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COMPOSITES THEORY AND PRACTICE

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COMPOSITE COATINGS INCLUDING SOLID LUBRICANTS DESIGNED FOR AVIATION

The article presents the fundamentals of the manufacturing, structure and selected properties of composite coatings (RGC) developed at the Silesian University of Technology designed for the aviation industry. The tribological properties of the developed coatings were compared with the properties of coatings used to date (TLML). The primary purpose of the coatings developed by the authors is to extend the time of correct operation of selected contacts of aircraft piston engines after the loss of lubrication due to a failure during flight. This time is necessary to fly to a safe landing place. Ensuring correct operation of the contact, i.e. maintaining the coefficient of friction at a level to prevent seizing, is possible due to a coating of a composite layer containing solid lubricants on the sliding surfaces. In the RGC coating, it is a glassy carbon and in the TLML coating it is molybdenum disulphide. During sliding with an insufficient amount of oil, more intensive wear of the coating takes place. Since the lubrication does not work, wear products are removed from the friction zone much more slowly. A mixture is formed from the wear products of the solid lubricant and oil residues, which is deposited on the cooperating surfaces, reducing friction. Even after the coating was worn off, the coefficient of friction in the conducted tests did not exceed 0.04. The developed coating can work at 120°C, with pressure p = 0.4÷2.0 MPa and at sliding velocity v = 0.55 m/s up to 30 minutes without being completely worn out. The TLML coating after about 24 minutes was worn out.

Keywords: solid lubricant, glassy carbon, aviation, friction, wear, composite coatings

POWŁOKI KOMPOZYTOWE ZAWIERAJĄCE SMARY STAŁE PRZEZNACZONE DLA LOTNICTWA

Przedstawiono podstawy wytwarzania, budowę i wybrane właściwości opracowanych w Politechnice Śląskiej powłok kompozytowych (RGC) przeznaczonych dla lotnictwa. Właściwości tribologiczne opracowanych powłok porównano z właściwościami powłok stosowanych dotychczas (TLML). Podstawowym celem opracowanych przez autorów powłok jest wydłużenie czasu poprawnej pracy wybranych skojarzeń tłokowych silników lotniczych po zaniku smarowania spowodowanego awarią podczas lotu. Czas ten jest niezbędny na dolot do miejsca bezpiecznego lądowania. Zapewnienie poprawnej pracy skojarzeń, tj. utrzymanie współczynnika tarcia na poziomie zabezpieczającym przed zatarciem, jest możliwe dzięki naniesieniu na współpracujące powierzchnie powłok kompozytowych zawierających smary stałe. W powłoce RGC jest to węgiel szklisty, a w powłoce TLML dwusiarczek molibdenu. Podczas współpracy ślizgowej, przy niewystarczającej ilości oleju, ma miejsce intensywniejsze zużywanie powłoki. Ponieważ smarowanie nie funkcjonuje, produkty zużycia są usuwane ze strefy tarcia znacznie wolniej. Z produktów zużycia smaru stałego i resztek oleju tworzy się mieszanina, która jest osadzana na współpracujących powierzchniach, zmniejszając tarcie. Nawet po zużyciu powłoki współczynnik tarcia w przeprowadzonych badaniach nie przekraczał 0,04. Opracowana powłoka może pracować w temperaturze 120°C, przy nacisku p = 0,4÷2,0 MPa i prędkości v = 0,55 m/s, do 30 minut nie ulegając całkowitemu zużyciu. Powłoka TLML po około 24 minutach została zużyta.

Słowa kluczowe: smar stały, węgiel szklisty, lotnictwo, tarcie, zużycie, powłoki kompozytowe

INTRODUCTION

Lubrication of the contacting parts of machines and devices is one of the most important activities during their operation. The importance of lubrication is increased even more in aircraft engines. The technical means of road, rail or water transport after a failure of the engine lubrication system can be stopped and repaired at the site of the failure or towed away to a garage. If there is a failure of the lubrication system in the technical means of air transport, there is no possibility of "stopping" and repairing. From the point of view of the safety of the crew, means of transport, cargo, and terrestrial areas within the measure, there is a need to enable landing in a suitable place. One of the factors determining this possibility is the time to arriving at a place for a safe landing. This is the time from the moment the lubrication disappears to the time of landing. Currently binding regulations allow producers to determine this time; some assume that it is 15 minutes [1, 2]. From the technical point of view, there are two groups of possibilities to ensure correct operation of the aircraft engine after the loss of lubrication, i.e. technical and material.

The first option that can be used during a pressure drop in the lubrication system caused by, e.g. a pump fault, may be the use of membrane accumulators. The second choice may be friction contacts made of the appropriate engineering materials, e.g. composites containing a built-in solid lubricant.

The rapid development of composite materials, including coatings, has contributed to their use in the construction of technical means of air transport means. The literature contains a great deal of information on the use of composites as engineering materials to reduce the weight [3], as an anti-icing coating and to reduce fuel consumption [4, 5]. Less information is available about sliding composites with embedded solid lubricants, e.g. graphite, molybdenum disulphide, glassy carbon, carbon nanotubes or graphene [6, 7]. Therefore, the Silesian University of Technology in cooperation with an aircraft engine repair company, undertook the task to develop composite coatings containing solid lubricants enabling engine operation after the loss of lubrication [8].

This article is devoted to the production, structure and selected properties of polymer composite coatings (RGC) with embedded glassy carbon particles acting as a solid lubricant. These coatings have been developed for the purpose of aircraft engines for covering sliding surfaces, e.g. the piston skirt and crankshaft shells. Their task is to enable operation of the engine after the loss of lubrication, for the time necessary to make a safe landing.

PRODUCTION OF COATINGS

Two types of coatings were used in the research, i.e. commercial (TLML) containing the addition of solid lubricant MoS_2 particles and a resin coating (R) containing 10% in mass glassy carbon (GC) with granulation under 40 μm. The TLML coating was applied in accordance with the manufacturer's requirements, i.e. by spraying, afterwards drying at 60°C for 1 hour and curing at 180°C for 2 hours. The coating containing GC particles (RGC) was prepared by mixing GC in an epoxy resin solution by ultrasound at 40 kHz for 20 minutes [9]. This ensured not only uniform distribution of the GC particles in the matrix but also a satisfactory connection at the interface between the resin and carbon particles. Subsequently, the coating, due to its high viscosity, was applied with a brush on a roughened and degreased disc and hardened under conditions analogous to the TLML coating (180°C/2 h). The discs were made of the AlSi12Ni1.8MgCu alloy, used in combustion engines.

TRIBOLOGICAL PROPERTIES

In order to check how long the developed RGC coating will withstand after the loss of lubrication, tribological tests were performed. The sliding partner was GJL-350 cast iron used for the production of cylinder liners. The tests were carried out on a T-11 tester, in which the friction node is a pin sliding on a rotating disc. Pins (φ = 5 mm) ended with balls made of GJL-350 cast iron, and discs (φ = 25 mm and thickness 5 mm) of coated silumin were used. The tests were carried out in the following conditions: unit pressure p = 0.5÷2.0 MPa; velocity v = 0.55 m/s; sliding time τ = 30 min.

a) b) c)

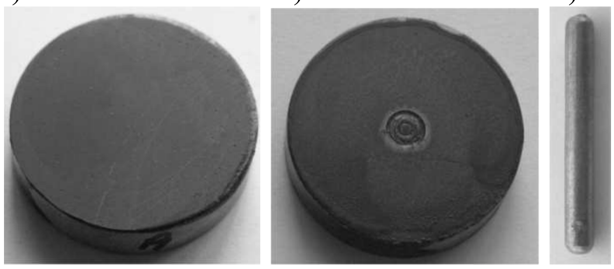

Fig. 1. Discs coated with RGC (a), TLML (b) and cast-iron pin (c)

Rys. 1. Tarcze pokryte powłokami RGC (a) i TLML (b) oraz trzpień żeliwny (c)

a) b)

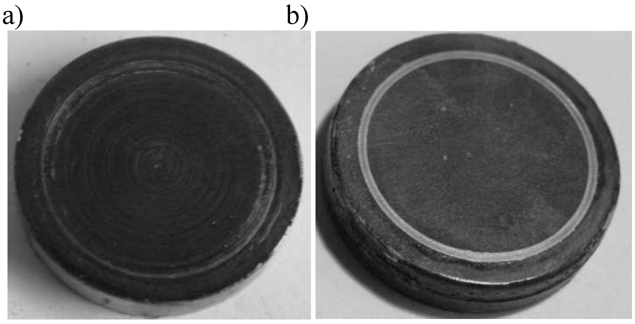

Fig. 2. Discs with RGC (a) and TLML (b) coating after sliding against cast-iron pin under boundary lubrication

Rys. 2. Tarcze z powłoką RGC (a) i TLML (b) po współpracy z żeliwnym trzpieniem w tarciu granicznym

Macro photos of the surface of these discs and the pin before sliding are shown in Figure 1, and after sliding in Figure 2.

The used tester enables the test contact to be heated to a temperature of 250°C, which covers the operating conditions of the cam/push rod, piston skirt and the plain bearings of the piston combustion engine. The temperature of the piston skirt and bearings does not exceed 120 and 90°C in the cam/push rod contact.

In the first stage, the coatings were tested under friction in air, and in the second stage the coatings were lubricated once with AeroShel 100 15W/50 engine oil, in a way that simulated engine operation conditions after a boundary lubrication. Diagrams of the friction coefficient of the lubricated contacts are shown in Figure 3. The friction coefficient during sliding in air was μ = 0.3÷0.4 for RGC and 0.45÷0.3 for the TLML coating.

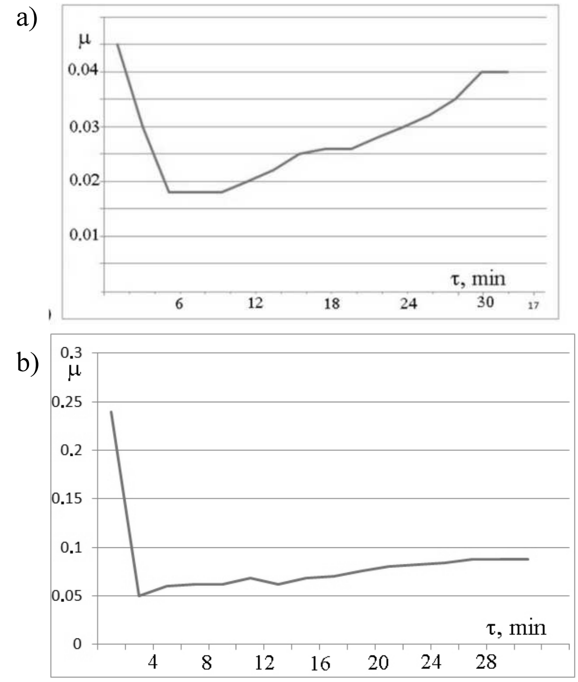

Fig. 3. Friction coefficient (μ) vs. sliding time (τ) in contact of GJL-350 against RGC (a) and TLML coating (b)

Rys. 3. Współczynnik tarcia (μ) w funkcji czasu współpracy (τ) w skojarzeniu z powłoką RGC (a) i TLML (b)

MICROSCOPIC EXAMINATION

The samples after the tribological tests were observed on a scanning electron microscope. The results are shown in Figures 4 and 5.

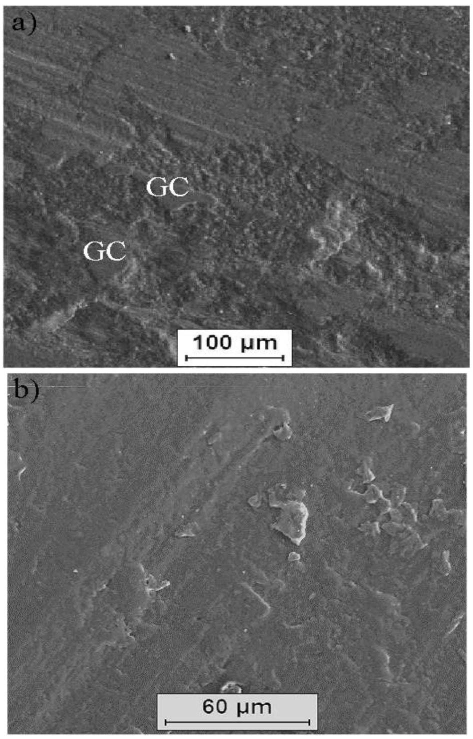

Fig. 4. Friction surface of disc coated with RGC (a) and TLML (b) after sliding against GJL-350 cast iron pin

Rys. 4. Powierzchnia tarcia tarczy pokrytej RGC (a) i TLML (b) po współpracy z trzpieniem żeliwnym

DISCUSSION OF RESULTS

The cast iron sliding against silumin not protected by the coating is characterized by a high coefficient of friction (μ = 0.5 at the beginning and 1.0 after 5 minutes) and adhesive wear. Applying the RGC and TLML coatings enables sliding in technically dry friction conditions (μ = 0.3÷0.4 for RGC and 0.45÷0.3 for TLML). The contact of GJL-350 cast iron with silumin coated with an RGC layer after engine oil lubrication ceases can work at 120°C for 30 minutes (μ = 0.045-0.04) and for 24 minutes with the TLML coating (μ = 0.24-0.08) until the coatings wear out (Figs. 2 and 3). This is possible due to the presence of the built-in solid lubricants, i.e. glassy carbon in the RGC coating and MoS_2 in the TLML coating. The coating wear products mixed with oil residues form a lubricant applied frictionally to the surface of the silumin, reducing the friction (a drop in μ after about 5 minutes of sliding, Fig. 3).

Similar behavior of the coatings during friction and the formation of solid lubricant on the surface were also confirmed in friction surface microstructure studies. The surfaces of the wear tracks presented in Figures 4 and 5 show that the abrasive wear of the coatings dominates (Fig. 4). At the end of sliding, after removal of the majority of oil from the friction zone, thermal wear and degradation of the resin occur near the glassy carbon particles.

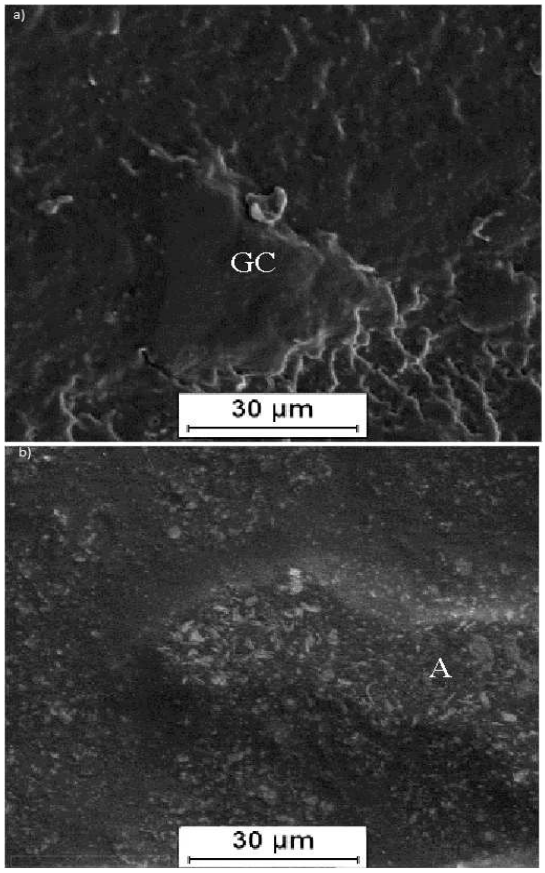

Fig. 5. Wear of friction surface of disc coated with RGC (a) and TLML (b) after sliding against cast iron pin

Rys. 5. Zużycie powierzchni tarcia tarczy pokrytej RGC (a) i TLML (b) po współpracy z trzpieniem żeliwnym

The coating material is replaced along the movement direction of the pin (Fig. 5). On the friction surface, larger particles of glassy carbon (GC, Figs. 4a and 5a) and smaller (<1 μm) molybdenum disulphide (brighter points in Fig. 5b) can be observed. As a result of a thermal degradation of the TLML coating, its fragments are removed, and the areas sliding against the pin during friction form agglomerates (A, Fig. 5b) in the shape of grains with a very large diameter of even up to 200 μm (Fig. 5b). There is a similarly situation in the friction zone of the RGC coating. In the area bearing the traces of rubbing, there are particles of glassy carbon protruding from the surface of the coating. Around them thermally degraded areas of plastic deformed epoxy resin are visible (Fig. 5a).

In the RGC coating, carbon particles up to 40 μm in size fulfill a similar role to the formation of MoS_2 agglomerates (A areas) in the TLML coating during friction. The EDS analysis of the elements distribution shows that abrasive products containing glassy carbon particles from the RGC coating or molybdenum disulfide grains from the TLML coating are evenly distributed over the entire surface of the wear track.

CONCLUSIONS

Based on the results of the examinations the following conclusions can be drawn:

1. The application of composite coatings, including glassy carbon (RGC) and molybdenum disulphide (TLML) as a solid lubricant enables GJL-350 cast iron to slide against silumin under technically dry friction conditions (μ = 0.3÷0.4 for RGC and 0.45÷0.3 for TLML) and allows the contact to operate after engine oil lubrication stops .
2. A more advantageous solution in the conditions of emergency operating is the use of a glassy carbon coating, because it exhibits a lower friction coefficient for almost 30 minutes until RGC coating wear out - μ = 0.04 than the TLML coating containing molybdenum disulphide - μ = 0.08 for 24 minutes.
3. The wear mechanisms of the glassy carbon coatings and molybdenum disulphide are comparable, i.e. immediately after the disappearance of lubrication abrasive wear prevails, and after the disappearance of residual oil, there is local degradation of the resin.

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