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DEVELOPMENT OF TECHNOLOGY FOR MANUFACTURING EFFICIENT COMPOSITE BEARING MATERIALS FOR HIGH-SPEED PRINTING MACHINES

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INTRODUCTION

Development of modern technical equipment in machine-building industry has given a great importance for problem of increase the machines and mechanisms durability. There is no more important problem among tasks of new technical objects creation. Extension of useful use period for machines, mechanisms and equipment even in a small measure there is equivalent an introduction of new production capacities[1].

Questions of the technical evolution were continually connected with the problems of materials science development. The questions of new materials' using take a central place in the general problem of machines and equipment quality increase including materials of contact pairs such as antifriction (bearing) materials.

These include bearing materials that operate under light and moderate operating conditions (low loads, speeds, temperatures up to 200 ºC).

But this is especially important for friction units that operate under extreme conditions such as high loads, aggressive environment, elevated and high temperatures 200−800 ºC, and high rotational speeds up to 10000 rpm. It is a well-known fact that 80% of machine and mechanism failures occur due to the friction units' destruction[2].

Such phenomena are inherent for the equipment of metallurgical industry, oxygen-converter equipments, waste-smelting aggregates, heating equipment, aggregates and equipment of power engineering industry and high-speed printing equipment.

The action of high rotational speeds, specific loads and oxidizing atmosphere is an incomplete list of aggressive factors that accompany the operation of rotary printing machines' parts and cause intense wear of friction units.

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[1] Tribology : handbook / ed. M. J. Neale. Elsevier Ltd. Butterworth-Heinemann, 1996. 640 p. ISBN 978-0-7506-1198-5, eBook ISBN: 9780080519661, URL: http://doi.org/10.1016/B978-0-7506-1198-5.X5000-0.

[2] Ibidem.

Large assortment of the cast and powder antifriction materials based on cast iron, copper and nickel are developed and applied for the listed too heavy working conditions[3, 4, 5]. Intensive wear and high friction coefficient of cast parts have been connected with imperfection of manufacturing technologies.

Moreover cast antifriction materials that use in extreme working conditions, such as, cast iron, bronze, the non-ferrous alloys cannot combine different additives in their composition that can form a strong matrix and contain antiscoring additives, such as sulfides, oxides, chalcogenides and fluorides.

1. Preconditions for the problem and problem statement

The high rotational speeds are inherent in the operation of printing equipment, where many units operate under the influence of not only high speeds of 5000−10000 rpm, but also increased loads in the oxidizing environment (atmospheric air). This fully applies to friction units operating in such conditions.

The rotary machines have antifriction parts (bearings) that are installed in the friction units of the offset printing cylinders in the printing equipment such as Heidelberg Speedmaster SM-102-FPL and KBA Rapida-105, Germany. Such bearings have a life cycle 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 such antifriction parts are not able to ensure the friction unit's stable operation.

High rotational speeds are accompanied by an increase in temperature up to 500°C on the contact surfaces.

Such temperatures and an oxidizing environment have led to the use of nickel alloys, in particular, for the manufacture of antifriction parts.

Among nickel alloys, the cast high-alloy heat-resistant nickel alloys and others are used for such conditions.

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[3] Tribology. Handbook. Op. cit. 525 p.

[4] Peter R., Childs N. Pneumatics and hydraulics. Mechanical Design Engineering: handbook. Elsevier Ltd., 2019. 874 p. URL: http://doi.org/10.1016/B978-0-08-102367-9.00005-6.

[5] Powder Metallurgy: ASM Handbook / ed. Prasan K. Samal and Joseph W. Newkirk. The Materials International Society. New York. USA. Volume 7, 2015. 907p., ISBN: 978-1-62708-089-3. URL: http://www.asminternational.org/search/-/journal_content/56/10192/23412238/PUBLICATION#tabs.

However, the use of cast nickel alloys as antifriction materials is ineffective due to their low wear resistance.

In this case liquid lubricants become inoperative due to high operating speeds when liquid oil is removed from the friction zone by centrifugal forces.

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[6, 7, 8].

Bearing composite materials based on iron, powder alloyed steel or some non-ferrous alloys are known to be used at speeds $V<1000$ rpm and loads up to 3.0 MPa. Composite materials based on nickel, cobalt and copper are usually used at higher speeds ($V\geq1000$ rpm) and loads up to 1.5−5.0 MPa[9].

As known, antifriction composites for a work at high temperatures (up to 700−800°C) are also used for work at high friction speeds[10].

The authors have developed efficient composites based on powder alloyed nickel alloys EP975, EI929. These antifriction composite materials are well proven when working in high-temperature friction units[11, 12].

However, the questions of these nickel composites behavior at high rotational speeds with the simultaneous action of increased loads still remain unexplored.

Therefore EP975 powder nickel alloy was selected as a basis for high-speed bearings composites.

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[6] Tribology. Handbook. Op. cit. 525 p.

[7] Peter R., Childs N. Op. cit. P. 849−874.

[8] Powder Metallurgy. Op. cit. 907 p.

[9] Tribology. Handbook. Op. cit. 525 p.

[10] Powder Metallurgy. Op. cit. 907 p.

[11] Jamroziak K., Roik T. Structure and Properties of the New Antifriction Composite Materials for High-Temperature Friction Units. In: Abdel Wahab M. (eds) Proceedings of the 7th International Conference on Fracture Fatigue and Wear. FFW-2018 (Ghent, Belgium, 9–10 July 2018). Ghent, 2018. Book ID: 459769_1_En. Chapter No 57. *Lecture Notes in Mechanical Engineering*. Springer. Singapore, 2019. P. 628–637. URL: http://doi.org/10.1007/978-981-13-0411-8_57.

[12] Kurzawa A., Roik T., Gavrysh O., Vitsiuk Iu., et. al. Friction mechanism features of the nickel-based composite antifriction materials at high temperatures. *Coatings*. MDPI. Basel, Switzerland. 2020. Vol. 10(5), No 454. P. 1–22. URL: http://doi.org/10.3390/coatings10050454, http://www.mdpi.com/2079-6412/10/5/454.

The main task in the development of new composite bearing materials for high-speed printing machines is to increase the life of such equipment by, for example, applying solid lubricants to operate under conditions of increased loads, temperatures or rotational speeds. Any liquid lubricant is inoperative at high rotational speeds due to the liquid lubricant ejection from the friction zone under the action of centrifugal forces. Therefore it is especially important to protect the friction surfaces from the increased wear and frictional seizure. Numerous studies show using solid lubricants as a component of antifriction materials improves the plain bearings' tribological characteristics[13, 14, 15]. For example, calcium fluoride (CaF_2) as thermal and chemical stable substance is widely used as a solid lubricant to improve frictional contact, especially in severe conditions[16, 17].

These arguments were a reason for complex researches, which are directed to development of the new nickel bearing composites for a work at rotational speeds up to 10000 rpm and increased loads on the basis of the scientifically grounded material science approach to obtain the possibility of prognostics and control of bearings' functional properties.

Moreover, this is a theoretical and practical importance to establish an effect of making technology on structure and properties, distribution of CaF_2 solid lubricant over the metal matrix, and its effect on the friction behavior of bearing composites based on EP975 powder nickel alloy in severe operating conditions such as high rotational speeds and increased loads.

The objective of the article is to study the structure and properties of new bearing composite materials based on the EP975 nickel alloy with the

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[13] Jianxin D., Tongkun C. Self-lubricating mechanisms via the in situ formed tribofilm of sintered ceramics with CaF_2 additions when sliding against hardened steel. *International Journal of Refractory Metals and Hard Materials*. Elsevier Ltd. 2007. Vol. 25, Issue 7. P. 189–197. URL: http://doi.org/10.1016/j.ijrmhm.2006.04.010.

[14] Sharma S. M., Anand A. Friction and wear behavior of Fe-Cu-C based self-lubricating material with CaF_2 as solid lubricant. *Industrial Lubrication and Tribology*. 2017. Vol. 69, P. 715–722. URL: http://doi.org/10.1108/ILT-04-2016-0085.

[15] Kotkowiak M., Piasecki A., Kulka M. The influence of solid lubricant on tribological properties of sintered Ni–20%CaF_2 composite material. *Ceramics International*. 2019. Vol. 45, P. 17103–17113. URL: http://doi.org/10.1016/j.ceramint.2019.-05.262.

[16] Jamroziak K., Roik T. Op. cit. P. 628−637.

[17] Friction mechanism features of the nickel-based composite antifriction materials at high temperatures, Vol. 10(5), No 454, Op. cit. P. 1−22.

CaF_2 solid lubricant additions, depending on the technological modes of manufacture and their effect on the friction pair's self-lubricating mechanism in units of printing machines.

2. Experimental procedure

2.1. Examination Techniques

Structure was studied using both optical and raster electron microscope; calcium fluoride in the matrix was identified using scanning electron microscopy (SEM). Phase composition was determined by X-ray diffraction analysis using the JDX-MAPI microdiffractometer (Japan) and JAMP-10SX microprobe (Japan).

Mechanical tests were performed using the standard methods.

Tribological tests were performed on a VMT-1 friction testing machine (rotational speed up to 10000 rpm and load P =3.5 MPa in air), the counterface is made of cast stainless high-alloy chrome-nickel steel EI961Sh. The counterface material EI961Sh steel corresponded to the material of the real shafts in the high-speed friction units. The EI961Sh cast steel has the following chemical composition, wt. %: 0.10–0.16 carbon, to 0.6 silicon, to 0.6 manganese, 10.5–12.0 chromium, 1.50–1.80 nickel, 1.60–2.00 tungsten, 0.35–0.50 molybdenum, 0.18–0.30 vanadium, to 0.025 sulfur, to 0.030 phosphorus, and iron as the base.

2.2. Preparatory procedures

The study focused on new antifriction composite materials based on powder nickel alloy EP975. This powder alloy EP975 was chosen as the basis for new materials. Powders of the high-alloyed nickel alloy EP975 have been produced by spraying method of molten metal by argon stream. This industrial spray method of molten metal is usually used for obtaining similar nickel powders[18]. Dispersed metal drops are crystallized as spherical particles of dimensions from 10 to 750 μm[19]. In our research alloy EP975 powders had dimensions of 40−200 μm (Fig. 1).

Chemical composition of the studied materials has been presented in Table 1. The spherical powder particles of high-alloyed nickel alloy EP975 are the microingots which exclude a problem of liquation at once[20].

[18] Ibidem. Jamroziak K., Roik T. Op. cit. P. 628−637.
[19] Ibidem.
[20] Ibidem. Jamroziak K., Roik T. Op. cit. P. 628−637.

Alloy elements' liquation is a big negative problem for the cast nickel alloys obtained by traditional technology.

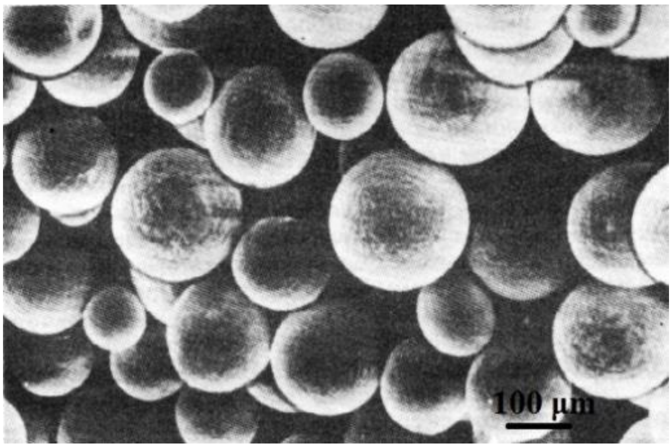


Fig. 1. Spherical particles of EP975 nickel alloy produced by spray method

Table 1

Chemical composition of the materials based on alloy EP975

Components, wt.%									
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

As it can be seen from Table 1, a solid lubricant powder of calcium fluoride was added to the original mixture according to the arguments described above.

2.3. Preparation of powder charge and composites fabrication

The traditional technology of powder metallurgy, such as pressing and sintering the initial mixture (EP975 + CaF_2) is not suitable in our case, because the minimum porosity is unacceptable.

That is why the method of hot isostatic-pressing (HIP) was used for creation of new materials. Hot isostatic pressing (or gas-static pressing) was executed using the special press, so called gasostat. Hot isostatic pressing is carried out in a liquid (hydrostatic) or gas (gas-static) environment.

A working environment creates a pressure by compressor in a range of the few thousands atmospheres inside hermetic chamber with initial powder mixture.

The isostatic pressing process combines high pressure with a high temperature that allows uniting the processes of forming and sintering in one technological process.

Thus, first of all the initial components of the EP975 nickel alloy sprayed powders and CaF_2 solid lubricant were mixed up during 4 hours.

Then the powder mixture was loaded into special steel containers. Here, a plasticizer was added to improve the compaction of the powder mixture. The filled containers are subjected to simultaneous action of pressure and temperature. First, the temperature was raised to 300 °C to burn out the plasticizer, after which the temperature and pressure were increased for the main hot isostatic pressing process.

The process of hot isostatic pressing was carried out at 1220±10 °C, during 4 hours, under argon pressure 140−160 MPa. HIP-process allows obtaining enough dense composites, almost without pores.

The briquettes had a relative density 99.8−99.9% after HIP technology.

After hot isostatic pressing, heat treatment was carried out to optimize the morphology of dispersed strengthening phases in the structure of materials and to obtain the antifriction properties required level.

Heat treatment consisted of the following stages: hardening, including heating to 1240–1260 °C, holding for 4 hours at a heating temperature, cooling at a rate of 40 deg/h to 1200 °C in a furnace, and then cooling in air.

The aging process was carried out at 910 °C for 16–17 hours in air after hardening.

The general scheme of the technological process for the manufacture of bearing composites based on powdered nickel alloy EP975 with the CaF_2 solid lubricant additions has been presented on Fig. 2.

As it can be seen on Fig. 2, in the general technological process, there are also additional technological operations in addition to the main operations.

For example, the heat treatment of the composites is followed by the mechanical processing of the obtained workpieces from the nickel composite.

Mechanical processing is necessary for the manufacture of finished parts from the resulting blanks after hot isostatic pressing.

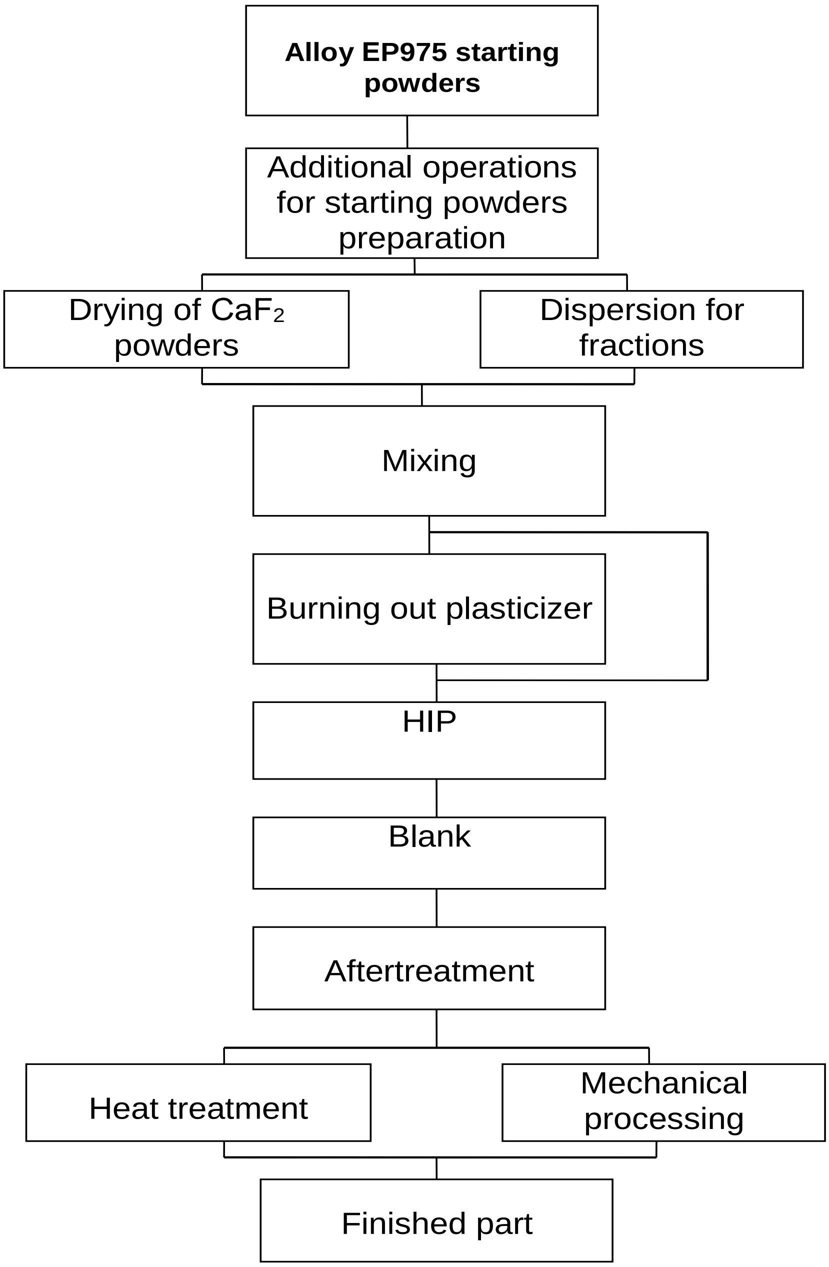
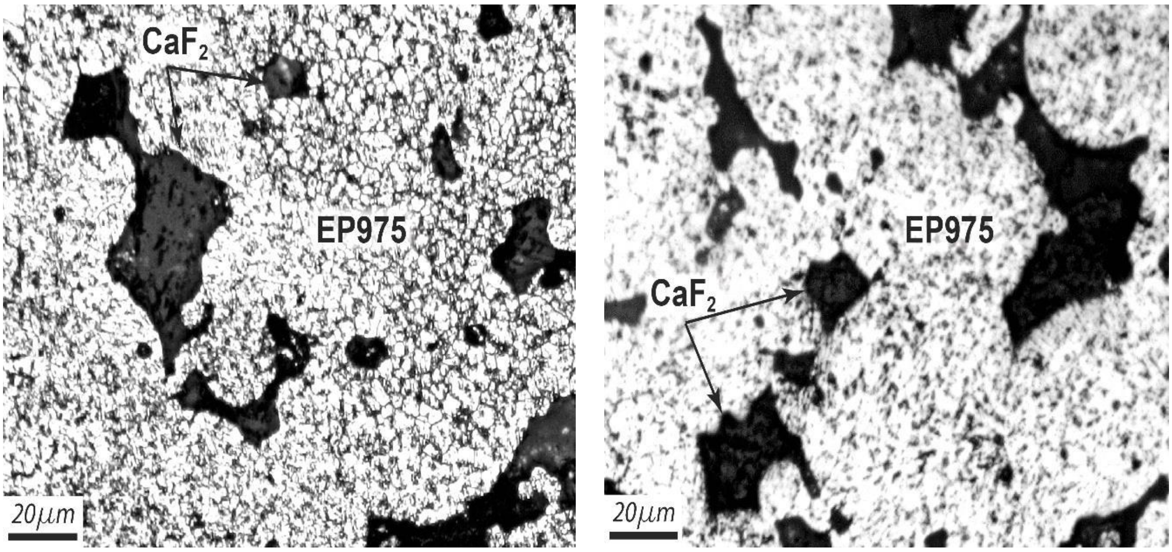


Fig. 2. Technological scheme of the composite bearing material EP975 + 6%CaF_2 manufacture

3. Results and discussion

The technological operations of the HIP with subsequent aging (Fig. 2) contribute to the formation of strengthening phases in the structure, which increase the mechanical and tribological properties of the material. This ensures the antifriction parts reliability. The microstructure of the EP975 + 8% CaF_2 composite material after heat treatment has been shown in Fig. 3.



a **b**

Fig. 3. Microstructure of material EP975 + 8%CaF_2 after heat treatment:

a−etched thin section; b− non-etched thin section; optical images

The microstructure of material is heterogeneous (Fig. 3). The structure of the material represents a γ−solid solution of alloy elements in nickel matrix with inclusions of calcium fluoride (CaF_2). Solid lubricant CaF_2 particles are uniformly distributed in the alloyed nickel matrix (Fig. 4).

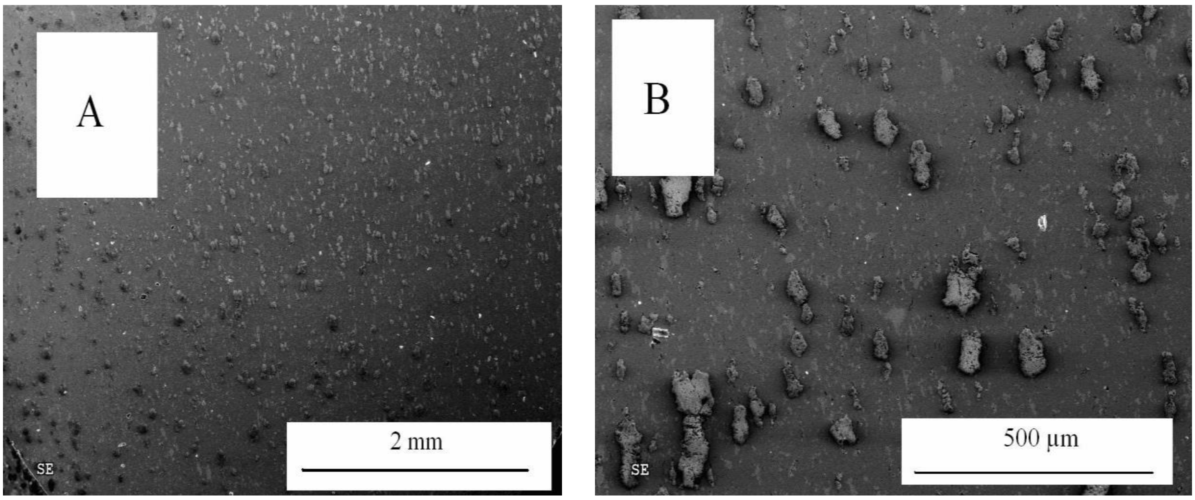


Fig. 4. SEM images of CaF_2 solid lubricant distribution:

a − CaF_2 in metal matrix; b − CaF_2 solid lubricant particle shape

Such CaF_2 solid lubricant uniform distribution (Fig. 4) confirms the correctness of the developed technology.

Nickel γ-solid solution is strengthened with the intermetallics, revealed by X-ray diffraction (Fig. 5).

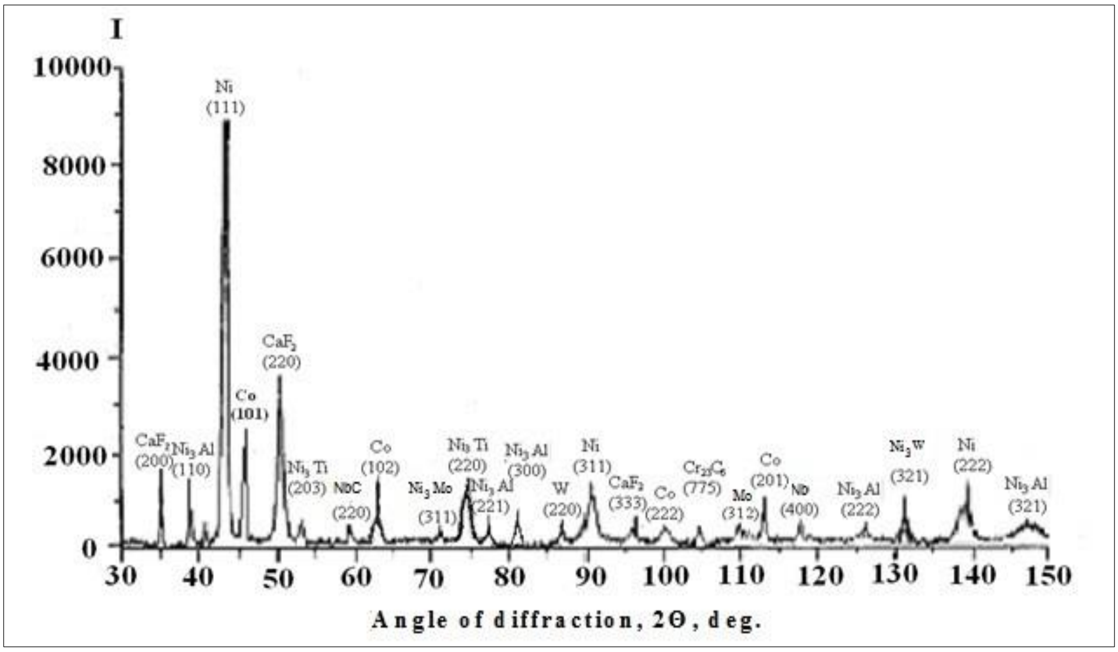


Fig. 5. Diffractogram of the material, wt.%: EP975+ 6CaF$_2$

Aging of a solid solution leads to its decomposition in several stages. Initially, the redistribution of Al and Ti atoms occurs in the middle of a solid solution. This causes the local enrichment by these elements.

Then the second phase appears in places where the Al and Ti atoms concentration were increased. Two phases with the same face-centered lattice were detected radiographically, but they are slightly differed from one another (lattice parameters − 0.358 and 0.360 nm).

The phase that is depleted by aluminum and titanium is the γ-phase, and enriched phase with these elements is the γ'-phase.

The close lattice parameters of the γ- and γ'-phases causes them to maintain a coherent bond at high temperatures[21 22].

Titanium and aluminum are the main reinforcing elements in the studied materials[23, 24].

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[21] Гуляев А. П. Металловедение : учебник для вузов. Москва : Металлургия. 1986, 544 с. URL: http://www.twirpx.com/file/2483266/.

[22] Смитлз К. Дж. Металлы: справочник / сокр. пер. с англ. Л. И. Гриппас [и др.]; под ред. С. Г. Глазунова. Москва : Металлургия. 1980, 447 с. URL: http://www.twirpx.com/file/1107200/.

[23] Ibidem. Гуляев А. П. Металловедение.

[24] Ibidem. Смитлз К. Дж. Металлы.

They form the intermetallic phases of Ni_3Ti and Ni_3Al, which were detected by X-ray diffraction analysis using the JDX-MAPI micro-diffractometer (Japan) (Fig. 5).

Aging of materials EP975 (4−8)% CaF_2 was observed due to the presence not only titanium and aluminum in their matrix, but also molybdenum and tungsten. The peaks of Mo and W elements were also found in solid solution using the JAMP-10SX microprobe (Japan). Mo and W contribute to the increase of mechanical properties due to the phases Ni_3Mo and Ni_3W formation.

The presence of cobalt has a positive effect on the composite material heat resistance. Cobalt partially replaces nickel in the Ni_3Al and Ni_3Ti phases (phase $(Ni, Co)_3Ti$ and $(Ni, Co)_3Al$) and positively influences for material's plasticity especially in a presence of Ti, W, Mo, Al, Cr[25, 26].

Aluminum and titanium, and to a lesser extent tungsten, molybdenum and niobium, contribute to the strengthening of the Ni-alloy[27, 28] due to the hardening phases formation.

The carbide phases are the numeral compounds of the $Cr_{23}C_6$, NbC, and TiC in the metal matrix. These carbides strengthen the metal matrix.

Ti, Al, Mo, W, Cr elements provide the increase strength, and besides Nb grinds down grains in composite's structure strongly[29, 30].

Thus, as a result of hot isostatic pressing and heat treatment, the matrix structure of the studied composites based on the powder alloy EP975 is an alloyed solid solution with a high concentration inhomogeneity with dispersed intermetallics and carbides large number.

The mechanical properties of the new composites have been presented in Table 2 compared to the EP975 standard cast alloy and EP975 powder material made by HIP technology.

For this, samples were made from a standard cast EP975 alloy, a composite material based on an EP975 alloy obtained by the HIP technology, and the investigated bearing composite, also manufactured using the HIP technology.

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[25] Ibidem. Гуляев А. П. Металловедение. Op. cit. 544 с.
[26] Ibidem. Смитлз К.Дж. Металлы. Op. cit. 544 с.
[27] Ibidem. Гуляев А. П. Металловедение. Op. cit. 544 с.
[28] Ibidem. Смитлз К.Дж. Металлы. Op. cit. 544 с.
[29] Ibidem. Гуляев А. П. *Металловедение*. Op. cit. 544 с.
[30] Ibidem. Смитлз К.Дж. Металлы. Op. cit. 544 с.

Table 2

Mechanical properties of materials

№	Composition, wt.%	Tensile strength, σ_t, MPa	Yield strength, $\sigma_{0,2}$, MPa	Relative elongation, δ,%	Relative constriction, ψ,%
1	EP975 (cast alloy)	1200	800	14	14
2	EP975 (powder, made by HIP technology)	1400	1120	12	15
3	EP975+6CaF_2 (powder, made by HIP technology)	1100	900	10	12

The Table 2 shows the studied composite № 3 containing CaF_2 is practically not inferior in terms of mechanical properties to the EP 975 cast alloy and the EP975 powder material obtained by the HIP technology. This indicates the efficiency of the HIP technology followed by heat treatment to obtain composites with high mechanical characteristics.

The series of tribological tests were carried out at various rotational speeds to determine the rational speed ranges for the new composites. During the experiments, 10 samples were tested at different speeds. The tribological properties of the new composites have been presented in Tables 3 compared to the known nickel powder materials[31] that are used under similar conditions.

Table 3 shows that the new nickel-based composite materials demonstrate higher antifriction properties during friction without a liquid lubricant at high rotational speeds and increased loads than the known Ni-based composite material, which showed unsatisfactory tribological characteristics.

This is due to the fact that the known material was manufactured using the traditional technology of powder metallurgy by pressing and sintering.

Therefore, the known material[32] has a high porosity of 12−14% and unsatisfactory mechanical properties, which leads to a decrease in the antifriction properties.

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[31] Киричок П. О., Роїк Т. А., Гавриш А. П., Шевчук А. В. та ін. Новітні композиційні матеріали деталей тертя поліграфічних машин : монографія. К. : НТУУ КПІ. 2015, 428 с. ISBN 978-066-622-692-4. URL: http://scholar.google.com.ua/scholar?hl=uk&as_sdt=0,5&cluster=6673344392320605039.

[32] Ibidem.

Table 3

Tribological properties of the studied composites

Composition, wt.%	Friction coefficient at 5000/8000 rpm	Wear rate, μ/km, at 5000/8000 rpm	Limit load, MPa	Limit rotational speed, rpm
EP975+4% CaF_2	0.271/0,274	58/65	3.5	10000
EP975+6% CaF_2	0.263/0,267	54/62	3.5	10000
EP975+8% CaF_2	0.269/0,271	56/67	3.5	10000
Ni+(18-45%) MoB_2+ZrB_2) + 5%(CaF_2 or BaF_2)[33]	0.355/0,367	380/420	1,5	1000–1200

Therefore, the known material[34] has a high porosity of 12−14% and unsatisfactory mechanical properties, which leads to a decrease in the antifriction properties.

At the same time, properties of the examined composite obtained by hot isostatic pressing technology differ from those of the known composite material.

The developed composite material based on powder Ni-alloy EP975 almost hasn't porosity and demonstrates higher properties.

During tribological tests the dense antifriction films were formed on the contact surfaces, both on the surface of examined materials and counterface (Fig. 6).

These films, probably, consist of alloying elements oxides and CaF_2 solid lubricant.

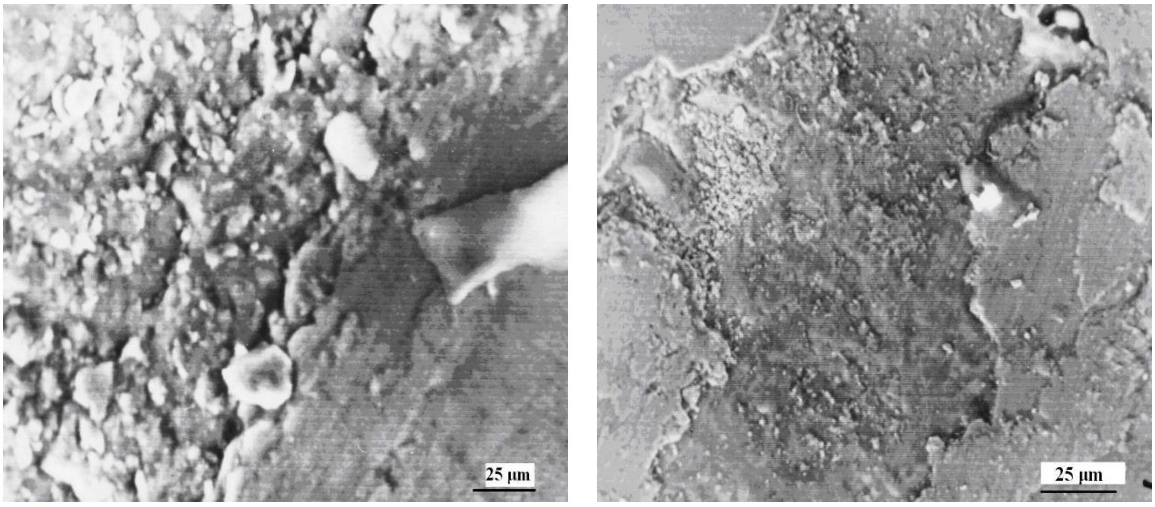
The smoothed microgeometry of the surface relief (Ra = 0.20−0.16 μm) stabilizes the contact pair operation and minimizes friction coefficient and wear rate.

During friction process the different chemical reactions take place between O_2 of air and chemical elements of researched composite and counterface of steel EI961Sh at high rotational speeds and increased loads.

Such chemical processes lead to the formation of antifriction films that protect the contact pair from intense wear and stabilize the friction unit operation.

[33] Ibidem. Киричок П. О., Роїк Т. А., Гавриш А. П., Шевчук А. В. та ін.
[34] Ibidem.

The anti-seize thin films are formed on the contacting surfaces, which are carriers of high antifriction properties. Such films are the third participant in the friction process. The self-lubrication mode is realized due to the formation of these antifriction films under the researched operating conditions (Fig. 6).



a **b**

Fig. 6. Images of the friction surfaces:

a− material EP975+ 6% CaF_2*; b− counterface of cast steel EI961Sh*

The formed antifriction films completely cover both the surface of the material and the counterface. Such films are constantly formed and wear out at the same time. Thus, they are constantly present on the friction surfaces and protect the contact pair from intense wear. A fragment of the flaking process of the friction film's worn-out section has been shown in Fig. 7.

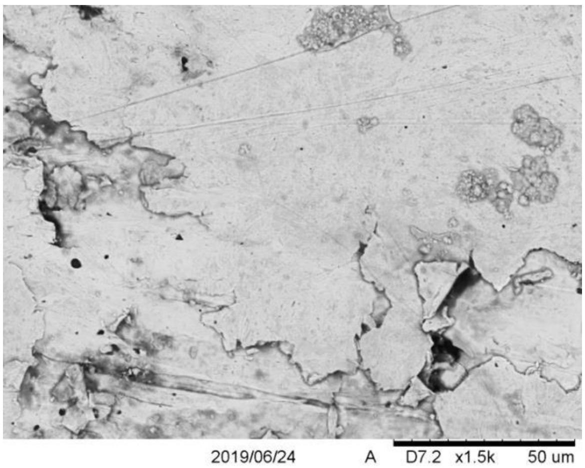


Fig. 7. Flaking of the friction film's worn-out area

Solid lubricant CaF_2 contributes to film formation together with other alloying elements oxides. The calcium fluoride solid lubricant is evenly distributed over the contact surfaces as it envelops the entire friction area during high-speed friction. This leads to a decrease in the level of plastic deformation in the friction zone under external loads on the friction pair. Plastic deformation is localized in the film, which increases the composite material wear resistance compared to the known one.

Multifactor external effects led to the complex synergetic processes on surface layers, which develop because the system is open and energy flows from outside[35].

This resulted in a multivariant synergetic system characterized by different internal processes in the antifriction films. These anti-seizure films are dissipative structures. Such friction films, the so-called secondary structures, as dissipative structures are complex, dynamically changing formations on the surfaces of the bearing composite and counterface (shaft) in the process of friction.

Such multiphase formations can develop according to the bifurcation mechanism, when they become prone to one or another attractor due to self-organization. Thus, such secondary structures can exist in two relatively long-term states of the system.

Due to this dualism, they have a different composition and therefore can manifest themselves in two ways, depending on the type and intensity of energy inflow from the outside: either as an antifriction lubricating layer, providing high tribological properties and stabilizing the friction pair work, or as a coarse abrasive layer, leading to the friction unit's intense wear.

The specific operating conditions of the friction pair have a decisive influence on the direction in which the system's bifurcation phenomena are realized in states far from equilibrium, and to which relatively the system's long-term state these conditions lead, i.e. system's attractor.

The internal processes in the films are very complex and largely depend on the manufacturing technology, lubricating conditions, and especially operating modes.

When the testing rotational speed rises to 10000 rpm there is a significant increase in the friction coefficient and wear rate (Table 3). In this case, the main reason for increased wear is the high intensity of the oxides formation processes on the studied composite's surface when high speed causes the increase of surface temperature in air.

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[35] Ibidem. Jamroziak K., Roik T. Op. cit. P. 628−637.

An imbalance occurs between the film's wear rate and the rate of its new areas formation. Therefore such a film wears out faster than a new one is formed.

As a result, individual zones of the contact surfaces are not covered with a friction film and remain unprotected, which leads to increased wear.

In our case solid lubricant CaF_2 provided the self-lubricating mode together with the chemical elements of the Ni-composite material and steel counterface.

Under established friction modes, there is a balance between the wear rate of these films and the rate of new films areas formation. Therefore, a lubricating film is constantly present on the contact surfaces at the researched operation conditions.

Antiscoring self-lubricating films with calcium fluoride stabilize the work of the friction pair and increase the reliability and durability of the high-speed friction unit in printing machine.

The performed studies have shown the correctness of the developed manufacturing technology, which was confirmed by the structural, mechanical and tribological research.

The industrial tests confirmed the experimental results. They showed an increase in wear resistance by a factor of 4.0–6.0 compared to the cast nickel bearings at the similar operating conditions.

CONCLUSIONS

The research results have shown the effectiveness of the developed technology to obtain new highly wear-resistant nickel composite antifriction materials for high-speed friction units.

The developed technology includes the main operations such as hot isostatic pressing with subsequent heat treatment. The studies showed the used technological modes provide the formation of a complex heterophase structure of composites based on EP975 powder nickel alloy with CaF_2 solid lubricant additives for exploitation at high rotational speeds up to 10000 rpm and increased loads up to 3.5 MPa, in air.

The structure of the material represents a γ-solid solution of alloy elements in nickel matrix with inclusions of calcium fluoride. Solid lubricant CaF_2 particles are uniformly distributed in the alloyed nickel matrix. Nickel γ-solid solution is strengthened by intermetallic compounds and carbides of alloying elements.

Such structure ensures the mechanical and tribological properties high level of nickel antifriction composites manufactured using the developed technology. Comprehensive studies have demonstrated the features of the formation of the composite's structure using EP975 powder nickel alloy as a basis, taking into account the nature of the components present.

This allows predicting the nature of the strengthening and material's antifriction behavior, and hence functional properties.

The performed mechanical tests showed a sufficiently high level of strength and plastic characteristics of the new composites with CaF_2, comparable to the level of these properties in the EP975 cast nickel alloy and the EP975 powder alloy obtained by the HIP technology.

Tribological tests have demonstrated significantly higher antifriction properties of the investigated composite and the known powder material used under similar conditions.

The advantageous level of tribological characteristics was observed due to the constantly forming antifriction films on the contact surfaces, when there is a balance between the wear rate of these films and the rate of new films areas formation.

The studies have shown the new material's rational operating range is followed: the external working loads on contact pair of 1.5−3.5 MPa at the rotational speeds 8000−10000 rpm in air.

The industrial tests showed an increase in wear resistance by a factor of 4.0–6.0 compared to the cast nickel bearings at the similar operating conditions of high-speed printing equipment.

SUMMARY

The modern development of engineering is impossible without the innovative technologies creation and implementation in industrial production the new effective materials, in particular, for contact pairs such as bearing materials for severe operating conditions. Known cast and composite bearing materials based on nickel have unsatisfactory functional properties at high rotational speeds of 5000−10000 rpm and increased loads up to 3.5 MPa in the air, which is characteristic for the operation of high-speed printing machines. The developed efficient antifriction composites based on powder alloyed nickel alloys are well proven when working in high-temperature friction. The effect of manufacturing technology on the functional properties of new bearing nickel composites at high rotational speeds still remains unexplored. Therefore, the development of new technology for the manufacture of effective bearing composites based on EP975 powder nickel alloy with CaF_2 solid lubricant that can significantly increase the service life of high-speed printing machines' friction units is a critical scientific and technical

problem. It was shown the mechanism of new composites' structure formation after using the manufacturing hot isostatic-pressing technology with subsequent heat treatment. Such technology is able to ensure the high and stable level of the functional properties. It was shown the dense antifriction films were formed on the contact surfaces during the tribological tests. Solid lubricant CaF_2 promotes the antifriction films formation during the friction process and provides a self-lubricating mode for the high-speed friction unit. Such films defend the contact surfaces against the intensive wear and stabilize a work of the high-speed printing machine's friction unit.

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