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THE EFFECTIVENESS OF MANUFACTURING TECHNOLOGY OF ANTIFRICTION COMPOSITE PARTS BASED ON NICKEL

Abstract: In a paper the research results of structural periodicity in the antifriction composite parts based on nickel with solid lubricant CaF_2 have been presented. The periodicity of structure was studied using Fourier analysis. Analysis of the structural status complexity and rheological characteristics of the friction surface was carried out by two-dimensional diffraction spectrum. This analysis determines the average size of structural components, the distance between them, the concentration and length of interphase boundaries. Fourier analysis method was used to check, prove and confirm the correctness of new composite antifriction parts' manufacturing technology. This method has shown the homogeneity of the composite material as a whole that proves the efficiency of the developed manufacturing technology. The developed technology provided the high tribological characteristics of the new parts for printing machines.

1. Introduction

Requirements for new wear-resistant parts are constantly increasing. This applies to both cast and powder parts. The main task in the development of new composite antifriction parts is to increase the life of machines and mechanisms, for example, printing equipment.

The known cast alloys based on copper, nickel (or cobalt) demonstrate unsatisfactory tribotechnical properties - high friction coefficient and wear at heavy-duty conditions of printing machines [1–5]. For example, it is known cast antifriction bronze bushings are able to operate only 0.5-1.0 year in printing machine' friction unit. After that catastrophic wear of bushing occurs.

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 [1–7]. This is due to their original physical properties [2].

Materials based on nickel are well known among antifriction composite materials intended for severe operating conditions of higher loads and rotation speeds [1–5]. Studies have shown very good results and opened up prospects of the new antifriction bushings' industrial use in the friction units of printing machines [2–5]. The developed manufacturing technology ensures a high level of properties for new composite antifriction parts based on powder nickel alloy EP975 with powders of solid lubricant CaF_2 [3, 4–7].

However, structural changes and other physical phenomena remained unexplored, that does not allow uniquely estimating the efficiency of manufacturing technology.

Therefore, the objective of the present paper is studying of the new composite parts' structural periodicity, the structural changes in the researched material based on powder high–alloyed nickel alloy EP975 with the solid lubricant CaF_2 powders by use the Fourier analysis method. Such approach gives a possibility to check, prove and confirm the correctness of new composite antifriction parts' manufacturing technology.

2. Experimental results and discussion

Examination Techniques. The object of the study was the composite antifriction material based on powder high–alloyed nickel alloy EP975 with the solid lubricant CaF_2 powders. Structure was studied using raster microscopy. The periodicity of structure was studied using Fourier analysis.

Method of determining the orientational anisotropy is as follows. Tensions of structure ordering can always be described by functions of the shift, rotation and changes of the periodicity, namely by functions $f(x, y, z)$, $f(\alpha, \beta, \gamma)$ and $P(x, y, z)$ accordingly. These characteristics reveal the degree of structure organization. They appear in the spectrum and can be registered and properly evaluated by scanning electron narrow beam on the investigated surface [8–10].

to the most modern computers. Two-dimensional Fourier spectrum is analyzed in this program.

Different areas of the structure reflect the scanning beam differently that causes change of the reflected signal.

The program works in two modes. In the first mode, the level of anisotropy and block's structure orientation quantitatively are estimated on the main operating tensions using autocorrelation and spectral analysis of surface fraktograms.

In the second mode the complexity of the structural state (the number of coefficients in the Fourier equation), the degree of anisotropy of main operating tensions and quantification of the degree of ordering structures on the friction surface (phase analysis) are qualitatively estimated in width and complexity of fraktograms. The angle between the axis of inertia and the abscissa for each image element is determined by direct scanning electron beam on the sample's surface.

In the reverse scan the histogram of chord length of image elements is calculated for each on the image angular ranges (0 to 180° at intervals of 10°).

Histogram is calculated by counting the hits number of the random value (in this case - the lengths of inertia axis on the image elements) into the specified classes.

Statistical analysis of the image elements orientation is summarized by the main orientation vector of image elements on the selected scan direction, coupled with the abscissa [9, 10].

Analysis of the structural status complexity and rheological characteristics of the friction surface was carried out by two-dimensional diffraction spectrum. This analysis determines the average size of structural components, the distance between them, the concentration and length of interphase boundaries. It also allows exploring the anisotropy of the structure as a whole, which is associated with anisotropy of optical, mechanical and other properties.

The results of the comparative analysis from the surface histograms allow estimating the nature and size of the packaging structural elements, to carry out a comparative estimation of the studied surface anisotropy over the histogram width and the number of maximums at the same magnification and direction of scanning on the electron raster image.

We also carried out a qualitative analysis of the material texture for background characteristics such as brightness, size, shape, spatial orientation. The texture can be described by several features: fine grain, coarse, smooth, granulated, chaotic, linear, and so on. Texture is formed by external power factors and micrometallurgical processes. Textures characterize the stresses' orientation on the boundaries of structural components.

Thus, the objects of the study were new wear−resistant parts [2−4] based on powder high-alloyed nickel alloy EP975 with powders of solid lubricant CaF_2 (tab. 1.).

Tab. 1. Chemical composition of researched materials

Components, mass.%									
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

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 [2].

The method of hot isostatic-pressing (HIP) was used for manufacture of new materials because the traditional technology of powder metallurgy doesn't ensure minimum porosity.

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 obtaining enough dense materials, almost without pores. The blanks had a relative density 99.9%.

After the hot isostatic pressing a 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 1240°C during 4 hours, cooling with speed a 40 degrees/hour with a furnace to 1200°C, and then cooling on air.

After a hardening an ageing was carried out at 910°C during 16 hours on air.

HIP with a next heat treatment have been ensured the formation of phases in a structure, which increase material' physical-mechanical properties (combination of strength and plasticity) and improve operating reliability of antifriction part. Developed materials' tribotechnical, physical and mechanical properties have been presented in tab. 2 in a comparison with known powder Ni material, which is applied in analogue conditions [2].

Tab. 2. Mechanical and antifriction properties of new bearings based on alloys EP975

№	Composition, mass.%	Bending strength, σ_s, MPa	Impact resistance KC, J/m^2	Hardness, HB, MPa	Friction coefficient	Wear, µ/km (V=1200 rpm)
1	EP975+4% CaF_2	540–610	600–650	2550–2600	0,27	50
2	EP975+6% CaF_2	550–600	550–600	2500–2600	0,26	30
3	EP975+ 8% CaF_2	520–570	520–550	2540–2600	0,27	55
4	Ni+(18-45%) MoB_2+ ZrB_2)+ 5%(CaF_2 or BaF_2) sintered alloy [2]	240–300	350–520	850–950	0,31	180

Fourier analysis of the structure periodicity was caried out by scanning along the surface of the samples' thin sections using software packages for image analysis to confirm the effectiveness of the developed manufacturing technology. In studies we used two modes: the first - in secondary electrons, from surface's relief - mode SE (inelastic scattering) and the second - phase contrast - BE mode - in reflected electrons (elastic scattering).

Results of analysis at the direct and reverse scan are presented on fig. 1 and 2.

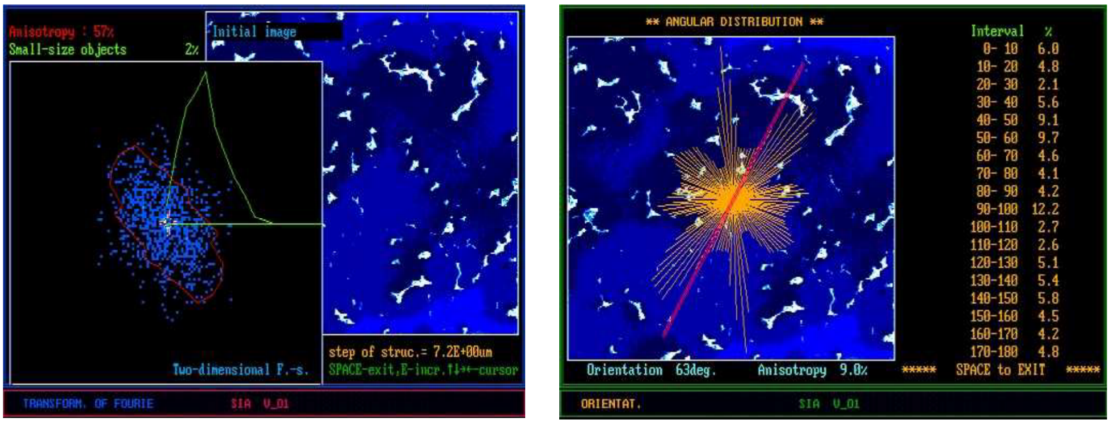
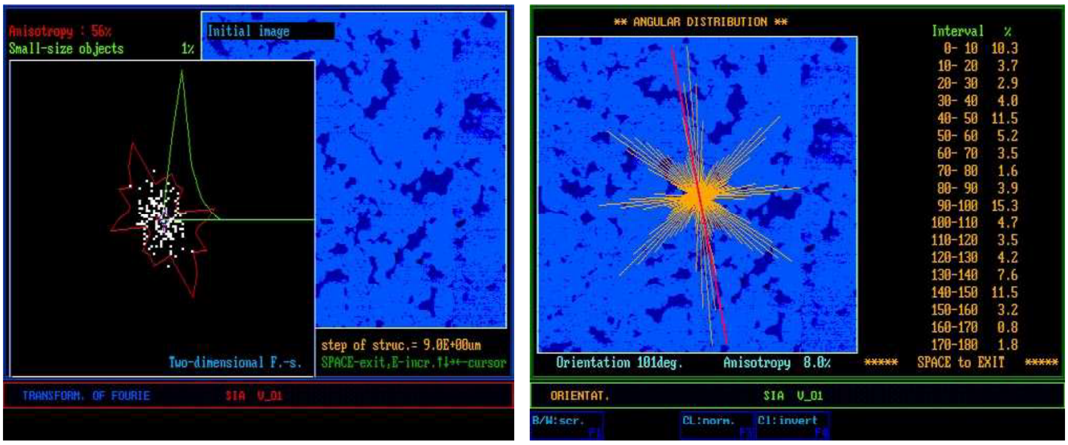


Fig. 1. Fourier - analysis of the material EP975+8%CaF$_2$ structure (mode SE - the secondary electrons): a) structural (physical) anisotropy (direct scan); b) orientation of the alloy's particles (reverse scan)



а *б*

Fig. 2. Fourier - analysis of the material EP975+8%CaF_2 *structure in phase contrast (mode BE - the reflected electrons), depth from the surface to 50 nm: a) structural (physical) anisotropy (direct scan); b) orientation of the alloy's particles (reverse scan)*

Tensions of structure ordering can always describe by functions of the shift, rotation and changes of the periodicity. These characteristics illustrate the degree of structure organization in material after manufacture. Also they are appeared in the reflected spectrum from the structural elements of composite material (from individual particles of researched material based on EP975+8%CaF_2), registered and quality evaluated at the scanning of narrow electron ray along analyzed surface of the sample. Since different parts of the structures are differed in their spatial orientation, they reflect differently scanning beam and it causes a change of the reflected signal.

Quantitatively it was estimated the structural (physical) level of anisotropy (fig. 1a, 2a) and orientation of the material's structural elements (geometric anisotropy) – Fig. 1b, 2b along the main operating tensions by analyzing the fraktograms of sample's surface, that is in the reflected electrons (depth ~ 50 nm) and in the secondary electrons – the surface relief. On fraktograms complexity we evaluated the structural status complexity (the number of coefficients in the Fourier equation), the degree of anisotropy (structural) of the main operating tensions, that is a result of hot pressing technology. We also obtained a quantitative estimation of the structural ordering degree in the material. Direct scanning method was used in both modes, SE and BE.

The angle between the inertia axis and the abscissa of each structural elements in the image was determined at the direct scanning of electron beam along the sample's surface (BE and SE modes), as shown in fig. 1a and fig. 2a.

At the reverse scanning (fig. 1b, 2b) we obtained the calculated histogram of the lengths of chords from structural elements in the image (particles of alloy EP975 and particles CaF_2) for each of the selected angular ranges in the image (from 0 to 180° at intervals of 10°).

A statistical analysis of the elements in images were obtained by the calculation in program SIA 1.00 of two-dimensional Fourier spectrum by counting the number of hits of a random variable at specified angular ranges (lengths of inertia axes of the structural elements in material). Then the obtained results were summarized by this program. So we got the main orientation vector of structural elements on the selected scanning direction, coupled with the abscissa.

It was determined amount of the smallest structural elements (in %) and number of structural blocks for each angular range as a result of structural analysis and rheological features of the original material's surface (fig. 1b, 2b). This allowed us to estimate the anisotropy of the material structure in general.

The results of the structural elements distribution in the composite antifriction material based on powder Ni-alloy EP975 with solid lubricant CaF_2 have been presented in tab. 3.

Tab. 3. The distribution of the structural elements in the material EP975 + 6% CaF_2

Analysis mode	Fourier analysis		Orientation	
	$A_{str.}$, %	Small objects, %	Angle, degrees	$A_{aver.}$, %
SE surface relief (the secondary electrons)	57.0	2.0	63.0	9.0
BE - in reflected electrons, in phase contrast (depth 50 nm)	56.0	1.0	101.0	8.0

As research shows (fig. 1, 2 and tab. 3) the manufacturing technology ensured obtaining the dense deformed material (porosity ≈ 0.1%), as structural anisotropy evidenced (real physical anisotropy, $A_{str.}$), which is 57 and 56% according to analysis places – on the surface and in the volume of the sample (SE, BE modes).

The material shows almost the same level of physical anisotropy on the sample's surface after its mechanical grinding during preparation process, and in volume, since the depth of ~ 50 nm. This shows the homogeneity of the composite material as a whole.

Structural anisotropy is 57% directly from the surface of the sample, which is possibly due to its slight increase at the fine grinding of the sample. This is also evidenced by the increasing of angle inclination from 63^0 to 101^0 for the main orientation vector of the material's structural elements.

In this case, average geometric anisotropy (orientation, $A_{aver.}$) is very low – 9.0 and 8.0% regardless of the analysis mode (SE or BE). It illustrates the uniform arrangement of powder alloy's particles in all its volume and confirms the high voluminous homogeneity of the obtained material structure. Such structure is the result of technology HIP. The presence of small inhomogeneities (anisotropy) is confirmed by studies of physical mechanical and tribotechnical properties (tab. 2). Wear of the material takes play evenly across the surface friction.

The distribution of solid lubricant CaF_2 particles is characterized by uniformity in the material (Fig. 1, 2), which promotes the formation of stable secondary structures (friction films) on the contact surfaces. It can ensure a high level of the material's functional properties. This, in turn, minimizes wear and stabilizes a friction pair's operation.

The texture of examined materials was formed by external technological factors – temperature and loading parameters during the manufacturing process (except biographical original signs when alloy EP975 was remelted and sprayed on the powder particles). That is, the fine grain structure was formed after manufacturing of the composite material by the developed technological process, as shown in fig. 1 and 2. Such structure ensures a high level of mechanical and tribotechnical properties (tab. 2) [2, 4].

Thus, the executed complex Fourier analysis of structural periodicity have confirmed the efficiency of the manufacturing technology of antifriction composite parts based on powder nickel alloy EP975. The developed technology can ensure a high and stable level of the antifriction parts' functional properties.

3. Conclusion

Thus, we had studied the structural changes and other physical phenomena in the antifriction composite parts based on powder nickel alloy EP975+CaF_2. In our research we used the Fourier analysis method. This method has shown almost the same level of physical orientational anisotropy on the sample's surface after its mechanical grinding during preparation process, and in volume, since the depth of ~ 50 nm. This shows the homogeneity of the composite material as a whole. The Fourier analysis method had confirmed the efficiency of new composite antifriction parts' manufacturing technology. The developed technology provided the high tribological characteristics of the new parts for printing machines.

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