

# Corrosion Behaviour of a Commercial NdFeB Magnet in Various Solutions

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**Abstract:** The corrosion behaviour of a commercial NdFeB magnet was investigated in various solutions by means of electrochemical methods. The test solutions used consisted of diluted  $H_2SO_4$  (0.05 M and 0.005 M), 10 % (wt)  $H_3PO_4$ , distilled water and  $NaH_2PO_4$  (0.15 M). The polarization curves of the magnet indicated the formation of a protective layer only in the  $NaH_2PO_4$  (0.15 M) solution. An active-passive transition was observed in the phosphoric solution but the current densities after the transition were large enough to indicate it as a highly protective passive layer. The corrosion current densities of the magnet in the sulfuric acid solutions were large and a limiting current density was reached during the anodic polarization in both sulfuric solutions. In distilled water the polarization curve suggested the occurrence of crevice corrosion.

## INTRODUCTION

Permanent magnets based on Rare Earth (RE) (RE = Nd, Pr), Iron and Boron present excellent magnetic properties. However, they are very susceptible to corrosion, which has been partially attributed to the presence of multiple phases in their microstructure.

The complex microstructure of RE-Fe-B magnets is composed of three main phases. The main magnetic phase is surrounded by more active phases which causes susceptibility to intergranular corrosion. Intergranular attack might lead to the detachment of grains and consequently disintegration of the material [1-4]. This would result in the deterioration of the magnetic properties and of the performance of other components in the proximity due to loose corrosion products [5-7].

The efforts made to improve the corrosion resistance of these materials have been concentrated on two main areas, the use of coatings to protect the magnet [1-4] and the addition of minor alloying elements to the alloy [8-12].

The improvement in the corrosion resistance by alloying elements usually results in modification of magnetic properties, thus the magnet composition is limited by the requirement of good magnetic properties. The corrosion characteristics of the substrate is known to affect the performance of the coated material and as such it is essential to study their behaviour in bare conditions to understand their response when coated and exposed to corrosive environments.

The aim of this study was to investigate the corrosion behaviour of a commercial permanent magnet by means of electrochemical techniques.

## EXPERIMENTAL

The magnet used in this investigation was a commercial NdFeB magnet (Crumax) provided by Crucible Materials Corporation.

The electrochemical techniques used consisted of the measurement of the open circuit potential as a function of immersion time and potentiodynamic polarization curves. The test solutions adopted were diluted  $H_2SO_4$  (0.05 M and 0.005 M), 10 % (wt)  $H_3PO_4$ , distilled water and  $NaH_2PO_4$ , (0.15 M). In

industrial atmospheres  $H_2SO_4$  is a main component which causes corrosion. Phosphoric acid was employed in the corrosion tests since it can be used for surface preparation before coating application. The concentration adopted (10 wt %) was chosen for comparison reasons with the literature[8]. Distilled water was also used to investigate the behaviour of the magnet in humid conditions.

The specimens were prepared by cold mounting in epoxy resin, followed by surface grinding with silicon carbide paper up to grade 1000. Immediately after surface preparation, the specimens were immersed in the test solutions and the open circuit potential (OCP) was measured using a high impedance voltmeter. After approximately one hour of immersion the specimens were polarized at a sweep rate corresponding to 1mV/s initially into the anodic direction (direct direction) the direction of polarization being reversed at potentials corresponding to approximately 500 mV (SCE) for the  $H_3PO_4$  and  $H_2SO_4$  solutions, and to around 1500 for the distilled water and .

## RESULTS AND DISCUSSION

The dislocation of the open circuit potential of the magnet as a function of immersion time in the various solutions used is presented in figure 1. It can be seen in this figure that the potential moves into the direction of more active potentials for both sulfuric acid solutions (0.05 M and 0.005 M), indicating the attack of the magnet. The potential was somewhat stable after periods corresponding to 1000 s and 3000 s in the 0.05 M and 0.005 M solutions, respectively, being more active in the less concentrated solution.

A dislocation of the potential into the negative direction was also observed for the magnet immersed in distilled water, indicating the attack of the magnet in this environment.

The potential of the magnet immersed in the phosphoric acid solution dislocated initially to more noble potentials, suggesting the formation of a protective layer on the surface. However, subsequently it moved into the negative direction implying that the layer formed was not very protective. On the other hand, the magnet immersed in the hydrogen sodium phosphate solution had its potential dislocated continuously into the positive direction attesting the formation of a protective layer.

Figure 1 shows that the magnet tested was fairly stable after 3000 seconds of immersion in all the solutions used. The polarization tests were carried out after one hour of immersion.

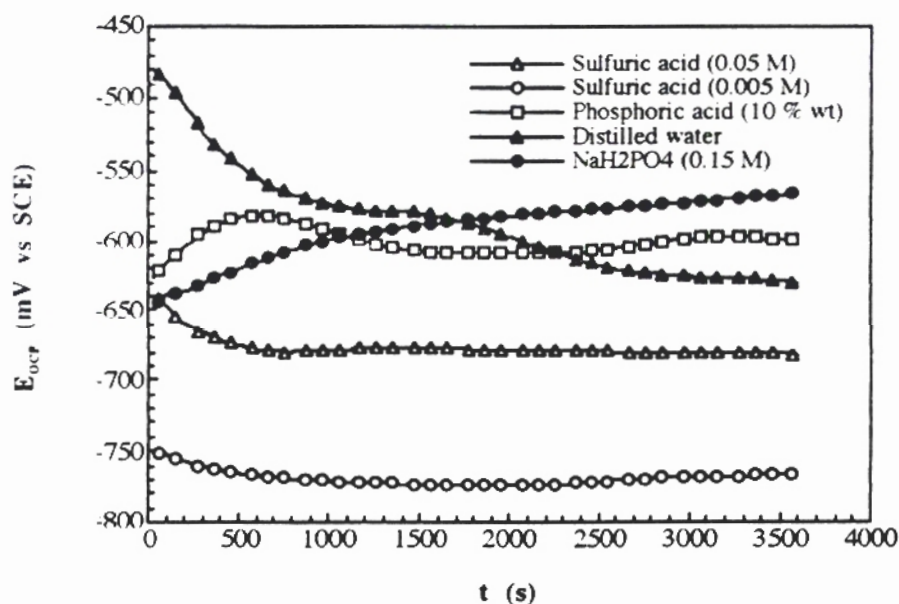


Figure 1 - Open circuit potential of the magnet versus immersion time.

The anodic polarization curves corresponding to the magnet in the sulfuric solutions used are shown in figure 2. These curves demonstrate that the formation of a passive layer does not occur in the sulfuric acid solutions used. In fact, a limiting current density ( $i_{L_1}$ ) is reached at potentials of approximately -200 mV (SCE) in these sulfuric solutions. The  $i_{L_1}$  values corresponding to 0.05 M solution ( $10^4$  A/cm<sup>2</sup>) were larger comparatively to that in the 0.005 M solution ( $4 \times 10^3$  A/cm<sup>2</sup>). The larger limiting current density for the more concentrated solutions was expected since  $i_L$  values are directly dependent on the concentration of the solution.

The polarization curve (direct and reverse direction) corresponding to the magnet immersed in the phosphoric acid solution is shown in figure 3. An active-passive transition can be seen in this figure at potentials about 100 mV (SCE). The current densities at the passive region were too large (around  $6 \times 10^4$



$A/cm^2$ ) to be typical of a protective passive layer. This is likely to be related to the formation of a phosphate on the surface which hinders the dissolution of the magnet underneath it. Two anodic peaks can be noticed on the reverse curve at potentials of approximately 250 mV (SCE) and 50 mV (SCE). These peaks could be related to the presence of the various phases in the magnet.

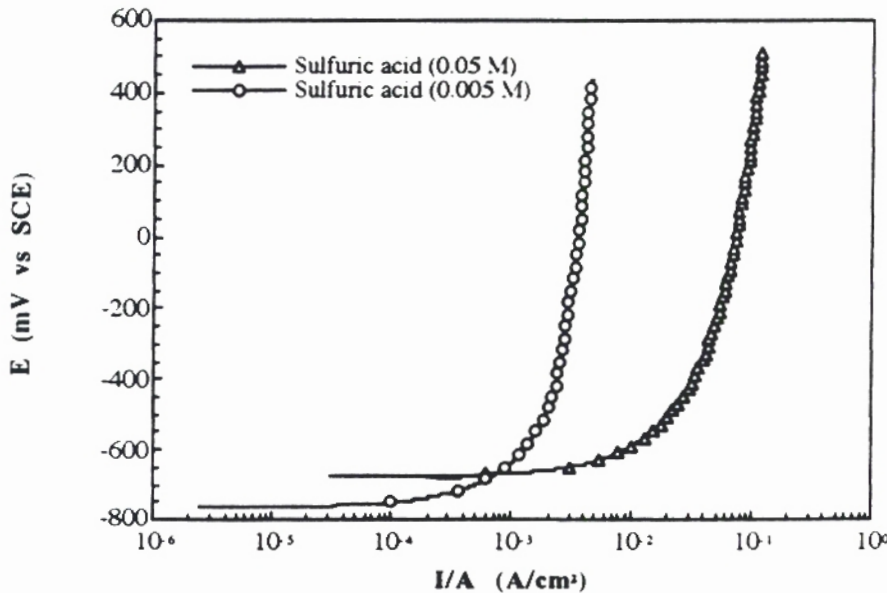


Figure 2 - Polarization curves of the magnet tested in two sulfuric acid solutions.

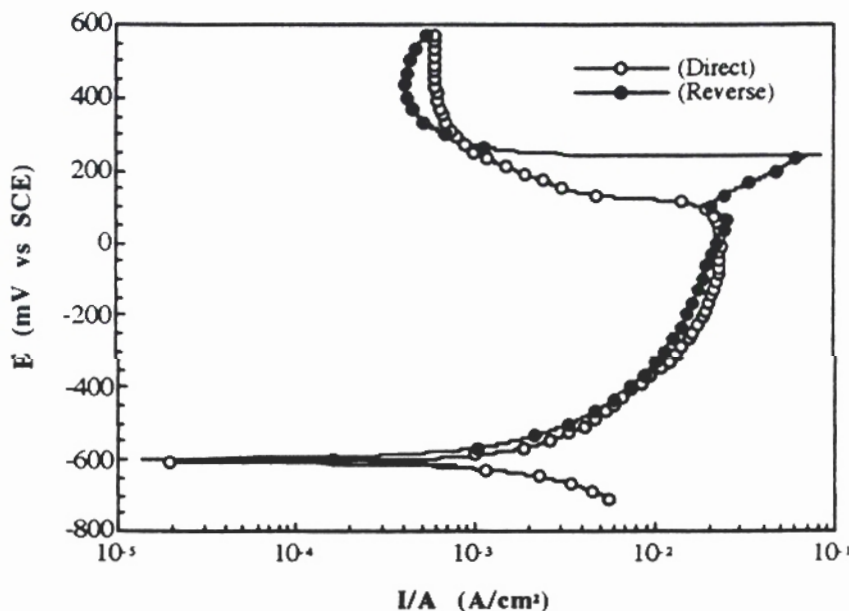


Figure 3 - Polarization curve of the magnet immersed in  $H_3PO_4$  (10 wt %) solution.

The polarization curves of the magnet exposed to distilled water and  $NaH_2PO_4$  (0.15 M) solution are presented in figure 4. An active-passive transition is not observed for any of these two last solutions. However, associated to the magnet immersed in the phosphate solution, the maximum current density reached was around  $7 \times 10^5 A/cm^2$  up to 1300 mV (SCE), indicating the formation of a protective layer on the magnet surface. The formation of this layer causes a decrease in the current density during the reverse scan and the dislocation of the corrosion potential into more noble values.

In the distilled water solution, the polarization curve shows an increase in current density at approximately 300 mV which could be indicative of pitting or crevice corrosion. The shape of the curve

(large hysteresis) seems to be more indicative of crevice corrosion. Crevice could have been created at the intergranular regions around the main magnetic phase. The reverse scan also shows oscillations in the current density values which could be due to irregularities on the surface caused by the attack during the direct scan.

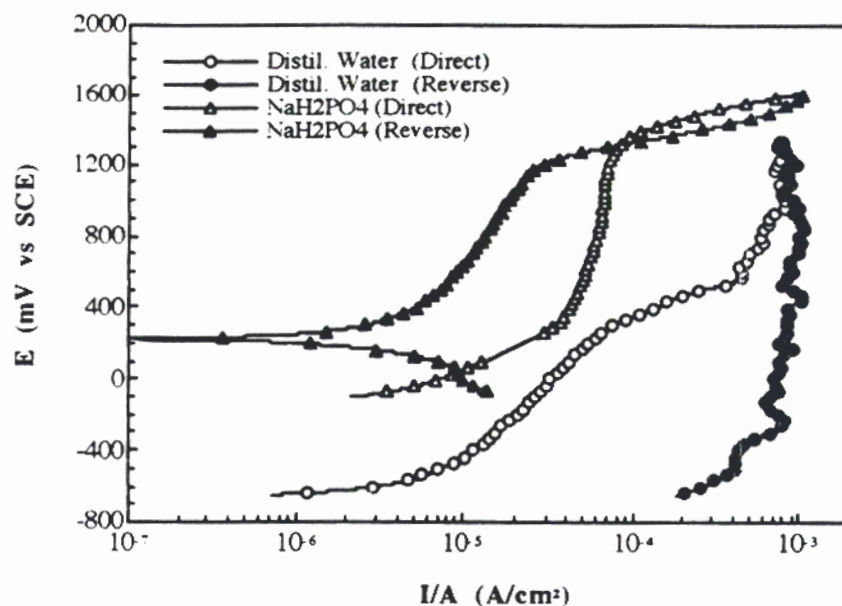


Figure 4 - Polarization curves of the magnet in distilled water and phosphate solution.

## CONCLUSIONS

Most solutions tested showed to be very aggressive towards the commercial magnet used. The exception was  $\text{NaH}_2\text{PO}_4$  (0.15 M) solution which caused the formation of a protective layer on the magnet surface. For surface preparation treatments of the magnet before coatings application this last solution could be employed. The magnet is liable to corrode intensely in atmospheres containing sulfates, such is the case of polluted industrial atmospheres. The magnet showed tendency to crevice in distilled water, which might have been caused by attack at intergranular regions.

## ACKNOWLEDGMENTS

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