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Tribological properties of aluminium alloy surface layer after finishing treatments

Właściwości tribologiczne warstwy wierzchniej po obróbkach wykończeniowych stopu aluminium

JANUSZ KALISZ *

Surface geometric structure and tribological properties of the aluminium alloy EN AW-AlCu4MgSi(A) processed by various finishing treatments: grinding, polishing and ball burnishing are presented. Abrasive resistance and friction coefficient were determined on a T-01M tester in dry friction conditions using the ball-on-disc method. A polished Al_2O_3 ceramic ball 6 mm in diameter was the counter-sample. Compared to grinding and polishing, burnishing resulted in approximately twice a reduction in volume wear rate. Depending on the type of surface treatment mean friction coefficients are 0.45 after grinding, 0.34 after polishing and 0.32 after ball burnishing.

KEYWORDS: ball burnishing, grinding, polishing, tribological properties, surface roughness

One of the main features of the technological quality of machine parts is their resistance to wear, most often determined by the properties of their surface layer, in particular the geometric structure of the surface, the hardness of the material and the state of residual stresses remaining after machining. Relevant properties of the surface layer of machine parts are most often from the machining processes, often preceded by heat treatment, and sometimes - thermo-chemical treatment. A significant influence on the wear of machine parts has, among others, surface roughness and hardness of the surface layer [1, 8].

Properties of the surface layer of machine parts can be determined, among others, by means of burnishing finishing treatment. It involves locally cold plastic deformation of the object through the force and kinetic interaction of a smooth tool with the machined surface. The displacement of unevenness and coldworking of the surface resulting from this process causes a reduction of the surface roughness and an increase in the material ratio of its profile, as well as the strengthening of the top layer of the material and obtaining a favourable state of stresses (compressive stresses). This in turn translates into increased abrasion resistance and adjustment of fitting of cooperating parts, enabling the transfer of higher surface pressures and improvement of fatigue strength [2-6, 9].

Bearing in mind the use of aluminum alloys in the automotive and aerospace industries, one of the important functional features are the tribological properties of these alloys.

Knowledge of tribological characteristics is important during the design, selection of material and production technology of machine parts [3, 6, 7]. Therefore, the purpose of the research described was the tribological characterization of a selected grade of aluminum alloy EN AW-AlCu4MgSi(A), used in these industries.

The tests were carried out after finishing surface coldworking and - for comparison - after grinding and polishing. The abrasive wear and dynamic coefficient of friction were determined. It should be noted that burnishing is a treatment without chips and dust, with low noise emission and low energy consumption, and therefore - ecological.

Research methodology

The aim of the research was to determine the basic tribological properties of the EN AW-AlCu4MgSi(A) alloy, in the hardened state after T451 treatment (with the metallurgical certificate 3.1). This alloy is used for structural elements of aircraft, machinery, military equipment and subassemblies for the automotive industry. It is characterized by high tensile strength and high fatigue strength.

In tab. I chemical composition is presented, and in tab. II the mechanical properties of the aluminum alloy.

TABLE I. Chemical composition of the EN AW-AlCu4MgSi(A) alloy according to the manufacturer's data

Ti %	Si %	Fe %	Cu %	Mn %	Mg %	Cr %	Zn %	Ti+Zr %	Other %
0,06	0,64	0,04	4,2	0,95	0,76	0,04	0,17	0,06	0,03

TABLE II. EN AW-AlCu4MgSi(A) alloy properties according to the manufacturer's specifications

Tensile strength R_m MPa	Limit of plasticity $R_{p0.2}$ MPa	Elongation A_5 %	Hardness HB	Density g/cm^3
445	292	17	110	2,80

As part of tribological testing, abrasion resistance and dynamic coefficient of friction for the alloy were determined. The sample used was after ball burnishing with a tool with an elastic clamp, which burnishing part was made of a nitride ceramics. For comparison, samples after grinding and polishing were tested. Finishing operations and testing were performed on end faces of the specimens.

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The burnishing process was carried out in one pass using a ball burnishing tool, made in IZTW, with a ceramic (Si_3N_4) burnishing part in the shape of a ball with a radius of 4 mm. The burnishing tests were carried out with a constant approach of 0.3 mm (deflection of the spring of the burnishing tool after contact of its working part with the worked surface), working feed f_t = 8000 mm/min, burnishing force F_n = 50 N and stepover of f_{wn} = 0.2 mm [4, 5].

The grinding was carried out on a surface grinder with a cubic boron nitride abrasive wheel with grain size B46. Polishing was carried out in a diamond suspension on a Struers DiaPro Mol R 3 µm Roto-Pol 21 grinding-polishing machine with a rotational speed 150 rpm.

Rotational ball-on-disc friction and wear tests of sample were made dry on a T-01M tribotester (fig. 1). The requirements set out in ASTM G 99-05, ISO 20808: 2004 were complied with. As a counter-sample, a polished Al_2O_3 ceramic ball with a diameter of 6 mm was used. In each test, the sample met a new surface of the ball. The ball was washed in acetone in every time and after drying it was placed in the mounting bracket. The sample surfaces were washed in alcohol and allowed to dry completely.

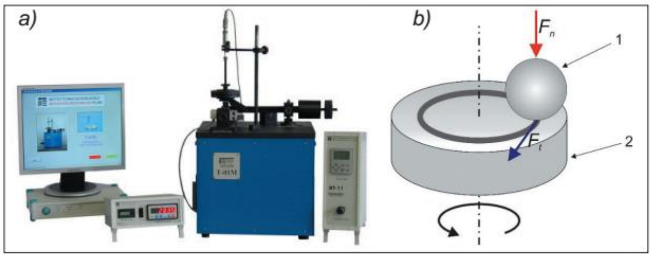

Fig. 1. Test stand (*a*) the ball-on-disc tester (*b*): 1 - counter-sample (Al_2O_3 ball), 2 – sample

Other test parameters: load F_n = 0.25 N, rotational speed n = 120 rpm, number of cycles N = 2000, radius of friction track r = 3 mm. The tests were carried out at ambient temperature of 22 ± 2 °C, relative humidity 60%.

The dynamic friction coefficient µ was calculated from the formula:

$$\mu = \frac{F_t}{F_n}$$

where: F_t - determined friction force, F_n - normal force.

Wear resistance was based on measurements of the size of the (abrasion) wear track created after friction by a ball. The wear track geometry was measured at four points on the circumference of the friction path (every 90°), transverse to the direction of movement (sliding). The wear rate was determined according to the following relationship:

$$W_s = \frac{V}{F_n \cdot L}$$

where: V - volume of material used, L - path of friction.

Measurements of the friction path profile showed the presence of a considerable uplifted material, located on both sides of the wear track. As the size of these uplifts for all samples is 15-20% of the furrow size, their contribution to the calculation of wear indicator has been taken into account. The volume of material V used is the volume of the wear track reduced by the volume of the uplifts.

The roughness of the surface after grinding, polishing and ball burnishing was measured using the TOPO 01P contact profilometer (IZTW construction). The apparatus was equipped with a measuring head with a 1 mm range, a diamond tip with a radius of 2 µm and a cone angle of 60 °. The geometrical state of the surface layer was determined by measuring surface roughness parameters in the 3D system according to the ISO 25178 and EUR 1517 EN standards.

Test results

Fig. 2 presents surfaces of samples after wear tests.

Tab. III presents the average values of roughness parameters, while figs. 3-5 present the isometric view and the distribution of surface ordinates of the samples.

TABLE III. Average values of selected roughness parameters after grinding, polishing and burnishing

Type of machining	Parameters						
	Sa µm	*Sq* µm	*Sz* µm	*Sk* µm	*Spk* µm	*Svk* µm	*Sku*
Grinding	0,270	0,342	3,922	0,801	0,249	0,439	3,96
Polishing	0,112	0,208	3,529	0,288	0,263	0,132	4,40
Burnishing	0,029	0,039	0,486	0,104	0,038	0,032	3,01

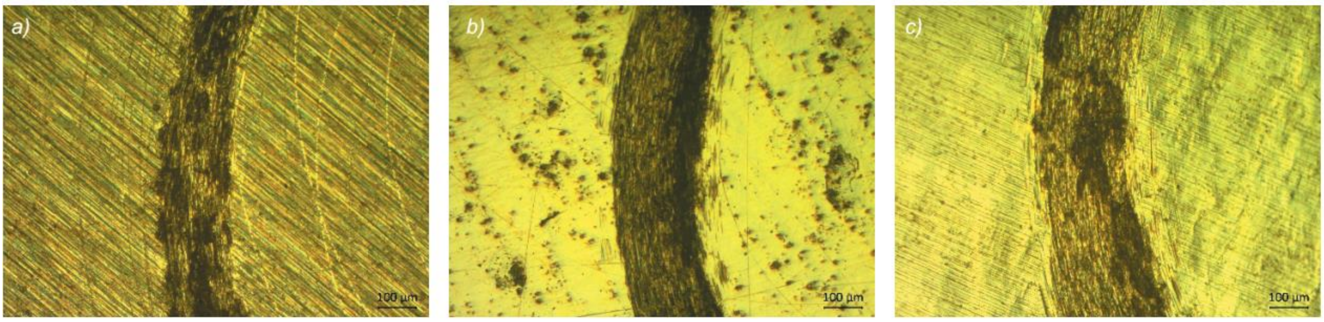

Fig. 2. Sample surfaces after wear testing: *a*) ground, *b*) polished, *c*) burnished

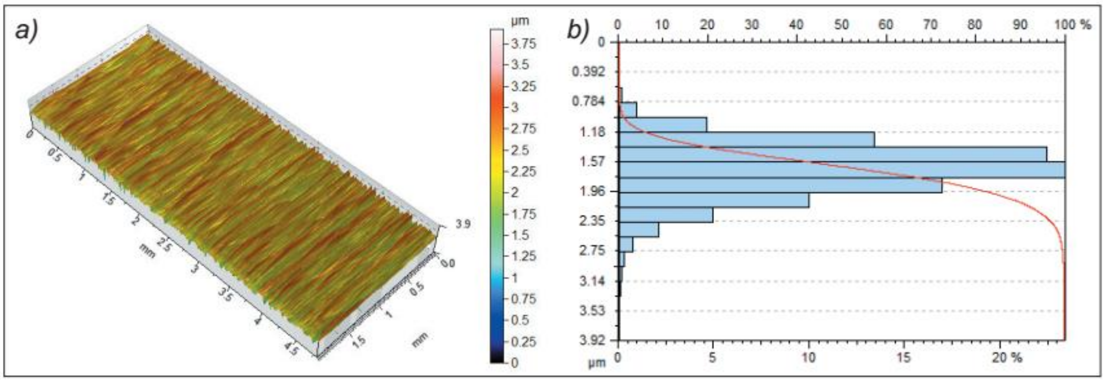

Fig. 3. Characteristics of the surface after grinding: *a*) isometric view, *b*) distribution of ordinates of the surface

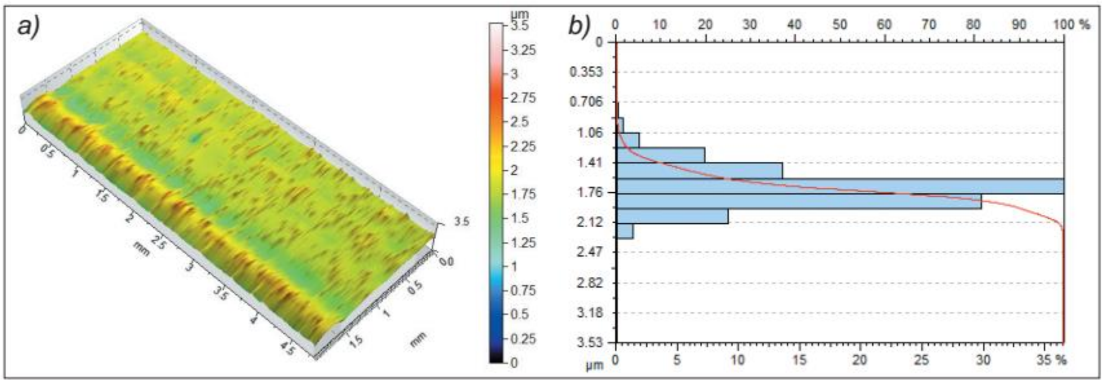

Fig. 4. Surface characteristics after polishing: *a*) isometric view, *b*) distribution of surface ordinates

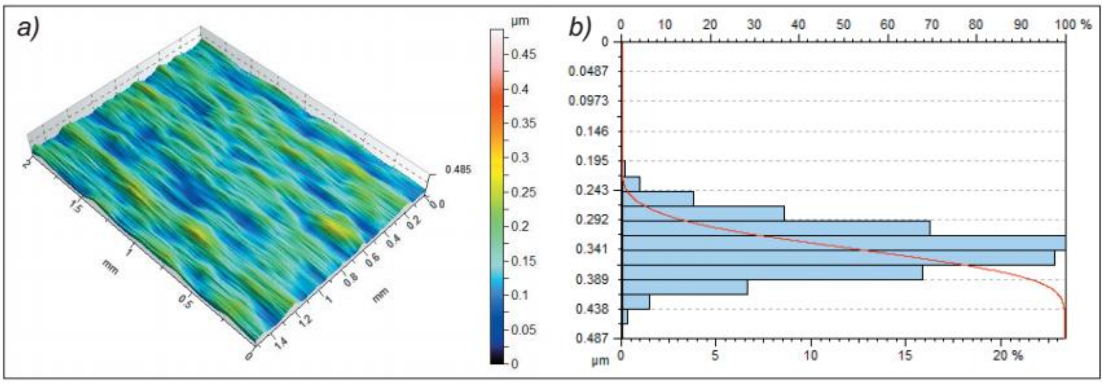

Fig. 5. Surface characteristics after burnishing: *a*) isometric view, *b*) distribution of surface ordinates

The lowest values of the roughness parameters: arithmetical mean height of the surface Sa, root mean squared height of the surface S_q, and the maximum height of surface S_z were obtained after burnishing.

Material ratio of surface can be evaluated by means of the distribution of spatial parameters, i.e.: reduced peak height S_{pk}, core height S_k and reduced dale height (valley depth) S_{vk}. The smaller the value of the S_{pk} parameter, the smaller the lapping allowance should be foreseen in service. It also shows better tribological properties of the surface.

A greater height of the dale S_{vk} than the S_{pk} peaks height in turn means the improvement of retention of a fluid in the valleys in the zone below the core.

Low values of S_k, S_{pk} and S_{vk} parameters after burnishing indicate a favourable distribution of the material ratio of roughness profile and good bearing properties of the surface.

Kurtosis of the surface S_{ku} informs about the distribution of irregularities on the analyzed surfaces. The value of parameter S_{ku} of 3 (obtained after burnishing) indicates an even (normal) distribution of irregularities, including defects, on the surface. The higher the value of the S_{ku} parameter, the more defects (deep valleys, high peaks) on the surface.

Fig. 6 compares exemplary roughness profiles after grinding, polishing and burnishing. After grinding, surfaces with specific geometrical features - very sharp peaks and valleys, were obtained. Burnishing caused a reduction in unevenness of the surface, with significant rounding of the peaks and valleys.

Fig. 7 compares the dynamic friction coefficient registered during wear tests. The average value of the coefficient of friction after ball burnishing was 0.32 and was lower than the value of this coefficient for the polished surface (0.34) and significantly lower than for the ground surface (0.45). This indicates the beneficial effect of the burnishing on this tribiological property of this aluminum alloy.

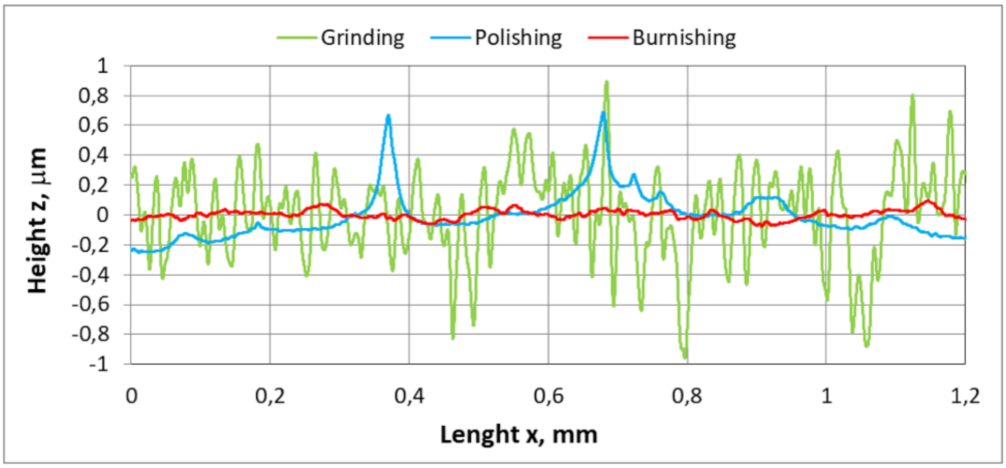

Fig. 6. Example roughness profiles after grinding, polishing and burnishing

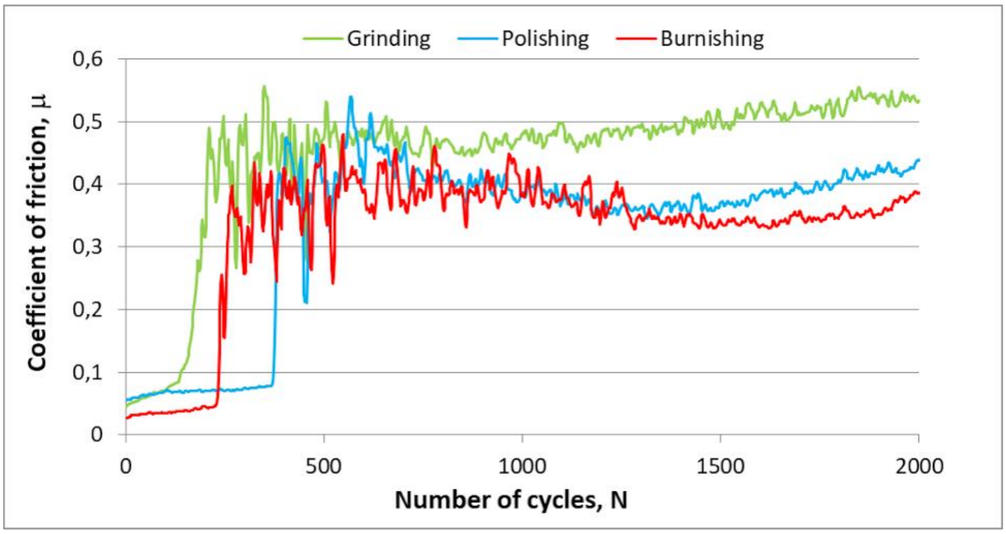

Fig. 7. Changes in the coefficient of friction during the wear test at a load of 0.25 N for the surface after grinding, polishing and burnishing

Fig. 7 compares the dynamic friction coefficient registered during wear tests. The average value of the coefficient of friction after ball burnishing was 0.32 and was lower than the value of this coefficient for the polished surface (0.34) and significantly lower than for the ground surface (0.45). This indicates the beneficial effect of the burnishing on this tribiological property of this aluminum alloy.

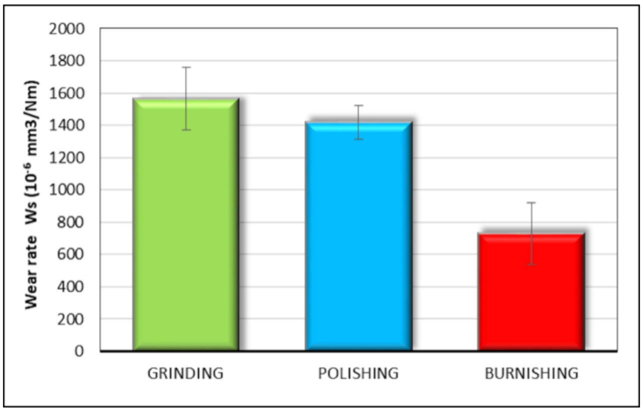

Fig. 8. Comparison of the volumetric wear rate after grinding, polishing and burnishing

Fig. 8 compares the volumetric wear rate after performed wear testing.

In comparison with grinding and polishing after burnishing, a two-fold reduction in the volume wear rate was obtained. This confirms the beneficial effect of burnishing on increasing wear resistance of components from this aluminum alloy.

Conclusions

The tests have shown that the use of burnishing as a finishing treatment results in a surface with low roughness and increased wear resistance. After burnishing of the aluminum alloy EN AW-AlCu4MgSi(A), it is possible to obtain a very smooth surface, with a high optical quality due to the value of the Sa parameter below 0.03 µm. Depending on the type of surface treatment, coefficients of friction are 0.45 after grinding, 0.34 after polishing and 0.32 after ball burnishing. In comparison with grinding and polishing, an almost two-fold reduction in the volume wear rate was obtained in tribological tests after burnishing. Knowledge of the basic tribological characterization of the tested aluminum alloy after ball burnishing, and especially positive results in this field - creates the possibility of improving the service properties of parts used in the automotive and aerospace industries by performing finishing machining with burnishing.

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