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Corrosion resistance of the polymer matrix hard magnetic composite materials Nd–Fe–B

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Abstract

The paper presents the characteristics of the protective polymer, lacquer, and metal coatings put down onto the hard magnetic composite substrate with the polymer matrix, reinforced with the Nd–Fe–B particles with additions of metal powders. Examinations of the coatings' structures were made with the scanning electron microscopy method. Hardness, thickness, and adhesion tests of the deposited coatings were also made. It was found out that the protective coatings are characteristic of the uniform deposition on the entire surface and of the same thickness all over their area. These coatings are characterised by a compact structure with no visible delaminations and defects. Polymer coatings demonstrate higher hardness compared to the lacquer ones. The highest hardness of 350s is characteristic of the polyester polymer coating. It was found that the highest adherence of 8.4 MPa is characteristic of the polyester–epoxy coating, whereas, the lowest adherence is displayed by the phthal-urethane coating—5.0 MPa. The paper presents also the corrosive wear of the hard magnetic composite materials with the polymer matrix, reinforced with the Nd–Fe–B particles from the rapid quenched strip, sintered Nd–Fe–B magnets, and composite materials coated with the protective polymer, lacquer, and metal coatings. The corrosive resistance values in the water environment and in the 5% NaCl solution environment were determined. It was found out that the composite magnets with the polymer matrix demonstrate better corrosive resistance than the sintered magnets; whereas, the best protection from the corrosive environment is provided by the polymer coatings. The neural network model for evaluation of the rate of corrosive wear of the polymer matrix hard magnetic composite materials with addition of metallic powder was established based on the research results from the investigations carried out in two corrosive environments. Three types of input data were used in the investigation: the contribution of the added powder, the nominal variable that defined the corrosive environment and the time duration of the test. The percentage corrosive wear of the surface was the output produced from such input data.

Keywords: Protective coatings; Permanent magnets; Nd–Fe–B; Composite materials; Corrosive wear; Neural network

1. Introduction

The dynamic development in the engineering and technology domains gives the reason to increase the requirements posed to various engineering materials, also to those used for hard magnets. They should have not only the advantageous magnetic properties but also the required mechanical properties and resistance to the corrosive environment. The economical issues also recommend the improvement of the mechanical properties of the magnets and increase of their resistance to the corrosive environment action. These materials are used for many precision and costly devices, so the improvement of their mechanical properties and corrosion resistance is connected with extending the life of both the magnets and the devices [1–3]. Currently, the attention is focused on materials based on the rare-earth and transition metals, which make it possible to make very good permanent magnets of the Sm–Co and Nd–Fe–B [2] types.

The surface of magnets changes under the influence of the external factors, like temperature and moisture, causing changes in the internal structure, corrosion, oxidation, absorption, or adsorption of moisture. The devices in which the hard magnetic materials are used work in various environmental conditions. In these conditions, the factors like temperature and moisture change in a broad range and in

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short time, even stepwise often. A big problem in using the neodymium magnets is their significant susceptibility to corrosion [4,5].

The neodymium magnets of the Nd–Fe–B type reveal a poor corrosion resistance in the moisture environment, which greatly limits their applicability. The reason for that is the high concentration of the rare-earth elements (about 30% mass concentration in case of the neodymium magnets), and their multiphase structure: ferromagnetic phase: $Nd_2Fe_{14}B$ (ϕ phase)—85% volume; boron phase: $NdFe_4B_4$ (η phase)—3%; neodymium phase: NdFe (n phase)—12%. The neodymium magnets have the multiphase skeleton structure, i.e., the neodymium and boron rich phases fill the space between the ϕ phase grains. The multiphase structure required to obtain the good magnetic properties is disadvantageous as regards the corrosion resistance of the material. Each phase demonstrates a different chemical activity. As a consequence of this, that material demonstrates the selective corrodibility on the $Nd_2Fe_{14}B$ phase grains [6,7].

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 are used, like nickel, chromium, aluminium, zinc, tin, silver, gold, as well as the multi-component, multilayer ones like Ni–Cr or Ni–Cu [8,9]. 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 an 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 neodymium magnets' surfaces extends their life by decreasing the corrosive wear [10–16].

Poor corrosion resistance of the Nd–Fe–B type magnets contributes to big economical losses. Research on the hard magnetic materials is focused on obtaining the magnets with the high magnetic and mechanical properties, as well as corrosion resistant in their operation conditions. One of the possibilities is making the composite magnets from the nanocrystalline Nd–Fe–B powder with the polymer matrix with the additions of metal powders improving their mechanical properties and covered with the lacquer, polymer, and metal coatings which additionally improve their resistance to the corrosive environment action.

Neural networks are used as a general-purpose tool for numerical modelling that is suitable to map complex functions. No need to develop an algorithm, no computer program is required to adapt neural networks to carry out a specific task. Instead, they are capable of learning using a series of standard stimuli and corresponding emulated responses. The strongest reason for using neural networks is their ability to generalise when confronted with new situations. Neural networks do not require a priori knowledge about problems, which they are intended to solve, they have ability to tolerate disruptions or discontinuities, accidental gaps or loss in the learned data set. Over the last several years, neural networks have gained increasing interest in the field of materials engineering. The growing popularity of neural networks is due their ability to model relations between investigated variables with no need to know the physical model of the phenomena. The results provided by neural networks very often exhibit better correlation with experimental data than those obtained from empirical explorations or mathematical models of the processes under investigation [17–23].

The goal of the work is to investigate structure and properties of the protective polymer, lacquer, and metal coatings put down onto the hard magnetic composite material with the polymer matrix, reinforced with the Nd–Fe–B particles with additions of metal powders and determining the corrosion resistance of the neodymium magnets with the polymer matrix, reinforced with the Nd–Fe–B particles, sintered magnets, and magnets coated with these coatings. Artificial neural networks were used to establish the rate of corrosive wear of Nd–Fe–B hard magnetic composite materials.

2. Experimental

The experiments were made with the polymer matrix hard magnetic composite materials reinforced with nanostructured particles of the powdered rapid quenched Nd–Fe–B strip MQP-B type made by Magnequench ($Nd_{14.8}Fe_{76}Co_{4.95}B_{4.25}$). Powders of metals and their alloys: iron, aluminium, CuSn10 casting alloy of copper with tin, and of the X2CrNiMo17-12-2 high-alloy (Table 1) were added to the composite material. The heat-hardening epoxy resin was used as the matrix (2.5 wt.%). Zinc stearate (0.2 wt.%) was used to ensure slip during compaction and pulling the test pieces out of the die. To obtain the composite materials the Nd–Fe–B powder was mixed with the epoxy resin powder. The composite materials with addition of metal and metal alloys powders were fabricated by mixing the Nd–Fe–B powder in a mechanical mixer with the addition powder, and next by mixing them with the epoxy resin powder. Portions of the matrix and slip agent powders, compacting pressure, as well as the temperature and curing time of the polymer material

Table 1
Chemical composition of composite materials

Range	Portion of addition [wt.%]			
	Iron	Aluminium	CuSn10 type cast copper–tin alloy	X2CrNiMo17-12-2 high-alloy steel
Min.	0	0	0	0
Max.	15	15	15	15