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Periodic microstructuring of iron cylinder surface in nitric acid in a magnetic field

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Abstract

The periodic surface microstructure of an iron cylinder is revealed under its corrosion in a solution of nitric acid in a constant magnetic field. The temporary dependencies of the microstructure parameters have been obtained for the cylinders with different diameters and lengths. The effect of microstructuring is a new example of nonlinear self-organization in a magnetic field. The results of the paper can be used for controlled etching of metallic surfaces with the help of a magnetic field application.

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1. Introduction

Today magnetic field effect on the interaction of the metallic surface with aqueous electrolytes (electrodeposition, corrosion, electrode voltage, etc.) attracts special attention [1–3]. Recently the self-organizing motion of an electrolyte (the complicated stirring effect) was revealed in the vicinity of the metallic surface under influence of a constant magnetic field (in the case when an electric field was not applied) [4–6]. The effect was investigated for different electrolytes, diversiform metallic objects of different sizes applying a magnetic field of different magnitudes and directions. The stirring effect has a general character when a chemical reaction takes place between metal and an electrolyte in a magnetic field. In particular, the origin of the multivortex dissipative structure of an electrolyte was observed under certain conditions in the vicinity of a metallic cylinder under influence of a magnetic field [5]. Besides, the self-organizing effect of electrolyte stirring in a magnetic field leads to acceleration of the corrosion rate of a steel wire in nitric acid [4].

It is shown in the paper that it is possible to change the rate of corrosion and to create the periodic

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microstructures on the surface of metallic objects with the help of a magnetic field. The characteristics of the microstructure depend on the properties of a metallic object, electrolyte and other parameters. The microstructuring of the metallic surface can be applied, for example, in microelectronics for the controlled etching.

2. Experiment

The installation consisting of an electromagnetic system and a visualization system was used for the investigation. The electromagnetic system was used to create a constant uniform magnetic field between the pole tips of an electromagnet. The visualization system consists of an optical microscope, connected with a camera-recorder, and a computer. The sample in the form of an iron cylinder was fastened to the container with a solution of nitric acid. The container was placed between the pole tips of the electromagnet and a magnetic field was applied parallel to the symmetry axis of the cylinder. The cylinders with initial diameters of 725, 490, 300 μm and lengths of 1, 2 and 3 cm were used as the samples. The multivortex flows of electrolyte arose in the vicinity of the surface of the cylinder (of steel, tin, lead and other metals) under its corrosion in a solution of nitric acid in a magnetic field [4,5]. The number of vortices depended on the cylinder length, concentration of the solution of nitric acid and time [4,5]. The regular periodically structured surfaces were obtained with the help of application of an external constant magnetic field to the system in which corrosion of an iron cylinder in a solution of nitric acid took place. The uniform corrosion happened in the same system without a magnetic field.

The image of the surface of the iron cylinder (with the diameter of 490 μm) before treatment is represented in Fig. 1(a). The cylinder has uniform (along its symmetry axis) and smooth surface structure. The typical images of the cylinder surface after 5 and 15 min of treatment in the 7% solution of nitric acid without a magnetic field are represented in Fig. 1(b) and (c) correspondingly. The uniform structure of the corroded surface was observed without a magnetic field.

The typical images of the iron cylinder (with the initial diameter of 490 μm) surface are represented in Fig. 1(d)–(f) after 15 and 30 min of treatment in the 7% nitric acid solution in the 3000 Oe magnetic field. Fig. 1(d) differs from (e) only in magnification. The periodic surface microstructure consisting of repeating elevations and cavities arose under corrosion in a magnetic field.

The image of the iron cylinder (with the diameter of 300 μm) surface before treatment is represented in Fig. 2(a). The images of the cylinder surface after 5 and 15 min of treatment in the 7% solution of nitric acid without a magnetic field are represented in Fig. 2(b) and (c) correspondingly.

Fig. 2(d)–(f) represents the typical images of the surface microstructure of the iron cylinder with the initial diameter of 300 μm after corrosion in the 7% nitric acid solution in the 3000 Oe magnetic field (under different magnifications).

Figs. 3–7 represent the typical temporary dependencies of the microstructure characteristics. The microstructure was obtained under corrosion of the iron cylinder in the 7% nitric acid solution in the 3000 Oe magnetic field.

The temporary dependencies of the microstructure period for the cylinders with different diameters are represented in Fig. 3. The microstructure period increases when the initial cylinder diameter increases. The microstructure period almost does not depend on time.

The temporary dependencies of the microstructure's elevation length are represented in Fig. 4. The elevation length increases when the initial cylinder diameter increases. The elevation length decreases in the course of time for all cylinders.

The temporary dependencies of the microstructure's cavity length are represented in Fig. 5. The cavity length decreases when the initial cylinder diameter increases. The cavity length increases in the course of time for all cylinders.

The temporary dependencies of the difference between the diameters of the elevation and the cavity are represented in Fig. 6. The difference decreases when the initial cylinder diameter increases and it increases in the course of time for all cylinders.

The temporary dependencies of the ratio of the corroded cylinder volumes with and without a magnetic field (for the cylinders with different initial diameters) are represented in Fig. 7. The ratio of the