

Tadeusz HRYNIEWICZ*, Krzysztof ROKOSZ**, Ryszard ROKICKI***, Robert CEP****

EFFECT OF MAGNETOELECTROPOLISHING ON CORROSION BEHAVIOUR
OF FERRITIC AISI 430 STAINLESS STEEL

EFEKTY MAGNETICKO-ELEKTRICKÉHO LEŠTĚNÍ BĚHEM KOROZE FERITICKÉ
NEREZAVĚJÍCÍ OCELI AISI 430

Abstract

The ferritic structure in the stainless steels introduces a number of complications of a metallurgical nature that can influence corrosion behaviour. Before the corrosion studies, three types of surface treatments have been performed on AISI 430 SS samples: mechanical/abrasive polishing MP, standard electrolytic polishing EP, and magneto-electro-polishing MEP. Polarization curves were studied to compare the corrosion behaviour of 430 SS surface in aqueous 3% NaCl solution. In the corrosion studies also extensive pitting corrosion phenomenon was evaluated.

Abstrakt

Feritická struktura v nerezových ocelích představuje množství komplikací v metalurgických vlastnostech, protože může mít vliv na korozi. Před studiem koroze, byly vykonány tři ošetření povrchu na vzorcích AISI 430 SS: mechanicko/abrazivní leštění MP, standardní elektrolytické leštění EP a magneticko-elektrické leštění MEP. Polarizační křivky byly studovány k porovnání průběhu koroze povrchu 430 SS ve 3% NaCl vodném roztoku. Ve studiích koroze byl taktéž hodnocen fenomén rozsáhlá důlková koroze.

1 INTRODUCTION

Type 430 is the basic 17%Cr ferritic stainless steel. For years it used to be the multipurpose ferritic stainless steel, with a range of chromium content between 14 and 18%, giving the user a choice of properties. Specifying chromium of about 14% in the steel improves its weldability, impact resistance, strength, and hardness, but some sacrifice in corrosion resistance appears. With chromium on the high side, there was a gain in corrosion resistance, particularly in nitric acid, but a loss in mechanical properties, particularly impact strength [1, 2].

The AISI 430 SS with 17%Cr is inferior to 304 SS as regards deep durability. Though it does not have good corrosion resistance properties as the Cr-Ni steels, it is used under less severe corrosive atmospheres for chemical processing equipment, furnace parts, heat exchangers, oil burner parts, petroleum roller equipment, protection tubes, recuperators, rubber plant machinery, scientific apparatus, storage vessels, tubing, television cones, electrical appliances, solar water heaters, air conditioners, kitchenware, household appliances, decorative trims, parts for washing machines, etc.

The ferritic structure in these stainless steels introduces a number of complications of a metallurgical nature that can influence corrosion behaviour. Austenitic stainless steels are non-magnetic,

* Ph.D. D.Sc. Eng., Department of Surface Electrochemistry, Faculty of Mechanical engineering, Koszalin University of Technology, Raclawicka 15-17, PL 75-620 Koszalin, tel. +48943478244, e-mail thdhr@tu.koszalin.pl

** Ph.D. MSc. Eng., Department of Surface Electrochemistry, Faculty of Mechanical engineering, Koszalin University of Technology, Raclawicka 15-17, PL 75-620 Koszalin, tel. +48943478354, e-mail rokosz@tu.koszalin.pl

*** MSc. Eng., Electrobright, Macungie PA, USA, e-mail info@electrobright.com

**** Ph.D., MSc. Department of Machining and Assembly, Faculty of Mechanical Engineering, VSB – Technical University of Ostrava, 17. listopadu 15/2172, 708 33 Ostrava, tel. +420597323193, e-mail robert.cep@vsb.cz

while ferritic and duplex are magnetic. The arrangement of atoms in the ferrite crystal (bcc) is different from the one in the austenite crystal (fcc). Pitting, an insidious localized type of corrosion occurring in halide media, can put complete installations out of operation in relatively short time. In general, resistance to pitting corrosion increases with chromium content [3, 4].

The study results, concerning the effect of electro polishing of the austenitic stainless steels both in absence and in the presence of a magnetic field have been reported elsewhere by the authors [5-12]. Here the ferritic stainless steel studies are reported. We have performed three surface treatments of the 430 SS, mechanical abrasive polishing MP, standard electrolytic polishing EP, and electro polishing in a magnetic field MEP, to compare corrosion behavior of the samples' surface.

2 METHOD

2.1 Material

The AISI 430 stainless steel, as the most frequently used ferritic material, was taken for the study. Three sets of AISI 430 stainless steel samples, cut of a sheet-steel of about 1.22 mm thick and of rectangular shape of 30×35 mm, have been used for the investigations.

2.2 Surface treatments

First the abrasive polishing (MP) was used for the prepared 430 SS samples. Samples were polished with an abrasive SiC paper of up to grit size 1000. Then the electropolishing experiments were carried out on the same material to evaluate the differences between these two processes.

The electrolytic polishing was performed both in the absence and in the presence of a magnetic field. For the experiments, a constant external magnetic field below 1T was applied to the EP system by neodymium ring magnets. For both processes, standard EP and MEP, the same type of a proprietary electrolyte was applied, being a mixture of sulphuric and orthophosphoric acids and the bath was unstirred during the process.

2.3 Corrosion measurements

Corrosion studies after abrasive polishing MP and after two different modes of electropolishing, beyond the plateau level (oxygen evolution regime), both in the absence (EP), and in the presence of a magnetic field (MEP), were carried out on 430 SS samples in an aqueous 3% NaCl solution, at 25 °C. The electropolishing polarization characteristics concerning the AISI 430 SS are presented in Fig. 1. In the picture (Fig. 1) the transpassive

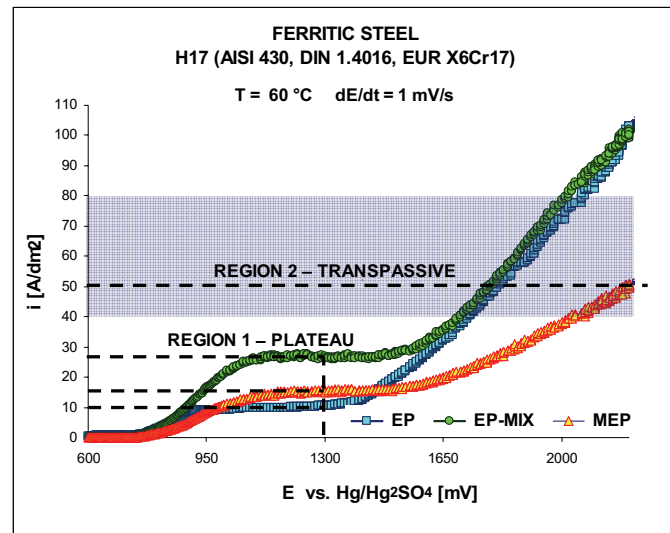


Fig. 1 Electropolishing polarization characteristics obtained on ferritic AISI 430 SS dependent on treatment conditions presenting two regions: 1 – plateau, 2 – transpassive.

The semi-shadowed area of typical industrial applications has been indicated region 2, marked as semi-shadowed, has been presented, with EP and MEP polarization characteristics taken into account in our corrosion studies. During the corrosion studies, polarization curves were performed on the samples' surfaces both after EP and MEP. The electrochemical system used for the corrosion measurements consisted of the potentiostat ATLAS 98 with the software IMP98, current platinum electrode Ept-101, and the saturated calomel electrode EK-101P used as a reference. The polarization curves were obtained each time after holding the samples in the solution at open circuit potential: (a) for 60 minutes, and (b) for 24 hours.

Pitting corrosion was also studied by counting the number of pits in the area of exposition, i.e. on the studied active samples' surface area of about 2 cm².

3 RESULTS AND DISCUSSION

3.1 Uniform corrosion

Electrochemical corrosion study results after 1 hour of exposition are presented in Figs. 1, 2. Potentiodynamic curves of AISI 430 SS in aqueous 3% NaCl solution presented in Fig. 2

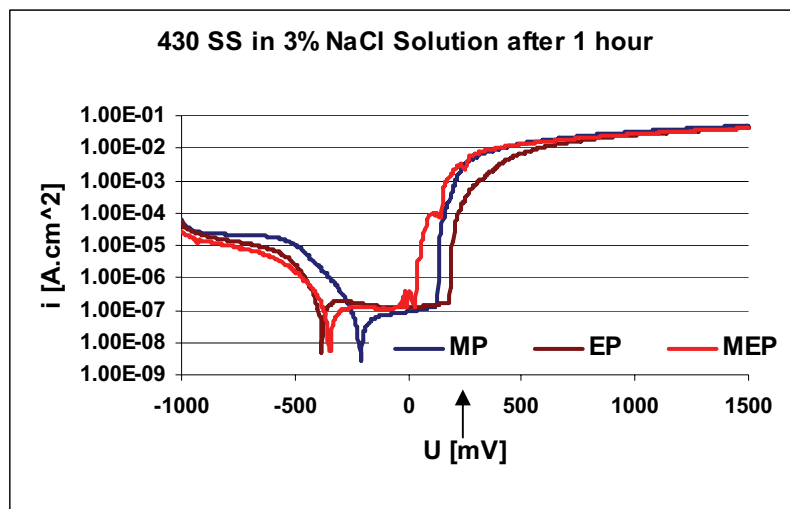


Fig. 2 Polarization curves obtained on AISI 430 SS in aqueous 3% NaCl solution after three treatments: (a) abrasive polishing MP, (b) standard electropolishing EP, (c) magnetoelectropolishing MEP.

Time of sample exposition: 1 hour indicate on differentiated course of the curves, with the smallest plateau though the highest corrosion potential revealed after MP, and the biggest plateau after EP. Polarization curve after MEP, with a smaller plateau than that after EP, reveals irregularities proving of arisen pitting corrosion (see arrow in Fig. 2). The critical potentials equalled after: MP -230 mV, EP -390 mV, and MEP -410 mV vs. SCE, respectively.

Corrosion rates have been calculated and the results are presented in Fig. 3. The obtained results show the highest corrosion rate to be after a standard electropolishing ($CR = 2 \times 10^{-3} \text{ mm.a}^{-1}$), and the lowest – after abrasive polishing ($CR = 5.15 \times 10^{-4} \text{ mm.a}^{-1}$). The corrosion rate calculated after magnetoelectropolishing equals $1.28 \times 10^{-3} \text{ mm.a}^{-1}$.

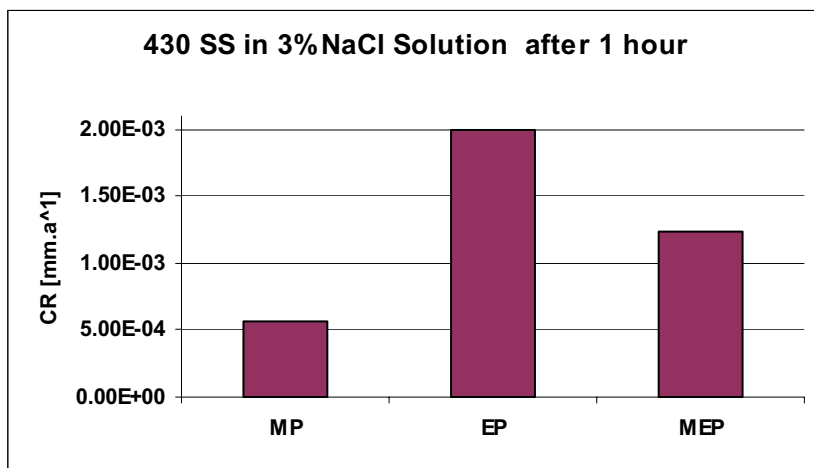


Fig. 3 Comparison of corrosion rates obtained on AISI 430 SS in aqueous 3% NaCl solution after three treatments: MP – abrasive polishing, (b) EP – standard electropolishing, (c) MEP – magneto-electropolishing. Time of sample exposition: 1 hour

Electrochemical corrosion study results after 24 hours of exposition are presented in Figs. 4, and 5. Potentiodynamic curves of AISI 430 SS in aqueous 3% NaCl solution presented in Fig. 4, apart from differentiated course of the curves, indicate on shifting the curve after a standard electropolishing EP closer to the curve after MP. In this Fig. 4, the potentiodynamic curve does not exhibit any irregularities (referred to the pits) in its course in comparison with that curve after 1 hour of exposition. The critical potentials after 24 hours of exposition in 3% NaCl solution equalled after: MP –281 mV, EP –295 mV, and MEP –387 mV vs. SCE, respectively.

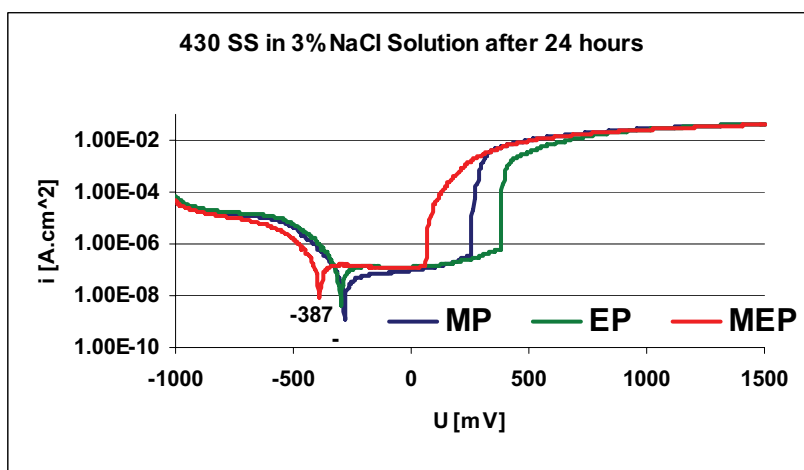


Fig. 4 Polarization curves obtained on AISI 430 SS in aqueous 3% NaCl solution after three treatments: (a) abrasive polishing MP, (b) standard electropolishing EP, (c) magnetoelectropolishing MEP. Time of sample exposition: 24 hours

Corrosion rates have been calculated and the results are presented in Fig. 5. The obtained results show the highest corrosion rate to be after magnetoelectropolishing ($CR = 1.36 \times 10^{-3} \text{ mm.a}^{-1}$), and the lowest – after abrasive polishing ($CR = 5.3 \times 10^{-4} \text{ mm.a}^{-1}$). The corrosion rate calculated after a standard electropolishing is comparable to CR after MEP and equals to $1.33 \times 10^{-3} \text{ mm.a}^{-1}$.

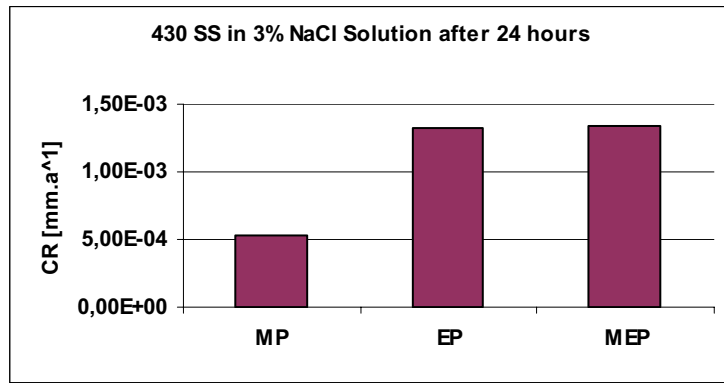


Fig. 5 Comparison of corrosion rates obtained on AISI 430 SS in aqueous 3% NaCl solution after three treatments: (a) MP – abrasive polishing, (b) EP – standard electropolishing, (c) MEP – magnetoelectropolishing. Time of sample exposition: 24 hours

3.1 Pitting corrosion

The results of pitting corrosion on AISI 430 SS surface submerged in aqueous 3% NaCl solution after three treatments: MP, EP, and MEP are presented in Figs. 6, and 7.

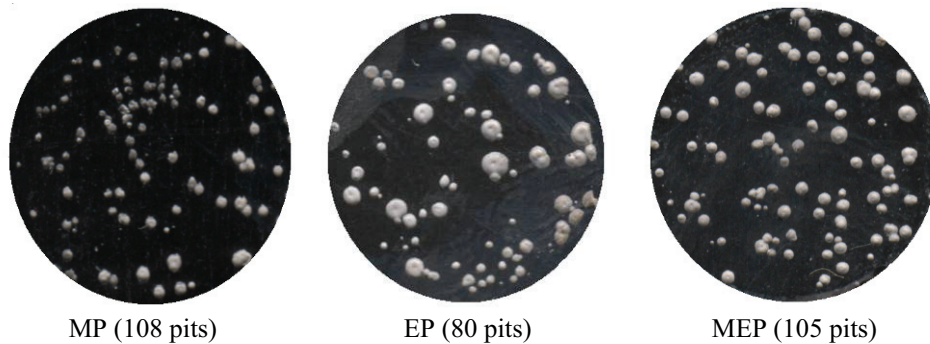


Fig. 6 Pits comparison on AISI 430 SS surface submerged in aqueous 3% NaCl solution after three treatments: (a) MP – abrasive polishing, (b) EP – standard electropolishing, (c) MEP – magnetoelectro-polishing

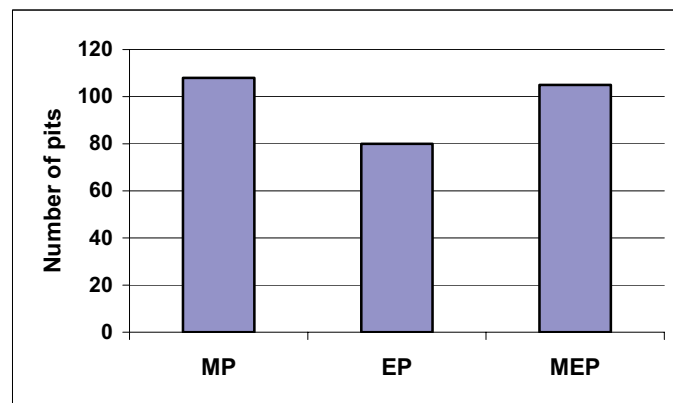


Fig. 7 Number of pits counted on AISI 430 SS surface submerged in aqueous 3% NaCl solution after three treatments: (a) MP – abrasive polishing, (b) EP – standard electropolishing, (c) MEP – magnetoelectropolishing

Comparable number of pits have been obtained on surfaces after MP and MEP. After a standard electropolishing EP the number of pits was 20 to 25% less though many of the pits were of bigger sizes.

The reverse behaviour of AISI 430 SS after MEP in comparison with the results after that treatment of austenitic steels [7-12] induced the Authors to carry out the investigations of corrosion behaviour of a carbon C45 steel after analogous treatments. The C45 steel samples were prepared by abrasive polishing (grit size 500) MP, by a standard electropolishing EP and by magnetoelectropolishing MEP. The obtained Nyquist plots of corrosion behaviour of C45 steel samples in aqueous 3% NaCl solution after MP, EP, and MEP are presented in Fig. 8. The obtained results show that the best corrosion resistance revealed the C45 sample after abrasive polishing MP, worse corrosion resistance was after a standard electropolishing EP, and the worst – after magnetoelectropolishing MEP.

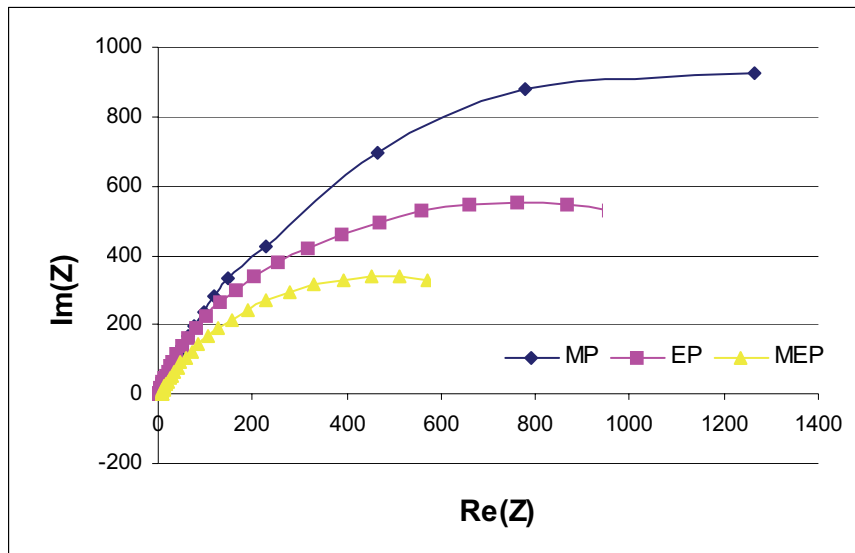


Fig. 8 Comparison of EIS corrosion results in 3% NaCl solution obtained on C45 non-alloyed steel samples after: 1-MP - abrasive polishing using a grit paper 500, 2 -EP – standard electropolishing, 2-MEP – magnetoelectropolishing

3 CONCLUSIONS

Application of a magnetic field in the process of electrolytic polishing of austenitic stainless steels [5-12] and other metallic materials (Ni-Ti alloy [13-16], Co-Cr-W alloys [17], CP Grade 2 titanium [18]) resulted in the increase of corrosion resistance of such treated surfaces. In this study we applied the magnetoelectropolishing to ferritic stainless steel of AISI 430, and non-alloyed C45 steel. The results of corrosion resistance in 3% NaCl indicate on different behaviour of 430 SS after this electrolytic polishing in a magnetic field. The highest corrosion resistance of 430 SS after one hour of exposition is observed on standard electropolished EP surfaces, and much lesser corrosion resistance after MEP, though it is still higher than after abrasive polishing (using grit size 1000). However, after 24 hours the surfaces of ferritic 430 SS samples after both MEP and EP indicate very similar corrosion resistance, with abrasive polished MP surfaces revealing the highest corrosion rate.

Pitting corrosion on 430 SS samples after three different treatments MP, EP, and MEP has been observed right after electrochemical corrosion studies (Fig. 6). In the field of corrosion studies (area of 2 cm²) there were from 105 up to 335 pits after MEP, and 82 pits after EP though they were much deeper and bigger (see Fig. 6 EP). The number of corrosion pits after MP was a little bit higher (108 pits, that is about 20% more) than that after EP.

The additional results obtained on a non-alloyed C45 steel (Fig. 8) have confirmed the reverse corrosion results with the worst corrosion resistance after MEP, better after a standard electropolishing EP, and the best after an abrasive polishing MP, even with the abrasive paper of grit size 1000.

The reason of different behaviour of ferritic materials (AISI 430 SS, C45) after MEP seems to be possible to explain on molecular level. During the process of MEP the surface film formed on magnetic materials presents much worse protective properties, resulting specifically in pitting. Further investigations are needed to reveal both composition and structure of the oxide/hydroxide film formed on the surface of ferritic materials.

REFERENCES

- [1] SEDRIKS A.J., Corrosion of Stainless Steels, 2nd edition, A Wiley-Interscience Publication, John Wiley & Sons, Inc., The Corrosion monograph series, New York/Chichester/Brisbane/Toronto/Singapore, 1996 (437 pages)
- [2] Metals Handbook, 10th edition, Vol. 1: Properties and Selection: Irons, Steels, and High-Performance Alloys (Wrought Stainless Steels, p. 841), ASM Intl., Materials Park, OH 44073, 1990
- [3] www.moly.imoa.info/Default.asp?Page=75
- [4] www.key-to-steel.com/Volume-1/Stainless-Steel.html
- [5] ROKICKI R., *Magnetic Fields and Electropolished Metallic Implants*, Medical Device & Diagnostic Industry, Vol. 28, No. 3/March, 2006, 116-123
- [6] ROKICKI R., 2006, *Apparatus and method for enhancing electropolishing utilizing magnetic fields*, US Patent Appl.#2006124472 (USPTO), 15 June, 2006
- [7] HRYNIEWICZ T., ROKICKI R., ROKOSZ K., *Magneto-electropolishing process improves characteristics of finished metal surfaces*, Metal Finishing, December, Vol. 104, No. 12/December, 2006, 26-33
- [8] HRYNIEWICZ T., ROKICKI R., ROKOSZ K., *Metal Surface Modification by Magneto-electropolishing*, Proc. of 16th International Metallurgical & Materials Conference METAL'2007, 22-24 May 2007, Hradec nad Moravici, Czech Republic, Surf.Engng., D2, 1-8
- [9] HRYNIEWICZ T., ROKICKI R., *On the surface modification of stainless steels*, Proc. of 15th Annual Intl.Confer. on Composites/Nano-Engineering, ICCE-15, 15-21 July, 2007, Haikou, Hainan Island, China, ed. by David Hui, pp. 345-346
- [10] HRYNIEWICZ T., ROKICKI R., ROKOSZ K., *Surface characterization of AISI 316L biomaterials obtained by electropolishing in a magnetic field*, Surface & Coatings Technology, Available online 7 August 2007
- [11] Hryniewicz T., Rokosz K., Rokicki R., *Electrochemical and XPS Studies of AISI 316L Stainless Steel after Electropolishing in a Magnetic Field*, Corrosion Science, 2008, Vol. 50(9), 2676-2681, doi:10.1016/j.corsci.2008.06.048, Available online 17 July 2008
- [12] HRYNIEWICZ T., ROKICKI R., ROKOSZ K., *Corrosion Characteristics of Medical Grade AISI 316L Stainless Steel Surface after Electropolishing in a Magnetic Field*, CORROSION (The Journal of Science and Engineering), Corrosion Science Section, August 2008, Vol. 64, No. 8, 660-665
- [13] ROKICKI R., HRYNIEWICZ T., *Nitinol Surface Finishing by Magneto-electropolishing*, Transactions of the Institute of Metal Finishing, 2008, September 2008, Vol. 86, No 5/September, 280-285

- [14] ROKICKI R., HRYNIEWICZ T., ROKOSZ K., *Modifying Metallic Implants with Magneto electropolishing*, Medical Device & Diagnostic Industry, 25 October 2007, invited paper, January 2008, Vol. 30, No. 1, 102-111
- [15] ROKICKI R., HRYNIEWICZ T., ROKOSZ K., *The effect of magneto electropolishing on corrosion and fatigue behavior of NiTi endodontic rotary files exposed to 5.25% sodium hypochlorite*, Proc. Intl. Conf. on Shape Memory & Superelastic Technologies (SMST-2008): Stresa, Italy, Sept. 21–25, 2008 (Poster Session)
- [16] HRYNIEWICZ T., ROKICKI R., *Advances in Metallic Biomaterials Surface Finishing*, Proc. of 2008 E-MRS Fall Meeting, 15-19 September, 2008, ID 15557, C14 (Poster Session) Warsaw University of Technology, <http://www.science24.com/paper/15557>
- [17] HRYNIEWICZ T., ROKICKI R., ROKOSZ K., *Co-Cr alloy corrosion behaviour after electropolishing and “magneto electropolishing” treatments*, Materials Letters, **2008**, 62, 3073-3076
- [18] HRYNIEWICZ T., ROKICKI R., ROKOSZ K., *Corrosion and Surface Characterization of Titanium Biomaterial after Magneto electropolishing*, Surface and Coatings Technology 2008, <http://dx.doi.org/10.1016/j.surfcoat.2008.11.028>