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USING COMPOSITE COATINGS CONTAINING SOLID LUBRICANTS TO MINIMIZE FRICTION IN PISTON COMBUSTION ENGINES FOR AVIATION

The paper presents the results of research on a composite coating with a polymer resin matrix containing glassy carbon microparticles as the modifying phase acting as a solid lubricant for piston aircraft engines. Comparative tests were carried out on a T-11 tribological tester at the temperature of 80°C, pressure of p = 8 MPa and relative velocity v = 0.55 m/s of a cam/push rod contact coated with a developed coating (RGC) and a cam/push rod contact coated with a reference coating (RC). 2 mg of AeroShell 100 oil were added to the contact for 10 hours of rubbing. This lubrication simulates the operating conditions of the combustion engine components after lubrication loss. As a result of the tests, it was found that the developed coating can work 10 hours after the lubrication disappears because the coating is porous and absorbs the oil during heating up to the engine's operating temperature. The oil sorption is indicated by the increase in the mass of the sample with the coating. Thanks to the coating material anchored in the roughness valleys of the push rod surface soaked with oil, the coefficient of friction, despite evaporation of the volatile parts of the oil, does not exceed μ = 0.1, which prevents seizure of the contact. The contact with the reference coating seized after 8.5 hours of sliding. The tests of the developed coating on the engine dynamometer as well as in the aircraft confirmed the usefulness of the developed coating.

Keywords: piston combustion engine, composite coatings, solid lubricant, loss of lubrication

ZASTOSOWANIE ZAWIERAJĄCYCH SMARY STAŁE POWŁOK KOMPOZYTOWYCH W TŁOKOWYCH SILNIKACH SPALINOWYCH DLA LOTNICTWA

Przedstawiono wyniki badań przeznaczonej do tłokowych silników lotniczych powłoki kompozytowej z osnową z żywicy polimerowej zawierającej jako fazę modyfikującą mikrocząstki węgla szklistego pełniącego rolę smaru stałego. Wykonano badania porównawcze na testerze tribologicznym T-11 w temperaturze 80°C przy nacisku p = 8 MPa i prędkości względnej v = 0,55 m/s skojarzeń krzywka/popychacz pokryty opracowaną powłoką (RGC) oraz krzywka/popychacz pokryty powłoką referencyjną (RC). Do skojarzenia podano 2 mg oleju AeroShell 100 na 10 h współpracy. Takie smarowanie symuluje warunki pracy podzespołów silnika spalinowego po zaniku smarowania. W wyniku przeprowadzonych badań stwierdzono, że opracowana powłoka może pracować 10 godzin po zaniku smarowania, ponieważ ta powłoka jest porowata i sorbuje olej podczas nagrzewania do temperatury pracy silnika. O sorbowaniu oleju świadczy przyrost masy próbki z powłoką. Dzięki materiałowi powłoki zakotwiczonemu we wgłębieniach chropowatości powierzchni popychacza nasączonemu olejem współczynnik tarcia mimo odparowania części lotnych oleju nie przekracza μ = 0,1, co zapobiega zatarciu skojarzenia. Skojarzenie z powłoką referencyjną zatarło się po 8,5 h współpracy. Badania opracowanej powłoki na hamowni silnikowej oraz w samolocie potwierdziły przydatność opracowanych powłok.

Słowa kluczowe: silnik tłokowy, powłoka kompozytowa, smar stały, zanik smarowania

INTRODUCTION

The use of composite materials in the construction and operation of machines as engineering materials is widely known. Using composites in heat management is somewhat less widespread, as cold-insulating materials (cryogenics) and heat-insulating materials (short-distance transport, e.g. technological liquids in pipelines, copper ore, sand driers) as well as heat dissipation materials (heatsinks of electronic components, e.g. processors in computers). A more recent task of composites is to reduce the friction and wear of sliding contacts by built-in solid lubricants [1-3]. An interesting aspect of using composites with built-in solid lubricants is the ability to protect the contact from seizure as a result of lubrication loss, which is very important in aircraft engines.

A engineering material with a built-in solid lubricant does not fully meet the requirements resulting from the definition of a composite. The basic task of the second component called the "reinforcing" or "strengthening" phase is to reinforce the matrix material. Adding a material with a low shear strength performing the role of a lubricant, e.g. graphite or glassy carbon to light metal alloys (Al, Mg, Ti) or plastics (polyurethanes, polyacetals) results in a reduction in friction and wear intensity, but does not always strengthening the matrix material. In composite sliding materials, i.e. operating in sliding contacts, the basic task of the second phase, referred to in this article as modifying, is to reduce the negative effects of friction [4]. If materials with higher compressive strengths are added to the matrix, e.g. glassy carbon applied on a spatial mesh of Al_2O_3 or SiC, they also have a strengthening function [2].

This article is devoted to the problems associated with using sliding composite coatings from a polymer matrix and particulate glassy carbon particles as the modifying phase in piston aircraft engines.

MATERIALS AND METHODS

A composite sliding material (RGC) based on a polymer matrix filled with glassy carbon particles was used for the tests. This material was prepared in the form of a suspension of glassy carbon microparticles in a resin with an addition of thinners and applied by spraying on the working surfaces of combustion engine push rods made of 17HNM steel. In order to ensure the required adhesion of the coating, the push rod surfaces were prepared by sandblasting [3]. The sanding conditions that resulted in obtaining a surface topography optimal for applying coatings was determined in optimization studies [3].

A view of the push rod working surface after coating and grinding with abrasive paper before and after testing on a test stand is shown in Figure 1 and after 50 hours of testing in an engine in Figure 2. The roughness profiles of the push rod surface prior to coating application are shown in Figure 3, and after tribological tests in Figure 4.

The sliding partner of the push rod was cams of the camshaft made of 19HMN steel with a hardness 5 HRC higher than that of the push rod.

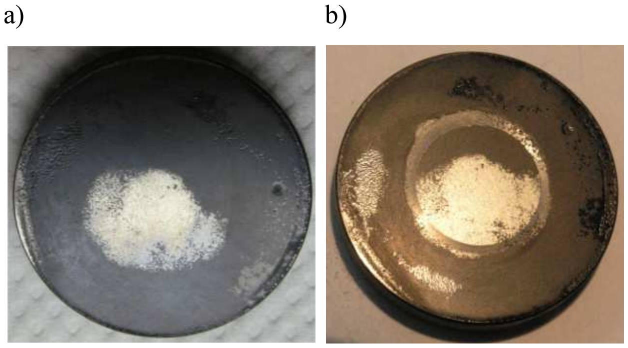

Fig. 1. Push rod with coating after grinding, before (a) and after (b) 10 h of testing on test stand

Rys. 1. Popychacz z powłoką po szlifowaniu przed (a) i po badaniach stanowiskowych 10 h (b)

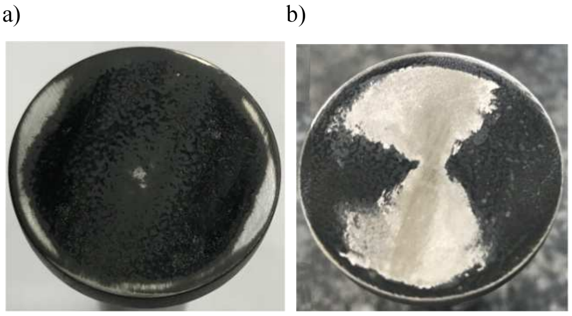

Fig. 2. Push rod with RGC coating after grinding, before (a) and after (b) 50 h of testing in engine

Rys. 2. Popychacz z powłoką R+GC po szlifowaniu przed (a) i po (b) badaniach w silniku

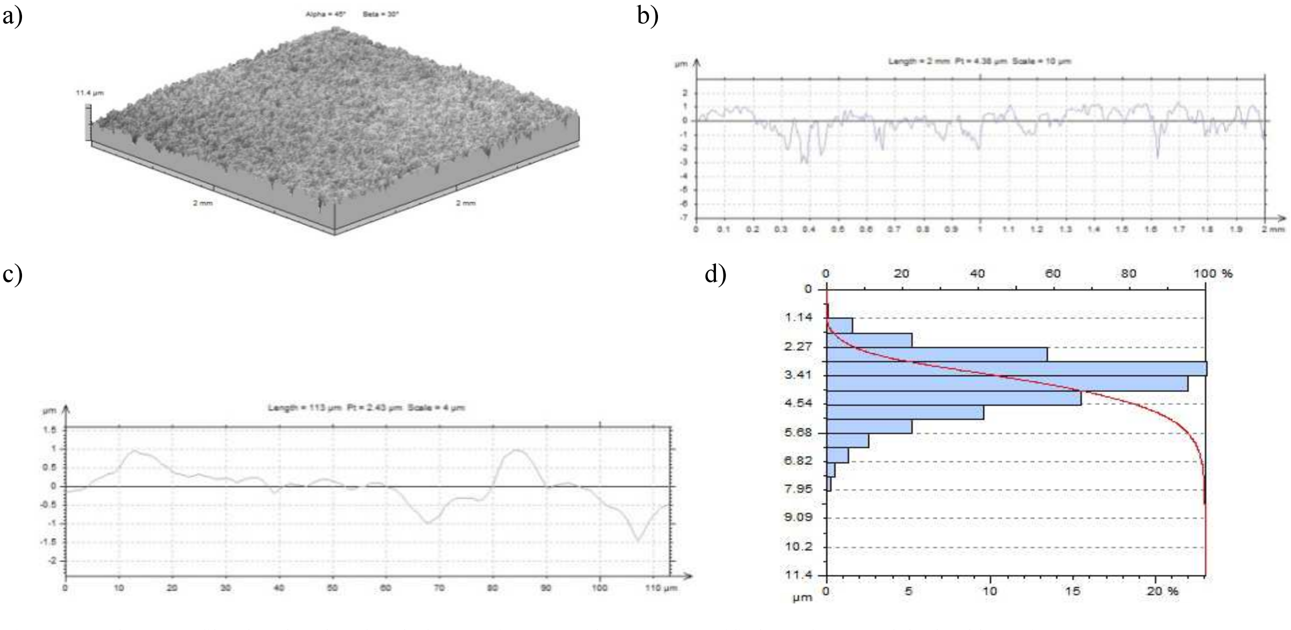

Fig. 3. Roughness profile of push rod surface before coating: a) 3D, b) 2D, c) magnified part from graph b, d) Abbott-Firestone curve

Rys. 3. Profil chropowatości powierzchni popychacza przed nałożeniem powłoki: a) 3D, b) 2D, c) powiększony fragment z rys. b, d) krzywa nośności profilu (Abbotta)

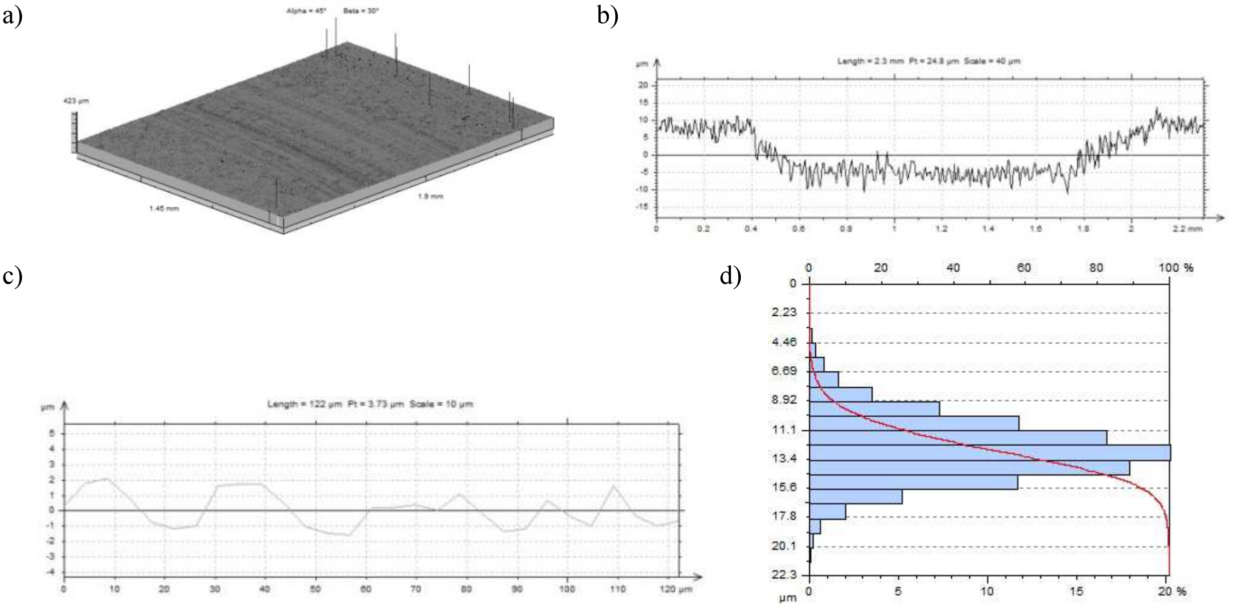

Fig. 4. Roughness profile of RGC coated push rod after tribological testing: a) 3D, b) 2D, c) magnified part from graph b, d) Abbott-Firestone curve

Rys. 4. Profil chropowatości powierzchni popychacza z powłoką RGC po badaniach tribologicznych: a) 3D, b) 2D, c) powiększony fragment z rys. b, d) krzywa nośności profilu (Abbotta)

TRIBOLOGICAL STUDIES

In order to check the suitability of the developed composite coatings for applications in aircraft engines, laboratory tests were carried out using a tribological tester and an aircraft engine placed on a dynamometer.

During the stand tests, a T-11 tester with the possibility of heating the contact was used. The tests were carried out at the pressure of p = 8 MPa at the beginning of the tests, velocity v = 0.55 m/s, for the time τ = 10 h and at the temperature of 80°C corresponding to the average oil temperature in the valve train. As a result of wear of the cam working surface, the actual contact area increased, which caused a slight drop in pressure. The coatings were applied to the working surfaces of the valve push rods. The camshaft cams were the sliding partner.

Comparative tests using the tribological tester lasted 10 hours after administering one drop (2 mg) of AeroShell 100 oil directly on the coating surface. A push rod with a commercial coating (RC) to prevent seizure of the engine after lubrication failure and the RGC coating were tested simultaneously. The coefficient of friction curves vs the sliding time are shown in Figure 5.

Composite coatings with a chemical composition ensuring the least wear, smallest coefficient of friction and the longest working time after administering 2 mg of oil were checked during stand tests on the engine dynamometer and examined by using of SEM (Fig. 6).

The RGC coating was applied, among others on the valve push rods (1 in Fig. 7). During the tests, selected engine operating parameters were monitored, including the friction torque and fuel consumption. After 50 hours, the engine was dismantled and its components were inspected. The components with the RGC coating were suitable for further use.

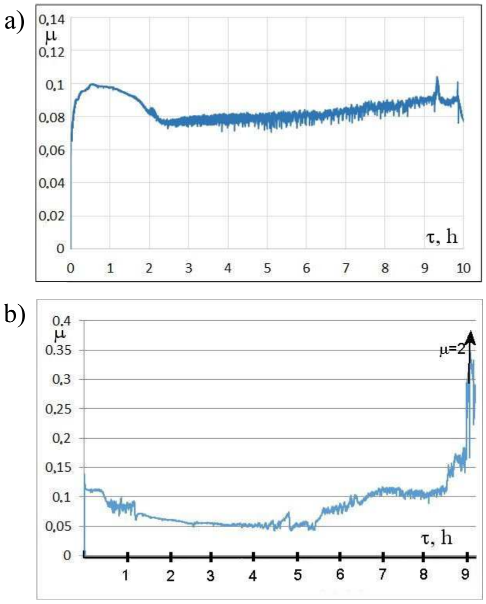

Fig. 5. Dependence of coefficient of friction on sliding time of tested contacts: a) with elaborated coating, b) with reference coating

Rys. 5. Zależność współczynnika tarcia od czasu współpracy badanych skojarzeń: a) z opracowaną powłoką, b) z powłoką odniesienia

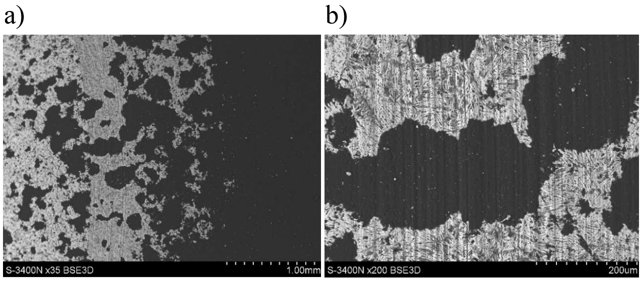

Fig. 6. View of composite coating after 10 h of sliding on friction boundary (a) and on friction surface (b), SEM

Rys. 6. Widok powłoki kompozytowej po 10 h współpracy na granicy tarcia (a) i na powierzchni tarcia (b), SEM

Fig. 7. Camshaft and coated push rods before testing in engine: 1 - push rod, 2 - cam

Rys. 7. Wałek rozrządu i popychacze z naniesioną powłoką przed badaniami w silniku: 1 - popychacz, 2 - krzywka

DISCUSSION OF RESULTS

The coefficients of friction were calculated on the basis of the friction forces recorded during the tests on the T-11 tester. The results are shown in Figure 5. The mass loss of the cam section was $\Delta_p = 0.1$ mg and the push rod with coating $\Delta_d = -5$ mg, despite the depth of the wear track to 5 μm (Fig. 4b). The negative loss of mass of the push rod means that during 10 hours of sliding at the temperature of 80°C the coating absorbed the oil, which allows the contact to work without seizure for a minimum of 10 hours.

During the sliding of the open contact at 80°C, slow evaporation of the volatile oil components as well as sorption of the oil through the porous coating followed. The evaporation, accompanied by an increase in oil viscosity increase, was demonstrated by a slow increase in the coefficient of friction between 2 and 10 h. As a result of friction, wear of a part of the coating (Fig. 4b) protruding above the tops of the irregularities of the push rod surface after sandblasting (2 h at the beginning of sliding, maximum value of $\mu = 0.10$) and peaks of these irregularities followed (Fig. 4c). A lubricant consisting of concentrated oil and coating wear products, including glassy carbon, formed on the surface. Small amounts of the porous coating remained in the valleys, which absorbed the oil and reduced friction. As a result, the coefficient of friction decreased to $\mu < 0.08$ (Fig. 5a).

During sliding of the cam with the push rod with the smooth reference coating, at the beginning of the tests there was enough oil on its surface, which reduced the coefficient of friction after reaching the value of $\mu = 0.125$ to $\mu = 0.06$ (Fig. 5b). The high temperature caused evaporation of the volatile parts of the oil and increased the coefficient of friction. After about 8.5 h, the lubrication was insufficient, leading to seizure of the contact, and the friction coefficient reached the value of $\mu = 2$. The fragment of the graph with $\mu = 2$ was not placed in Figure 5b in order to show the changes in μ until the appearance of adhesive wear (seizure).

The contact is dominated by abrasive wear of the coating material with the hard cam material. This is evidenced by scratches along the direction of push rod movement (Figs. 4a and 6). From the analysis of the push rod surface Abbott-Firestone curves, it can be seen that before applying the coating, peaks with heights from 2.27 to 4.68 μm dominate (Fig. 3), and after sliding from 6.9 to 15.6 μm (Fig. 4). The shape of the Abbott-Firestone curve before application indicates that the irregularity valleys constituting coating depots have a depth of up to 9 μm. During friction against the cam material, new cavities appear up to 20 μm, which makes it easier to retain wear and oil residues.

CONCLUSIONS

Introducing glassy carbon microparticles into a porous polymeric resin coating applied to the rough surface of a heat treated steel push rod protects the cam/push rod contact to be protected against seizure during lubricant loss.

Developing the surface as a result of sanding allows changes the topography of the push rod surface and contributes to an increase in mechanical adhesion of the coating. This provides increased adhesion, making it difficult to completely remove the applied polymer coating. As a result, during friction, there is no direct contact between the rubbing elements leading to seizure.

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