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MODIFICATION OF THE T-17 TESTER HOLDER TO ENABLE TRIBOLOGICAL TESTS TO BE CARRIED OUT IN A ROLLER-PLATE COUPLE

MODYFIKACJA UCHWYTU TESTERA T-17 UMOŻLIWIAJĄCA PRZEPROWADZENIE BADAŃ TRIBOLOGICZNYCH W SKOJARZENIU TYPU ROLKA–PŁYTKA

Key words: oxide layer, plastic, roller-plate couple, sliding friction, tribological properties.

Abstract The aim of this paper is to propose a solution that will make it possible to perform tribological tests of materials intended for rolling elements (e.g., rollers) interacting with a flat surface (e.g., sliding door guide). Tribological tests were carried out on a T-17 test stand, which was equipped with a holder that made it possible to perform tests in the roller-plate couple. The paper presents the results of tribological tests of a typical polymer PA 6 used in sliding door systems interacting with anodised and non-anodised aluminium alloys. The analysis of the tribological tests was supplemented by stereometric studies. The studies showed the possibility of performing tests for the roller-plate couple with the use of a T-17 test stand. The influence of the modification of the aluminium alloy surface (material of the sliding door guide) on tribological properties of the examined friction node was also shown.

Słowa kluczowe: tarcie toczne, skojarzenie rolka-płytka, tworzywo sztuczne, warstwa tlenkowa, właściwości tribologiczne.

Streszczenie Celem artykułu jest zaproponowanie rozwiązania dającego możliwość przeprowadzania testów tribologicznych materiałów przeznaczonych na elementy toczne (np. rolki) współpracujące z powierzchnią płaską (np. prowadnicą drzwi przesuwnych). Badania tribologiczne zostały przeprowadzone na stanowisku badawczym T-17, które wyposażono w uchwyt umożliwiający przeprowadzenie testów w skojarzeniu typu rolka–płytka. W pracy zostały przedstawione rezultaty badań tribologicznych typowego polimeru PA 6 mającego zastosowanie w systemach drzwi przesuwnych w skojarzeniu z anodowanym i nieanodowanym stopem aluminium. Analiza testów tribologicznych została uzupełniona badaniami stereometrycznymi. Badania wykazały możliwość przeprowadzania testów dla skojarzenia typu rolka–płytka z użyciem stanowiska badawczego T-17. Wykazano również wpływ modyfikacji powierzchni stopu aluminium (materiału prowadnicy drzwi przesuwnych) na właściwości tribologiczne badanego węzła tarcia.

INTRODUCTION

Materials for tribologically interacting elements should be selected based on tests performed in conditions as close to real conditions as possible. The process of friction is directly connected with the process of wear and the transfer of materials to the interacting elements. This is due to particle chipping, abrasion, cracking, or adhesive bonding of materials, which assume different forms depending on the type of the friction node. Tribological tests carried out on stands whose friction node most accurately reflects the actual couple are the basis for drawing conclusions on the tribological properties of materials interacting in given operating conditions. Friction nodes of tribological testers reflect the varied nature of the geometry of friction contacts, the vast majority of which are installed in testers that can be used to perform sliding friction tests. Examples of testers with rolling-sliding motion of test specimens are, e.g., T02U and T03 machines **[L. 1]** designed for testing

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the properties of lubricants and construction materials in a ball-ball friction node, or a T-30 device **[L. 2]** designed for testing lubricants and fatigue wear of gear wheels. Another popular tester with a rolling-sliding motion of test specimens is the Amsler test stand **[L. 3]**. At the friction node of this tester, cylinder-cylinder specimens roll on each other with a sliding effect whose value can be increased or decreased by selecting a suitable diameter of the specimens while maintaining a constant distance of their axes. The T-17 **[L. 4]** device (manufactured by ITeE – PIB) is designed for testing tribological properties of materials in a sliding interaction in reciprocating motion. The friction node consists of a fixed pin mounted in a holder, pressed with force *F* against a plate that is performing a reciprocating motion with a set frequency and amplitude. Replacing the T-17's factory-mounted holder with a holder with a modified design (innovation) makes it possible to carry out tribological tests of the roller-plate in rolling motion type. The proposed solution may be used to test materials intended for rolling elements (e.g., rollers), which interact with a flat surface (e.g., a sliding door guide). Aluminium sections for sliding door guides are frequently modified by anodising. Hard anodising is carried out to ensure that the surface of aluminium is adequately protected, mainly from the effects of tribological cooperation. Anode layers are characterized by a characteristic structure **[L. 5, 6]** and surface morphology **[L. 7, 8]** as well as very good adhesion to the substrate and high hardness **[L. 9, 10]**. The thickness of the oxide layer depends on multiple parameters of the anodising process, including current conditions. As the current conditions increase, thicker Al_2O_3 coatings are obtained.

RESEARCH MATERIAL

The tribological test material comprised specimens made of a polyamide designated PA 6. Polyamides are polymers belonging to the group of thermoplastic materials characterised by high strength, stiffness, hardness, and high stability of shape in the conditions of thermal loads. Polyamides are also characterised by good sliding properties and high vibration dampening capacity. Therefore, they are some of the most commonly used polymers in machine building and in the production of tribologically interacting elements. The specimens were made of a rod ø20 mm by machining, rings with an external diameter ø15 mm, internal diameter ø9 mm, and height 4 mm. The roughness of the surface of the rings before the tribological interaction was Ra = 1.4±0.1 µm. The second research material was aluminium alloy EN AW-6063. This alloy is characterised by high mechanical strength and corrosion resistance. Its surface can be modified by anodising. Thanks to its high susceptibility to pressing, it is widely used to manufacture sections with complex shapes. It is used to manufacture architectural elements with a good surface appearance. Aluminium alloy counter-specimens (plates with a surface are of 0.1 dm^2) were cut out from the section of a sliding door guide. All surfaces were etched in a 5% KOH solution and then tin-plated in a 10% HNO_3 solution in order to neutralise them. The treatment ended with rinsing in distilled water. The surfaces of counter-specimens (except for the reference plate) were modified by creating an Al_2O_3 layer using the electrochemical method on their surface. The surface of the specimens was anodised by means of the direct-current method, using a GPR-25H30D feed, at a constant current density of 3 A/dm^2. During anodising, a variable electrical charge density value was applied for each plate to determine how the thickness of the oxide layer formed on the surface of the aluminium alloy affects tribological parameters interacting with polymer rings. The use of a variable value of the electrical charge density (with a constant current density value) makes it necessary to use different process times. The electrolyte was an aqueous solution of sulphuric, oxalic, and phthalic acids. The conditions of the anodising process are shown in **Table 1**.

Table 1. Conditions of the anodising process
Tabela 1. Warunki procesu anodowania

Determination of the counter-specimen	Current density I [A/dm^2]	Electrical charge density G [$A\cdot min/dm^2$]	Temperature T [K]	Process time t [min]
A	-	-	-	-
B	3	45	298	15
C	3	90	298	30
D	3	135	298	45
E	3	180	298	60

RESEARCH METHODOLOGY

The thickness of the layers after anodising was measured with a Dualscope MP40 thickness gauge manufactured by Fischer. 10 thickness measurements were made along the length of the plate and then the average value was calculated. Tribological tests were carried out on a T-17 test stand that was equipped with a modified holder that made it possible to perform tests for a roller-plate couple in a rolling motion with a linear contact. The modified holder **(Fig. 1)** consists of a clamp nut (1), a holder pin (2), bolt (5), and a ball bearing (3). The clamp nut of this holder has an internal thread, which is identical with the thread of the original holder of the T-17 tester. The specimen from the material intended for tribological tests (4) is made as a ring with an inner diameter identical to the outer diameter of the bearing ring. The height of the specimen is equal to the height of the bearing. The tests were performed under conditions of technically dry friction, in an ambient temperature of 298±1 K at a relative humidity of the air of 60±5%. A constant load value of 66.78 N and a constant value of the average speed, 0.2 m/s, were applied for all the investigated couples. The value of the load of the friction node was determined based on the manufacturer's data concerning the average weight of sliding doors which impose a load on the door's rolling carriages. Tribological tests were carried out on a distance of 15 km. The friction force was measured with an analogue-to-digital converter using a 50 Hz sampling rate. The average value of the friction force of interacting elements was calculated from the ranges of stabilised tribological interaction, and then friction coefficient values were determined for individual couples.

a) b)

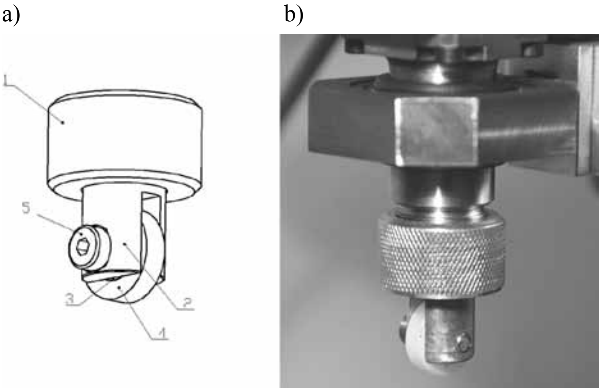

Fig. 1. Modified holder for the T-17 test machine which allows tribological tests to be carried out in rolling motion: a) diagram of the holder, b) the holder mounted on the T-17 machine

Rys. 1. Zmodyfikowany uchwyt do maszyny badawczej T-17 umożliwiający przeprowadzanie testów tribologicznych w ruchu tocznym: a) schemat uchwytu, b) uchwyt założony w maszynie T-17

The weight wear of the specimens was determined using a WPA 60 analytical balance manufactured by RADWAG. Stereometric measurements of the surface of specimens and counter-specimens were carried out with a Form Talysurf Series 2 contact profilometer using 3D and systematic scanning methods. Wear products were observed with an Olympus BX60M microscope.

RESEARCH RESULTS

The results of measurements of the thickness of oxide layers formed on the surface of the counter-specimens (excluding the reference plate) are shown in **Figure 2.**

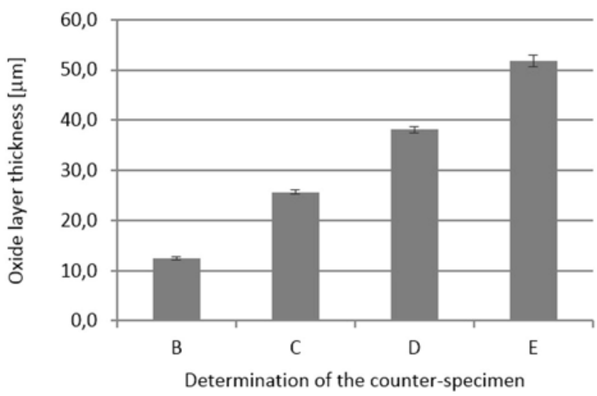

Fig. 2. Influence of anodising conditions on the thickness of oxide layers formed on the surface of aluminium alloy EN AW-6063 T6

Rys. 2. Wpływ warunków anodowania na grubość warstw tlenkowych wytworzonych na powierzchni stopu aluminium EN AW-6063 T6

The tests have shown significant differences in layer thickness resulting from the conditions of the anodising process. The dependence of the layer thickness on the electrical charge density is linear (**Fig. 2**). The thickness of the Al_2O_3 layer grows with the density of the electrical charge; therefore, the duration of the process increases. The surfaces of counter-specimens evaluated on a microscope have shown the dependence of the colour of the layers on their thickness. Thicker layers are darker in colour. Elements of the examined friction node after tribological tests are shown in **Figure 3.**

Preliminary observations of tribological wear products obtained as a result of the friction tests showed the influence of the modification of the aluminium alloy surface on the value of wear of polymer rings. Loose wear products were observed on the surface of the plates (A, B, and C) after the interaction with the PA 6 polymer, and wear products bonded with its surface were found on the ring. No loose wear products were observed in other couples. However, in the couple made up by the plate

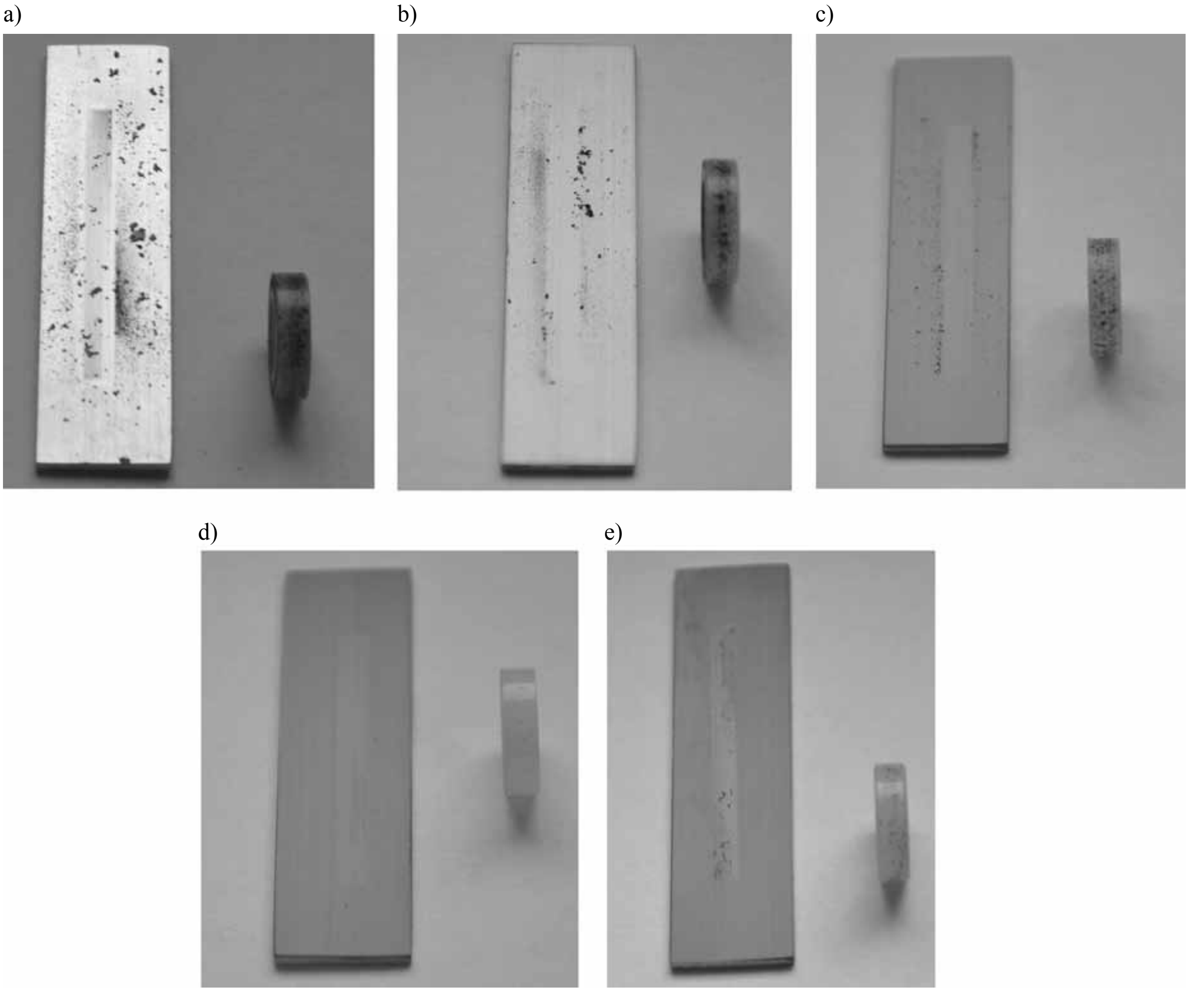

Fig. 3. Elements of the examined friction node of a polymer ring with surface: a) A, b) B, c) C, d) D, e) E after tribological tests
Rys. 3. Elementy badanego węzła tarcia pierścienia polimerowego z powierzchnią: a) A, b) B, c) C, d) D, e) E po testach tribologicznych

(E) oxide layer and polymer specimen, the plastic was transferred to the surface of the layer and a polymer film was formed. Microscopic observations **(Fig. 4)** showed that the amount of wear products was the highest for the non-anodised surface couple (A) and that it decreased for anodised surface couples (B, C) interacting with the PA 6 polymer.

The analysis of the results of tribological tests also showed the influence of the modification of the surface of the aluminium alloy on the value of the friction coefficient and wear intensity of polymer rings. The non-anodised surface (PA 6 polymer couple) is characterised by a high friction coefficient value **(Fig. 5)** and significant wear of the ring material **(Fig. 6)**.

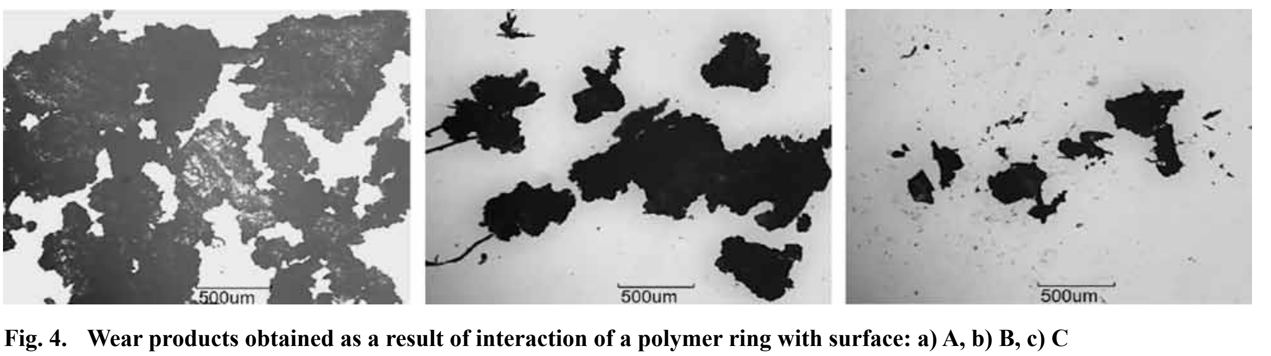

Fig. 4. Wear products obtained as a result of interaction of a polymer ring with surface: a) A, b) B, c) C
Rys. 4. Produkty zużycia otrzymane w wyniku współpracy pierścienia polimerowego z powierzchnią: a) A, b) B, c) C

Couples of a polymer ring with aluminium alloy surfaces on which oxide layers were formed were characterised by lower values of friction and wear coefficients of the polymer than in the case of the non-anodised surface. The values of these parameters depended on the thickness of the oxide layer formed on the surface of the aluminium alloy and decreased along with the increase of the thickness of the layer for plates B, C, and D, and then there was an increase for plate E. This indicates that there are certain optimum values of anodising parameters for obtaining the best tribological properties. The lowest values of the polymer's wear and friction coefficients were shown for the couple of the polymer ring and plate (D) on the surface of which an oxide layer was formed with the electrical charge density of 135 A·min/dm^2. An increase in the values of tribological parameters was shown for the ring-plate (E) couple. This was probably the result of adhesion bonds of the surface of the oxide layer with the polymer material and the transfer of the material to the surface of the layer. In other couples, loose wear products bonded with the surfaces of polymer rings **(Fig. 3)** and not with the surfaces of the layer. The geometric structure of the surface of plates and polymer rings was studied in order to determine their roughness, which makes it possible to assess the course of tribological phenomena of interacting elements of a kinematic node. **Figures 7** and 8 show the values of the average arithmetic deviation of the profile from the mean line (*Ra*) for all interacting surfaces. The values of the average arithmetic deviation of the profile from the mean line indicate the low surface roughness of both the non-anodised plate and the plates with an electrochemically formed oxide layer. When comparing the value of parameter *Ra*, it can be noticed that the non-anodised surface (A) shows the lowest value of this parameter. The highest value was found for the oxide layer on plate (D). However, the difference between these values is small. The value of parameter *Ra* determined for rings interacting with plate surfaces decreased in all cases. The surface of the ring interacting

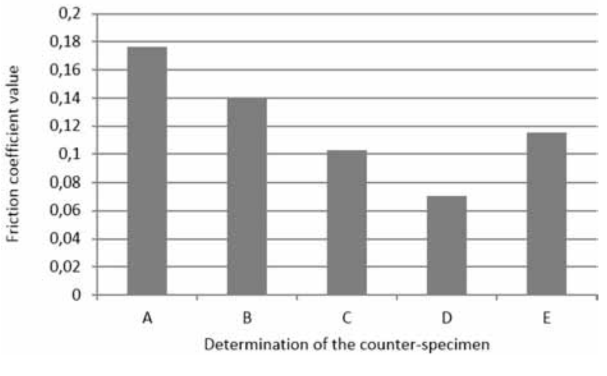

Fig. 5. Influence of modification of the surface of aluminium alloy EN AW-6063 T6 on friction coefficient value in a couple with the PA 6 polymer

Rys. 5. Wpływ modyfikacji powierzchni stopu aluminium EN AW-6063 T6 na wartość współczynnika tarcia w skojarzeniu z polimerem PA 6

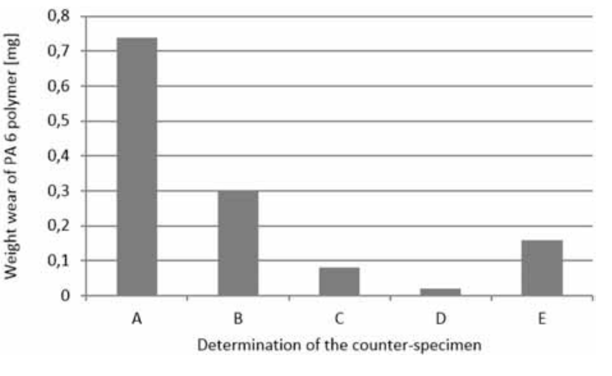

Fig. 6. Influence of modification of the surface of aluminium alloy EN AW-6063 T6 on wear intensity of the PA 6 polymer as a result of tribological interaction

Rys. 6. Wpływ modyfikacji powierzchni stopu aluminium EN AW-6063 T6 na intensywność zużywania polimeru PA 6 w wyniku współpracy tribologicznej

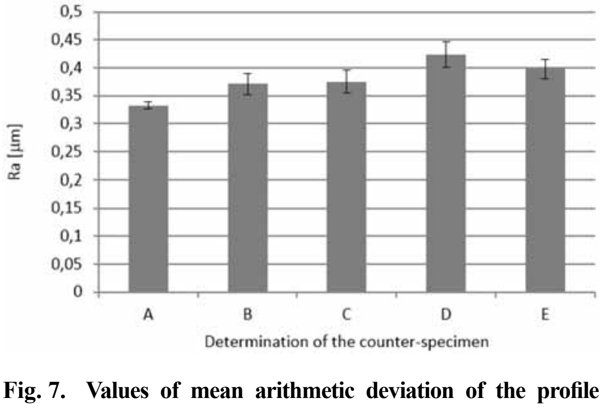

Fig. 7. Values of mean arithmetic deviation of the profile from the mean line (*Ra*) of the surface of the plates after tribological interaction with a PA 6 polymer ring

Rys. 7. Wartości średniego arytmetycznego odchylenia profilu od linii średniej (*Ra*) powierzchni płytek po współpracy tribologicznej z pierścieniem polimerowym z PA 6

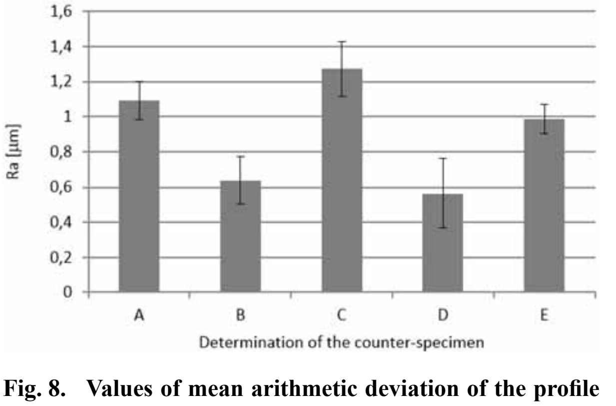

Fig. 8. Values of mean arithmetic deviation of the profile from the mean line (*Ra*) of the surface of the rings after tribological interaction with plate surfaces

Rys. 8. Wartości średniego arytmetycznego odchylenia profilu od linii średniej (*Ra*) powierzchni pierścieni po współpracy tribologicznej z powierzchniami płytek

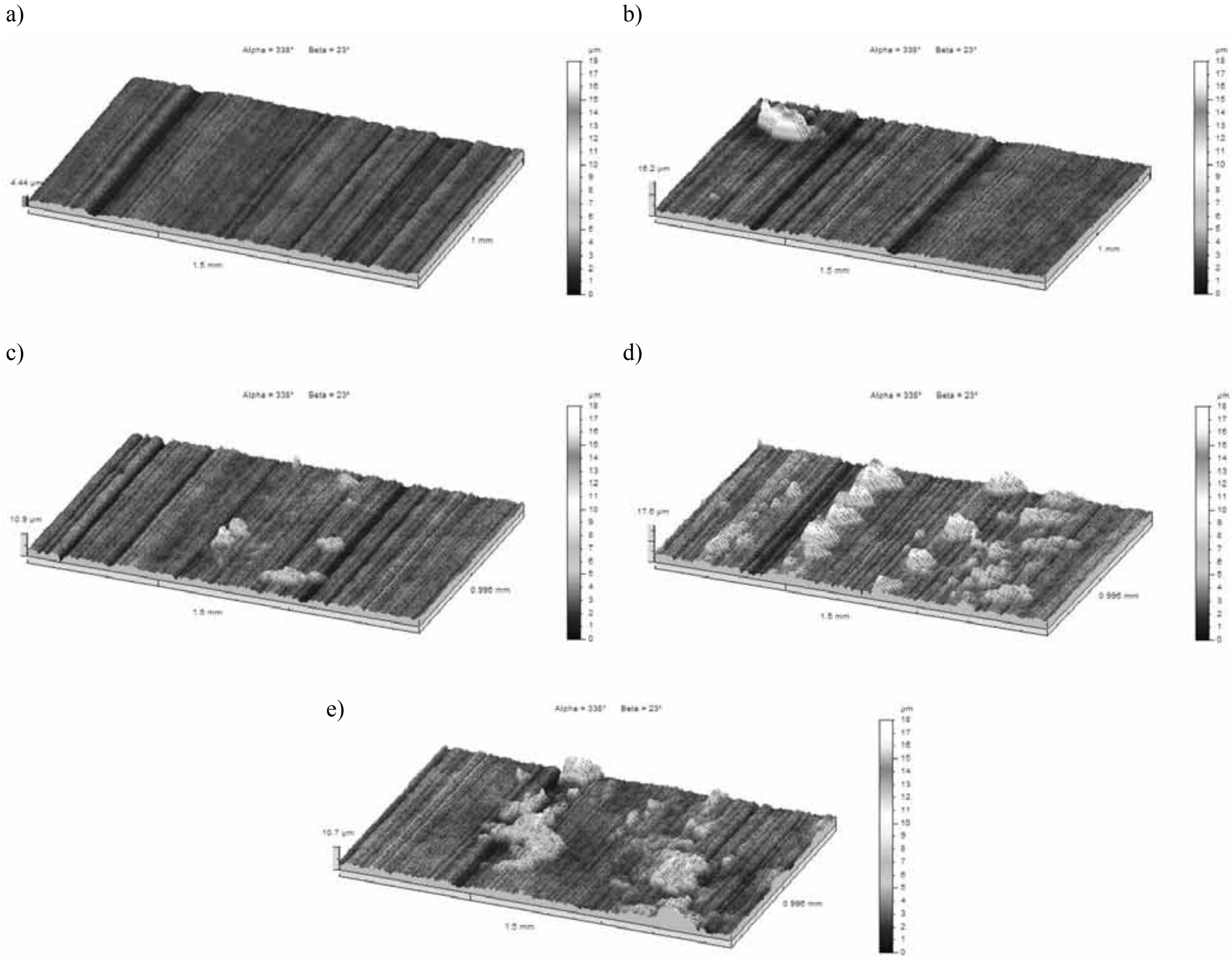

Fig. 9. Isometric image of the surface of plates after tribological interaction with a PA 6 polymer ring: a) A, b) B, c) C, d) D, e) E

Rys. 9. Obraz izometryczny powierzchni płytek po współpracy tribologicznej z pierścieniem polimerowym z PA 6: a) A, b) B, c) C, d) D, e) E

with the oxide layer on plate (C) shows the highest roughness value out of all the tested surfaces. This may be due to the transfer of the polymer to the surface of the counter-specimen and the secondary transfer of wear products to the specimen, which, in turn, explains the slightly higher value of the surface roughness of this ring.

Figures 9 and **10** show isometric images of the surface of plates and rings.

In isometric images of fragments of the tested plate surfaces, an increasing amount of wear products deposited on anodised surfaces **(Figs. 9b-e)** can be observed as the layer thickness increases. In isometric images of the surface of thinner layers (Plates B, C) **(Figs. 9b, c)** and of the non-anodised surface (Plate A) **(Fig. 9a)**, the products of wear are invisible or few in number. This fact may indicate the presence of loose wear products (not bonded to the surface of the layers), which is consistent with the results of macroscopic tests **(Fig. 3)**. The isometric image of an example of a reference surface **(Fig. 10f)** shows surface irregularities characteristic of machining. The isometric images of rings interacting with layers on which loose wear products have been revealed **(Figs. 10a-c)** show a change in the geometric structure of the surface compared to the reference surface. This effect is most likely caused by the depositing of loose wear products **(Figs. 3a-c, Fig. 4)** on surfaces of the rings. In the isometric image of the ring surface (D) **(Fig. 10d)**, only the smoothing of the ring surface is visible, which, in turn, explains the lowest value of the parameter (*Ra*) **(Fig. 8)**. The tests show that the presence of loose wear products adversely affects the values of resistance to motion.

CONCLUSIONS

The studies have shown that it is possible to carry out tests for the roller-plate couple on a T-17 test stand in a rolling motion using a modified specimen holder. Tribological tests carried out for the above-mentioned

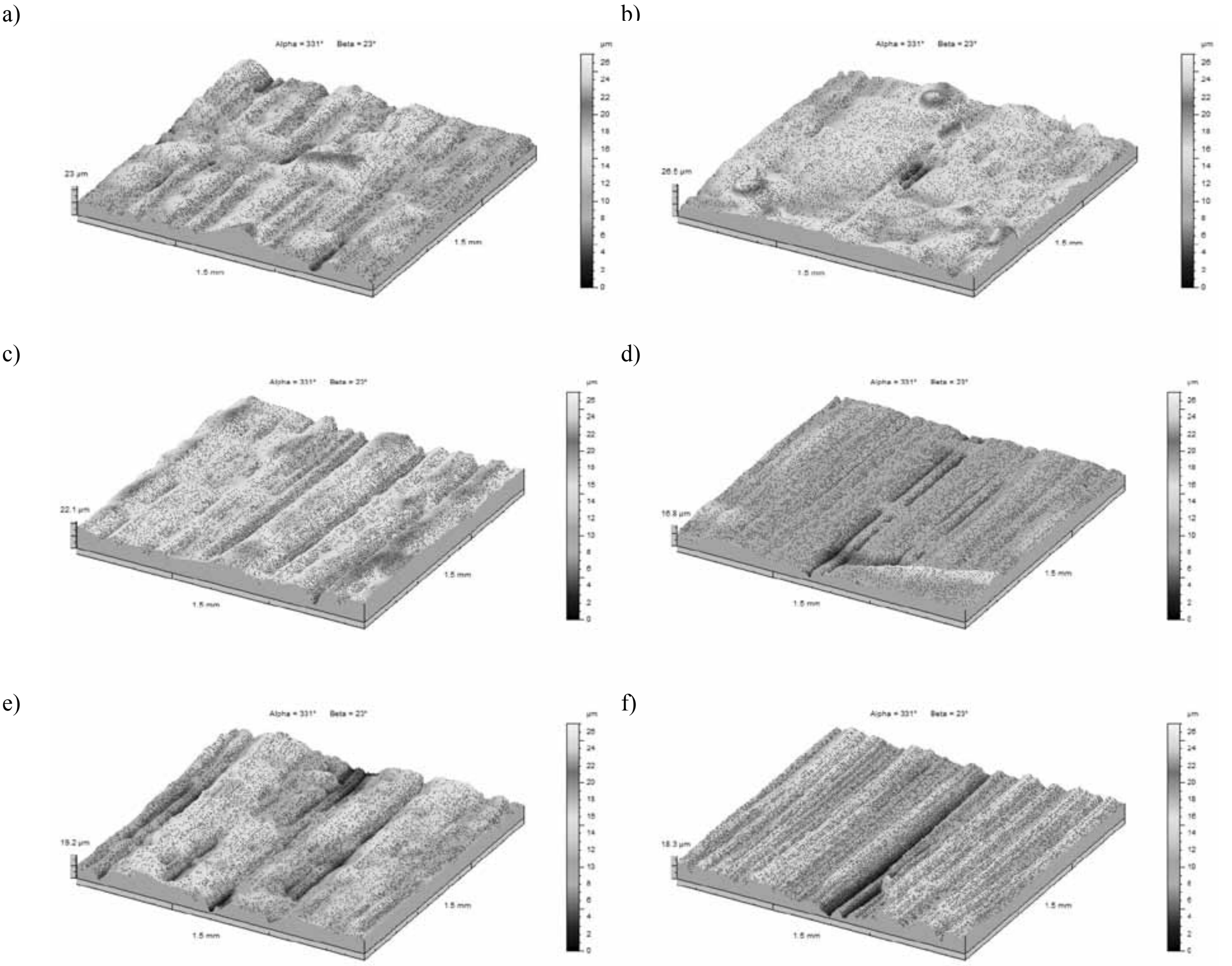

Fig. 10. Isometric image of the surface of rings after tribological interaction with the surface of plates: a) A, b) B, c) C, d) D, e) E and f), example of a reference surface before tribological interaction

Rys. 10. Obraz izometryczny powierzchni pierścieni po współpracy tribologicznej z powierzchniami płytek: a) A, b) B, c) C, d) D, e) E i f), przykładowa powierzchnia referencyjna przed współpracą tribologiczną

friction node showed the effect of the modification of the surface of aluminium alloy EN AW-6063 T6 (sliding door guide material) on tribological properties in a couple with a PA 6 polymer ring (sliding door roller material). The non-anodised surface in a couple with a ring has the highest friction coefficient value and very high weight wear compared to anodised surfaces. The couple of the PA 6 polymer and oxide layer formed on a substrate of EN AW-6063 T6 alloy at a current density of 3 A/dm^2 and electrical charge density of 135 A·min/dm^2 can be considered the most advantageous among the tested couples. The value of the friction coefficient of this couple is more than two and a half times lower, and the value of the weight wear of the ring is thirty seven times lower than in the case of the couple of the PA 6 polymer and a non-anodised surface. The performed tests are preliminary tests on the basis of which the possibility of using the T-17 machine for friction-wear tests of the roller-plate couple in a rolling motion was presented. However, in order for this method to be considered useful for tribological studies, it must be verified on the basis of a series of studies and repeatability analyses. At this stage, only its use has been presented, which is not a basis for generalisation.

REFERENCES

1. Michalczewski R., Szczerek M., Tuszyński W., Wulczyński J.: Aparat czterokulowy do badania właściwości przeciwzużyciowych, przeciwzatarciowych i powierzchniowej trwałości zmęczeniowej z możliwością podgrzewania środka smarowego, Tribologia, 1, 2009, 113–127.

2. Tuszyński W., Kalbarczyk M., Michalak M.: Badania tribologiczne kół zębatych stożkowych, cz. I – urządzenie i metodyka badawcza, Tribologia, 2, 2012, 83–96.
3. Służałek G., Bąkowski H.: Zastosowanie MES do wyjaśnienia mechanizmu zużywania w węzłach tarcia, Biuletyn VAT, LVI, 2007, 9–16.
4. ITeE – PIB: Tribologiczny zestaw badawczy typu trzpień–płytka T-17 Instrukcja obsługi, 2008, 1–32.
5. Fratila-Apachitei L.E., Tichelaar F.D., Thompson G.E., Terryn H., Skeldon P., Duszczyk J., Katgerman L.: A transmission electron microscopy study of hard anodic oxide layers on AlSi(Cu) alloys, Electrochimica Acta, 49, 2004, 3169–3177.
6. Jia Y., Zhou H., Luo P., Luo S., Chen J., Kuang Y.: Preparation and characteristics of well-aligned macroporous films on aluminum by high voltage anodization in mixed acid, Surface & Coatings Technology 201, 2006, 513––518.
7. Bara M., Kubica M.: Influence of substrate preparation on the shaping of the topography of the surface of nanoceramic oxide layers, Applied Surface Science, 293, 2014, 306–311.
8. Jia Y., Zhou H., Luo P., Luo S., Chen J., Kuang Y.: Preparation and characteristics of well-aligned macroporous films on aluminum by high voltage anodization in mixed acid, Surface & Coatings Technology, 201, 2006, 513––518.
9. Morks M.F., Hamdy A.S., Fahim N.F., Shoeib M. A.: Growth and characterization of anodic films on aluminum alloys in 5-sulfosalicylic acid solution, Surface & Coatings Technology, 200, 2006, 5071–5076.
10. Fratila-Apachitei L.E., Duszczyk J., Katgerman L.: Vickers microhardness of AlSi(Cu) anodic oxide layers formed in H2SO4 at low temperature, Surface and Coatings Technology, 165, 2003, 309–315.