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FRICTION BEHAVIOR OF NEW COMPOSITE BEARING MATERIALS FOR PRINTING MACHINES AND THEIR SPECIAL USE UNDER HEAVY OPERATING CONDITIONS

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Abstract:

In the paper the friction film formation analysis of the new composite bearings based on powder nickel alloy EP975 with solid lubricant CaF2 powder after tribological tests has been presented. Dense films are formed during friction of contact surfaces for tribological tests at high speed (or temperature) and loads. Such films consist of chemical elements of friction pair and air oxygen. Friction film is a determining factor for the antifriction material. It is connected with the nature of friction films. The films can minimize friction and ensure stability of a friction unit. It depends on the combination of chemical elements and oxygen in the films formed. The chemical composition of friction films not only allows explaining the mechanism of their formation, but also gives the possibility to forecast and control the functional properties of bearing materials in wide range of printing machines under operating conditions. New composite bearings can be successfully used in the military equipment nodes, such as sliding divices nodes of artillery weapons.

Keywords:

friction film, EP975–CaF2 material, secondary structure, chemical composition, composite bearings, printing machines, special military use

INTRODUCTION

Now existing friction parts (especially of cast alloys) in friction units of military and civilian equipment, for example, printing machines are not capable to satisfy the modern severe operating conditions for such equipment, for example, rotary printing machines [1–4]. There are such friction parts both in military equipment rotating machinery and in the friction units of civilian apparatus (for example, in the offset printing cylinders friction units in Heidelberg Speedmaster SM-102-FPL and KBA Rapida-105, Germany, and in the nodes of sliding devices of artillery weapons).

Such friction parts have a life cycle of only near 0.5-1.5 year. It is connected with their unsatisfactory antifriction properties. This is due to the imperfections of the existing production technologies. Therefore these antifriction parts are not able to ensure the high quality of the contact surface [1].

Scientists developed the new effective composite antifriction materials based on powder nickel alloy EP975 with solid lubricant CaF2 added and new technology for their manufacturing [4, 5].

These materials were designed for antifriction units bearings both for civilian and military equipment. There were studied physical-mechanical, tribotechnical properties and the status of the contact surfaces after tribological tests. New materials demonstrated increase in wear resistance by a factor of 3.2 – 6.0 compared with the known bearings at high speed [4, 5].

But until now, the friction film formation mechanism remains unclear. In addition, the effect of friction films on the frictional behavior of contact pair still has not been researched especially under heavy operating conditions. It does not allow forecasting functional properties of the friction pair. Also it does not give the possibility to choose a certain kind of friction materials for heavy exploitation conditions.

Though the formation of tribofilms, the so called secondary structures, on the contact surfaces under heavy duty conditions is still inadequately understood, they impart antifriction properties to nickel alloy EP975-based materials with CaF2 added.

Therefore, it is of theoretical and practical importance to establish the self-lubrication mechanism, distribution of CaF2 over the metal matrix, and its effect on the friction behavior of nickel alloy EP975-based materials in extreme operating conditions.

The objective of the presented paper is to study the formation of the film on the working surfaces of friction pair under the heavy-duty conditions (the speed of rotation 1200 rpm and the pressure up to 8.5 MPa).

1. EXPERIMENTAL RESULTS AND DISCUSSION

1.1. Experimental procedure

The subjects of study were new composite nickel alloy EP975-based materials with known solid lubricant CaF_2 added, mass %: powder nickel alloy EP975 + (4.0–8.0) CaF_2 [4, 6, 7].

Sample making. The starting powder nickel alloy EP 975 was produced by powder spraying method of melted metal by argon stream [4]. Dispersed metal drops were crystallized as spherical particles with dimensions from 50 to 250 µm. The powders of solid lubricant CaF_2 after drying at a temperature of 120°C for 1 h had a particle size of 100 µm. The chemical composition of the powder alloy EP975 is presented in Table 1 [4].

Table. 1. Chemical composition of powder nickel alloy EP975

Element	C	W	Cr	Mo	Ti	Al	Nb	Co	Ni
Quanti-ty, mass %	0.038-0.076	8.65-9.31	7.6-9.5	-3.04	1.71-2.09	4.75-5.13	1.71-2.59	9.5-11.4	basis

Source: Own elaboration

The samples were prepared with powder metallurgy methods. First of all, the initial components of the sprayed powders of nickel alloy EP975 and solid lubricant (CaF_2) were being mixed up for 4–6 hours. The method of the hot isostatic–pressing (HIP) was used to manufacture new bearing materials as the traditional technology of powder metallurgy does not ensure the minimum porosity [4]. The hot isostatic pressing (or gas–static pressing) was executed on the special press – gasostat. In this case the gasostat of «Quintus 16-206» (ASEA, Sweden) was used for the realization of the hot isostatic pressing process. Mixed powders were pressurized to set the vacuum density in the gasostat. The process of the hot isostatic pressing was carried out at 1210 ± 10^{o}C, for 4 hours, under the pressure of argon up to 140 MPa [4]. The blanks had the relative density of 99.9% after the hot isostatic–pressing process (HIP).

Then, the heat treatment (hardening and ageing) was carried out for the optimization of the morphology of dispersible phases in the structure of materials and for obtaining a necessary level of the properties [1, 4, 6].

Examination Techniques. The structure was studied using the metallographic and raster electron microscopes. Calcium fluoride in the matrix was identified with the use of the scanning electron microscopy (SEM). Moreover, the SEM images were used for the quantitative description of CaF_2 in the composite. The amount of CaF_2 was preliminarily assessed using the Micrometer software [7, 8].

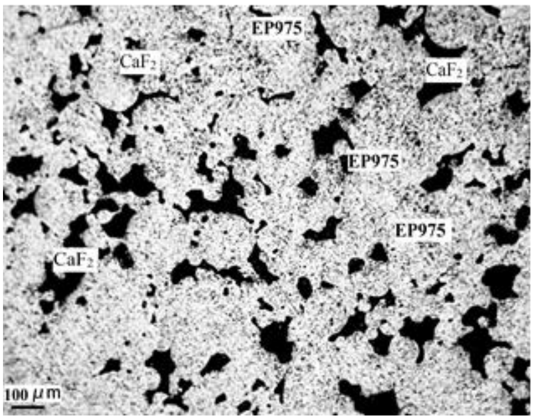
Friction films (secondary structures) being formed after tribological tests were studied with the usage of the micro-X-ray method and the scanning electron microscope. Tribological tests were performed on the VMT-1 friction testing machine (the rotation speeds of V = 1000 − 1200 rpm and the pressure of P = 5.0 MPa), the counterface was made of R18 tool steel (HRC = 53–55); shaft–pin friction pair [1, 4, 9]. The tool steel R18 is high speed steel. Such steel consists of mass %: C= 0.73–0.83; Si = 0.2–0.5; Mn = 0.2–0.5; up to 0.6 Ni; up to 1.0 Mo; W = 17.0–18.5; Cr = 3.8– 4.4; V= 1.0–1.4; up to 0.5 Co; up to 0.25 Cu; up to 0.03 S; up to 0.03 P [1, 10].

1.2. Results and discussion

There was produced heterogeneous composite material consisting of a metal matrix and inclusions of solid lubricant CaF_2 (Figure 1). In turn, the matrix was the nickel-based γ-solid solution doped with a significant number of nickel alloy EP975 elements. Moreover, there were particles of the intermetallic compounds and carbides (Figure 1b) [1, 3, 10]. It was established that CaF_2 is uniformly distributed over the entire matrix (Figure 1).

The particle sizes of CaF_2 and the dimensions of these regions (the average diameter d = 24.9 µm, the minimum diameter d_{min} = 17.6 µm, the maximum diameter d_{max} = 32.2 µm) were determined.

a)



b)

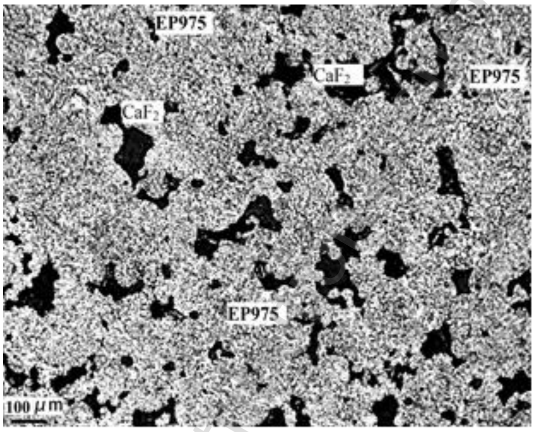


Fig. 1. The microstructure of the composite EP975 + 6.0% CaF_2
a) unetched sample; b) etched sample

Source: Own elaboration

The next step in the research was to carry out tribological tests. Fifteen benchmark evaluations of friction units were made. The visual inspection and measurement of surface roughness showed that the contact surfaces of bearings were not damaged, had high quality and were usable.

The dense friction films (secondary structures) were formed on the contact surfaces, both on the surface of examined materials and the surface of the counterface during tribological tests. These results are presented in the Figures 2–4. The distribution of the chemical elements in formed secondary structures was determined with the chemical analysis in points at selected areas of the friction films using the micro-X-ray spectroscopy method.

The data for spectrums 7−9 (Figures 3, 4) confirm the presence of all components from friction pair material:

- the chemical composition in the Spectrum 7 area, mass %: C-80.13; O-6.77; Na-0.37; Al-1.27; Si-2.63; S-1.19; Cl-1.45; K-0.35; Ca-1.44; Cr-0.91; Fe-2.33; Ni-0.54; Cu-0.63;
- the chemical composition in the Spectrum 8 area, mass %: C-30.46; O-2.40; F-1.67; Al-0.82; Ca-0.56; Ti-0.39; Cr-8.39; Mn-0.39; Fe-34.90; Ni-15.40; Mo-0.74; Er-2.06;
- the chemical composition in the Spectrum 9 area, mass %: C-49.73; O-21.13; Na-0.91; Al-0.52; Si-0.87; K-2.76; Ca-1.17; Ti-0.24; Cr-0.86; Fe-1.13; Ni-1.01; Cu-0.76; Mo-18.90.

a) b)

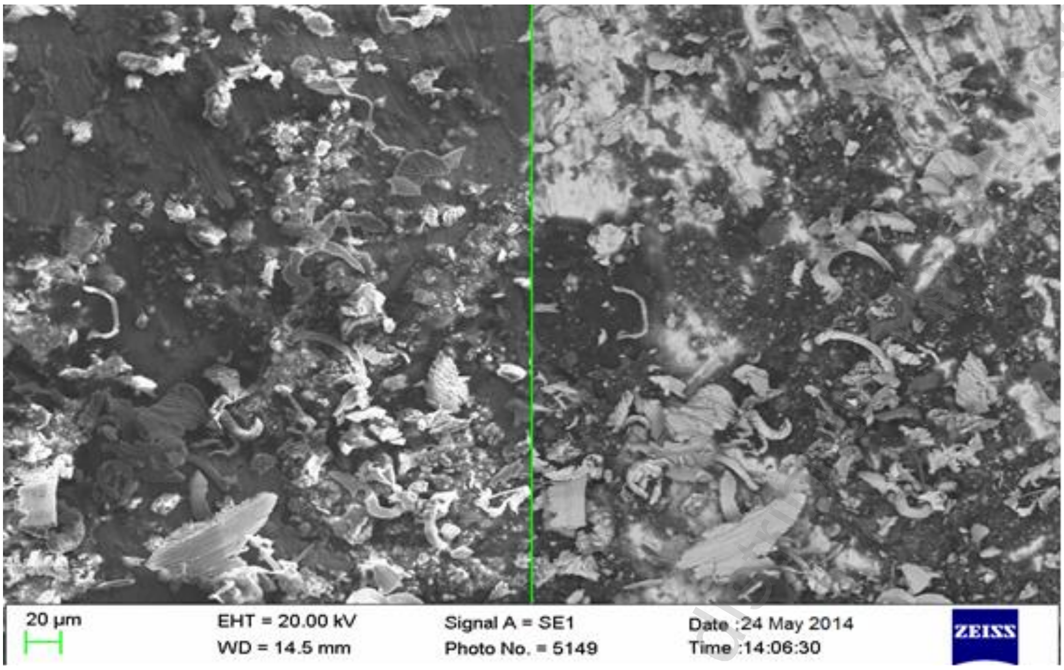


Fig. 2. The friction surface of material EP975 + 6% CaF_2 (the electron microscope)
a) the image in secondary electrons, b) the phase contrast image

Source: Own elaboration

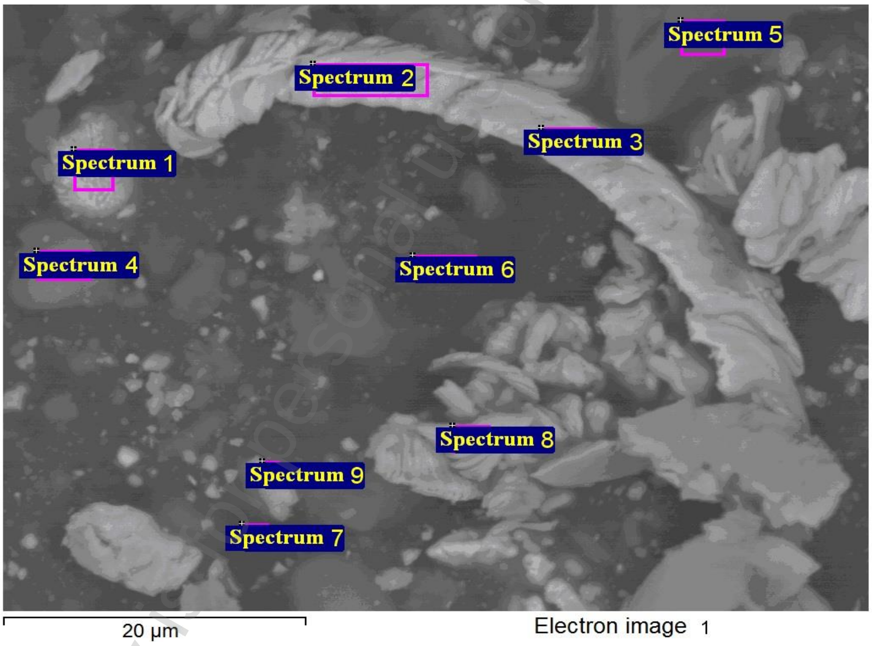


Fig. 3. Places of the examined friction surface of the material for micro-X-ray analysis

Source: Own elaboration

Figure 4 illustrates X-ray spectrums 7, 8 and 9 from the examined friction surface.

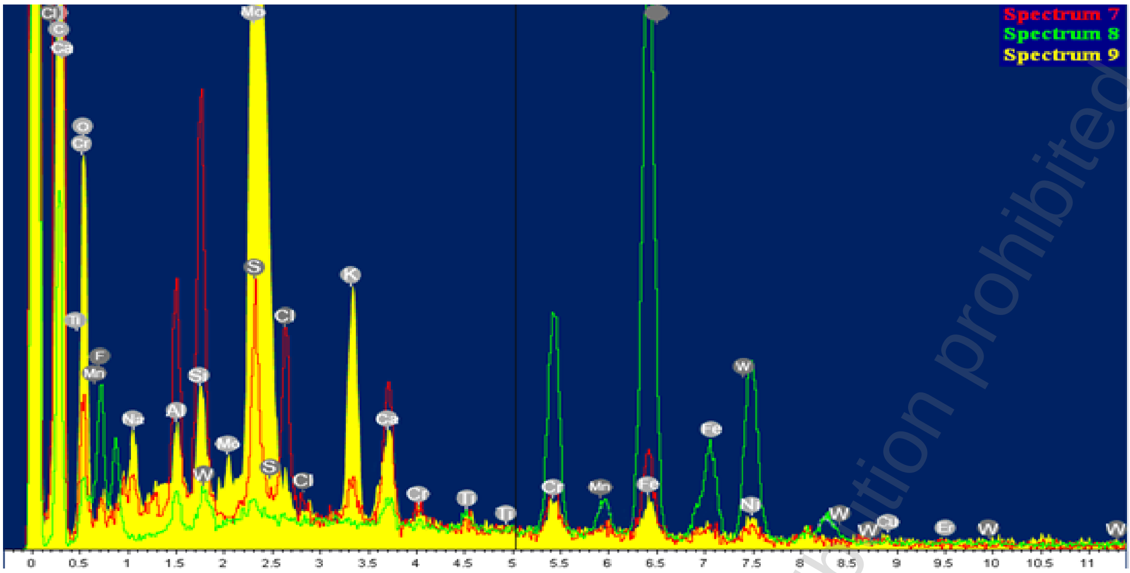


Fig. 4. X-ray spectrums 7, 8 and 9 from the examined friction surface

Source: Own elaboration

As it can be seen in the Figures 3, 4, the spectrums 7 and 9 from the dark areas of the friction film were enriched with C, O, F, Ni and Fe. It was probably connected with the different chemical reactions at heavy operating conditions between air oxygen O_2 and chemical elements from researched specimen and steel R18 counterface at high rotation speeds and loads in air. Such chemical processes resulted in the formation of friction films, the so-called secondary structures. Perhaps, these secondary structures consist of various phases, which include the chemical elements both examined materials and the steel counterface.

In the dark areas there is a high concentration of C, which is present in the steel R18 of the counterface (steel R18 contains about 1% C).

For similar reason, the presence of iron in dark areas of the friction surface could be explained. The concentration of Ca shows the participation of CaF_2 in the friction film formation as well.

The spectrum 8 from the white area has the high concentration of C, Fe, Cr, W, F and Ni.

It should be noted, that the secondary structures probably consist of complex phases from those chemical elements.

The scanning electron microscopy images of the friction surfaces after tribological tests confirm the presence of a thin dense layer (tribofilm) of the solid lubricant CaF_2 and chemical compounds of alloy elements (Figure 2).

The formation of tribofilms is probably due to the presence of the solid lubricant CaF_2 and a great number of alloy elements from the material examined, the steel counterface and air oxygen at the increased speeds and loads. These films provide a high level of antifriction properties of the friction pair (Table 2) [4].

Table. 2. Tribological Test Data

Composition, mass %	Friction co-efficient	Wear, µm/km (V=1200 rpm)	Limit load, MPa	Limit rota-tion speed, rpm
EP975+(4-8)% CaF_2	0.26-0.27	30-55	5	1300
Ni+(18-45%) MoB_2+ ZrB_2)+ 5%(CaF_2 or BaF_2) known sintered alloy [1, 4]	0.31	180	1.5	500-600

Source: Own elaboration

The examined material has a much lower coefficient of friction and a wear rate than those of known sintered material [1, 4] used in similar operating conditions, especially under the high rotation speed up to 1300 rpm (Table 2). This is attributed to the smaller quantity of alloy elements and the solid lubricant (5% CaF_2 or 5% BaF_2) in known composite material. As the result the formed friction films are ineffective to protect the contact surfaces against intensive wear under heavy operating conditions. In such conditions, the bearings have a dry friction contact with the shaft because the surfaces remain unprotected. The friction of the new materials EP975 + (4-8)% CaF_2 is accompanied by the formation of the continuous homogeneous tribofilm, which is clearly seen on the friction surfaces. It serves as a lubricant layer between the sample and the counterface, and improves antifriction properties.

CONCLUSIONS

In the work the mechanism of the friction films formation on the working surfaces of the new composite bearings based on the powder nickel alloy EP975 with the solid lubricant CaF_2 added was presented.

The authors analyzed the chemical composition of secondary structures (tribofilms), which were formed on contact surfaces of the new composite antifriction material and the counterface after tribological tests under heavy operating conditions.

Summarizing the results it has been observed that the formed friction films consist of the chemical elements both the examined composite material and the counterface of steel R18. It should be emphasized that the solid lubricant CaF_2 and the air oxygen are very important participants in the film formation process at increased rotation speeds and loads.

Formed tribofilms are determining factors for the trouble-free operation of bearings. They can minimize friction between bearings and shaft and ensure durability of the friction unit. It depends on the phase composition and phase combinations in the formed films.

During the film formation process new phases are formed, and they, together with a solid lubricant ensure reliable operation of the friction pair. Formed tribofilms protect the contact pair against intensive wear and stabilize the work of the friction unit under heavy operating conditions.

Next authors' steps will be directed to studying the nature of these phases and their quantitative ratio in friction films.

Also it is necessary to research friction films after tribological tests of materials under different loads, speeds of sliding, temperatures and then to identify phases that are presented in tribofilms and which can provide the best antifriction properties under hard operating conditions.

The solution of these problems will allow to forecast and control functional properties of the antifriction material in wide range of loads, speeds of rotation and temperatures depending on the type of civilian or military equipment.

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BIOGRAPHICAL NOTES

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