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THE INFLUENCE OF FINISHING ON THE TRIBOLOGICAL PROPERTIES OF PLASMA SPRAYED MMC 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 Al_2O_3 In this article, the use of plasma sprayed Ni-5% Al-15%Al_2O_3 composite coatings were proposed. The surfaces of coatings by turning and burnishing treatments were shaped. 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 MMC coatings, the tribological tests were performed on the "T05" machine with head roll- piece type. It has been found that the burnishing favours 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 MMC coatings in the initial time of friction, which may indicate a shorter time needed to grind of cooperating elements.

Keywords: *plasma spraying, composite coating, MMC, friction test, T05 machine test*

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) [1-5, 11].

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 [13, 14]. The authors of article [14] presented the tribological wear mechanisms of the composite AK12-Al_2O_3 . 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 [14]:

I. Beginning of cooperation, in which the surface of the counter body 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 counter body 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 counter body 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 counter body.

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.

V. 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 [7-11].

2. Sample 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 Al_2O_3 particles. The volume fraction of alumina in the MMC coatings was 15%. The average diameter of ceramic particles was equal to 60 μm. Plasma spraying of MMC coatings was carried out in the „Plasma System SA" company from Siemianowice Slaskie (Poland). The PN 120 plasma gun to the spraying of coating was used. Plasma spraying parameters have been selected experimentally by the contractor.

Machining was carried a cutting tool made of CBN (CB 7015), WNGA080408S01030A insert mounted in the DWLNRL-2525M08 tool holder. The CB7015 is a material based on boron nitride (CBN) with the addition of titanium nitride and the coated TiN coating. The cutting parameters were used:

- cutting speed: $v_c = 214$ m/min,
- feed: $f = 0.06$ mm/rev,
- depth of cut: $a_p = 0.3$ mm.

Finishing operations was realized by burnishing. The working element of burnish tool was in a shape of a roller. The finishing was carried out Yamato SRMD burnishing tool. Technological parameters of plastic working of coatings were as follows:

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

After machining, the surface roughness of plasma sprayed Ni-5% Al-15% Al_2O_3 coatings was: Ra = 1.06 μm – after turning and Ra = 0.77 μm – after burnishing.

3. Testing methods

The tribological properties of the regenerative coatings applied on journals seawater pump shafts being on a T-05 (block-on-ring tester) were studied. Immersion as method lubrication was used. An oil machine as lubricant was used. The block (counter body) was made of hardened C45 (0.45%C) steel with a hardness of 52-55 HRC. The block surface roughness was Ra = 0.6 to 0.7 μm. In Tab. 1, the tribological research programs are presented.

Tab. 1. Plans of tribological tests [12]

I	**Mass wear Z_m; n_t = 600 1/min (v_t = 1,1 m/s), P_t = 300 N**						
	Time, τ [min]	10	20	30	40	50	60
II	**The impact of speed on coefficient of friction μ; P_t = 300 N, τ = 60 s**						
	Rotational speed n_t [1/min] (linear speed v_t [m/s])	350 (0.64)	400 (0.73)	500 (0.92)	600 (1.1)	700 (1.28)	750 (1.37)
III	**The impact of load on coefficient of friction μ n_t = 600 1/min (v_t = 1.1 m/s)**						
	Force P_t [N]	100	150	200	300	350	400

4. Results

Mass wear of turned plasma sprayed composite coatings as a result of friction with steel block; amounted to 24.7 mg. Burnishing resulted in about a fivefold increase in resistance to wear of coatings. The mass wear of burnished composite coatings was equal 4.4 mg (Fig. 1).

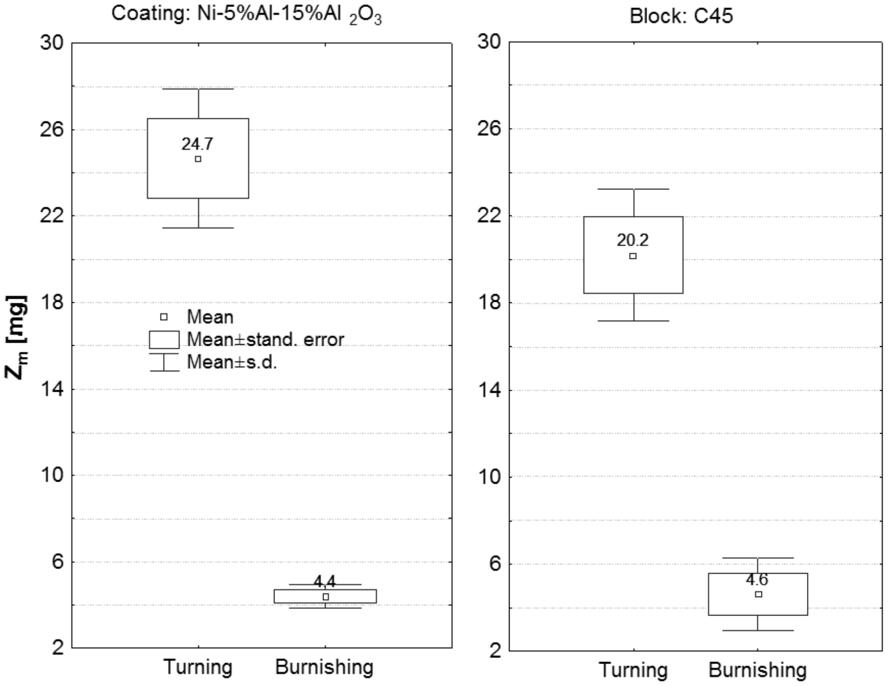

Fig. 1. The mass wear of the coatings and the blocks; friction parameters: P_t = 300 N, v_t = 1.1 m/s, τ = 1 h

The intensity of wear of plasma sprayed Ni-5%Al-15%Al_2O_3 coatings treated turning with time of friction was changed. After 10 minutes, the intensity of wear was equal to 2.2 mg/min (Fig. 2). As a result of grind-in of cooperating components of the tribological pair after an hour trying to the value of intensity of wear decreased five times to a value of 0.46 mg/min. It can be assumed that grind-in is not yet completed, because not achieved a constant of intensity of wear. In the case of burnished Ni-5%Al-15%Al_2O_3 coatings intensity of wear was stabilized. Intensity of wear varied in a narrow range of from 0.082 to 0.1 mg / min. The surfaces of composite coatings after plastic working by low values of intensity of wear were characterized. Therefore, during the cooperation of coatings with hardened steel blocks they do not require grind-in.

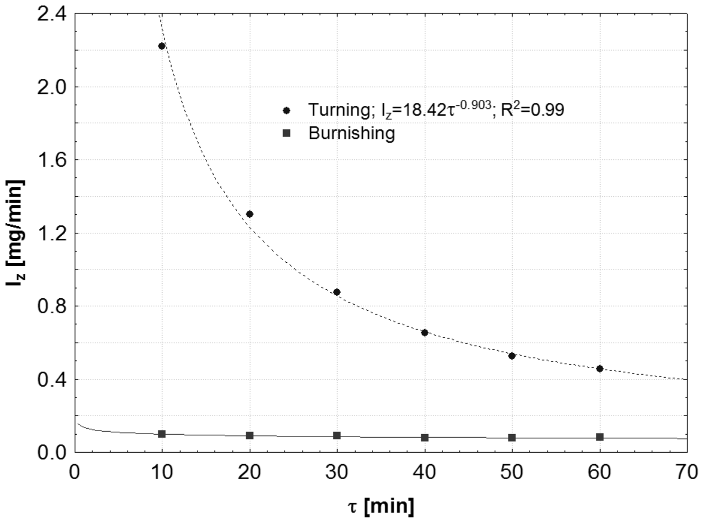

Fig. 2. The examples of relation between friction time and the intensity of wear of composite coatings; friction parameters P_t = 300 N, v_t = 1.1 m/s, τ = 1 h

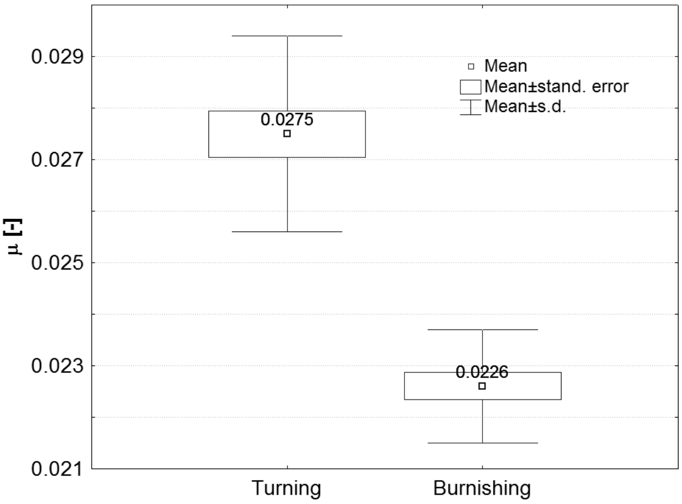

Fig. 3. The influence of finishing on the coefficient of friction value of tribological pair: Ni-5%Al-15%Al_2O_3 coating and steel block; friction parameters P_t = 300 N, v_t = 1.1 m/s, τ = 1 h

Wear of metal block cooperating with the plasma Ni-5% Al-15% Al_2O_3 coatings ranged from 4.6 to 20 mg. Higher values of block mass wear recorded during his cooperation with the composite coatings whose surface structure was constituted by turning (Fig. 1). Burnishing of surface coatings contributed to approx. fourfold reduction in wear of mating blocks. After an hour of tribological test, the average value of mass wear of steel counter body was 4.6 mg.

The average values of coefficient of friction determined for evaluation of frictional resistance of plasma sprayed composite coatings and steel counter sample, during the hours test amounted for burnished surface μ = 0.023, and turned coating μ = 0.028 (Fig. 3) The friction resistance occurring between the cooperating elements for burnished coating was 20% lower than in the turned coating.

In Fig. 5 the influence of the linear speed (v_t) of ring on coefficient of friction values are presented. The impact of linear speed of sample on frictional resistances was observed. The higher the linear speed, the lower the coefficient of friction value. Statistical analysis including two non-parametric tests (Kruskal-Wallis test and median test) for multiple independent variables allows on the assumed significance level (α = 0.05) to state about statistical significance of linear speed on the friction occurring in the evaluated kinematic pairs (Tab. 2).

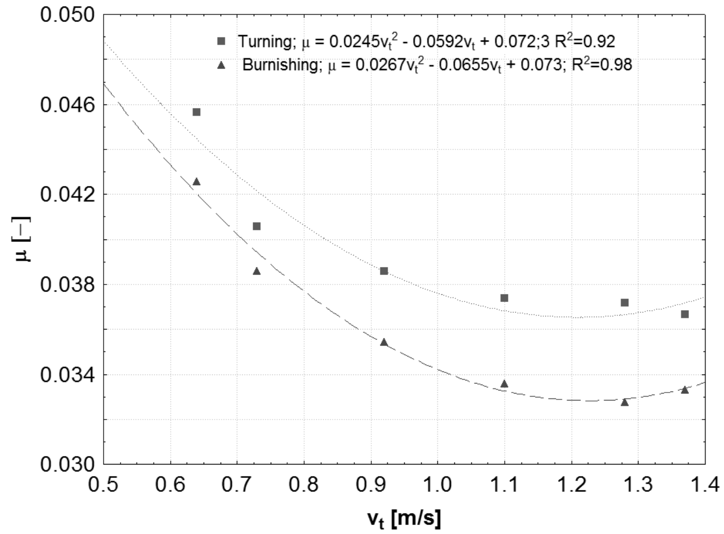

Fig. 4. The influence of linear speed of rings on the coefficient of friction values of kinematical pair: Ni-5%Al-15%Al_2O_3 coating and C45 steel block friction parameters: P_t = 300 N, τ = 60 s

Tab. 2. The results of non-parametric tests of significance of differences between the values of the coefficient of friction μ depending on the linear speed of rings for kinematic pair: Ni-5%Al-15%Al_2O_3 coating and C45 steel block

Kruskal – Wallis test		**median test**	
test value (H)	**p level**	**test value (χ^2)**	**p level**
Turning			
11.59	0.041	12	0.035
Burnishing			
15.5	0.0084	18	0.029

During semi-fluid friction occur with a change linear speed the changes so-called “height floating”. When semi-fluid friction in the micro wedges the oil pressure increases with rising the value of float (hydrodynamic action), although that external forces has a constant value. As the increases value of the “height floating” it decreases deformations on contact of the unevenness, as part of the normal load per micro lubricating wedges increases, and a part attributable to metal contact area decreases. By reducing the normal load in the contact, microareas followed a reduction in a real load and the pressure per unit area. The load carried by the protrusions unevenness decreases the value of floating force [6].

By burnishing obtained the surface structure, characterized by the advantageous shape of the curve of the material ratio, progressive addition type, for small values of reduced peak heights (Rpk) and core roughness depth (Rk). During the grind-in and period of stable wear of tribological pair at a low of “height floating” can be found greater the real contact area of the cooperating parts than in the case of turned coatings [12].

Tab. 3. The results of non-parametric tests of significance of differences between the values of the coefficient of friction μ depending on the contact force of the block to ring

Kruskal-Wallis test		**median test**	
test value (H)	**p level**	**test value (χ^2)**	**p level**
Turning			
1.52	0.91	2.85	0.72
Burnishing			
5.01	0.41	9.6	0.087

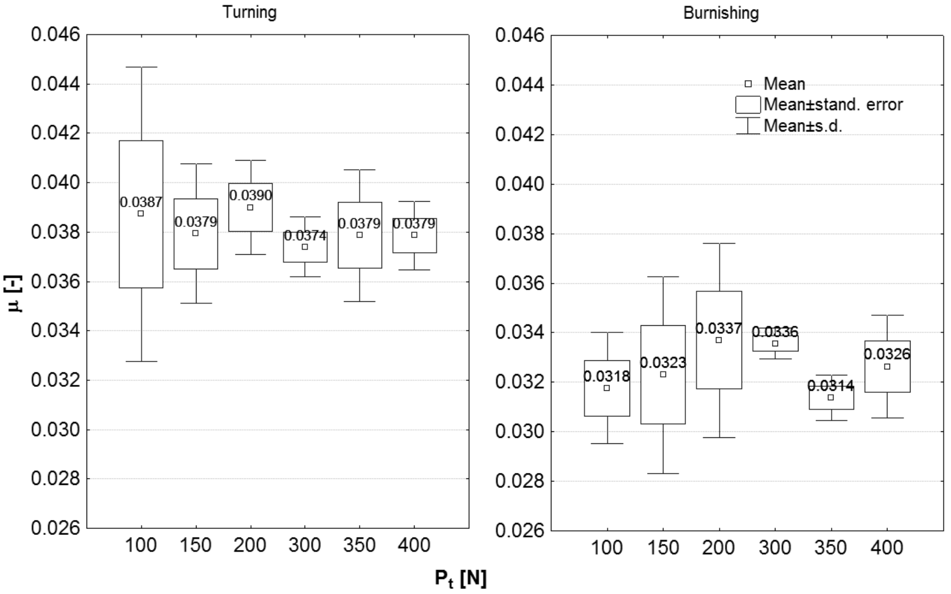

Fig. 5. Effect of force on the coefficient of friction values of composite coating friction parameters: $v_t = 1.1$ *m/s,* $\tau = 60$ *s*

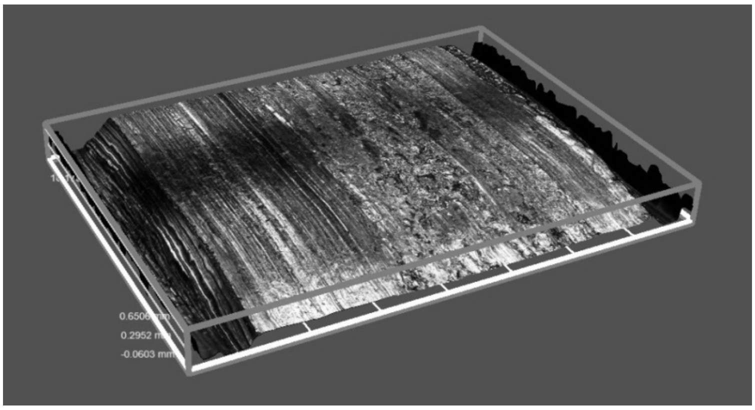

Fig. 6. The surface of burnished composite coating after tribological tests friction parameters: $v_t = 1.1$ *m/s,* $\tau = 60$ *s,* $P_t = 200$ *N*

Figure 5 shows the impact of force P_t on coefficient of friction values. The Fig. 5 indicates no relation between the analysed variables. This is confirmed results of nonparametric tests of significance for the independent variables (Kruskal-Wallis and median test) (Tab. 3). The lack of influence of the applied force on the coefficients of friction for all tested tribological pairs can be concluded. According to the Kostecki theory in the operating range of normal friction, the grinded-in surfaces for a given set of material and lubrication the friction coefficient has a constant value, independent of load. Hebda [6] proves that the minimum (limit) value of the coefficient of friction have the same value even when varying loads are applied [6, 12]. The linear speed used during tribological tests allows obtaining the conditions nearly of fluid friction.

Figure 6 shows the burnished surface of composite coating after tribological testing. The main wear cause is abrasive.

5. Conclusions

1) The burnished coatings have up to five times less tribological wear of mass as compared to the coatings after turning. In addition, burnishing of the surface contributes to three times the reduction of wear of the steel block (counter body) and the coefficient of friction.

2) The burnished coatings need a shorter time on running-in than turned coatings.
3) In the case of burnished coatings in compared to turned coatings, the faster stabilization of the intensity of wear was observed.

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