



Electropolishing Processes for Better Implants' Performance



Tadeusz Hryniewicz*

Division of BioEngineering and Surface Electrochemistry, Department of Engineering and Informatics Systems, Poland

Received:  November 11, 2018; **Published:**  November 15, 2018

***Corresponding author:** Tadeusz Hryniewicz, Division of BioEngineering and Surface Electrochemistry Department of Engineering and Informatics Systems, Koszalin University of Technology, Raclawicka 15-17, PL 75-620 Koszalin, Poland

Abstract

In the paper, a review of electropolishing processes is presented, beginning from a standard electropolishing (EP), through high-current-density electropolishing (HDEP, and high-voltage electropolishing (HVEP), being a commence of a new plasma electrolytic oxidation (PEO) process performed in concentrated 85% phosphoric acid (H₃PO₄). This work provides a several-decade history of developing the electropolishing processes, starting from simple surface finishing for obtaining roughness-free, bright and glossy metal surface, through a considerable progress in surface engineering in view of getting real advantages while applying it in medicine for biomedical parts, devices and implants. This review reveals how a big step was done by introducing the magnetic field into the process, with the name of magneto electropolishing (MEP). The most important features of MEP-treated metal/alloy parts is a big increase in corrosion resistance, substantial decrease of hydrogenation, huge increase in mechanical and fatigue resistance in cyclic bending, up to much better surface hydrophilicity, with improved biocompatibility.

Keywords: Magneto electropolishing (MEP); Fatigue resistance; Metallic biomaterials; Implants; Biocompatibility

Introduction

The process of electropolishing (EP) has been developed for many decades now in view of obtaining shiny, bright and glossy surface on metals and alloys [1-5]. Some characteristic features of machine parts are usually obtained after EP [4-7] due to removal of surface roughness and formation of passive surface film on them, including possible changes in color [6]. Firstly it was considered as the process designed to improve surface finishing, much better than that gained after abrasive polishing processes [1,8]. During the years of studies it was found that not only surface roughness decay and gloss effects normally appear as the real effects of the EP process, but many more interesting features were revealed on the treated metal surface. They are generally an increase in corrosion resistance and a considerable improvement of mechanical properties of the treated parts [9-15]. In the anodic processes of electropolishing (EP) in acidic electrolytes, passive thin films revealing improved corrosion resistance are obtained [3-5, 11-22].

Progress in Electropolishing

By introducing a magnetic field into the EP process, a new process patented by Rokicki [9] named as a magneto electro polishing (MEP), has been developed. In view of displaying its advantages and features, extensive investigations over the MEP

process were carried out [9-51]. Meanwhile, the studies on the theory of electropolishing were also continued [2,8,36]. Results of the studies have proved that the MEP process is characteristic with many meaningful features, prevailing over a standard electropolishing EP, starting from diminished surface roughness [10-12,14,15,17,20,24,30,43,45], more advantageous surface film composition [14-18,26,29,32-34,38,40,41,43,45-51], increased nanohardness [34,38-40,43,46,47], through the increased corrosion resistance [12-15,17-22,27,28,30,34,43,45,47-49], including one of the most significant improvement of biocompatibility of metallic biomaterials [11,12,15,18-21,22-24,30,31,34,35,43-45,48-51]. These improved characteristics were revealed to appear after MEP of both metals and alloys. To prove these, numerous metals and alloys, including metallic biomaterials were investigated, starting from austenitic stainless steels (AISI 304, 304L, 316, 316L, 316L vm) [10-13,15-19,23,25,27,38,39,41-43,45], ferritic AISI 430 stainless steel [22], duplex stainless steels LDX 2101 [38] and 2205 [55], cobalt Co-Cr alloys [17], through titanium (CP Titanium Grade 2) [4,20,30,32,33,37,39], shape memory alloy – Nitinol [11,14,21,26-28,31,35,36,45,48,49,51,59-61], and next titanium alloys (e.g. Ti6Al4V, Ti2448, or titanium niobium-zirconium TNZ alloy) [42,46], as well as niobium and other metallic materials [34,50,57,63].

During MEP of alloys, magnetic elements such as iron in austenitic stainless steels, or nickel in Nitinol could be completely removed from the surface layer. This way, the surface film in stainless steel was highly enriched in chromium oxides, and mostly titanium oxide (TiO_2) was formed on NiTi alloy surface. Besides, the oxide layer formed during MEP of NiTi intermetallic compound appeared to be thinner (about 6 nm) than that one obtained after a standard EP with the increased regularity of oxide layer formed. Another characteristic feature is an increase of surface energy and with this a better surface hydrophilicity of parts obtained after MEP.

Mixture of concentrated acids is mostly used as the electrolyte for electropolishing processes, with some of them being proprietary and not revealed nor openly presented in literature. Low voltage (3-15 V) is used for a standard EP and magneto electropolishing MEP processes performed generally on the plateau level [1,2,8,25,36]. For instance, for Nitinol a mixture of non-halogen acid with alcohol was used as the electrolyte at temperature 0 °C, the processing time for 5 min, electropolishing voltage 10 V, current density was above plateau – under oxygen evolution regime, Al as electrode/cathode material, with no agitation under EP, and whirling caused by a Lorentz force during MEP. Besides, high-current density HDEP (EP1000 and EP2000) [47,52-55], and high-voltage electropolishing HVEP (up to 450 V) [56] processes were also studied, proving their usability for specific purposes, e.g. the HVEP disclosed the entrance to Plasma Electrolytic Oxidation PEO [64,65] in concentrated acids. Under a standard electropolishing EP on the plateau level, high-current density electropolishing HDEP, and magneto electropolishing MEP, the Nano-coatings on metals and alloys are formed. These Nano-coatings/films are characteristic with a variety of unique properties, concerning increased corrosion resistance in harsh environments and greatly improved important mechanical properties of parts for specific applications [57-63]. MEP additionally improves metal surface properties, fundamentally diminishes surface layer hydrogenation, and basically results in increased fatigue resistance of parts [27-34,42,43,45,46,59-61].

One of the most serious problems to solve was de-hydrogenation of the surface layer after numerous mechanical and electrochemical operations. The problem is of importance to avoid hydrogenation in titanium alloys (Nitinol) in implants, peripheral stents, needles, endodontic files and another medical device. The avoidance of hydrogenation is expected also in niobium used for superconducting radio frequency cavities, or electromagnetic radiation detectors, and in nuclear industries. Specifically, niobium as the alloying element improves the strength of the alloys, especially at low temperatures. Our recent studies performed on selected metals and alloys indicated consecutive lowering of hydrogenation, the highest noted in as-received (AR) samples of metals and alloys, some lower after EP, and the lowest in MEP samples [29,32,58,61,63]. The subsequent studies using secondary ion mass spectroscopy SIMS as well as glow discharge optical emission spectroscopy GDOES show that the depth of appearance and the amount of hydrogen content after MEP is very low, revealing only traces and/or decaying almost completely [61,63]. In some cases that de-hydrogenation may result also from a new electrolyte composition used for MEP

of niobium [57] in comparison with that one used in Siemens process [66]. Our recent finding connected with the MEP process is a considerable increase of mechanical properties, specifically referred to the fatigue under samples bending. Over a decade ago, the Author noticed that during 180-degree bending (acc. to a Polish Standard, 90 degree static bending) of a ϕ 1.6-mm titanium wire after EP the number of bends was about 3-4 cycles, whereas after MEP it was 7-8 cycles- in both cases until fracture. Next a similar behavior of samples was also found in case of stainless steels, and Nitinol (surgical blades and suture needle pushers) [57,59-61]. Nitinol surgical needles after MEP under composed bending (90° in one direction and 70° in reverse) revealed 3 to 5 times higher resistance to bending than those after a standard EP.

One example of biomaterials performance is presented in Figure 1. Displayed in Figure 1 implants come from a human body after a period of time they were inserted. In Figure 1a, the austenitic stainless steel implant after a very fine finishing underwent corrosion in the harsh human environment. On the other hand, in Figure 1b a fatigue breakage is visible to occur in a very similar stainless steel implant. Our solution to prolong the life of this type of implants is the change of biomaterial used (say into a titanium alloy), and the advice for final surface finishing by MEP. A variety of measurement techniques were used to study Nano-coatings after EP, MEP. They are: scanning electron microscopy with electron dispersive X-ray SEM/EDX, Auger electron spectroscopy AES, X-ray photoelectron spectroscopy XPS, X-ray/grazing incidence diffraction XRD/GIXRD, glow discharge optical emission spectroscopy GDOES, secondary ion mass spectroscopy SIMS, atomic force microscopy AFM, contact angle measurement CAM, electrochemical impedance spectroscopy EIS, 2D and 3D surface roughness studies with Ra and Sa parameters noted, nanoindentation measurements, fatigue resistance testing, and others.



Figure 1: Examples of austenitic stainless steel (SS) implants affected in human body.

Note:

- a) corrosion visible on the SS implant's surface,
- b) mechanical fatigue visible in broken implant

Conclusion

In conclusion, MEP effects in comparison with the samples after EP are: lower roughness and passive film thickness, advantageous

film composition with a modified compact structure, higher corrosion resistance, increased resistance to cyclic bending of part, until fracture. Interestingly, a huge increase in mechanical resistance to fracture is one of the most unexpected features of parts after that kind of metal finishing [32,57-61]. It may be connected with the decrease in surface roughness, thinner film with modified composition obtained after MEP, and general diminishing of hydrogenation in comparison with the same samples/parts after a standard electropolishing EP.

Acknowledgments

Medicine Doctor Andrzej Hryniewicz, Chief Consultant and Vice-Supervisor of Surgery of Regional Hospital in Kołobrzeg, Poland, is highly thankful for delivering examples of the implants, presented in this paper. The used implants were acquired from patients during surgery.

Dr Krzysztof Rokosz, DSc PhD, professor of the Koszalin University of Technology, is greatly acknowledged for his scientific co-operation in developing electropolishing processes and extending the experiments, throughout the HVEP, onto the plasma electrolytic oxidation.

Mr Ryszard Rokicki, recently deceased, inventor and the owner of Electrobright, Macungie PA, USA, as the author of PhD Thesis: "Magnetoelectropolishing as a novel method for improving Nitinol parts and devices" (with my part as the Promoter), is greatly acknowledged for his long-term and fruitful co-operation by developing electropolishing processes on industrial scale. The acknowledgment is directed to the family, straight to his wife, Ms Małgorzata Rokicki.

References

- Tegart WJ (1956) The Electrolytic and Chemical Polishing of Metals for Research and Industry; Pergamon Press: London, UK.
- Hryniewicz T (1986) On Discrepancies Between Theory and Practice of Electropolishing, *Materials Chemistry and Physics*. 15(2): 139-154. [https://doi.org/10.1016/0254-0584\(86\)90119-7](https://doi.org/10.1016/0254-0584(86)90119-7).
- Rokicki R (1989) Electropolishing of high purity gas handling equipment. *Metal Finishing* 87(5): 38-39.
- Rokicki R (1990) The passive oxide film on electropolished titanium. *Metal Finishing*. 88(2): 69-70.
- Rokicki R (1990) The effect of electropolishing on SS welds and heat effected zones. *Metal Finishing* 88(4): 31-32.
- Rokicki R (1991) Coloring of electropolished stainless steel. *Metal Finishing* 89(6): 103-104.
- Rokicki R (1993) Electropolishing of high nickel alloys. *Metal Finishing* 91(6): 103-114.
- Hryniewicz T (1994) Concept of micro smoothing in the electropolishing process. *Surface and Coatings Technology*. 64(2): 75-80. [https://DOI.org/10.1016/S0257-8972\(09\)90006-8](https://DOI.org/10.1016/S0257-8972(09)90006-8).
- Rokicki R (2009) Apparatus and method for enhancing electropolishing utilizing magnetic fields. US Patent Number 7632390, 2009.
- Hryniewicz T, Rokosz K, Rokicki R (2006) Magnetoelectropolishing Process Improves Characteristics of Finished Metal Surfaces. *Metal Finishing* 104(12): 26-33.
- Rokicki R (2006) Magnetic field and electropolished metallic implants. *Medical Device & Diagnostic Industry* 28(3): 116-123.
- Hryniewicz T, Rokicki R, Rokosz K (2007) Magnetoelectropolishing for metal surface modification, *Transactions of the Institute of Metal Finishing* 85(6): 325-332.
- Hryniewicz T, Rokicki R, Rokosz K (2007) Corrosion characteristic of medical grade AISI 316L stainless steel surface after electropolishing in magnetic field, *The Journal of Corrosion Science and Engineering*.10(45): 1-10.
- Rokicki R, Hryniewicz T (2008) Nitinol surface finishing by magneto electropolishing. *Transaction of the Institute of Metal Finishing* 86(5): 280-285.
- Rokicki R, Hryniewicz T, Rokosz K (2008) Modifying Metallic Implants with Magnetoelectropolishing. *Medical Device & Diagnostic Industry* 30(1): 102-111.
- Hryniewicz T, Rokosz K, Rokicki R (2008) Electrochemical and XPS Studies of AISI 316L Stainless Steel after Electropolishing in a Magnetic Field. *Corrosion Science* 50(9): 2676-2681. DOI:10.1016/j.corsci.2008.06.048.
- Hryniewicz T, Rokicki R, Rokosz K (2008) Co-Cr alloy corrosion behavior after electropolishing and "magnetoelectropolishing" treatment. *Materials Letters* 62: 3073-3076. DOI:10.1016/j.matlet.2008.01.130.
- Hryniewicz T, Rokicki R, Rokosz K (2008) Surface characterization of AISI 316L biomaterials obtained by electropolishing in a magnetic field. *Surface and Coatings Technology*. 202: 91668-91673. DOI:10.1016/j.surfcoat.2007.07.067.
- Hryniewicz T, Rokicki R, Rokosz K (2008) Corrosion characteristic of medical-grade AISI 316L stainless steel surface after electropolishing in magnetic field. *Corrosion* 64(8): 660-665.
- Hryniewicz T, Rokicki R, Rokosz K (2008) Corrosion and Surface Characterization of Titanium Biomaterial after Magneto electropolishing. *Surface and Coatings Technology* 203(10-11): 1508-1515. DOI:10.1016/j.surfcoat.2008.11.028.
- Shabalovskaya S, Anderegg J, Van Humbeek J (2008) Critical overview of nitinol surfaces and their modifications for medical applications. *Acta Biomaterialia* 4(3): 447-467.
- Hryniewicz T, Rokosz K, Rokicki R, Cep R (2009) Effect of Magneto electropolishing on corrosion behavior of ferritic AISI 430 stainless steel, *Transactions of the VSB Technical University of Ostrava, Mechanical Series, Ostrava, Czech* 55(1): 101-108.
- Hryniewicz T, Rokosz K, Filippi M (2009) Biomaterial Studies on AISI 316L Stainless Steel after Magnetoelectropolishing. *Materials* 2(1): 129-145. DOI:10.3390/ma2010129.
- Hryniewicz T, Rokosz K, Rokicki R (2009) Surface investigation of NiTi rotary endodontic instruments after magnetoelectropolishing, *MRS Proceeding Biomaterials (of XVIII International Materials Research Congress, 9. Biomaterials, Cancun, Mexico 1244E: 21-32.16-20 August 2009, 1244E (2009) 21-32; ISBN 978-1-60511-221-3*.
- Hryniewicz T, Rokosz K (2010) Polarization Characteristics of Magneto electropolishing Stainless Steels. *Materials Chemistry and Physics*, 122(1): 169-174. DOI:10.1016/j.matchemphys.2010.02.055.
- Rokicki R (2010) Detecting nitinol surface inclusions. *Medical Devices and Diagnostic Industry* 32(2): 44-48.
- Praisanti C, Chang J, Cheung G (2010) Electropolishing enhances the resistance of nickel-titanium files to corrosion-fatigue failure in hypochlorite. *Journal of Endodontics* 36(8): 1354-1357.
- Simka W, Kaczmarek M, Baron Wiechec A, Nawrat G, Marciniak J (2010) Electropolishing and passivation of NiTi shape memory alloy. *Electrochimica Acta* 55(7): 2437-2441. DOI:10.1016/j.electacta.2009.11.09.

29. Hryniewicz T, Konarski P, Rokosz K, Rokicki R (2011) SIMS analysis of hydrogen content in near surface layer of AISI 316L SS after electrolytic polishing under different conditions. *Surface and Coatings Technology* 205(17-18): 4228-4236. DOI:10.1016/j.surfcoat.2011.03.024.
30. Hryniewicz T, Rokicki R, Rokosz K (2011) Chapter 11. Magneto-electropolished Titanium Biomaterial, in *Biomaterials Science and Engineering / Book 2*, ISBN 978-953-308-118-2, InTech, pp. 227-248, website: <http://www.intechweb.org/>, <http://www.intechopen.com/articles/show/title/magneto-electropolished-titanium-biomaterial>
31. Rokicki R, Haider W, Hryniewicz T (2012) Influence of sodium hypochlorite treatment of electropolished and magneto-electropolished nitinol surfaces on adhesion and proliferation of MC₃T₃ pre-osteoblast cells. *Journal of Materials Science: Materials in Medicine* 23(9): 2127-2139. DOI:10.1007/s10856-012-4696-1.
32. Hryniewicz T, Konarski P, Rokicki R, Valiček J (2012) SIMS studies of titanium biomaterial hydrogenation after magneto-electropolishing. *Surface and Coatings Technology* 206(19-20): 4027-4031. DOI:10.1016/j.surfcoat.2012.03.083.
33. Hryniewicz T, Rokosz K, Valiček J, Rokicki R (2012) Effect of magneto electropolishing on Nano hardness and Young's modulus of titanium biomaterial. *Materials Letters* 83: 69-72.
34. Hryniewicz T, Rokosz K, Zschommler Sandim HR (2012) SEM/EDX and XPS Studies of Niobium after Electropolishing. *Applied Surface Science* 263: 357-361. DOI:10.1007/s10856-012-4696-1.
35. Rokicki R, Haider W, Hryniewicz T (2012) Influence of Sodium Hypochlorite Treatment of Electropolished and Magneto electropolished Nitinol Surfaces on Adhesion and Proliferation of MC₃T₃ Pre-osteoblast Cells. *Journal of Materials Science: Materials in Medicine* 23(9): 2127-2139.
36. Rokicki R, Hryniewicz T (2012) Enhanced oxidation-dissolution theory of electropolishing. *Transactions of the Institute of Metal Finishing* 90(4): 188-196.
37. Hryniewicz T, Rokosz K, Valiček J, Rokicki R, Harničarova M (2013) Measurements of Nano hardness and elasticity modulus of titanium after magneto electropolishing PAK. (*Measurement Automation and Monitoring*) 59(7): 676-679.
38. Rokosz K, Hryniewicz T (2013) XPS measurements of LDX 2101 duplex steel surface after magneto-electropolishing. *International Journal of Materials Research (former: Zeitschrift für METALLKUNDE)*, 104(12): 1223-1232.
39. Hryniewicz T, Rokosz K, Valiček J, Rokicki R, Harničarova M, Vyležik M (2013) Measurements of Nano hardness and elasticity modulus of titanium after magneto-electropolishing, PAK (*Measurement Automation and Monitoring*) 59(7): 676-679.
40. Rokosz K, Hryniewicz T, Raaen S (2014) Cr/Fe ratio by XPS spectra of magneto-electropolished AISI 316L SS fitted by Gaussian Lorentzian shape lines. *Tehn. Vjesn-Technical Gazette* 21(3): 533-538. DOI:UDC/UDK 543.55:669.15:620.197.5.
41. Rokosz K, Hryniewicz T, Rokicki R (2014) XPS measurements of AISI 316LVM SS biomaterial tubes after magneto-electropolishing. *Tehn. Vjesn-Technical Gazette* 21(4): 799-805.
42. Hryniewicz T, Rokosz K, Rokicki R, Prima F (2014) Nanoindentation Studies of TNZ and Ti2448 Biomaterials after Magneto-electropolishing. *Advances in Materials Science* 3(41): 34-44. DOI:10.2478/adms-2014-0014.
43. Hryniewicz T, Rokosz K, Rokicki R (2014) Magnetic Fields for Electropolishing Improvement: Materials and Systems. *International Letters of Chemistry, Physics and Astronomy* 23: 98-108.
44. Hryniewicz T, Rokosz K (2014) Corrosion resistance of magneto electropolished AISI 316L SS biomaterial. *Anti-Corrosion Methods and Materials* 61(2): 57-64. <http://dx.doi.org/10.1108/ACMM-03-2013-1249>.
45. Hryniewicz T, Rokosz K (2014) Highlights of magneto-electropolishing *Frontiers in Materials: Corrosion Research* 1(3): 1-7. DOI:10.3389/fmats.2014.00003.
46. Hryniewicz T, Rokosz K, Rokicki R, Prima F (2015) Nanoindentation and XPS studies of titanium TNZ alloy after electrochemical polishing in a magnetic field. *Materials* 8(1):205-215. DOI:10.3390/ma8010205.
47. Rokosz K, Lahtinen J, Hryniewicz T, Rzakiewicz S (2015) XPS depth profiling analysis of passive surface layers formed on austenitic AISI 304L and AISI 316L SS after High-Current-Density Electropolishing. *Surface and Coatings Technology* 276: 516-520. DOI:10.1016/j.surfcoat.2015.06.022.
48. Rokicki R, Hryniewicz T, Pulletikurthi C, Rokosz K, Munroe N (2015) Towards a Better Corrosion Resistance and Biocompatibility Improvement of Nitinol Medical Devices. *Journal of Materials Engineering and Performance* 24: 1634-1640. DOI:10.1007/s11665-015-1429-x (7 pages).
49. Gill P, Musaramthota V, Munroe N, Datye A, Dua R, et al. (2015) Surface modification of Ni-Ti alloys for stent application after magneto electropolishing. *Materials Science and Engineering C, Materials for Biological Applications* 50: 37-44.
50. Rokicki R, Haider W, Kaushal S (2015) Hemocompatibility Improvement of Chromium-Bearing Bare-Metal Stent Platform after Magneto electropolishing. *Journal of Materials Engineering and Performance* 24(1): 345-352. DOI:10.1007/s11665-014-1277-0.
51. Pulletikurthi C, Munroe N, Stewart D, Haider W, Amruthaluri S, et al. (2015) Utility of magneto-electropolished ternary nitinol alloys for blood contacting applications. *Journal of Biomedical Materials Research Part B, Applied Biomaterials* 103(7): 1366-1374. DOI:10.1002/jbm.b.33317.
52. Rokosz K, Simon F, Hryniewicz T, Rzakiewicz S (2015) Comparative XPS analysis of passive layers formed on AISI 304L SS after standard and very-high-current density electropolishing. *Surface and Interface Analysis* 47(1): 87-92. DOI: 10.4028/www.scientific.net/SSP.227.167.
53. Rokosz K, Hryniewicz T, Rzakiewicz S, Raaen S (2015) High-Current-Density Electropolishing (HDEP) of AISI 316L SS (EN 1.4404) Stainless Steel. *Tehn. Vjesn-Technical Gazette* 22(2): 415-424. DOI: 10.17559/TV-20140722110711.
54. Rokosz K, Hryniewicz T, Rzakiewicz S (2015) XPS study of surface layer formed on AISI 316L SS after high-current-density electropolishing. *Solid State Phenomena* 227: 155-158. DOI:10.4028/www.scientific.net/SSP.227.167.
55. Rokosz K, Simon F, Hryniewicz T, Rzakiewicz S (2016) Comparative XPS analysis of passive layers composition formed on duplex 2205 SS after standard and high-current density electropolishing. *Tehn. Vjesn-Technical Gazette* 23(3): 731-735. DOI:10.17559/TV-20141107094438.
56. Rokosz K, Hryniewicz T, Raaen S (2017) XPS analysis of nanolayer formed on AISI 304L SS after High-Voltage Electropolishing (HVEP). *Tehn. Vjesn-Technical Gazette* 24(2): 321-326. <https://doi.org/10.17559/TV-20151125085632>.
57. Rokicki R, Hryniewicz T, Konarski P, Rokosz K (2017) The alternative, novel technology for improvement of surface finish of SRF niobium cavities. *World Scientific News* 74: 152-163.
58. Hryniewicz T, Konarski P, Rokicki R (2017) Hydrogen Reduction in MEP Niobium Studied by Secondary Ion Mass Spectroscopy (SIMS) *Metals* 7(10): 442. DOI:10.3390/met7100442.
59. Hryniewicz T, Rokicki R (2018) On the Nitinol properties improvement after electrochemical treatments. *World Scientific News* 95: 52-63.
60. Hryniewicz T, Rokicki R (2018) Modification of Nitinol Biomaterial for Medical Applications. *World Scientific News* 96: 36-58.
61. Hryniewicz T, Rokicki R (2018) Highly improved Nitinol biomedical devices by magneto-electropolishing (MEP). *World Scientific News* 106: 175-193.

62. Rokosz K, Hryniewicz T, Solecki G (2018) The studies of corrosion resistance of AISI 316Ti SS in Ringer's solution after electropolishing and passivation in nitric acid. *World Scientific News* 98: 46-60.
63. Hryniewicz T, Rokosz K, Gaiaschi S, Chapon P, Rokicki R, Matysek D (2018) GDOES analysis of niobium de-hydrogenation after electropolishing processes. *Materials Letters* 218: 299-304. DOI:10.1016/j.matlet.2018.02.027 .
64. Rokosz K, Hryniewicz T, Raaen S, Chapon P, Prima F (2017) Development of copper-enriched porous coatings on ternary Ti-Nb-Zr alloy by Plasma Electrolytic Oxidation. *The International Journal of Advanced Manufacturing Technology* 89(9-12): 2953-2965. DOI: 10.1007/s00170-016-9206-z.
65. Rokosz K, Hryniewicz T, Gaiaschi S, Chapon P, Raaen S, et al. (2017) Characterization of Calcium and Phosphorus-Enriched Porous Coatings on CP Titanium Grade 2 Fabricated by Plasma Electrolytic Oxidation. *Metals* 7: 354. DOI: DOI:10.3390/met7090354.
66. Efremov VM, Sevriukova LM, Hein M, Ponto L (1991) Improved method for electrochemical polishing of niobium superconducting cavities, Proc of the 5th Workshop on RF Superconductivity, pres. At the 2nd Intern. TESLA Workshop DESY, Hamburg, Germany, August SFR91E08: 433-455. DOI: DOI:10.3390/met7090354
67. Lin ZC, Denison A (2004) Nitinol fatigue resistance-a strong function of surface quality. *Medical Device Materials: Proceeding of the Materials & Processes for Medical Devices Conference2003*: 205-208.

ISSN: 2574-1241

DOI: [10.26717/BJSTR.2018.11.002046](https://doi.org/10.26717/BJSTR.2018.11.002046)

Tadeusz Hryniewicz. Biomed J Sci & Tech Res



This work is licensed under Creative Commons Attribution 4.0 License

Submission Link: <https://biomedres.us/submit-manuscript.php>



Assets of Publishing with us

- Global archiving of articles
- Immediate, unrestricted online access
- Rigorous Peer Review Process
- Authors Retain Copyrights
- Unique DOI for all articles

<https://biomedres.us/>