

The influence of mechanical treatment type on the tribological properties of flame sprayed Ni-5%Al-15%Al₂O₃ composite coatings

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Abstract: - During operation of marine pumps, one of the most common disability is tribological wear of shaft neck cooperating with the gland. In the practice, worn shafts are exchanged for new or are regenerated by chromium plating, padding or thermally sprayed of ceramic coatings, mainly Al₂O₃. In this article, the use of flame sprayed Ni-5%Al-15%Al₂O₃ composite coatings were proposed. The surfaces of coatings by turning, grinding are burnishing treatments were formed. Tribological properties of composite materials are dependent on the proportion and size of the reinforcing phase particles contained in a metal matrix. A reinforcement composite with very small dimensions and the amounts may result in increased wear and increase the coefficient of friction. It is therefore important to check whether the advisable of phase composition will not adversely affect the wear of the composite and the cooperating the part. The presence of a 15% volume fraction of the alumina particles on the selected tribological properties of the Ni-5%Al matrix composite coatings were evaluated. In order to assess the effect of the applied tapes of finishing on wear of composite coatings, the tribological tests were performed on the "T05" tribometer with head roll- piece type. It has been found that the burnishing favors a lower wear of composite coating and the cooperating element compared to the coatings after turning treatments. At the same time observed more than ten times less wear intensity of composite coatings in the initial time of friction, which may indicate a shorter time needed to running-in of cooperating elements.

Key-Words: - Tribological test, T-05 tribometer, composite coating, Ni-Al-Al₂O₃ coating, thermal spraying

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1 Introduction

The shafts necks of centrifugal pumps cooperating with seal of water gland are subject to wear. Although a small hardness of sealants on surface of journals a mechanical wear often is observed. Wear of journals is caused by: deposits of solid pollutants, occurring at the interface of interacting elements, wrong assembly or too firmly pressed against the packing gland.

Important is the choice of such technology surface treatment, which should help to reduce the wear process of the pivot. Durability of machines working in conditions of friction depends on many factors, which can be divided into three main groups: material and design, the technological, exploitation. One way to obtain potentially more resistant on tribological wear of machine parts is the use of composite materials. For example, base materials: aluminium, nickel or titanium which are strengthened by non-metallic particles (so-called metal matrix composites - MMC) [1-6, 14].

One of the factors influencing the tribological wear processes of materials are the properties of their

surfaces, which depend, inter alia, on the applied method of shaping and finishing. This paper presents the influence of three mechanical methods of shaping the geometric structure of the surface of thermally (flame) sprayed Ni-Al-15%Al₂O₃ composite coatings on their frictional wear. The following mechanical treatments were used: turning, grinding and roll burnishing. Another factor that may positively affect the wear of coatings is the presence of reinforcement located in the metal matrix of composite coatings. The proposed composite coatings with an appropriately shaped geometric structure could potentially be used as coatings increasing the service life of marine pump rotor shafts or as regenerative coatings.

The wear resistance of the composites is related to the size and number of reinforcement phase particles. The presence of small particles in a small number can cause plucking them from the matrix and speed up the process of tribological wear a pair of friction [14]. The authors of article [17] presented the tribological wear mechanisms of the composite AK12-Al₂O₃.

Composite abrasive wear is dependent on the ratio "penetration deep" of abradant and the average distance between the particles of the composite reinforcement. The composite should be considered as resistant to abrasion in case that the ratio of the value is less than one. Then reinforcement is an obstacle to moving abradant which causing ridging and scratching on matrix surface. Otherwise the reinforcement particles are crushed and pulled out from the metal matrix of composite. The process of wear of the composite is divided into the following steps [17]:

I - beginning of cooperation, in which the surface of the counterbody rest on a protruding after machining particles of the reinforcement. Starting wear process produces initially ridging on matrix surface (grind-in).

II - through the running-in process of friction surface increases the contact area between the mating surfaces. At this time, the reducing and stabilizing the friction coefficient value is observed. Unevenness of surface of counterbody affects the reinforcement particles and the matrix, causing the gradual wear of the composite, especially by scratching.

III - is associated with pull reinforcement particles out of matrix and intensification of the process of wear. This can result from pull reinforcement particles out of a matrix surface of counterbody and enhance the effect on abrasive wear the composite materials or rolling the loose particles between the mating surfaces. Rolling the particle may cause scratching each of the mating surface or plastic deformation of unreinforced parts of the matrix. Sometimes pushing reinforcement particles into the matrix of composites is observed. Consequently, it may occur to be joined adhesively the matrix composite portion to counterbody.

IV - alignment of area the matrix, after pull the particle out, by plastic deformation and gradual abrasive wear the matrix, leading to unveiling further reinforcement particles.

Burnishing is one of the methods to increase resistance to tribological wear of material. It is assumed that the burnishing, in connection with a reduction in roughness and waviness and strengthening of materials, affects not only the reduction of tribological wear, but often to reduce friction resistance [7-12].

2 Samples preparation

On the samples in the shape of ring, with an outer diameter of 35 mm, made of X5CrNi18-10 (304L) steel were applied the Ni-5%Al matrix composite coatings with a reinforcing phase in the form of Al₂O₃

particles. The volume fraction of alumina in the metal matrix composite coatings was 15%. The average diameter of ceramic particles was equal to 60 μm. The surface of the rings was cleaned of solid impurities by blasting. The degree of surface preparation was Sa = 2 1/2 (PN-EN ISO 8501-1: 2008), and the roughness of the outer surface of the ring was Ra = 3 μm. Immediately before the thermal spraying operation, the surface was flame degreased. The substrate preheating temperature was 60 ÷ 80 °C. For the preparation of coatings the Casto DS-Dyn 8000 gas torch (acetylene - oxygen) to the flame spraying was used. During flame spraying the following technological process parameters were used:

- acetylene pressure: 0.07 MPa,
- oxygen pressure: 0.4 MPa,
- compressed air pressure: 0.1 MPa,
- spraying rate (moving speed of the torch): 20 m/min,
- feed rate: 3 mm/rev,
- distance between torch and sprayed surface: 150 mm,
- number of applied layers: 6 (estimated thickness of layers on external cylindrical surfaces is 1 ÷ 1.2 mm),
- interlayer temperature of samples: 80 ÷ 100 °C.

The tested metal-ceramic coatings obtained by the flame method were machined in accordance with the guidelines of Messer-Castolin (manufacturer of coating material). Turning was performed with a monolithic tool ISO 2R 2525 K10, with the following blade geometry [15]:

- side rake angle: $\gamma = -5^\circ$,
- side clearance (relief) angle: $\alpha_0 = 6^\circ$,
- nose radius: $r_e = 0.8$ mm,
- nose angle, $\varepsilon_r = 90^\circ$.

entering angle of the turning tool κ_r was 45°. The cutting parameters were as follows:

- cutting speed: $v_c = 28.26$ m/min,
- feed rate: $f = 0.08$ mm,
- cutting depth: $a_p = 0.2$ mm.

The use of higher cutting speed values resulted in rapid damage to the tool. The coating turning was performed on a CDS 500x1000 lathe. The surface roughness of the turned composite coatings was Ra = 2.9 μm [3].

To obtain a surface with less surface roughness, grinding and burnishing were also used. Abrasive treatment carried out using a pneumatic lathe grinder. In accordance with the manufacturer's recommendations of the coating material, a grinding wheel with the marking: 01-90x10x32 39C-60-H6V was used. Grinding data were as follows: infeed 0.02

mm, linear speed of the machined journal 28 m/min, linear speed of the grinding wheel 25 m/s, longitudinal feed 0.06 mm/rev. After grinding, the Ra parameter value of the composite surface roughness was 1.17 μm [16].

Finishing was also carried out by smooth burnishing using the static method. The burnishing element was roll-shaped. The burnishing treatment was carried out with Yamato's SRMD tool. The following technological parameters of by plastic forming were used [3, 16]:

- burnishing force: $F_n = 700\text{ N}$,
- burnishing speed: $v_n = 28\text{ m/min}$,
- feed: $f_n = 0.04\text{ mm/rev}$.

After burnishing, the surface roughness of the flame sprayed composite coatings Ni-5%Al-15%Al₂O₃ was the lowest. The Ra parameter value was 0.7 μm [16]. In Fig. 1 the topography of the burnished of composite coating surface are presented.

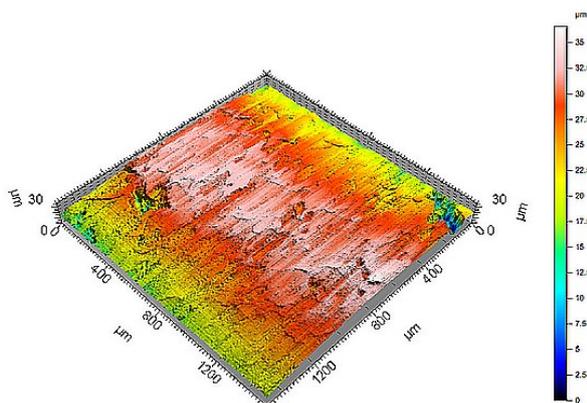


Fig. 1. Unfiltered topography of burnished surface of Ni-5%Al-15%Al₂O₃ coating obtained by Casto-Dyn DS 8000 torch.

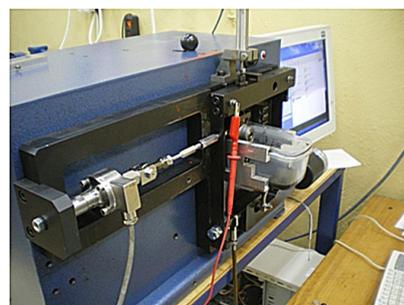
3 Testing methods

Tribological properties of regenerative composite coatings Ni-5%Al-15%Al₂O₃ flame sprayed by a Casto-Dyn DS 8000 with a surface shaped as a result of the following finishing treatments: turning, grinding and burnishing. The tests were carried out on the laboratory stand of the Maritime University of Gdynia. The measurements on a T05 machine with a roller-block tribological head (the so-called Amsler machine) were made (Fig. 2). The steel test block applied by a force P to the rotating roller a line contact was formed. Samples with applied coatings were shaped like a roll (ring). The counter-sample was a block (cuboid) of hardened C45 non-alloy steel with a hardness of 52 \div 55 HRC. The active surfaces

of the counter-sample were grinded to obtain a surface roughness $R_a = 0.6 \div 0.7\ \mu\text{m}$.

Table 1 shows the tribological research program used. At the outset, the mass consumption of the tribological pair was determined. The total test time was 60 min, pressure force $P_t = 300\text{ N}$, rotational speed of the sample $n_t = 600\text{ mm}^{-1}$ (circumferential speed $v_t = 1.1\text{ m/s}$). The mass of the samples was measured every 10 minutes and the counter-samples after a full cycle. The accuracy of the mass measurement was 10^{-4} g . During test the friction force (T), counter-sample temperature (t) were recorded and the friction coefficient (μ) was determined. The value of the friction coefficient was determined as the average value from the total of wear test. For the selected samples, additional load characteristics $\mu = f(P_t)$ and speed characteristics $\mu = f(v_t)$ were made. During test an oil bath lubrication method of lubrication of the tribological node was used. Machine oil as the lubricant was used. During operation, centrifugal pumps with a suitably shaped surface of the journals cooperate with a gland with a soft (elastic) seal or a slide gland, therefore the tests carried out were only comparative.

a)



b)

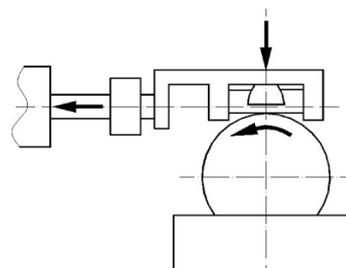


Fig. 2. Position for tribological tests: a) T05 tribometer, b) test head diagram

Table 1. Tribological tests plan

| | | | | | | | |
|----------|--|---------------|---------------|---------------|--------------|---------------|---------------|
| Test I | Mass wear Z_m at $n_t = 600 \text{ min}^{-1}$ ($v_t = 1.1 \text{ m/s}$), $P_t = 300 \text{ N}$ | | | | | | |
| | τ [min] | 10 | 20 | 30 | 40 | 50 | 60 |
| Test II | Impact of speed on μ at $P_t = 300 \text{ N}$ and $\tau = 60 \text{ s}$ (speed characteristic), | | | | | | |
| | n_t [min^{-1}] (v_t [m/s])) | 350 (0.64) | 400 (0.73) | 500 (0.92) | 600 (1.1) | 700 (1.28) | 750 (1.37) |
| Test III | Impact of load on μ at $n_t = 600 \text{ min}^{-1}$ ($v_t = 1.1 \text{ m/s}$) and $\tau = 60 \text{ s}$ (load characteristic), | | | | | | |
| | P_t [N] | 100 | 150 | 200 | 300 | 350 | 400 |

3 Research results

Fig. 3 shows the results of measurements of mass wear (Z_m) of Ni-5%Al-15%Al₂O₃ composite coatings obtained by flame sprayed with a Casto-Dyn DS 8000 torch. The coatings after treatment of turning after an hour test were characterized by mass wear $Z_m = 43.1 \text{ mg}$. As a result of burnishing, approximately 6 reduction of composite coating wear was observed.

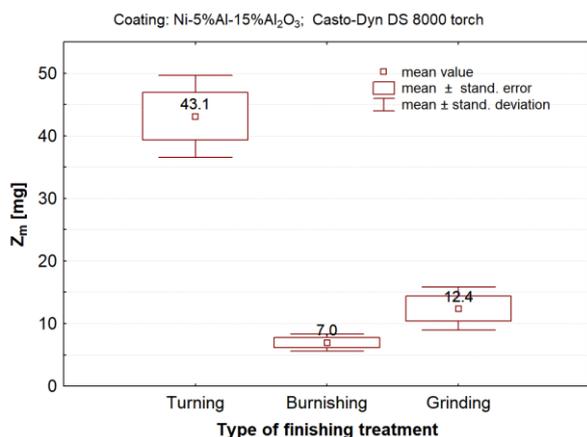


Fig. 3. Mass wear (Z_m) of coatings Ni-5% Al-15%Al₂O₃ obtained by flame spraying with Casto-Dyn DS 8000 torch; friction parameters: $P_t = 300 \text{ N}$, $v_t = 1,1 \text{ m/s}$, $\tau = 60 \text{ min}$.

The mean value of Z_m was 7 mg. Grinded composite coatings, while working with a steel counter-sample, underwent an average wear of 12.4 mg. Statistical analysis (Kruskal-Wallis test, median test) showed that the type of finishing technology used significantly affects the tribological wear of composite coatings sprayed with the Casto-Dyn DS 8000 torch (Table 2). Due to the relatively high plasticity of the nickel matrix of coatings, the particles of the reinforcing phase moving in the matrix cause furrow and strengthening the matrix by plastic deformation. This process continues until the

inhibition of movement of the particles through the lower-lying grains of alumina. It is also possible to pull out and then push the oxide phase back into the matrix.

Table 2. Results of nonparametric tests of significance of differences in distribution of the variable Z_m

| Variable | Kruskal – Wallis test | | Median test | |
|--|-----------------------|---------|---------------------|---------|
| | H test value | p level | χ^2 test value | p level |
| Ni-5%Al-15%Al ₂ O ₃ coating; „Casto-Dyn DS 8000” torch | | | | |
| Z_m | 12.57 | 0.002 | 10.18 | 0.006 |
| The counter sample: C45 | | | | |
| Z_m | 10.3 | 0.047 | 6.67 | 0.036 |

In Fig. 4 the relationships showing a change in the wear intensity (I_z) of the coatings as a function of time were presented. The wear rate of the tested materials, represented by I_z , testifies to the decreasing tribological wear of the tested coatings along with the longer working time of the friction pair. Variable but decreasing wear intensity is related to the running-in period of the cooperating elements. Analyzing the determined course of the wear process, it can be assessed that tribological pairs, in which the surface structure of composite coatings was shaped by burnishing and grinding, should have a shorter running-in period compared to turned coatings. In the case of burnished and grinded coatings, a stabilized course of the wear process was obtained after about 50 minutes of cooperation between friction pair elements. The coatings machined by turning during the hourly test were unstable in the wear process. Along with the extension of the test time, the difference between the wear intensity of machined by turning coatings and burnished and grinding layers was reduced.

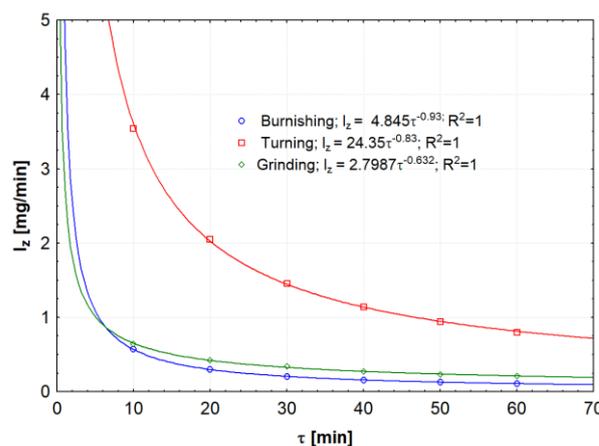


Fig. 4. Examples of relationships between friction time and wear intensity of Ni-5%Al-15%Al₂O₃ coatings obtained by Casto-Dyn DS 8000 torch.

The average wear of hardened C45 non-alloy steel after an hour test, depending on the type of finishing treatment of composite coatings ranged from 5.2 to 27 mg (Fig. 5). The smallest value of the mass loss of the counter-sample was recorded during its cooperation with composite coatings subjected to burnishing. The surfaces of turned coatings Ni-5%Al-15%Al₂O₃ caused the highest consumption of hardened C45 steel. The average wear of a steel block cooperating with grinded coats was 15.7 mg. Statistical analysis, the results of which are given in Table II, showed that the finishing technology of composite coatings sprayed with the "Casto-Dyn 8000" torch significantly affects the wear of the tribologically cooperating steel block.

The average values of friction coefficients occurring during the cooperation of C45 steel with the composite coating obtained by the flame method depending on the finishing treatment used ranged between 0.029 and 0.034 (Fig. 6). The highest frictional resistance occurred in the case of coatings subjected to turning treatment. The lowest friction coefficient was recorded for burnished coatings. The friction coefficient of the grinded surface of the coatings during friction with a steel counter sample was 0.031. Statistical significance (Kruskal–Wallis, median) tests show the high significance of the choice of finishing treatment of composite coatings for frictional resistance that occur in the tribological node. Friction resistance in the tribological node results in an increase in the temperature of the friction steam. During the friction with the composite coating, the temperature of the steel block was 138°C. It should be expected that the temperatures at the contact point were higher.

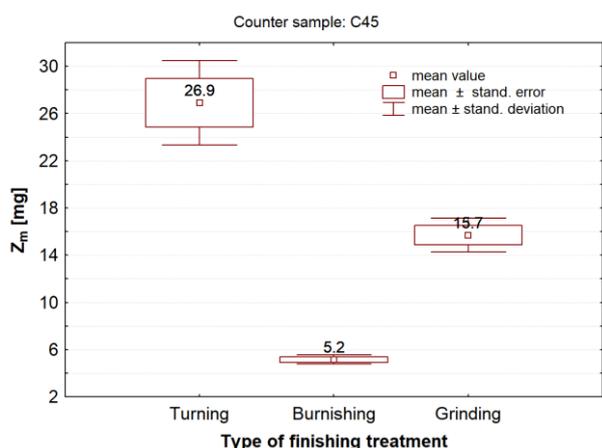


Fig. 5. Mass wear of steel counter samples; friction parameters:
 $P_t = 300 \text{ N}$, $v_t = 1,1 \text{ m/s}$, $\tau = 60 \text{ min}$.

It is therefore possible to reduce the hardness of hardened C45 steel on active surfaces associated with its tempering during a one-hour test. Additionally, reinforcing phase particles in the matrix of the coating lead to abrasive wear of the cooperating steel surface of the counter-sample. The calculated coefficients of friction obtained very low values. The most likely reason for obtaining such results are the properties of the coating matrix material. Producer of PROXON 21021 spray powder, Messer Eutectic Castolin, says that this material is highly abrasion resistant, despite its low hardness (180 HV). This material has been used as a material for the regeneration of hydraulic system components, e.g. pumps or cylinders. Low frictional resistance may also result from the porosity of the heat sprayed coatings. The pores are lubrication "pockets" that hold the oil on the surface of the coatings.

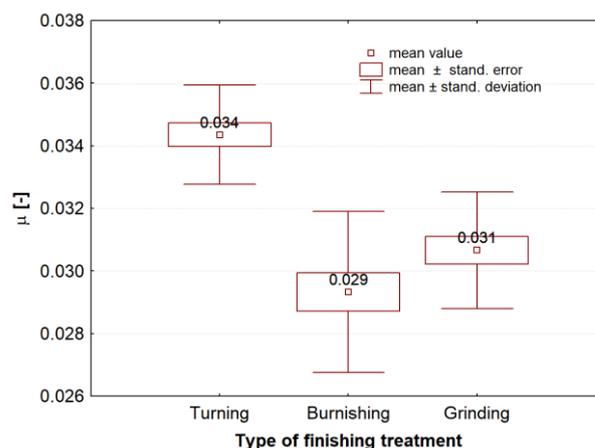


Fig. 6. Influence of finishing treatment on the value of the coefficient of friction (μ) of tribological pair: Ni-5% Al-15% Al₂O₃ composite coatings obtained by flame spraying with Casto-Dyn DS 8000 torch - C45 steel; friction parameters:
 $P_t = 300 \text{ N}$, $v_t = 1,1 \text{ m/s}$, $\tau = 60 \text{ min}$.

In Fig. 7 the influence of linear speed of rings on the coefficient of friction values of kinematic pair: Ni-5%Al-15%Al₂O₃ flame sprayed coating and C45 steel block are presented. Coatings, whose surfaces were constituted as a result of burnishing, were characterized by lower values of friction coefficients in comparison to the coats subjected to turning. The average reduction in friction coefficient values as a result of burnishing in composite coatings was close to 20%.

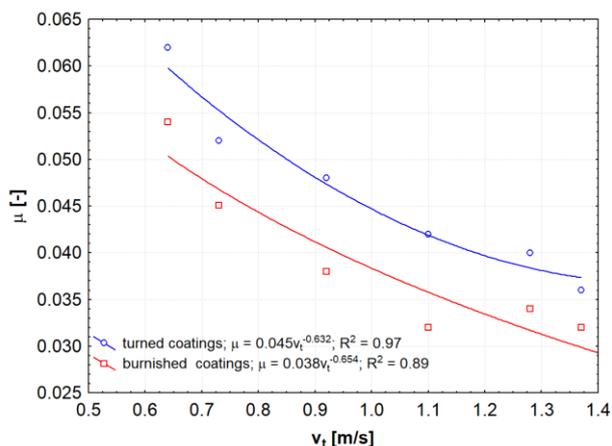


Fig 7. The influence of linear speed of rings on the coefficient of friction values of kinematical pair: Ni-5%Al-15%Al₂O₃ flame sprayed coating and C45 steel block; friction parameters: P_t = 300 N, τ = 60 s.

The influence of sliding speed on friction resistance was also found. The higher the sliding speed, the lower the coefficient of friction. The statistical analysis, including two non-parametric tests (Kruskal-Wallis test and median test) for many independent variables, allowed for on assumed level of significance ($\alpha = 0.05$) to conclude on the statistical significance of the influence of linear speed on friction resistance in the evaluated tribological node. During semi-fluid friction with a change sliding speed follows so-called "drift height" change. With semi-fluid friction, the oil pressure in the microline increases with "drift height" value (hydrodynamic action), although the external load is constant. As the value of "drift height" increases, the surface contact deformation decreases because the part of the normal force to the lubricating microline increases and the part of the force for the metallic contact areas decreases. When the normal force is reduced in the contact micro-areas the surface unit load values are reduced. When the normal force is reduced for the contact micro-areas the surface unit load values are reduced. The force carried by the roughness tops decreases by the value of force causing the "drift height"

The burnishing treatment resulted in a surface structure characterized by the favorable shape of the progressive type material ratio curve with small values of means reduced peak height (Rpk) and core roughness depth (Rk). During the running-in process and during a period of stable wear of the tribological pair at a low "drift height", there is a greater actual contact surface of the cooperating parts than it is the case with turned coatings.

In Fig. 8 and Fig. 9. the relationship between the values of the friction coefficient and the load of the

friction node consisting of a composite coating after finishing treatment and a steel counter-sample were presented. The high positive correlation ($r = 0.91$ for turning, $r = 0.86$ for burnishing) between the pressure force applied during the test and the average values of friction coefficients was found. In the case of composite coatings, which surface was obtained after turning, the correlation coefficient (r) was 0.89. However, for coatings whose surface geometrical structure was shaped as a result of burnishing, the correlation coefficient (r) was 0.85. It can be seen in Fig. 8 and Fig. 9 that for particular load values used, a very large span (standard deviation) of the measured values of the friction coefficient was obtained. Therefore, the calculated mean values of the coefficient of friction are burdened with relatively high random error represented by the standard error. The expected values of friction coefficients for individual pressure forces fall within similar ranges: mean value ± 1.96 standard error (for significance level $\alpha = 0.05$).

In Table 3 the results of non-parametric significance tests for independent variables (Kruskal-Wallis test, median test) were presented. Therefore, it can be concluded that there is no statistically significant (at the assumed significance level $\alpha = 0.05$) influence of the applied pressure force on the values of friction coefficients of all tribological pairs examined. It is believed that according to Kosteci's theory, in the normal friction of run-in surfaces, for a given set of material and lubrication, the friction coefficient has a constant value, independent of load [10].

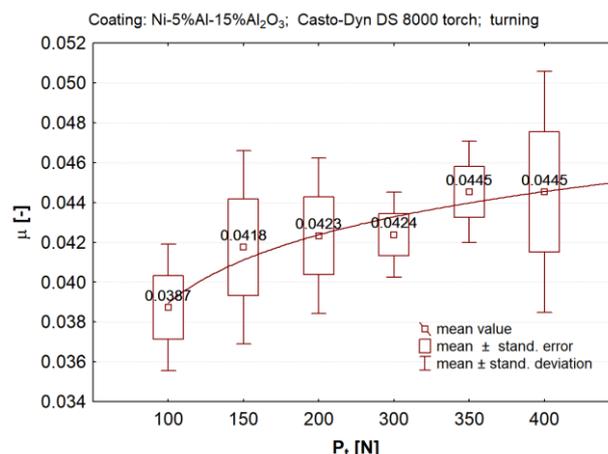


Fig. 8. Impact of pressure force on the value of the friction coefficient of Ni-5%Al-15%Al₂O₃ flame sprayed coatings after turning; v_t = 1.1 m/s, τ = 60 s.

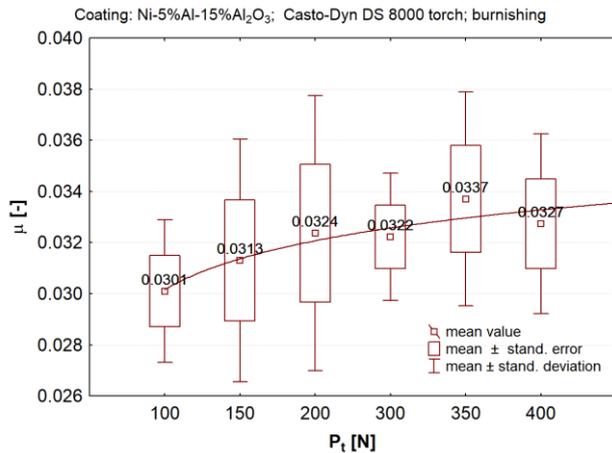


Fig. 9. Impact of pressure force on the value of the friction coefficient of Ni-5%Al-15%Al₂O₃ flame sprayed coatings after burnishing;
 $v_t = 1.1$ m/s, $\tau = 60$ s.

In the case under analysis, it is doubtful whether within 60 seconds it could have running-in of mating surfaces. All the more so because after an hour of tribological node work, the average value of the friction coefficient decreased. It is assumed that the minimum (limit) value of the coefficient of friction for equal areas at different loads has the same value [7].

Table 3. Results of nonparametric tests of significance of differences in distribution of the variable μ

| Variable | Kruskal–Wallis test | | Median test | |
|---|---------------------|---------|---------------------|---------|
| | H test value | p level | χ^2 test value | p level |
| Turned of Ni-5%Al-15%Al ₂ O ₃ coating; „Casto-Dyn DS 8000” torch | | | | |
| μ | 5.44 | 0.36 | 4 | 0.55 |
| Burnished of Ni-5%Al-15%Al ₂ O ₃ coating; „Casto-Dyn DS 8000” torch | | | | |
| μ | 2.4 | 0.78 | 4.1 | 0.5 |

4 Conclusion

The conducted research allows to formulate the following conclusions:

- The type of finishing treatment used largely affects both the tribological wear of the Ni-5%Al-15%Al₂O₃ composite coatings obtained by flame spraying with Casto Dyn DS 8000 torch and the cooperating frictional element.
- Coatings treated with burnishing show up to six times lower mass wear in comparison to turned coatings. At the same time, burnishing contributes to a five-fold reduction in counter-sample wear and degresion a friction coefficient value.
- Burnished and grinded coatings need shorter running-in times than turned coatings. In the case of burnished and grinded composite coatings,

compared to turned coatings, there is a faster stabilization of wear intensity.

- Composite coatings whose geometrical surface structure was formed in the burnishing process were characterized by a nearly 20% lower value of the friction coefficient compared to turned coatings.
- In the scope of the values of the tribological nodes loads assumed during the tests, no statistically significant influence of the load on the frictional resistance of composite shells was found.

Thermal sprayed of Ni-5%Al-15%Al₂O₃ composite coatings, the surfaces of which have been shaped as a result of burnishing treatment, can be used as coatings increasing the service life of the shafts of centrifugal pumps or as regenerative coatings.

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References:

- [1] P. Baghery, M. Farzam, A. B. Mousavi, M. Hosseini, Ni-TiO₂ Nanocomposite Coating with High Resistance to Corrosion and Wear, *Surface and Coatings Technology*, Vol. 204, 2010, pp. 3804–3810.
- [2] C. H. Chang, M. C. Jeng, C. Y. Su, T. S. Huang, A Study of Wear and Corrosion Resistance of Arc-sprayed Ni-Ti Composite Coatings, *Journal of Thermal Spray Technology*, Vol. 20, 2011, pp. 1278-1285.
- [3] A. Charchalis, R. Starosta, Effect of Finishing on the Corrosion Properties of Flame Sprayed Ni-5%Al and Ni-5%Al-Al₂O₃ Coatings, *Journal of KONES*, Vol. 21, No. 4, 2014, pp. 30-36.
- [4] C. Courbona, A. Sovaa, F. Valiorguea, H. Pascala, J. Sijoberta, G. Kermoucheb, P. Bertranda, J. Rech, Near Surface Transformations of Stainless Steel Cold Spray and Laser Cladding Deposits After Turning and Ball-burnishing. *Surface and Coatings Technology*, Vol. 371, 2019, pp. 235-244.
- [5] V. Franzen, M. Trompeter, A. Brosius, A.E. Tekkaya, Finishing of Thermally Sprayed Tool Coatings for Sheet Metal Forming Operations by Roller Burnishing, *International Journal of Material Forming*, Vol. 3, 2010, pp. 147-150.
- [6] H. Gul, F. Kılıc, M. Uysal, S. Aslan, A. Alp, H. Akbulut, Effect of Particle Concentration on the Structure and Tribological Properties of Submicron Particle SiC Reinforced Ni Metal

- Matrix Composite (MMC) Coatings Produced by Electrodeposition, *Applied Surface Science*, Vol. 258, 2012, pp. 4260-4267.
- [7] M. Hebda, Friction, Lubrication and Wear Processes of Machines, *Publishing Institute for Sustainable Technologies*, Warsaw – Radom 2007 (in Polish).
- [8] B. Karpuschewski, H. J. Pieper, F. Welzel, K. Risse, Alternative Strategies in Finishing Cylinder Running Surfaces, *CIRP Annals-Manufacturing Technology*, Vol. 61, 2012, pp. 559-562.
- [9] W. Labuda, R. Starosta, Estimation of the Influence of Burnishing Parameters on X5CrNi18-10 Steel, *Solid State Phenomena*, Vol. 165, 2010, pp. 300-305.
- [10] Z. Lawrowski, *Tribology. Friction, wear and lubrication*, PWN, Warsaw, 1997 (in Polish).
- [11] K. O. Low, K. J. Wong, Influence of Ball Burnishing on Surface Quality and Tribological Characteristics of Polymers under Dry Sliding Conditions. *Tribology International*, Vol. 44, 2011, pp. 144-153.
- [12] G. Lu, X. Shi, J. Zhang, H. Zhou, Y. Xue, A. M. M. Ibrahim. Effects of Surface Composite Structure with Micro-grooves and Sn-Ag-Cu on Reducing Friction and Wear of Ni₃Al Alloys. *Surface and Coatings Technology*, Vol. 387, 2020, 125540.
- [13] A. Rehman, S. Das, G. Dixit, Analysis of Stir Die Cast Al-SiC Composite Brake Drums Based on Coefficient of Friction, *Tribology International*, Vol. 51, 2012, pp. 36-41.
- [14] R. Starosta, and A. Zieliński, Effect of Chemical Composition on Corrosion and Wear Behaviour of the Composite Ni-Fe-Al₂O₃ Coating, *Journal of Materials Processing Technology*, Vol. 157–158, 2004, pp. 434-441.
- [15] R. Starosta, Effect of Cutting Parameters on Surface Texture of Flame Sprayed Coatings, *Solid State Phenomena*, Vol. 199, 2013 pp. 396-401.
- [16] R. Starosta, Manufacturing of Composite Coatings in the Processes of Regeneration of Machine Elements and Devices Operated in the Sea Water Environment, *Publishing Gdynia Maritime University*, Gdynia 2013 (in Polish).
- [17] J. Wiczorek, J. Śleziona, J. Myalski, A. Dolata-Grosz, M. Dyzia, Surface Wear and Structure After Cooperation in Technically Dry Friction Conditions in AK12 Composites - Ceramic Particles, *Kompozyty*, No. 6, 2003 pp. 131-135 (in Polish).
- [18] P. Zhanga,, Z. Liub, J. Dua, G. Sua, J. Zhanga, C. Xua, On Machinability and Surface

Integrity in Subsequent Machining of Additively - Manufactured Thick Coatings: A review. *Journal of Manufacturing Processes*, Vol. 53, 2020, pp 123-143.

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