

Electrochemical response of permanent magnets in different solutions

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Abstract

Materials for permanent magnets like barium ferrites and Alnicos and more recently Nd–Fe–B based magnets have found a wide range of industrial applications. However, corrosion can be a serious problem for these materials. The present research work is devoted to analyse the electrochemical response of magnetic materials like Nd–Fe–B and Alnico. Both materials were tested under three different electrolytes at room temperature. The results showed that, for a given material exposed to the various solutions, their corrosion potentials varied slightly. However, a comparison between both materials showed significant differences in corrosion potentials. Further, differences in corrosion rates of about four orders of magnitude were recorded. So far, the Nd–Fe–B material disclosed the best corrosion resistance.

Keywords: Potentiodynamic polarisation; Corrosion rates; Permanent magnets.

Introduction

Corrosion is a metal–environment reaction and often leads to degradation in physical and mechanical properties of metallic components. It is therefore essential to control corrosion. This can be done by altering aspects related to the metal or the environment, or by introducing a barrier between the metal and the environment. It is often essential to determine the corrosion behaviour of new material/alloy systems in specific environments to evaluate their susceptibility and therefore the need to be



protected. Hence, attempts are in progress to characterise their corrosion behaviour and develop protective coatings.

Alnico magnets are comprised of elements such as aluminum, nickel and cobalt (may include trace amounts of iron, copper and titanium), which possess an excellent temperature stability and high residual induction. Materials for permanent magnets like Alnicos are highly resistant to corrosion. However, its low coercive force limits its applications in many cases.

The Nd–Fe–B alloy provides the highest maximum energy product and remains currently available. As indicated by its name, this material contains iron and boron, two elements that are readily available. Neodymium–iron–boron is less expensive than a samarium–cobalt material, which are more common components for magnets alloys, but of higher cost. Collectively known as rare earth magnets, samarium–cobalt (SmCo) and neodymium–iron–boron (Nd–Fe–B) magnets are alloys of the lanthanide group of elements.

The Nd–Fe–B permanent magnets have assumed an important position due to their outstanding magnetic properties with maximum energy products, $(BH)_{max}$, as high as 48 MGOe, leading to a substantial technical and economic impact on the permanent magnet industry [1,2]. These magnets have found wide use in automobiles, personal computers, consumer electronics, computer peripherals, acoustics, office automation, magnetic resonance image and some other commercial products. However, the temperature stability of Nd–Fe–B magnets is not as good as the stability of Sm–Co

magnets. Thus, the magnetic performance of Nd–Fe–B magnets will deteriorate rapidly above about 180 °C.

In last years, efforts have been done to increase the magnetic properties of this material, based on evolution of corrosion resistance. In this kind of materials, corrosion occurs superficially if no coating is provided for protection, then oxygen diffuses inside the magnet, causing metallurgical changes on their surface layer [3].

Once the magnet is oxidised, the surface layer will show a lower intrinsic coercivity and this region is easily demagnetised. Due to the coercivity of the Nd–Fe–B magnets, they have to be designed very thin. Therefore, this increases the relation area to volume and then corrosion might be a problem.

A traditional corrosion measurement technique like potentiodynamic polarisation scan was used to provide information about corrosion rates, which are found by obtaining the corrosion current densities, i_{corr} , from using the Tafel extrapolation with the corrosion potentials, E_{corr} , in the polarization curves. Corrosion potential measurements are useful since they can provide information on the tendency of a material to corrode.

The aim of the present work was to study the corrosion performance of two important permanent magnets, Alnico and Nd–Fe–B; exposed in distilled water, sulphuric acid 1N and Ringer's solution at room temperature.

Experimental procedure

Electrochemical measurements of Nd–Fe–B and Alnico specimens were carried out at room temperature using the potentiokinetic polarisation technique [4] in a



potentiostat/galvanostat instrument [5]. The potentiokinetic polarization scans were carried out according to the ASTM G5-94 standard. Three solutions were studied: 1N sulphuric acid, Ringer's solution (NaCl 9 g, KCl 0.425 g, CaCl₂ 0.119 g, NaHCO₃ 0.1 g in 1 l of aqueous solution), and distilled water. All solutions were deaerated. A constant potential sweep rate of 0.6 V/h was used in all experiments. All potentials were measured with respect to a saturated SCE (0.244V versus SHE at 25 °C) as reference electrode. Two parallel graphite rods served as counter electrode for the current measurements.

Results and discussion

Table 1 shows the chemical composition of the supermagnet NdFeB and the Alnico magnet. The potentiodynamic polarisation curves for the magnetic materials are shown in Fig. 1. For each material, there was a small shift in the open circuit corrosion potential as the test solution was changed.

The corrosion rates were calculated using the Stern–Geary [6] relationship as shown in Eq. (1)

$$i_{\text{corr}} = \frac{\beta}{\Delta E / \Delta I} = \frac{\beta}{R_p} \quad (1)$$

where β is the Stern–Geary constant, ΔE the potential gradient, ΔI the current gradient and $\Delta E / \Delta I$ is the polarization resistance (R_p) (linear polarisation resistance slope).

Table 2
Results of potentiodynamic polarisation scans and calculated corrosion rates for both materials

Electrolyte		Materials	
		Supermagnet NdFeB	Magnet Alnico
Distilled water	E_{corr} (mV)	-70	-859
	i_{corr} (mA/cm ²)	1.13×10^{-5}	5.07×10^{-1}
	Corrosion rate (mm per year)	1.31×10^{-5}	5.86
Sulphuric acid 1N	E_{corr} (mV)	-47	-857
	i_{corr} (mA/cm ²)	1.26×10^{-5}	6.14×10^{-1}
	Corrosion rate (mm per year)	1.46×10^{-4}	7.1
Ringer's solution	E_{corr} (mV)	-105	-876
	i_{corr} (mA/cm ²)	1.53×10^{-5}	6.71×10^{-1}
	Corrosion rate (mm per year)	1.77×10^{-4}	7.76

The Stern–Geary constant is calculated from the anodic (b_a) and cathodic (b_c) Tafel slopes, as shown in Eq. (2)

$$\beta = \frac{b_a b_c}{2.3(b_a + b_c)} \quad (2)$$

In general, the sulphuric acid and Ringer's solutions were more aggressive electrolytes than distilled water, i.e. the corrosion rate increased in the presence of a more aggressive solution. Table 2 shows the results derived for E_{corr} , i_{corr} and corrosion rates values for the supermagnet Nd–Fe–B and the Alnico magnet in the various solutions. For the former material it was observed (Fig. 1a) that the values of E_{corr} in distilled water are slightly less negative than that recorded for the of the Ringer's solution, and the corrosion rates values are smaller than those derived in other solutions, with the Ringer's solution producing the highest corrosion rates. From Fig. 1b,



the electrochemical behaviour of the Alnico magnet in all the solutions tested is somewhat different from the Nd–Fe–B magnet, and it can be seen that the anodic and cathodic polarisation curves are not displaced from their corrosion potentials as was observed for the Nd–Fe–B magnet in Fig. 1a. It can be seen that the anodic behaviour for the sulphuric acid and Ringer's solutions is quite similar, and it is noted a passivation-like region at more positive potentials after a big current density demand. The Alnico magnet exhibited the most active E_{corr} values ranging from -857 to -876mV .

Table 1
Chemical composition (wt.%) of the materials used in this work

Materials	Fe	Co	Ni	Al	Ti	Cu	Nd	B	Nd	Si
NdFeB	71.62	0.034	–	–	–	–	–	1.016	26.79	0.059
Alnico	37.5	35.0	12.6	6.75	4.5	2.7	0.5	–	–	0.45

The lower corrosion rates recorded for the Nd–Fe–B specimens could be related with the rare earth content i.e. the Neodymium ensuring a high local concentration of the active element modifying in some way the oxide film/material interface thus protecting the material. This deserves further attention. Other investigations have focused their work on the effect of surface coatings, including nickel, zinc and gold coatings on the corrosion performance of NdFeB magnetic materials [7].

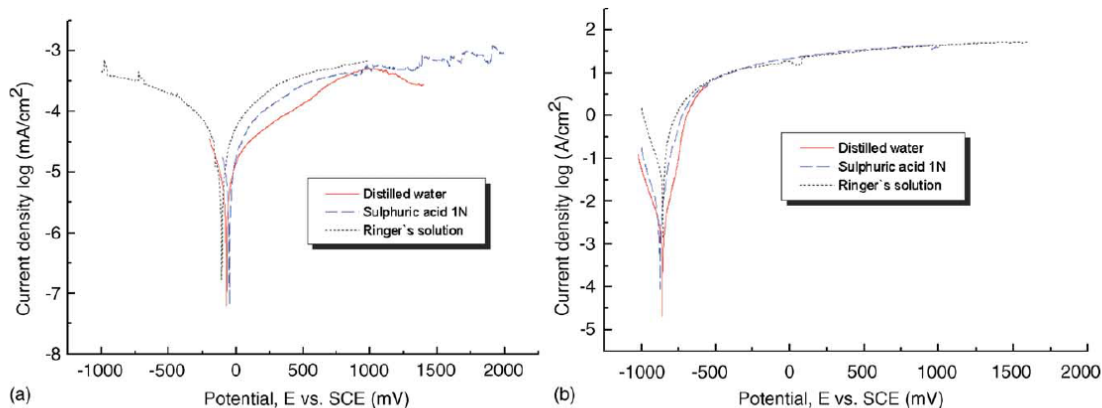


Fig. 1. Potentiodynamic polarisation curves for (a) Nd-Fe-B supermagnet and (b) Alnico magnet.

Conclusions

Polarisation curves offers a suitable alternative in order to evaluate the corrosion rate of materials exposed to different electrolytes; and be successfully used to evaluate the main corrosion parameters.

From the results obtained from the potentiodynamic polarization curves, it could be observed that an increase in current density causes an increment in the corrosion rate.

The corrosion rate of Alnico was about four orders of magnitude greater than that of Nd-Fe-B.

Overall, the highest corrosion rates were obtained when using the Ringer's solution, irrespective of the material used.

We believe that the present results represent a contribution in the study of the electrochemical behaviour of magnetic materials under corrosion conditions

It is important to recognise that further work is required to access the corrosion resistance of different types of materials and coatings and the effect of parameters such as chemical composition, porosity and superficial roughness.

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