Materials Science-Poland, Vol. 24, No. 4, 2006

Quasi-periodic microstructuring of iron cylinder surface under its corrosion under combined electric and magnetic fields

O. YU. GOROBETS, D. O. DERECHA*

Institute of Magnetism of NAS of Ukraine, Kiev, 03142, Ukraine

The phenomenon of quasi-periodic microstructuring of the surface of iron cylinder under its corrosion in the nitric acid, under combined electric and homogeneous permanent external magnetic fields has been investigated. Temporary dependences of microstructure parameters on the strength of the magnetic field, voltage and concentration of acid are presented in the paper.

Key words: *microstructuring; self-organization; magnetoelectrolysis; magnetic field*

1. Introduction

Technologies of metal electrodeposition to create surfaces possessing functional properties constitute about 25% of the surface modification market [1]. Magnetoelectrolysis is one of the most prospective directions in this field [2–12]. In particular, magnetic field applied to electrolytic cell allows obtaining "branchy" structure of a fractal surface as well as surfaces with improved smoothness and reflectivity [13, 14]. It is also well known that magnetic field influences the corrosion rate of metals, for example, copper [15] and iron [16]. However, use of magnetic field in structuring metal surface under corrosion has been much less investigated than its application to electrodeposition. Magnetohydrodynamic stirring of electrolytes has a considerable influence on structuring of metal surface under combined magnetic and electric fields. It is explained theoretically on the basis of the magnetohydrodynamic equations and the theory of the convective diffusion [2–16]. Recently multivortex stirring of nitric acid solution was revealed in the vicinity of the surface of a metallic cylinder under its corrosion under constant magnetic field when electric field was not applied [16]. In such conditions, quasi-periodic microstructuring of the surfaces of steel and iron cylinders was found

*Corresponding author, e-mail: dderecha@yandex.ru

[17, 18]. The effect of quasi-periodic microstructuring of a surface corroding under magnetic field is an example of nonlinear self-organization. Thereupon investigation of the influence of magnetic field on the surface structure of a metallic cylinder under its cathode and anode corrosion represents fundamental and applied interest.

2. Experimental

The surfaces of iron cylinders were investigated under corrosion in solutions of nitric acid under external constant magnetic and electric fields. The installation consists of an electromagnet with pole tips and a visualization system [16]. Two iron cylinders 1 are fixed in a container 2, parallel to each other at the distance of 3 cm as is shown in Fig. 1. Brass plates 3 with the gaps are used for fixing the cylinders outside the container and for the contact with the electric circuit which is connected to the plates. The circuit consists of a voltage source, the resistor 4 used to change the voltage between the two cylinders, and the voltmeter 5. The voltmeter is connected with the copper plates 3 and the voltage between the cylinders is measured. The container is fixed between the pole tips of the electromagnet in such a way that magnetic field is parallel to the symmetry axes of the cylinders. Thus, the direction of magnetic field is perpendicular to the direction of the electric field in the vicinity of the surface of each cylinder.

The experiments were carried out in external magnetic field from 80 to 240 kA/m, the concentrations of nitric acid solution ranged between 7 and 21%. The voltage was changed in the range of 0.1–1.5 V.

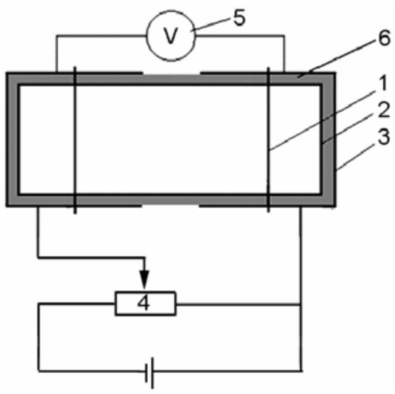

Fig. 1. The functional scheme of the electric circuit connected to the container with iron cylinders. See the text for further discussion

In this work, a comparison of the structures of the surfaces of the iron cylinders was made under the following conditions of corrosion:

a) without electric and without magnetic field; b) under electric field only; c) under magnetic field only; d) under combined electric and magnetic fields.

3. Results and discussion

The microstructure of the surface resulting from corrosion does not depend on the coordinate along the cylinder axis (Fig. 2), i.e., the long-range ordering of the corroded surface is not observed along the cylinder axis.

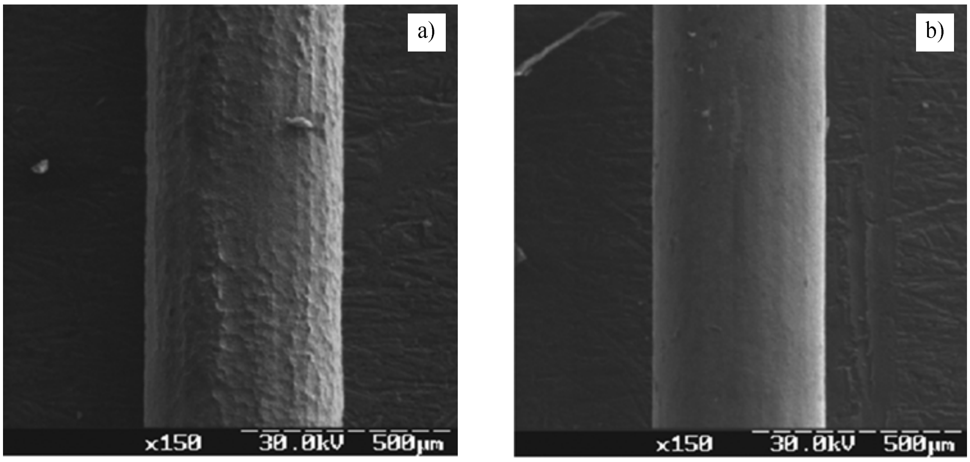

Fig. 2. An iron cylinder after corrosion in 14% solution of nitric acid, the voltage between the cylinders is 1.5 V, the duration of experiment – 10 min: a) cathode corrosion; b) anode corrosion

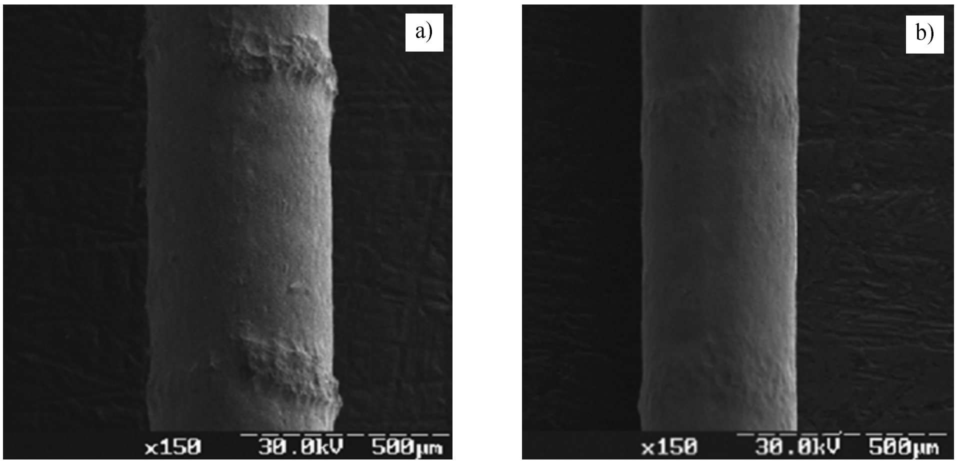

Fig. 3. An iron cylinder after corrosion in 14% solution of nitric acid, the voltage between the cylinders is 1.5 V, the magnetic field strength – 240 kA/m, the duration of experiment – 10 min: a) cathode corrosion; b) anode corrosion

Quasi-periodic structuring of the surface of the cylinder was observed under applied magnetic field only (condition c)). Periodically repeated elevations and cavities are formed as is reported in [17, 18, 23]. The period of the quasi-periodic surface structure T ($T = L + l$, where L is the elevation length, l is the cavity length) is much greater than the characteristic size of the surface microstructure, i.e. in this case, long -range ordering of the shape of corroded surface is observed along the cylinder axis.

The long-scale quasi-periodic microstructuring of the corroded surface is observed under the combined electric and magnetic fields (condition d)), as well as in the case of application of a magnetic field only (Fig. 3).

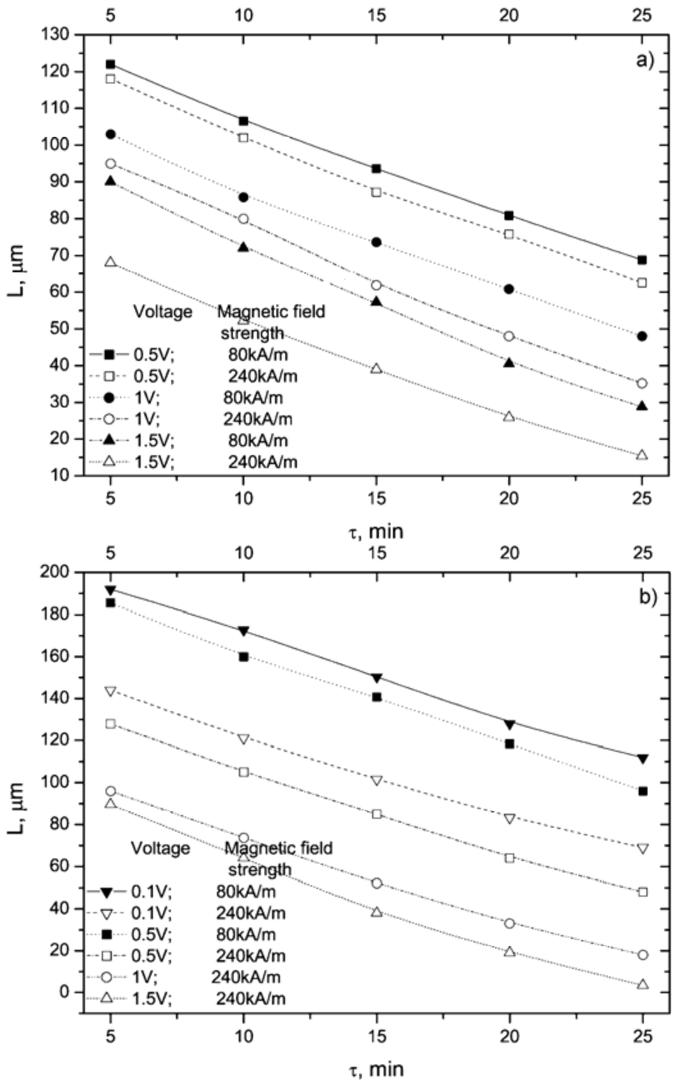

Fig. 4. Time dependences of the elevation length L of the quasi-periodic surface structure of the cylinder: a) under its cathode corrosion in the 7% solution of nitric acid, b) under its anode corrosion. Mean error ~25%

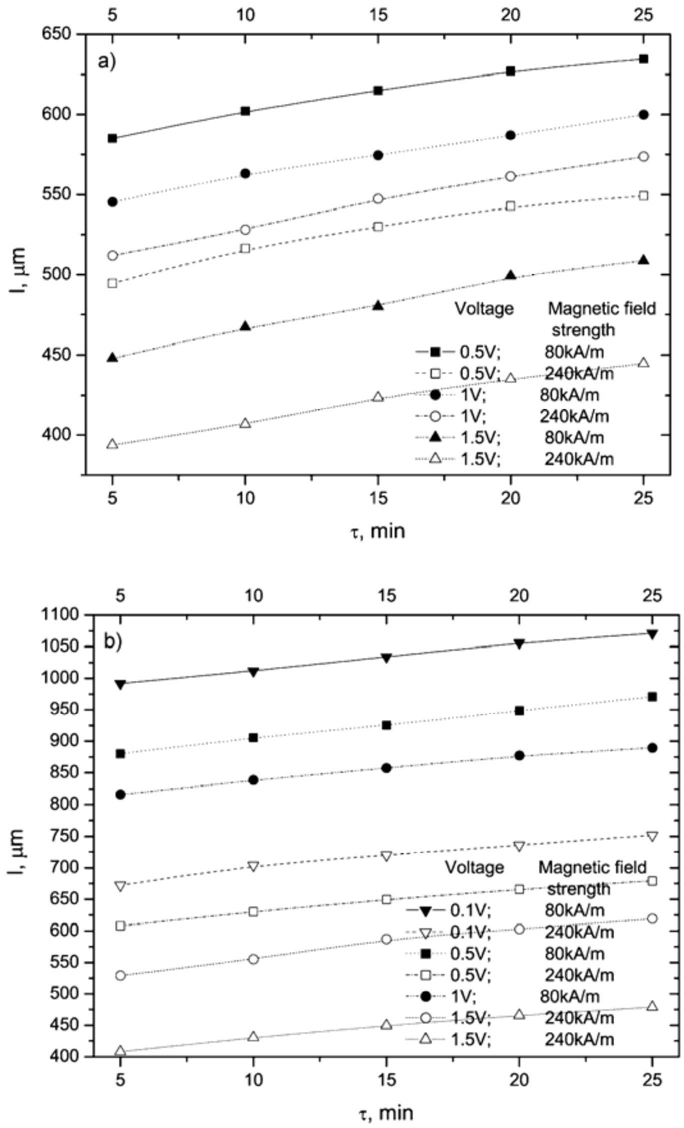

Fig. 5. Time dependences of the cavity length *l* of the quasi-periodic surface structure of the cylinder: a) under its cathode corrosion in 7% solution of nitric acid, b) under its anode corrosion. Mean error ~25%

Characteristic parameters of the structure of quasi-periodic surface of the cylinder (period *T*, elevation length *L*, cavity length *l*, amplitude *A*, being the difference between the cylinder diameters at the elevation and at the cavity, cylinder diameter at the elevation *D* differ in the cases c) and d). In the case d), they also differ for the cathode and anode corrosion. The microstructure period under anode corrosion is longer than under cathode corrosion. The period *T* decreases when the external magnetic field strength, the voltage between the cylinders and the concentration of nitric acid increase, i.e. the quasi-periodic surface structure becomes more small-scale. The elevation length *L* decreases in the course of time while the cavity length increases both for the cathode and anode corrosion (Figs. 4, 5). The higher magnetic and electric field, the smaller are the elevation lengths *L*.

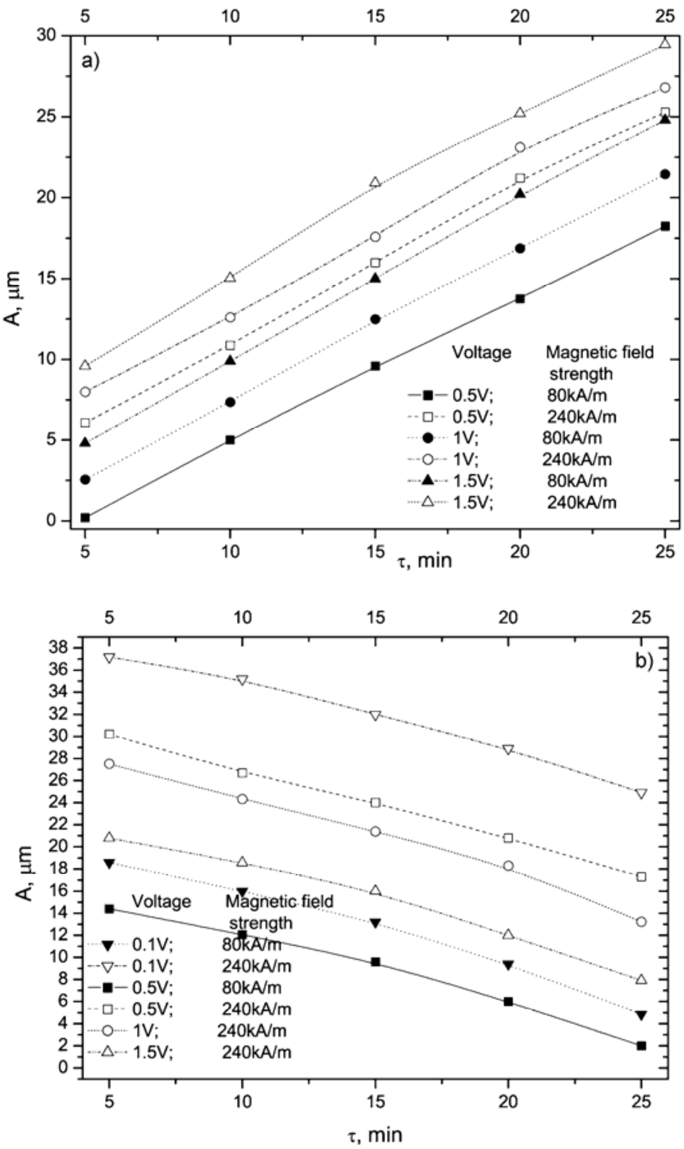

Fig. 6. Time dependences of the amplitude *A* of the quasi-periodic surface structure of the cylinder: a) under its cathode corrosion in the 7% solution of nitric acid, b) under its anode corrosion. Mean error ~25%

The amplitude of the structure of surface under the anode corrosion decreases when the voltage between the cylinders increases; the amplitude *A* tends to zero at the voltage higher than 0.5 V, i.e. *A* becomes smaller than the characteristic size of the surface roughness under corrosion without magnetic field. At the same time, the quasi-periodic structure is formed at the cathode surface at 1±0.5 V and its amplitude increases when the voltage increases. It is shown in Fig. 3: the quasi-periodic structure at the cathode surface is visible, while there is no such structure at the anode

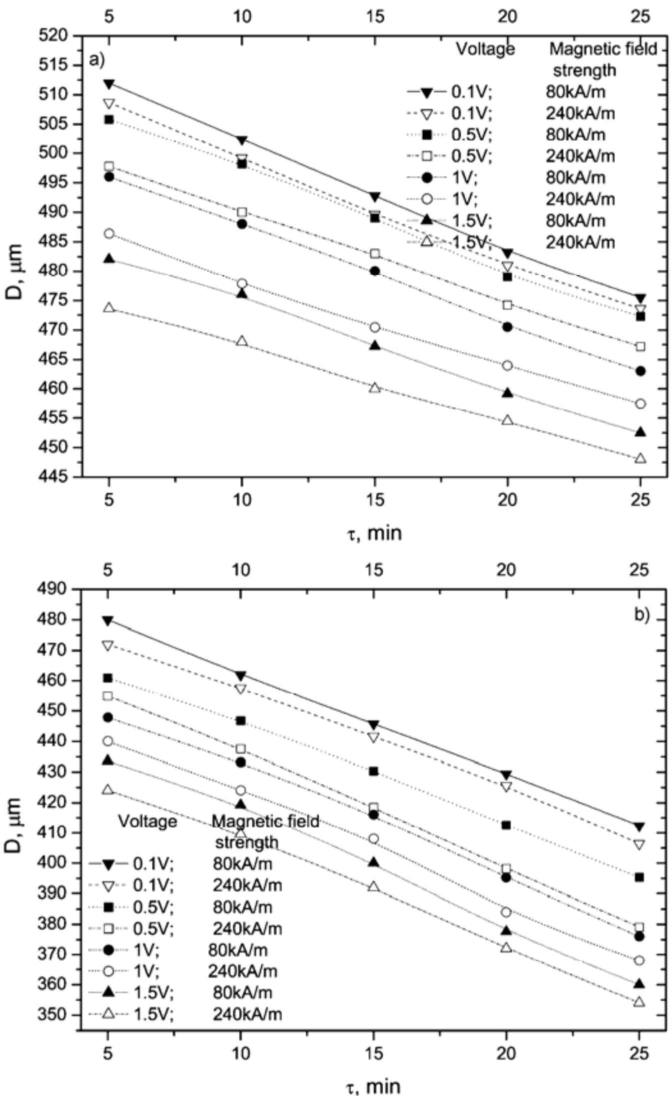

Fig. 7. Time dependences of the cylinder diameter *D* at the elevation of the quasi-periodic surface structure of the cylinder: a) under its cathode corrosion b) under its anode corrosion in the 7% solution of nitric acid. Mean error ~25%

surface by this time. Besides, the amplitude A decreases under the anode corrosion and it increases under the cathode corrosion with time (Figs. 6a, b).

It is obvious from Figs. 2 and 3 that the cylinder diameter is greater under the cathode corrosion than under the anode one. The diameter D decreases with time both for the cathode and the anode corrosion (Figs. 7a, b).

4. Conclusion

The characteristic parameters of the quasi-periodic structure of surface of an iron cylinder depend on the concentration of the nitric acid solution, the voltage between the cylinders, the value of the external magnetic field and time. The results of the present work can be used to control the structure of the corroded metallic surface under external electric and magnetic fields. It may find application for production of components of microelectronics, micromachinery, microelectromechanical systems [19–21], high gradient ferromagnetic matrices for magnetic filters [22] and in other fields where the controlled corrosion is used.

Acknowledgements

This work was executed owing to funds of the Ministry of Education and Science of Ukraine, rendered as the grant of the President of Ukraine for support of scientific researches of young scientists.

References

[1] CELIS J.P., DE BONTE M., ROOS J.R., Trans. I.M.F., 72 (1994), 89.
[2] FAHIDY T.Z., Prog. Surf. Sci., 68 (2001), 155.
[3] MOFFAT T.P., BONEVICH J.E, HUBER W.H., J. Electrochem. Soc., 147 (2000), 4524.
[4] YANG S.Y., YANG I.J., HORNG H.E., HONG CHIN-YIH, YANG H.C., Magnetohydrodyn., 36 (2000), 16.
[5] BODEA S., VIGNON L., BALLOU R., MOLHO P., Phys. Rev. Lett., 83 (1999), 2612.
[6] FAHIDY T.Z., *The Effect of Magnetic Fields on Electrochemical Processes*, [in:] B.E. Conway, J. O'M. Bockris, R.E. White, *Modern Aspects of Electrochemistry*, Kluwer, New York, 1999, 404.
[7] WASKAAS M., KHARKATS Y.I., J. Phys. Chem., B103 (1999), 4876.
[8] COEY J.M.D., HINDS G., LYONS M.E.G., Europhys. Lett., 47 (1999), 267.
[9] LEVENTIS N., CHEN M., GAO X., CANALAS M., ZHANG P., J. Phys. Chem., B102 (1998), 3512.
[10] ALBOUSSIÈRE T., GARANDET J.P., MOREAU R., Magnetohydrodyn., 32 (1997), 359.
[11] TACKEN R.A., JANSSEN L.J., J. Appl. Electrochem., 25 (1995), 1.
[12] FAHIDY T.Z., J. Appl. Electrochem., 13 (1983), 553.
[13] OLIVAS P., ZAHRAI S., BARK F.H., J. Appl. Electrochem., 27 (1997), 1369.
[14] ALEMANY A., OLIVAS P., J. Appl. Electrochem., 34 (2004), 19.
[15] SHINOHARA K., AOGAKI R., J. Appl. Electrochem., 67 (1999) 35.
[16] GOROBETS S.V., GOROBETS O.YU., RESHETNYAK S.A., J. Magn. Magn. Mater., 272 (2004), 2408.
[17] GOROBETS S.V., GOROBETS O.YU., MAZUR S.P., SLUSAR A.A., Phys. Stat. Sol., 12 (2004), 3686.
[18] GOROBETS YU.I., GOROBETS O.YU., MAZUR S.P., BRUKVA A.N., Phys. Met. Metallogr., 99 (2005), 139.

[19] DATTA M., IBM J. Res. Devel., 42 (1998), 5.
[20] TUMMALA R.R., RYMASZEWSKI E.J., *Microelectronics Packaging Handbook*, Van Nostrand Reinhold, New York, 1989, 905.
[21] DATTA M., *Electrochemical Micromachining* [in:] N. Masuko, T. Osaka (Eds.), *Electrochemical Technology: Innovations and New Developments,* Kodansha Gordon and Breach, Tokyo, 1996, 302.
[22] O'BRIEN N., SANTHANAM K.S.V., J. Appl. Electrochem., 20 (1990), 781.
[23] GOROBETS S.V., GOROBETS O.YU., BRUKVA A.N., Appl. Surf. Sci., 252 (2005), 448.

Received 10 September 2005
Revised 29 November 2005