

## Corrosion of Nd-Fe-B permanent magnets

**M. Drak, L.A. Dobrzański\***

Division of Materials Processing Technology, Management and Computer Techniques in Materials Science, Institute of Engineering Materials and Biomaterials, Silesian University of Technology, ul. Konarskiego 18a, 44-100 Gliwice, Poland

\* Corresponding author: E-mail address: leszek.dobrzanski@polsl.pl

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### Properties

#### ABSTRACT

**Purpose:** purpose of the paper is to presents results of corrosion wear of bonded and sintered hard magnetic materials Nd-Fe-B and magnets covered by protective polymer, lacquer and metal coatings.

**Design/methodology/approach:** Corrosion tests were made in two corrosive environments in water and in 5% NaCl solution.

**Findings:** It was found that the bonded magnets with the polymer matrix demonstrate better corrosion resistance than the sintered magnets. Employment of the protective coatings on the Nd-Fe-B bonded magnets surfaces may feature the effective protection of the substrate material from the corrosive action of the aggressive agent.

**Practical implications:** Magnets covered by protective polymer, lacquer or metal coating are less susceptible to corrosion so employment of these coatings can lower the losses caused by the corrosion of magnets. Corrosion protection of Nd-Fe-B magnets needs further investigations.

**Originality/value:** Analysis of the surface topography of the deposited protective coatings makes it possible to determine coating defects resulting from the action of the aggressive agent. The obtained results can be use in practice to decrease the corrosion wear of these materials.

**Keywords:** Corrosion; Composites; Magnetic materials

### 1. Introduction

In contemporary world there are many devices in which magnets play a significant role so it is very important to improve properties of these materials. Currently attention is focused on materials based on rare earth metals (RE) and transition metals (TM). These materials allow to obtain permanent magnets with high magnetic properties. Depending on the technology magnets are characterized by different magnetic and mechanical properties and show different corrosion resistance. Application of RE-TM type magnets allow to obtain good magnetic properties, to improve mass-to-performance ratio and to simplify the construction of devices. [1-4]

Application properties of these materials depend both on their ability of keeping magnetic properties and transfer of mechanical

load and also resistance on corrosive environment. Nd-Fe-B magnets are prone to corrosion in damp air and this is a major factor in limiting their overall usability. The reason of this is a high concentration of rare earth constituents (roughly 30% by mass) and the material's multi-phase structure: ferromagnetic phase of  $\text{Nd}_2\text{Fe}_{14}\text{B}$  (phase  $\phi$ ) - 85% by volume, boron phase of  $\text{NdFe}_4\text{B}_4$  (phase  $\eta$ ) - 3%, neodymium phase of NdFe (phase  $\eta$ ) - 12%. [5,6] Neodymium-based magnets have a multiphase skeleton-like microstructure i.e. their neodymium- and boron-rich phases are embedded in phase  $\phi$  grains. Such multiphase morphology, that ensures good magnetic properties, on the one hand, it is responsible for poor corrosion resistance of material on the other hand. Each phase exhibits different chemical activity. As a consequence, this material is prone to a selective corrosion along grain boundaries of  $\text{Nd}_2\text{Fe}_{14}\text{B}$  phase. [5-8]

Neodymium magnets are very corrosive in acid environment. Even momentary acidification of industrial environment leads to substantial destruction of magnets. Low corrosion resistance causes the lack of passivation, mechanical destruction as a result of hydriding and even loss of coherence and fast pulverization of magnets. [5-7]

The significant susceptibility to corrosion of the neodymium magnets calls for using the protective coatings that safeguard them from corrosion during their operation in the devices. Protective coatings protect also from falling out of the single powder grains from the completed magnets, which may be the reason for damaging the costly and precision devices. The neodymium magnets are coated with the protective coatings, whose task is to protect them from fast wearing out due to action of the corrosive environment. Both single component metal coatings such as nickel, chromium, aluminium, zinc, tin, silver, gold, as well as the multi-component, multilayer ones like Ni-Cr or Ni-Cu are used [5-10]. Putting down the protective paints and lacquers, as well as resins resistant to moisture, acids and alkalis onto the neodymium magnets, is a method making it possible to protect them from corrosion in a simple way. These coatings are applied using many techniques, beginning from the traditional brush painting, dipping, spraying, and electrostatic painting. Putting down coatings on to the surfaces of neodymium magnets extends their life by decreasing the corrosive wear. [10-15]

The goal of the work is to determine the corrosion resistance of Nd-Fe-B bonded magnets, sintered magnets and the comparison with magnets covered by the metal, polymer and lacquer protective coatings.

## 2. Materials

The experiments were made with the polymer matrix hard magnetic composite materials reinforced with particles of the powdered rapid quenched Nd-Fe-B strip, commercially sintered magnets and magnets covered by the metal, polymer and lacquer protective coatings. Composite materials were made using the following compacting process parameters: unilateral uniaxial compaction, room temperature, pressure 800–900MPa.

Table 1. Characteristics of protective coating deposited on the composite materials

Coating	Thickness [ $\mu\text{m}$ ]	Process
Polyurethane lacquer	45	PS
Phtal-uretane lacquer	60	PS
Epoxy lacquer 1	45	PS
Epoxy lacquer 2	55	PS
Polymer epoxide	80	EP
Polymer poliester	80	EP
Polymer poliester-epoxy	80	EP
Zinc	45	G
Nickel	38	G
Cooper	20	G
Chromium	15	G

PS – pressure spraying, EP - electrostatic painting, G – galvanization

The polymer matrix of the composite materials was cured at the temperature of 180°C for 2 h after compacting. On the magnets

surface following protective coating were put on (Table 1). Lacquer coatings were sprayed under pressure, polymers were electrostatic painted, and then held at the temperature of 160°C for 20 min while metal coatings were put down galvanically.

Corrosion tests were made in two environments with the following parameters (Table 2). In order to characterise damages of the magnets surface, microscopic observations were carried out using LEICA MEF4A optical microscope. The Computer Assisted Image Analysis was employed to evaluate the impact of corrosion on the surface during the test and after the test has been finished. Corrosion examinations were also made on magnets covered by protective coatings with and without “scratch” and the corrosion damages were observed on light microscope.

Table 2. Parameters of corrosion environments

Test No	1	2
Temperature [°C]	40	35
Environment	humidity 93%	solution NaCl 5%
	Test time [h]	
Magnets	96	6
Magnets covered by coatings	240	72

## 3. Results

Functional properties of magnets were evaluated on the base of corrosion tests results. Corrosion wear of magnets surface during and after corrosion tests were evaluated by the use of colour materialography. It was shown that the surface of sintered magnets was damaged after 96h in water environment and after 24h in 5% NaCl solution (Fig.1.). Besides, after 72h in 5% NaCl solution sintered magnets undergo pulverization. The surface of sintered magnets is getting destroyed at a uniform rate while on the surface of bonded magnets corrosion centres were found and their further growth is observed.

Employment of the protective coatings on the Nd-Fe-B magnets surfaces may feature the effective protection of the substrate material from the corrosive action of the aggressive agent. Analysis of the surface topography of deposited coatings allows to determine defects of coatings resulting from corrosion environment acting. Results of experiments indicate that magnets covered by protective coatings are less susceptible to corrosion and their surface damages are smaller. The best corrosion resistance was evaluated for polymer coatings deposited by electrostatic painting. These coatings almost didn't undergo damages after 240h in water environment and 72 h in 5%NaCl solution. As it was shown in [9] these coatings are characterized by good tightness and adherence to the substrate. Corrosion agent has low possibility to attack the substrate so it was wasn't affected by the corrosion both in water and in 5%NaCl solution environments. Fig. 2. presents the example of corrosion wear in so called “scratch” test of the magnets covered by protective coatings. No blisters or coating spalling were revealed on the polymer coating. Corrosion proceeds only where the coating was damaged. Occurrences of single blisters in the polymer coatings were revealed only after 72 h in the 5% NaCl environment.

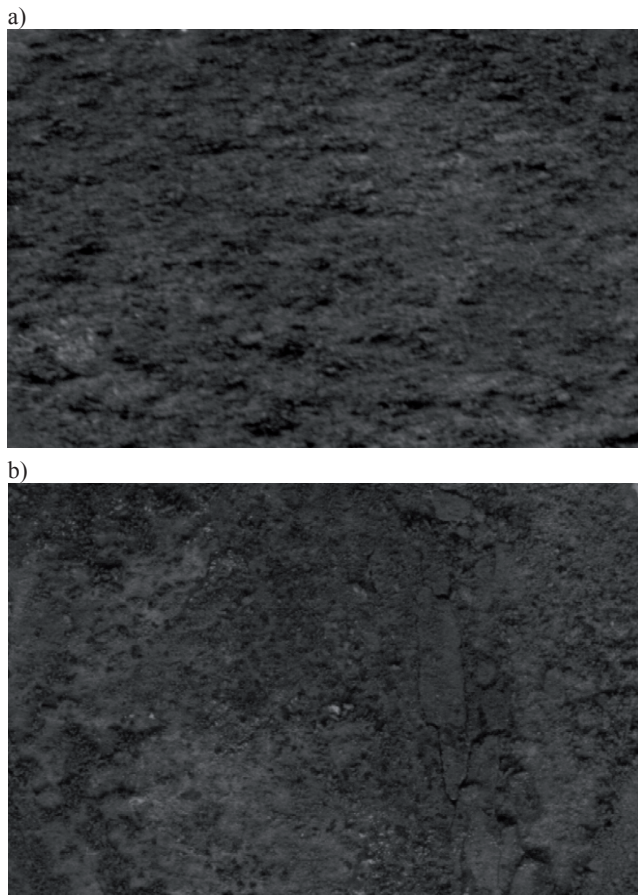


Fig. 1. Topography of the sintered magnet's surface after test: a) in water, b) 5%NaCl solution

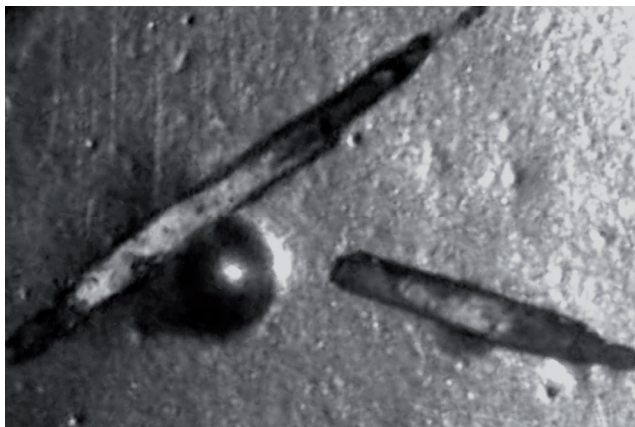


Fig. 2. Topography of scratched surface of magnet covered by protective polymer coating after 72h in 5% NaCl solution

Single, local coating defects were revealed on the protective lacquers in the water corrosion test after 240 h. After 72 h of test duration in the 5% NaCl solution, some single coating cracks were revealed on the polyurethane lacquer coating; whereas on the phthal-urethane one – many fine blisters were revealed (Fig.3.),

attesting to local delamination of the coating from the substrate. Lacquer coatings show lower tightness and adhesion to the substrate in comparison to polymer coatings. That allows the penetration of aggressive agent under the coating surface, formation of blisters and development of sub-coating corrosion.

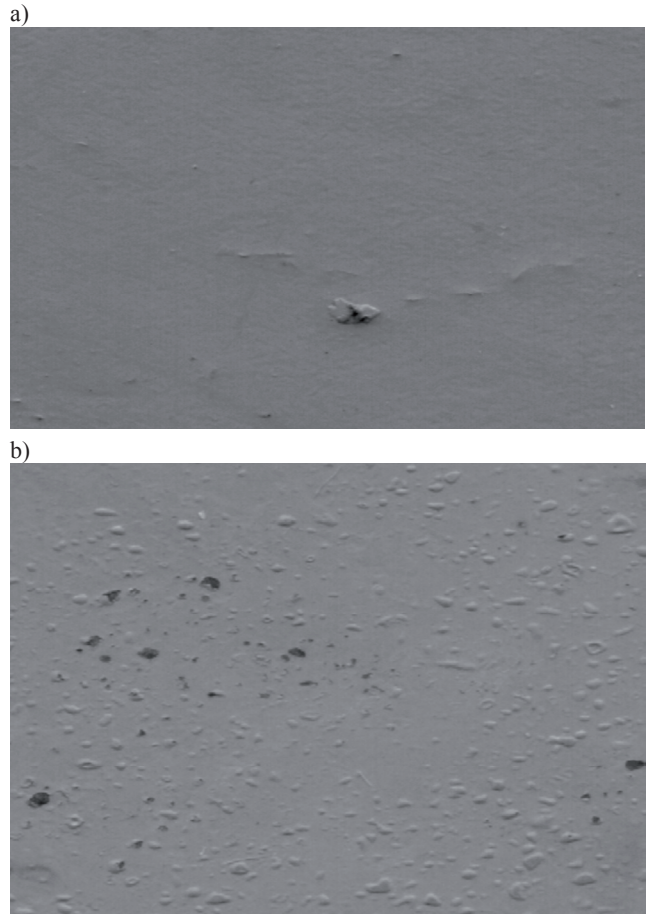


Fig. 3. Surface topography of bonded magnets covered by phthal-urethane lacquer after corrosion test in: a) water, b) NaCl solution.

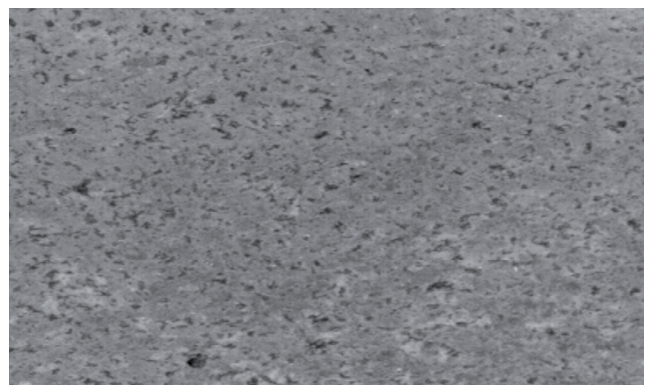


Fig. 4. Surface topography of bonded magnets covered by zinc after corrosion test in water

Metal coatings demonstrate a lower corrosion resistance compared to the polymer and lacquer ones in both these corrosive environments. The best resistance in the water environment is demonstrated by zinc coating (Fig.4.). Occurrences of single corrosion centres were observed after 240 hour of test duration. Chromium coating protects the magnet properly up to 96 h, later islands of corrosion damages occur, joining with time. Nickel and copper coatings are subjected to blistering and spalling after 48 h of test in the water environment. Magnet surface is exposed and its corrosion proceeds.

The lowest corrosion protection assures metals coating. Their adhesion is much lower than polymer or lacquer coatings. This can be probably the result of technology – galvanization because the surface of bonded magnet has low conductivity of current. Low adhesion of metals coating to the bonded magnet surface causes blisters and spalling of the coatings.

In the case of metal coating put on the sintered magnets it can be seen that the coating is beaked and spalling is observed. Corrosion of the magnet surface started in the place of coating damage and then wss spreading on the whole surface (Fig.5.).

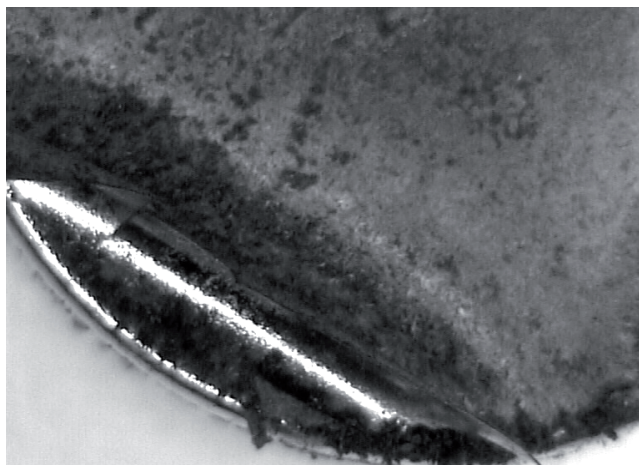


Fig. 5. Surface topography of bonded magnets covered by zinc after corrosion test in water

#### 4. Conclusions

The carried out corrosive environment resistance tests made it possible to determine the corrosive wear of the hard magnetic Nd-Fe-B composite materials with the polymer matrix, sintered Nd-Fe-B magnets, and composite materials coated with the lacquer, polymer, and metal coatings.

It was found out that the composite materials made from the powder from the rapid quenched strip bound with the polymer material are less susceptible to the corrosive environment than the sintered magnets. Polymer coatings demonstrate the best resistance in both corrosion tests. The lacquer coatings are resistant in the water environment; whereas, in the 5% NaCl solution environment they get locally blistered and are torn away from the substrate. Metal coatings demonstrate a lower corrosion resistance compared to the polymer and lacquer ones in both

corrosive environments. The best resistance among the metal coatings is characteristic of the zinc coating, a good resistance is characteristic of the chromium one; whereas the nickel and copper coatings get blistered and are spalling.

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