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PHYSICAL, MECHANICAL AND TRIBOTECHNICAL PROPERTIES OF NEW COMPOSITE BEARINGS FOR PRINTING EQUIPMENT

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In the article the research results of structure, physical, mechanical and tribotechnical properties formation of new bearings on the nickel alloy EP975–based composite materials with solid lubricant CaF_2 additions for high speed printing machines have been presented. The paper summarizes the formation of new materials' structure and properties after using new making hot isostatic–pressing technology. The efficiency of developed making technology with next heat treatment for new high speed bearings that is confirmed by the results of complex experimental and industrial tests was shown. Such technology is able to ensure the high and stable level of functional properties. The experimental results of the new composite bearing material properties in comparison with known nickel composite have been presented. It was shown that the dense friction films were formed on the contact surfaces during tribological tests. Friction films defend contact surfaces against intensive wear and stabilize the work of friction unit in printing machine. The full–scale industrial tests of EP975–CaF_2 bearings showed increase in wear resistance by a factor of 3.2–6.0 compared with known bearings in friction units of Heidelberg Speedmaster SM–102–FPL and KBA Rapida–105 high speed printing machines.

Keywords: *printing machines, composites, bearings, technology, properties, EP975– CaF2 alloy*

INTRODUCTION

The questions of friction materials use take a central place in general problem of increasing the machines and equipment quality. First of all, it concerns the bearing materials for friction joints, which fall under the influence of contact interaction different kinds. Tenure of employment and systematic work of machines are determined by resistance of friction pairs to intensive wear at different exploitation conditions [1−5]. Most heavy operating conditions are high loading (3.0–7.0 MPa), temperature 500–600°C or high speeds of rotation up to 1200 rpm [2−4].

Such effects are peculiar to the friction units of printing machines (high speed revolution machines), equipment of thermal and rolling shops, and also energy equipment.

Action of the increased loads, high speeds of rotation and influence of the oxidizing environment built a list of aggressive factors, which cause the intensive wear rate of the friction units in printing equipment [1−5].

Now a great variety of cast and composite bearing materials on the basis of ferrous and non–ferrous alloys have been developed and used in hard operating conditions [4, 5]. Intensive wear and high friction coefficient were connected with imperfection of manufacturing technologies. Moreover, a high cost unites these materials. And also cast materials which are used in extreme working conditions, such as cast iron, bronze, the non–ferrous alloys, are unable to combine different additives in a composition, which would form a strong matrix and contain antiscoring additives, such as sulfides, oxides, chalcogenides and fluorides [1−4].

The main task in the development of new composite bearing materials for printing machines is to increase the life of such equipment by, for example, applying lubricants to operate under conditions of high loads and rotation speeds on air.

Among antifrictional composite materials intended for severe operating conditions and incorporating solid lubricants, materials based on copper, iron, nickel, cobalt, and ceramics (Al_2O_3/TiC/CaF_2, Al_2O_3/ CaF_2/AgO/ CaF_2) are well–known [1–3, 6].

Powder composite materials based on iron or alloy powder steel are known to be used at speeds $V<400$ rpm and loads up to 3.0 MPa. At higher speeds ($V\geq600$ rpm) and loads up to 1.5–5.0 MPa, materials based on nickel, cobalt and copper are used [1–4]. This is due to their original physical properties [1].

Known powder and cast alloys on the basis of nickel (or cobalt) demonstrate unsatisfactory tribotechnical properties – high friction coefficient and wear at heavy–duty conditions of printing machines [1, 5].

Therefore as a basis for bearings materials composite nickel alloy – mark EP975 for heavy–duty conditions, such as increased loadings, air environment and rotation speeds 1000–1200 rpm was selected. This choice was caused the complete absence of known alloys' operability both cast and powder on the basis of copper, iron, nickel at such operation conditions. A big number of alloy elements in the nickel matrix (more than 35 mas.%) gives an alloy EP975 high physical and physical–mechanical properties [7, 8].

At high rotation speeds of printing machines any liquid lubricant is disabled because of liquid lubricant throwing out from friction zone by centrifugal forces. It is especially important to protect the friction surfaces from the increased wear and frictional seizure. Numerous studies show that using solid lubricants as a embedded component of materials improves the tribotechnical characteristics of plain bearings [1−5]. For instance, calcium fluoride CaF_2 as thermal and chemical stable substance is widely used as a solid lubricant to improve frictional contact, especially in heavy–duty conditions [7−9].

These arguments were a reason for complex researches, which were directed for studying tribotechnical properties of new bearings for loadings 3.0–5.0 MPa and rotation speeds 1000–1200 rpm on the basis of the scientifically grounded material science approach with the purpose to obtaining the possibility of prognostics and control of materials functional properties.

Moreover, it is of theoretical and practical importance to establish a structure and properties, distribution of CaF_2 over the metal matrix, and its effect on the friction behavior of nickel alloy EP975–based materials in extreme operating conditions of printing machines.

The objective of the present paper is to research bearing nickel alloy EP975–based composite materials with CaF_2 additions for heavy–duty conditions (high rotation speeds and loads) and to study the formation physical mechanical and tribotechnical properties of new bearings.

1. EXPERIMENTAL RESULTS AND DISCUSSION

1.1. Examination techniques

Structure was studied using a raster electron microscope; calcium fluoride in the matrix was identified using scanning electron microscopy (SEM). The physic mechanical properties of the samples were determined as well. Tribological tests were performed on a VMT–1 friction testing machine (rotation speeds V = 1000–1200 rpm and pressure P = 5.0 MPa), the counterface is made of R18 tool steel (HRC = 53–55); shaft–pin friction pair.

1.2. Results and discussion

Powders of the high–alloyed nickel alloy EP975 have been produced by powder spraying method of melted metal by argon stream. Dispersed metal drops are crystallized as spherical particles with dimensions from 10 to 750 μm. Usually optimum dimensions of fractions are in the range of 37–250 μm. In our case powders of alloy EP975 were of 50–250 μm. Chemical composition of materials has been presented in table 1 [7].

Table. 1. Chemical composition of materials based on alloy EP975

Components, mas.%									
C	W	Cr	Mo	Ti	Al	Nb	Co	Ni	CaF_2
0.038–0.076	8.65–9.31	7.6–9.5	2.28–3.04	1.71–2.09	4.75–5.13	1.71–2.59	9.5–11.4	basis	4.0–8.0

Source: Own elaboration

Thus, in our experiments we researched bearing compositions−EP975+(4.0–8.0)% CaF_2.

In the hard spherical powder particles of high–alloyed nickel alloy EP975 there is a real microingot that excludes the problem of liquation at once. This problem has been characterized for the cast nickel alloys obtained by traditional technology [1−5].

The method of hot isostatic–pressing (HIP) was used to manufacture new bearing materials because the traditional technology of powder metallurgy does not ensure minimum porosity.

Hot isostatic pressing (or gas–static pressing) is executed on the special presses – gasostat. Hot isostatic pressing is carried out in a liquid (hydrostatical) or gas (gasostatical) environment. A working environment is forced to a hermetic chamber by compressors and creates pressure of a few thousand bars. The isostatic pressing can combine high pressure with high temperature that allows one to combine the process of forming and sintering [1−4, 7].

First of all, initial components of the sprayed powders of nickel alloy ЕП975 and solid lubricant (CaF_2) are mixed up during 4–6 hours. And then mixed powders are loaded to the special steel containers. The filled containers are pressurized to set a vacuum density. The process of hot isostatic pressing was carried out at 1210±10 °C, during 4 hours, under pressure of argon up to 140 MPa.

Hot isostatic–pressing allows one to obtain enough dense materials, almost without pores. The blanks had a relative density of 99.9%.

a) b)

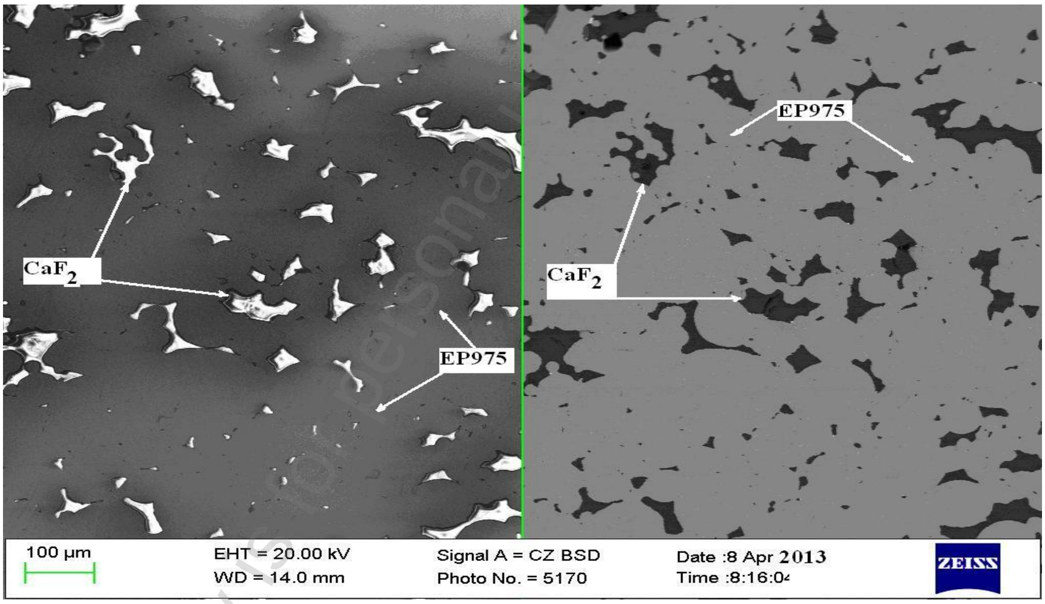

Fig. 1. Microstructure of material EP975 + 6% CaF_2
(raster electron microscope)
a) image in secondary electrons; b) phase contrast image

Source: Own elaboration

After the hot isostatic pressing heat treatment was carried out for optimization of dispersible phases' morphology in the structure of materials and for obtaining a necessary level of physical mechanical and antifriction properties.

Heat treatment includes hardening – heat to 1240ºC during 4 hours, cooling with a speed of 40 degrees/hour in a furnace of 1200ºC, then cooling on air.

After hardening, ageing was carried out at 910ºC during 16 hours on air.

HIP with the next heat treatment has ensured the formation of phases in a structure, which increase physical–mechanical properties of materials (combination of strength and plasticity) and improve operating reliability of a friction part.

Microstructure of the new composite bearing material EP975+8% CaF_2 after heat treatment is presented in Figure 1.

The structure of material is heterogeneous. There is a metallic matrix with inclusions of solid lubricant CaF_2. Solid lubricant CaF_2 particles were uniformly arranged [8, 9]. Presence of a big number of alloy elements in a nickel matrix gives new bearing materials a high level of physical–mechanical and tribotechnical properties. Tribotechnical and physical–mechanical properties of new materials have been presented Tables 2–4 in a comparison with known Ni–powder material [1], which is applied under analogue conditions.

Table 2. Strength properties of materials at room temperature

No.	Composition, mas.%	Ultimate stress at tension, σ_t, MPa	Yield strength, $\sigma_{0,2}$, MPa	Extension strain, δ,%	Contraction, ψ,%
1	EP975 (cast)	1200	800	14	14
2	EP975 (powder, made by gas–static pressing technology)	1400	1120	12	15
3	EP975+6CaF_2 (powder, made by gas–static pressing technology)	1100	900	10	12

Source: Own elaboration

Table 3. Physical mechanical properties of new bearings based on alloys EP975

No.	Materials content, mas.%	Bending strength, σ_s, MPa	Impact resistance KC, J/m^2	Hardness, HB, MPa
1	EP975+ 4% CaF_2	540–610	600–650	2550–2600

No.	Materials content, mas.%	Bending strength, σ_s, MPa	Impact resistance KC, J/m^2	Hardness, HB, MPa
2	EP975+ 6% CaF_2	550–600	550–600	2500 –2600
3	EP975+ 8% CaF_2	520–570	520–550	2540–2600
4	Ni+(18–45%) MoB_2+ ZrB_2)+ 5%(CaF_2 or BaF_2) sintered alloy[1]	240–300	350–520	850–950

Source: Own elaboration

Table. 4. Antifriction properties of materials based on alloy EP975

No.	Composition, mas.%	Friction coefficient	Wear, μ/km (V=1200 rpm)	Limit load, MPa	Limit rotation speed, rpm
1	EP975+4% CaF_2	0.27	50	5	1300
2	EP975+6% CaF_2	0.26	30	5	1300
3	EP975+8% CaF_2	0.27	55	5	1300
4	Ni+(18–45%) MoB_2+ ZrB_2)+ 5%(CaF_2 or BaF_2) sintered alloy [1]	0.31	180	1.5	500–600

Source: Own elaboration

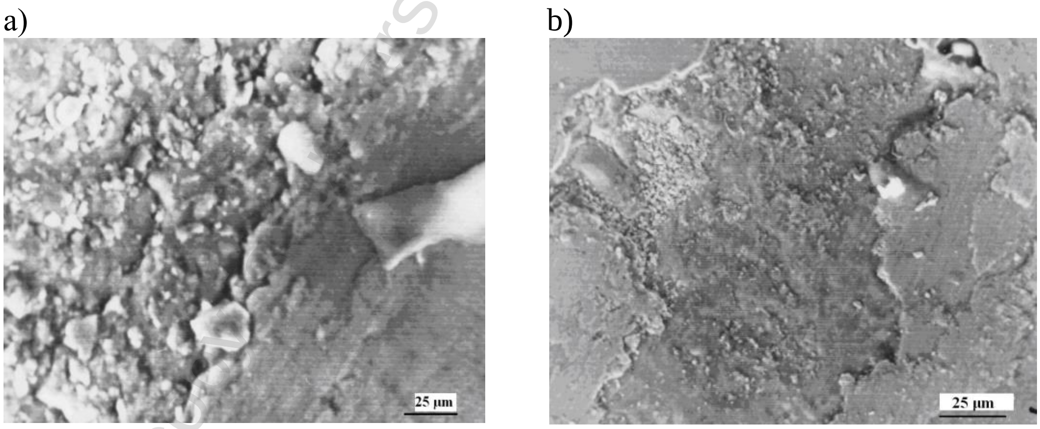

Fig. 2. Images of friction surfaces
a) material EP975+ 6% CaF_2; b) counterface of steel R18

Source: Own elaboration

The analysis of information in Tables 2–4 evidently show that the new high–speed bearings materials on the basis of alloy EP975 with the addition of CaF_2 have higher properties in comparison with the known material [1] and they are able to operate at higher rotation speeds and loads.

During tribological tests the dense friction films were formed on the contact surfaces, both on the surface of examined materials and counterface (Figure 2).

As it is shown in Figure 2, all friction surfaces are covered by dense antiscoring films, the so–called secondary structures. They consist of the chemical elements of bearing and counterface and solid lubricant CaF_2. During the friction process the different chemical reactions take place between O_2 of air and elements of researched specimen and steel R18 counterface at high rotation speeds and loads. Such chemical processes result in the formation of friction films, which protect contact pair against intensive wear and stabilize the work of friction unit in printing machine.

CONCLUSION

We have developed new effective bearing materials based on Ni alloy EP975–CaF_2 system with high physical mechanical and tribotechnical properties that perform well in more severe conditions than the known sintered alloy.

The new materials have an advantageous level of tribotechnical characteristics due to the tribofilms formed on contact surfaces by dragging of calcium fluoride to cover the entire friction area.

The full–scale industrial tests of EP975–CaF_2 bearings showed increase in wear resistance by a factor of 3.2–6.0 compared with known bearings in friction units of Heidelberg Speedmaster SM–102–FPL and KBA Rapida–105 high speed printing machines.

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FIZYCZNE, MECHANICZNE I TRIBOLOGICZNE WŁAŚCIWOŚCI NOWYCH KOMPOZYTOWYCH ŁOŻYSK DO SPRZĘTU POLIGRAFICZNEGO

Streszczenie

W artykule przedstawiono wyniki badań struktury, fizycznych właściwości mechanicznych i tribologicznych nowych łożysk wykonanych ze stopu niklu EP975 wypełnionych smarem CaF2 przeznaczonych do szybkich maszyn drukarskich. Artykuł podsumowuje powstawanie struktury i właściwości nowych materiałów przy wykorzystaniu technologii izostatycznej tłoczenia na gorąco. Wykazano skuteczność technologii obróbki cieplnej nowych łożysk wysokiej prędkości, która została potwierdzone przez wyniki kompleksowych badań doświadczalnych i przemysłowych. Technologia ta jest w stanie zapewnić wysoki poziom i stabilność właściwości funkcjonalnych.

Przedstawiono wyniki porównawcze właściwości nowego materiału kompozytowego przeznaczonego na łożyska w porównaniu z kompozytem niklu.

Ponadto przedstawiono tarcie na powierzchniach stykowych podczas testów tribologicznych. Film smarowy chroni powierzchnie styku przed intensywnym zużyciem oraz umożliwia ustabilizowanie pracy jednostki tarcia w maszynie drukarskiej.

Pełna skala testów przemysłowych łożysk EP975 – CaF2 wykazała zwiększoną odporność na zużycie współczynnik 3,2 – 6,0 w porównaniu ze znanymi łożyskami w jednostkach tarcia Heidelberg Speedmaster SM –102– FPL i KBA Rapida – 105 szybkich maszyn drukarskich .

Słowa kluczowe: *maszyny drukarskie, kompozyty, łożyska, stop EP975–CaF2*

BIOGRAPHICAL NOTE

Professor, Doctor of engineering sciences, Tetiana ROIK – a member of special–purpose scientific councils for the defence of theses for a Doctor's degree and Ph.D. theses in the field of “Machines and processes of printing industry”, “Material science” in the Academy of Science of Ukraine and in the National Technical University of Ukraine "Kyiv Polytechnic Institute". Her main field of scientific interest: development of new composite antifriction materials, material science, machine–building in printing industry. Professional achievements: an author of 8 monographs, 45 patents, more than 250 articles, a member of program and organizational committees of the international scientific technical conference “Machine–building and technosphere of XXI century”.

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Dr Mukafat ASKEROV – his main field of scientific interest: material science, machine–building in printing industry. An author of 2 monographs, 2 patents and more than 40 articles.