by washing in alcohol and subsequent ultrasonic rinsing in acetone. The specimen electrode was coated with silicon rubber leaving an uncoated area of 15 x 5 in mm. Testing solution should be prepared considering that the specimen described above has low corrosion resistance. In our experiment, therefore, 2.5 %  $\text{Na}_2\text{SO}_4$  aqueous solution of pH 6.4 was used, and the potentiodynamic polarization curves and the Nyquist plots were obtained.

It was clarified by the potentiodynamic polarization curves that the corrosion potential shifted to nobler state with an increase of the substitution amount of Co. This indicates an increase of the corrosion resistance. The Nyquist plots show that measurements taken at high frequencies reveal the solution resistance, while measurements taken at low frequencies show both solution and charge transfer resistances, and hence the difference between low and high frequencies represents the charge transfer resistance. Therefore, this difference ( $R$ ) is inversely proportional to the corrosion rate. In this study, the value of  $R$  increased with increasing amount of the additional Co, which shows the improvement of the corrosion resistance for the  $\text{Nd}_{11.8}\text{Fe}_{8.2.3-x}\text{Co}_x\text{B}_{5.9}$  specimens by Co addition. The comparison of free corrosion potentials between R (Rare earth metals)-TM (Transition metals) compounds and the  $\text{Nd}_{11.8}\text{Fe}_{8.2.3-x}\text{Co}_x\text{B}_{5.9}$  alloys with Co gave the following results. Assuming that free corrosion potential for Nd-rich phase is equal to that for Nd-metal phase, difference of the corrosion potential between main phase and the grain boundary phase would be 0.77 V. Considering the fact that the difference of the corrosion potential between the main phase and B-rich phase would be 0.16 V, the difference of the free corrosion potential values between the main phase and Nd-rich phase would be the driving force of the corrosion for the Nd-Fe-B permanent magnets. Alternatively, the free corrosion potential of  $\text{Nd}_3\text{Co}$  phase is -0.655 V and that for  $\text{NdCo}_2$  is -0.635 V. The difference of the free corrosion potentials between 2-14-1 phase and these grain boundary phases in study is much smaller than that between 2-14-1 phase and Nd-rich phase, which indicates the improvement of corrosion resistance for the Nd-Fe-B permanent magnets.