THE ANALYSIS OF FINISHING TOOLING INFLUENCE ON CORROSION PROPERTIES RESEARCHED BY EIS

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Abstract

Angular momentum pumps are very often applied onboard ships. These pumps are used in cooling circuits of medium and high power engines, power plant boilers and in bilge, ballast and fire installations. Very extensive use of angular momentum pumps on board is connected with their numerous advantages. During operation the wear of marine hull, the rotor and shaft seals take place. The research attempts to increase the service life of shafts.

The article presents the research results referring to the analysis of the influence of finish treatment (lathing, grinding and burnishing) on the corrosion properties of steel applied to marine pump shafts. The research was performed on a roller of 40 mm in diameter made of X5CrNi18-10 (AISI 304 L) stainless steel.

The lathing process was carried out by means of a WNMG WF 080408 Sandvik Coromant cutting tool with replaceable inserts. The grinding process was performed by grinding attachment for lathes. The 1 - 80x10x32 - 99C 80-N V grinding wheel was used for the process. The process of burnishing was done by SRMD burnisher by Yamato. In addition, the influence of the burnisher passes number on the corrosion properties was determined.

The paper will present the results of electrochemical impedance spectroscopy research. To conduct the survey the Atlas 0531 EU & IA potentiostat was used. Determination of the corrosion process parameters was performed computer programs: AtlasLab 2.0 and EIS Spectrum Analyzer.

Keywords: *burnishing, surface layers, angular momentum pump, corrosion properties, EIS.*

Introduction

Sea water pumps belong to a group of centrifugal angular momentum pumps. Their wide application on board vessels is related to their numerous advantages, which comprise simple construction, good performance characteristic, easy adjustment, quiet work and the possibility of applying direct electric motor drive. Centrifugal angular momentum pumps are utilized in the cooling system of high and medium speed engines, for supplying boilers, in bilge systems, ballast systems and in firefighting installations. During their service, the wear of pump body, rotor, sealing and shaft takes place. The research work made an effort to improve the shafts service durability and was based on carrying out tests for contact fatigue, friction wear and electrochemical corrosion.

Due to hard service conditions, marine pumps working in sea water environment are made of corrosion resistant materials. In spite of the fact that pump shafts are made of an expensive material, it is not possible to avoid service damage. This damage includes cracking, plastic deformation, excessive wear of pins in places of mounting rotor discs and sealing chokes, corrosive wear, friction wear, erosive wear and splineways knock outs. During service experience, the most common problem that is observed is excessive wear of pins causing their diameter decrease as well as exceeding the permissible shape deviations in place of chokes mounting.

Technology used in production process has a vital influence on the reliability and service life of machine parts. The final formation of surface layer, that is the dimensions and service properties, is achieved during finish treatment of a given element. The basic methods of final tooling of shafts include precise lathing, grinding or burnishing operation.

The process of burnishing shafts proposed here aims at increasing the service durability of marine pump shafts of sea water installations, which should give economic benefits in comparison with traditional methods. Burnishing process enables the achievement of high smoothness of machined surface together with the surface layer hardening. This process has been performed in industrial experience on universal machine tools and on CNC machines but it is regarded as plastic tooling. Therefore, the final formation of dimensions and service properties with the use of burnishing constitutes a chipless and dustless treatment, which allows for ranking burnishing among ecological tooling methods. The review of literature pointed out three fundamental purposes of the application of burnishing in the machine elements production process:

– smoothness tooling – which results in the reduction of the surface roughness after machining that precedes burnishing,
– strengthening tooling – which increases service properties (i.e. resistance to fatigue wear, abrasive wear and corrosive wear) by change of material properties in the surface layer,
– dimension-smoothness tooling – which increases the dimension accuracy with simultaneous reduction of surface roughness to its required value.

Burnishing process enables surface working at high dimensional precision (accuracy class 7 and 6) which makes it possible to achieve such advantages as [11-13]:

– ability to reach high surface smoothness (Ra = 0.32 – 0.04 μm) and high bearing surface of roughness profile (90%),
– increase of the surface hardness,
– increase of resistance to fatigue (both surface and volumetric),
– increase of resistance to abrasive and mashing wear,
– lack of abrasive grit, sharp and hard built-up edge fragments and chips on burnished surface,
– ability to use burnish tools on universal lathes (the concept of one stand working),
– elimination or reduction of the time consuming operations such as: honing, lapping, grinding and polishing,
– ability to eliminate heat treatment in certain cases,
– high process efficiency (one pass of a tool) and production costs reduction,
– high durability of burnishes,
– reduction of expenses related to machine parts production.

Numerous scientific centres all over the world deal with burnishing treatment and its impact on the surface layer. Research programmes usually cover issues related to burnishing of cast iron, some heat resisting alloys, stainless steel, copper and aluminium alloys, titanium and its alloys, composite and intermetallic coatings [6, 7] as well as parts produced by sintering metal powders.

The surface layer of material is specifically subjected to various degradable factors. However, it is not possible to avoid adverse phenomena of surface degradation during working conditions as well as corrosive influence of work environment. Therefore, the aim of the paper is to obtain proper technological quality and suitable service properties of angular momentum pump shaft pins applied to sea water systems in marine engines. Within the research, the optimization of burnishing technological parameters was carried out and the influence of the number of burnishing tool passes on the hardness and stereometric parameters of angular momentum pump shaft pins was defined. Therefore burnishing should be performed because of the minimization of R_a surface roughness factor as well as maximization of S_u surface layer relative hardness degree. The article will present the results of the research on pins corrosive properties in the form of electrochemical impedance spectroscopy research.

1. Samples preparation

The process of turning and burnishing of shaft pins ϕ 40 mm in diameter, made of X5CrNi18-10 stainless steel was carried out on a universal CDS 6250 BX-1000 centre lathe. The preliminary lathing process was conducted by a cutting tool with WNMG 080408 WF removable plates by

Sandvik Coromant. The super finishing Wiper plates ensure high efficiency of finishing and semi – finishing treatment. Properly designed geometry made it possible to apply two times more feed at the same surface finishing quality in comparison with traditional plates. Therefore, during the preliminary lathing (Fig. 1) the following machining parameters were used: machining speed V_c=112 m/min, feed f=0.27 mm/rev, machining depth a_p=0.5 mm.

Fig. 1. The view of working assembly (machine tool, fixture, object, tool) - lathing

The grinding process was performed by grinding attachment for lathes (Fig. 2). The 1 - 80x10x32 - 99C 80-N V grinding wheel was used for the process.

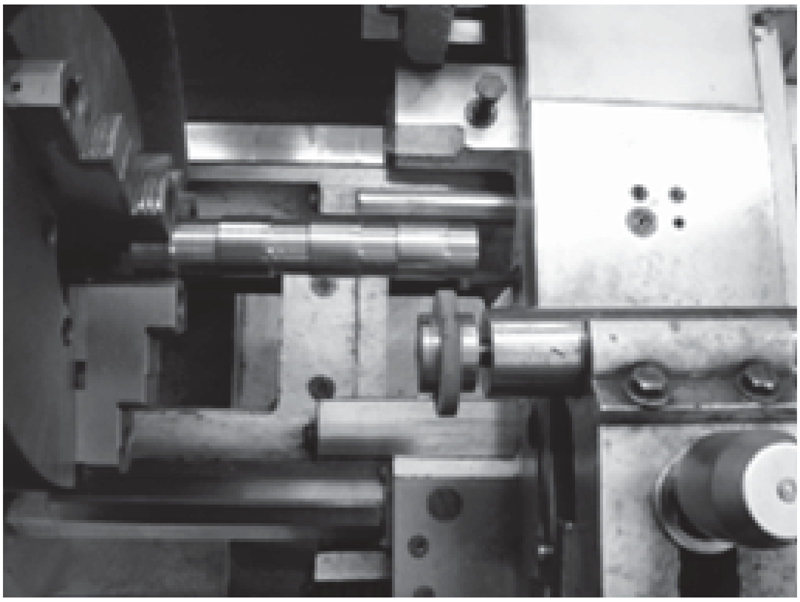

Fig. 2. The view of working assembly (machine tool, fixture, object, tool) - grinding

The process of burnishing (Fig. 3) was conducted by SRMD one roller burnish by Yamato (Fig. 4). Within the research, the optimization of burnishing technological parameters was conducted on account of the minimalization of Ra surface roughness coefficient as well as the maximization of S_U degree of surface layer relative hardness [5, 8, 9]. The multi criteria optimization conducted by min-max method [4] with regard to minimum surface roughness as well as maximum degree of surface layer hardness demonstrated that burnishing process should be carried out at the following technological parameters: burnishing force 1.1 kN, burnishing speed 35 m/min, feed 0.13 mm/rev. In addition, the influence of the burnisher passes number on the surface layer quality was determined [3]. The applied parameters of technological process of surface tooling were presented in Tab. 1. The research also covered the determination of the influence of burnish tool passes number on corrosive properties.

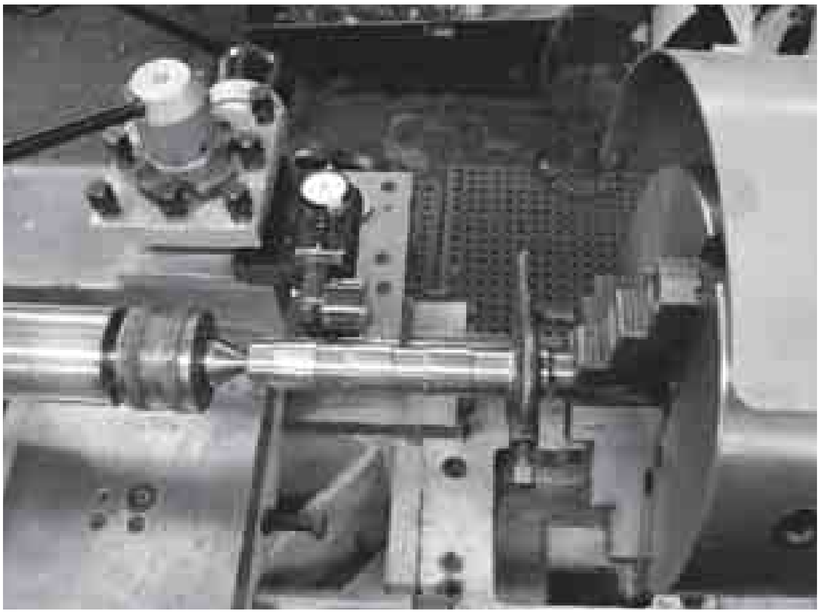

Fig. 3. The view of working assembly (machine tool, fixture, object, tool) -burnishing

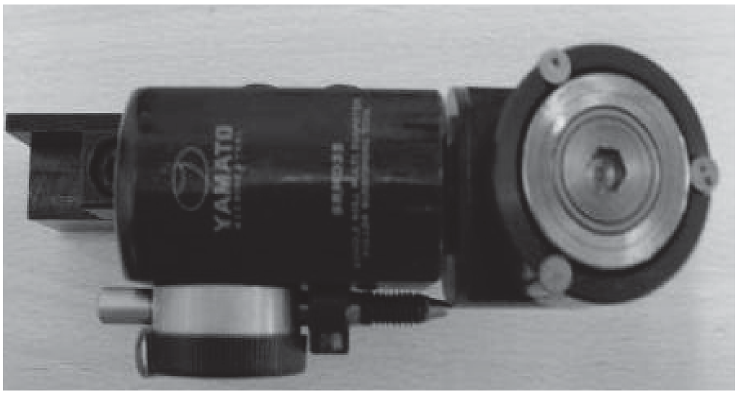

Fig. 4. Burnishing tool

Tab. 1. Technological parameters of burnishing process

Parameter	Values	
Burnishing force - F	[kN]	1.1
Burnishing speed – V_n	[m/min]	35
Feed - f	[mm/rev]	0.08

2. Research methodology

The measurement of corrosion resistance was performed by potentiodynamic method in a tri-electrode system. The degreased sample with the area of 1 cm^2 together with auxiliary (polarization) electrode made of plated titanium and reference electrode (calomel saturated electrode) were immersed in a vessel containing substitute sea water (PN-66/C-06502). Before taking measurements, the samples were subjected to explosion in electrolyte in order to stabilize the corrosion potential. During measurement, the electrolyte was being mixed [1, 2, 10, 14].

Electrochemical impedance spectroscopy measurements were conducted at the corrosion potential. The amplitude of the voltage signal varied in the range ± 10 mV, and the extent of the changes was the signal frequency: 100 kHz - 0.1 Hz. Studies have been conducted from high to low frequencies [14].

Determination of the corrosion process parameters was performed computer programs: AtlasLab 2.0 and EIS Spectrum Analyzer.

Chosen for the test object model in the form of an electrical equivalent circuit of the replacement. Selected model electrical circuit showing a replacement is presented in Fig. 5.

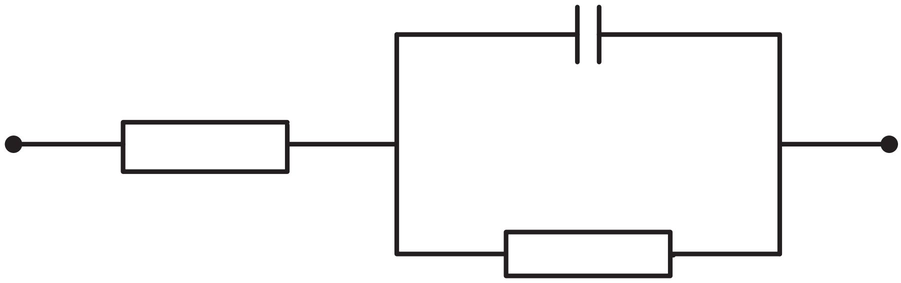

Fig. 5. The selected replacement of corrosion electrical circuit

In the selected model, the R_s element is the electrolyte resistance, which is reflected in corrosive environment. R_{ct} element is characterized by the charge transfer resistance of the interface metal / electrolyte, associated with the process of oxidation of metal, while the constant phase element CPE_{dl} - double layer capacitance, occurring on the border of phases under consideration.

For the selected alternative resultant impedance of the circuit can be described by the following relationship:

$$Z = R_s + \frac{1}{\frac{1}{R_{ct}} + Y_{dl}(j\omega)^{n_{dl}}}, \tag{1}$$

In this case, the impedance of the constant phase element (CPE) describes relationship:

$$Z_{CPE} = \frac{1}{Y(j\omega)^n}, \tag{2}$$

where:

Y, n - parameters determined during the study, describing the capacitive impedance.

3. Research results

The results of samples impedance spectroscopy after being machined are presented in Tab. 3. The mean values of parameters characterizing the corrosion process that were listed define particular components of the model that is the substitute electric circuit.

The analysis of the results demonstrated that the sample being ground showed the lowest resistance to electrochemical corrosion. The load transfer resistance value is the lowest by the double layer R_{ct} (3.67E+03) which indicates the lowest resistance in load exchange (ions, electrons) between the electrolyte and the material. The highest R_{ct} (1.26E+05) value during the research was registered for the sample, which underwent triple burnishing treatment where this parameter was almost thirty four times higher than in case of the ground sample.

Tab. 3. The results of EIS research.

Sample	R_s [$\Omega \cdot cm^2$]	Std Def	R_{ct} [$\Omega \cdot cm^2$]	Std Def	Z_{CPE} [$\Omega \cdot cm^2$]			
					Y_{dl} [S/cm^2]	Std Def	n_{dl}	Std Def
T	0.95	0.32	4.24E+04	2.18E+03	6.64E-05	3.61E-06	7.33E-01	2.01E-02
S	0.65	0.25	3.67E+03	6.80E+02	1.43E-04	3.15E-05	8.04E-01	4.84E-02
N	0.55	0.26	8.59E+04	1.09E+04	2.55E-06	4.04E-07	8.39E-01	3.23E-02
3N	0.47	0.16	1.24E+05	1.72E+04	3.68E-05	4.51E-06	9.30E-01	3.03E-02

The second parameter describing the corrosion process is impedance of solid phase element representing the capacity of double layer CPE_{dl} that was defined by means of two components. The first one is the admittance of the Y_{dl} parameter. In this case, the burnished sample showed the best, that is the lowest values. This indicates the fastest charge of the double layer at the metal-electrolyte phase border, after which the stoppage of electric charges flow occurs and consequently the inhibition of the corrosion process. The capacity component Y_{dl} reaches its highest value for the ground sample.

The index component n_{dl} determining the homogeneity of the corrosive process occurring on the surface of the samples examined reached its lowest value for the turned sample (0.733) which points out the highest inclination to pitting corrosion. The most uniform corrosive process should take place after machining on the sample surface, for which the n_{dl} parameter value was the most closest to 1. The n_{dl} parameter value for the sample after three passes of burnisher tool amounted to 0.930.

The electrolyte resistance constituting R_s the corrosive environment for all considered samples was at the same level and took mean values in the range of 0.47-0.95, which proves a very high electric conductivity of the solution. However, this parameter does not have a crucial importance in discussing the corrosion resistance of the samples examined.

The results of the electrochemical impedance spectroscopy are also shown graphically in Nyquist charts, and matched them with the theoretical curve (Fig. 6a, 7a, 8a, 9a). Matching this curve, that is comparing the computer simulation results of frequency impedance characteristics of the proposed substitute circuit with the characteristics determined in the measurements are shown in Bode graphs (Fig. 6b, 7b, 8b, 9b).

The analysis demonstrated the compatibility of frequency impedance characteristics determined experimentally with the computer calculated characteristics for a chosen substitute electric circuit, in the whole range of frequency changes of the input signal. It proves the legitimacy of applying such a model for conducting research and guarantees the credibility of the results obtained.

a) b)

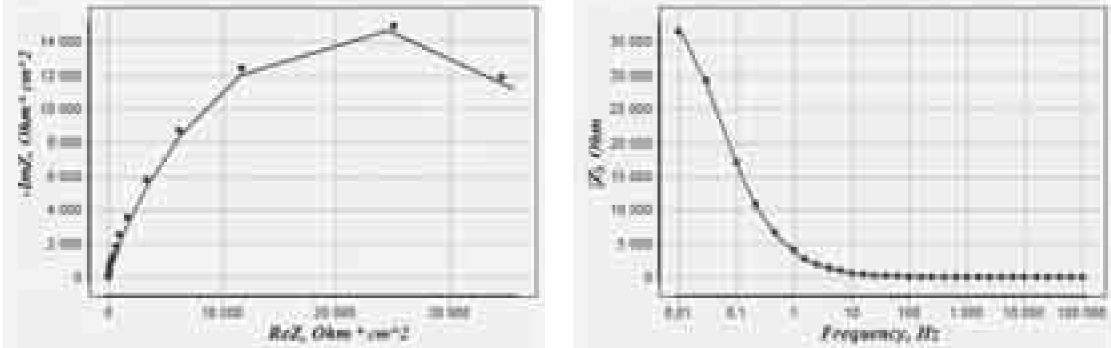

Fig. 6. An example of the Nyquist chart for a sample after lathing

a) b)

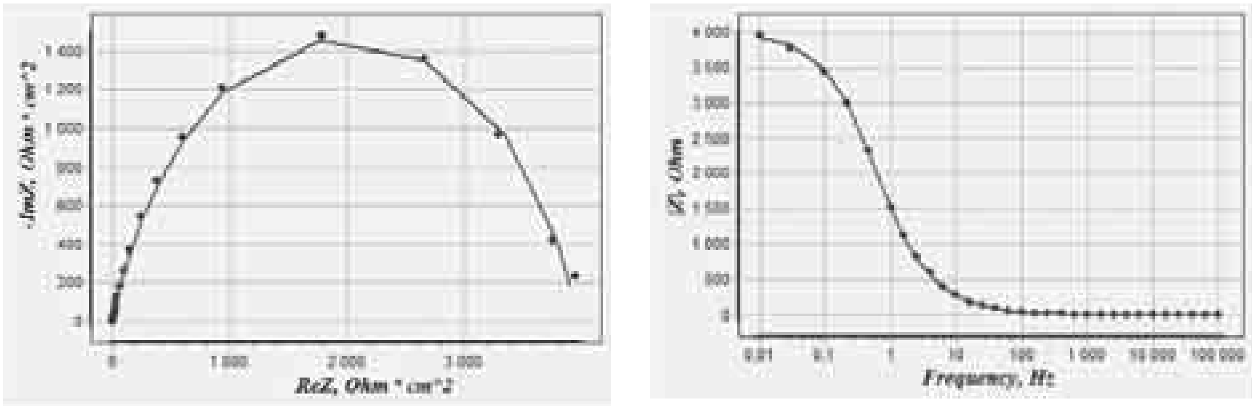

Fig. 7. An example of the Nyquist chart for a sample after grinding

a) b)

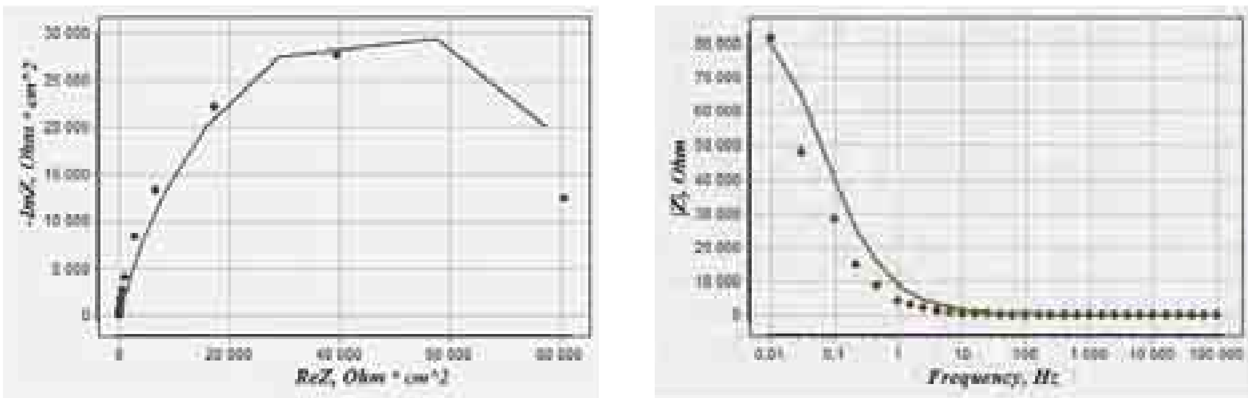

Fig. 8. An example of the Nyquist chart for a sample after burnishing

a) b)

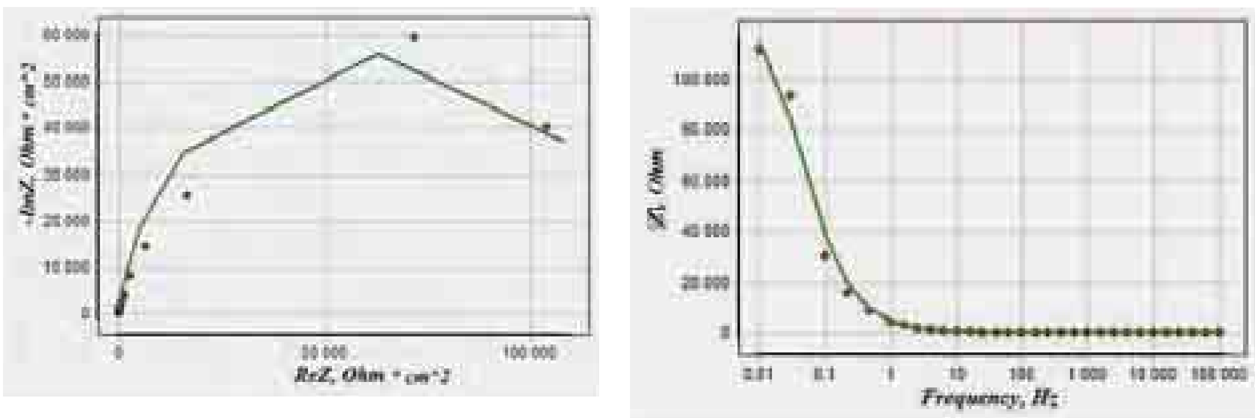

Fig. 9. An example of the Nyquist chart for a sample after III passes of burnisher tool

4. Conclusions

The results analysis of electrochemical corrosion research indicates that in spite of applying corrosion resistant steel, burnishing is beneficial to this service parameter compared to traditional methods of finish machining. The highest corrosion resistance is shown in the sample after three passes of burnisher tool. However, the lowest electrochemical corrosion resistance is demonstrated in a sample, which underwent grinding. The electrolyte resistance forming the Rs corrosive environment testifies very high electric conductivity of the solution. The analysis proved the rightness of using a substitute electric circuit in the whole range of frequency changes of the input signal, which guarantees the reliability of the results, obtained.

References

[1] Bala, H., *Korozja materiałów – teoria i praktyka*, Wydawnictwo Wydziału Inżynierii Materiałowej i Fizyki Stosowanej Politechniki Częstochowskiej, Częstochowa 2002.

[2] Budniok, A., Łągiewka, E., *Problemy elektrochemii w inżynierii materiałowej*, Wydawnictwo Uniwersytetu Śląskiego, Katowice 2009.

[3] Charchalis, A., Starosta, R., Labuda, W., *Estimation of the influence of burnishing tool passes number on ships pumps shafts surface layers strengthening and roughness changes*, Journal of KONES Powertrain and Transport, Vol. 16, No. 4, pp. 43–50, Zakopane 2009.

[4] Charchalis, A., Starosta, R., Labuda, W., *Multi-criteria optimization of steel burnishing parameters applied to marine pumps shaft pins,* Journal of KONES Powertrain and Transport, Vol. 17, No. 3, pp. 55–62, Jurata 2010.

[5] Charchalis, A., Starosta, R., Labuda, W., *The influence of burnishing parameters on the roughness, plastic strain and shape deviations of marine pumps crankshaft pins in fresh water installations*; Journal of KONBiN, No 1-2 (9,10), pp. 57-66, Warszawa 2009.

[6] Dyl, T., Skoblik, R., Starosta, R., *The Effect of the Ceramic Dispersion on the Nickel Matrix Composite Coating Properties after Plastic Working*, Solid State Phenomena, Vol. 147-149, pp. 813-818, Switzerland 2009.

[7] Dyl, T., Starosta, R., Skoblik, R., *The effect of the unit pressure on the NiAl and Ni3Al intermetallic coatings selection parameters after plastic working*. Solid State Phenomena, Vol. 165, p. 19-24, Switzerland 2010.

[8] Labuda, W., Starosta, R., *Estimation of the influence of burnishing parameters on X5CrNi18-10 steel,* Solid State Phenomena, Trans Tech Publication, Vol. 165, pp 300–305, Switzerland 2010.

[9] Labuda, W., Starosta, R., Dyl, T., *Estimation of the influence of burnishing parameters on steel X5CrNi1810 surface layers strengthening and roughness changes*, Journal of KONES Powertrain and Transport, Vol. 15, No. 3, pp. 259–267, Warszawa 2008.

[10] Starosta, R., *The influence of plastic strain on the corrosive properties of plasma sprayed intermetallic NiAl and Ni3Al coatings*, Solid State Phenomena, Vol. 165, pp. 165-177, Switzerland 2010.

[11] Przybylski, W., *Wpływ stanu warstwy wierzchniej konstytuowanej przez nagniatanie na trwałość elementów maszyn*, Wybrane problemy Trybologii, PWN, Warszawa 1990.

[12] Przybylski, W., *Współczesne problemy w technologii obróbki przez nagniatanie,* Wydawnictwa Politechniki Gdańskiej, Gdańsk 2005.

[13] Przybylski, W., *Współczesne problemy w technologii obróbki przez nagniatanie, Tom 2,* Wydawnictwa Politechniki Gdańskiej, Gdańsk 2008.

[14] Trzaska, M., Trzaska, Z., *Elektrochemiczna spektroskopia impedancyjna w inżynierii materiałowej*, Wydawnictwa Politechniki Warszawskiej, Warszawa 2010.