Technological methods to improve wear resistance of porous, sintered materials based on iron powder for antifriction purposes

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Abstract. Technological methods of increasing wear resistance of porous, sintered materials based on iron powder for friction pairs of sliding of various agricultural machines are offered. The results of the research carried out with the aim of developing iron-based material compositions for sintered products of mass parts of sliding bearings, shaft supports of drawing devices, gears and others are given.

1. Introduction

In the production of a number of mechanical engineering parts, such as sliding bearings of reflon cylinders, drafting devices and a number of others, where finishing machining is required to obtain the desired shape of the product, along with the need to obtain high antifriction properties, there are issues of ensuring good machinability of parts by cutting, quality of working surfaces of finished products and durability of cutting tools [1-16].

2. Materials and methods

The most widely used in industry for sintered materials based on iron is iron graphite with a content of 1.0 to 3.0 % of carbon (graphite). The use of a charge of iron powder with graphite in the sintering process of pre-pressed products forms the structure of carbon steel, often containing grains of structurally free cementite. This leads to unsatisfactory low durability of the cutting tool in the process of cutting. It is known that during cold machining of porous material even from pure iron powders without additions of graphite in the charge, durability of cutters is lower in comparison with dense materials of the same composition. This is due to the presence of pores, which create additional dynamic loads on the edge of the cutting tool in the process of cutting.

We carried out research with the purpose of development of composite materials on the basis of iron for sintered products of mass parts of sliding bearings, support of shafts of drawing devices, gears, etc. The main requirements that we were guided by when creating the materials were that the materials should have three properties: high wear resistance in conditions of semi-dry (boundary) friction, good machinability and sufficiently high strength. The use of powder metallurgy techniques and the assignment of one or another type of heat or chemical-thermal treatment of sintered and machined products were supposed to ensure the obtaining of such properties.
3. Structural research

The search experiments have established that it is advisable to use powders of sulfur, graphite, copper and phosphorus as components of the charge, in the initial experiments in the form of ferrophosphorus. It is established that the materials obtained from the charge with the introduction of ferrophosphorus are difficult to be machined by cutting. In addition, the particles of powders and ferrophosphorus introduced into the charge during sintering with a holding time of up to 120 minutes do not have time to dissolve in the iron base and it is not possible to obtain a homogeneous homogeneous structure. The analysis of microstructures and the study of microhardness revealed that the hardness of individual grains of sintered materials based on iron, after sintering fluctuates within large limits. In order to obtain a more uniform uniform structure of materials containing phosphorus, sulfur and copper, we took it expedient to introduce them into the charge in the form of solutions of chemical compounds. In the process of sintering in a reducing environment compounds of this type decompose in the resulting structure of the material.

Figure 1. Variation of carbon (C), nitrogen (N) and phosphorus (P) content by layer depth on sintered porous iron-based material at the introduction of 2.0 % of the preparation "Majef" into the charge.

We used such phosphorus-containing compounds as: phosphorus ammonium and preparation "Majef", containing free phosphoric acid and one-substituted phosphorus manganese. The use of the second compound - preparation "Majef" proved to be preferable, when heating the pressed charge above 600 °C, the preparation disintegrates and its constituent elements are after sintering evenly distributed in the main component - iron.

Figure 1 shows changes in the content of carbon, nitrogen and phosphorus according to the depth of the layer on the sintered porous material based on iron, adding the preparation "Majef".

The tables show the results of comparative bench wear tests and values of friction coefficients for some variants of sintered porous sliding bearings technology for caterpillar tractors.
Table 1. Wear test results and friction coefficients of some sintered iron-based ring variants

| №  | Tested variant | Total porosity, % | Relative wear | Friction coefficient |
|----|----------------|-------------------|---------------|---------------------|
|    | Material of the charge ring containing majeure salt | | | |
| 1  | A) 0.5         | 17                | 0.65          | 0.040               |
|    | B) 1.0         | 20                | 0.68          | 0.038               |
|    | C) 2.0         | 24                | 0.68          | 0.030               |
|    | D) 3.0         | 24                | 0.70          | 0.033               |

Table 2. Wear rate of a bushing made of different porous sintered materials in contact with a steel shaft in sliding friction with grease containing 0.2% abrasives (load 0.728 MPa, sliding speed 1.831 m/s)

| Number experience | Average wear rate (J)·10^-9 | Coefficient of friction |   |
|-------------------|----------------------------|-------------------------|---|
| 1                 | 1.03                       | 0.08                    | 1.11 0.025 |
| 2                 | 0.63                       | 0.06                    | 0.69 0.022 |
| 3                 | 0.78                       | 0.06                    | 0.84 0.029 |
| 4                 | 0.38                       | 0.04                    | 0.42 0.022 |
| 5                 | 0.90                       | 0.10                    | 1.00 0.028 |
| 6                 | 0.92                       | 0.08                    | 1.00 0.020 |
| 7                 | 0.92                       | 0.09                    | 1.10 0.026 |
| 8                 | 0.70                       | 0.07                    | 0.77 0.025 |

Based on the results of the performed research, the optimal technological process for the production of sliding bearing supports of different sizes of sliding bearing supports operating at boundary friction is developed and mastered in production. The developed material composition and technological process for sintered porous sliding bearing supports are transferred to the manufacturer of caterpillar tractors.

4. Theoretical Studies

Theoretical studies were carried out to verify the laboratory and operational research. Operating conditions of machine parts working in a dusty environment are characterized by the possibility of penetration of dust particles into the lubricant. During the operation of machines, abrasive particles get into the mating gap of the parts, causing abrasive wear. The load acting on the friction surface can be transmitted through abrasive particles, provided the size of these particles is commensurate with the size of the gap and they interact with both friction surfaces. If the forces acting on the abrasive particle reach critical values exceeding its strength limit, the particle begins to crush (pulverize). As a result of crushing the abrasive particles to sizes smaller than the value of the gap and the thickness of the oil film, they lose their activity and the load in the friction pair is transferred through the oil film with uniform distribution over the nominal contact area. As a result, oxidative wear prevails in the friction pair. Based on the above, it can be assumed that the probability of surface destruction by abrasive β_а and oxidative β_o wear depends on the receipt and availability of lubricant on the friction surface, since the main carrier of abrasive particles is oil.

The probability of abrasion depends on the activity time of the particles:

$$\beta_a = \frac{t_a}{T},$$  \hspace{1cm} (1)

here \(t_a\) is the activity time of abrasive particles, \(h\); \(T\) - time of unit or unit operation, \(h\).

According to [1] activity time of abrasive particles

$$t_a = \frac{\ln\varepsilon}{\omega \ln(1-A)},$$  \hspace{1cm} (2)

here \(\varepsilon\) is the concentration of abrasive particles in the oil, \%; \(\omega\) - angular velocity, \(\text{c}^{-1}\).
To simplify formula (3) we will use the transformation:

$$A = \frac{n \pi r d_a}{d_{cp}},$$  

(3)

Then from (2), (3) and (4) we have

$$\beta_a = \frac{\ln \varepsilon}{T \omega \ln(1 - \frac{n \pi r d_a}{d_{cp}})}$$  

(4)

The volume of normal oil inflow to the friction surface $q_n$, mm$^3$/h, according to [2] is determined

$$q_n = 0.5 \omega d^2 q \psi,$$  

(5)

here $q$ –is the grease outflow coefficient; $\psi$ –is the relative mating gap;

$$\psi = \left(\frac{\omega d \mu |S_0|}{N}\right)^{\frac{1}{2}},$$  

(6)

here $\mu$ –is the dynamic viscosity of the oil, Poise;

$[S_0]$ is the critical value of Sommerfeld [2].

Taking into account (5), (6), (7) from (1) we have

$$\omega = \frac{567}{t_{cp}} \ln(1 - \frac{n \pi r d_a}{d_{cp}}) - 0.5 \ln(1 - \frac{n \pi r d_a}{d_{cp}}),$$  

(7)

Under friction conditions without lubrication or with boundary lubrication, fatigue wear occurs. In this case

$$\beta_f + \beta_a + \beta_o = 1.$$  

(8)

Then, given (1), we have

$$\beta_f = 1 - \frac{q_o}{q_a} = 1 - \frac{q_o}{0.5 \omega d^2 q \left(\frac{\omega d \mu |S_0|}{N}\right)^{\frac{1}{2}}}.$$  

(9)

The wear of friction surfaces $U$ is determined from the expression

$$U = \beta_f U_f + \beta_a U_a + \beta_o U_o,$$  

(10)

here $U_f, U_a, U_o$ - wear of surfaces at respectively fatigue, abrasion and oxidative wear, mm.

The values of different types of wear are determined using the well-known formulas of Professors I.V. Kragelsky [3], B.M. Kostetsky [4] and U.A. Ikramov [5].

Time of destruction of surfaces by this or that type of wear denote $t_f, t_a, t_o, t_p$ h, then operating time of the node $T_p$ is defined:

$$T_p = t_f + t_a + t_o + t_p.$$  

(11)

The probability of fatigue $\beta_f$, abrasion $\beta_a$ and oxidative $\beta_o$ wear is determined from the expressions:

$$\beta_f = \frac{t_f}{t_p}; \ \beta_a = \frac{t_a}{t_p}; \ \beta_o = \frac{t_o}{t_p}.$$  

(12)

The duration of abrasive and oxidative wear of the surfaces depends on the purity of the oil entering the friction pair clearance. It is possible that abrasive particles enter the sliding bearing clearance together with the oil and become active in the wear process before they are crushed or embedded in one of the surfaces. In this case, the activity time of the abrasive particles is defined as

$$t_a = \ln \varepsilon / \omega \ln(1 - \frac{n \pi r d_a}{V_0}),$$  

(13)
here \( V_\phi = \frac{q_\phi}{n} \) - the volume of oil consumed per cycle, \( \text{mm}^3 \); \( q_\phi \) – the volume of oil actually entering the friction surface, \( \text{mm}^3/\text{h} \); \( n \) – number of load cycles, times/h.

Then

\[
\beta_a = \frac{\ln e}{T_p \omega \ln (1 - \frac{n \pi r d a}{q_\phi})} . \tag{14}
\]

If during the crushing process abrasive particles arise the dimensions of which do not exceed the dimensions of the gap and the thickness of the oil film, these particles lose their activity and the load in the friction pair is transferred through the oil film with a uniform distribution over the nominal contact area. Then oxidative wear occurs in the pair.

However if there is an abrasive particle in the friction pair, the size of which is greater than the thickness of the oil film, then not only oxidative but also abrasive wear occurs in the pair.

In this case

\[
\beta_a + \beta_o = \frac{q_\phi}{q_u} . \tag{15}
\]

Here, \( q_u \) – is the calculated volume of oil normally (maximum) coming to the friction surface, \( \text{mm}^3/\text{h} \). Using formulas (6) and (7), we have

\[
\beta_o = \frac{T_p q_\phi \ln \left(1 - \frac{n \pi r d a}{q_\phi}\right) - 0.5 T_p \omega d^2 q \left[\frac{\text{ad} \mu \text{s} \sigma}{N}\right]^2 \ln (1 - \frac{n \pi r d a}{q_\phi})}{0.5 T_p \omega d^2 q \left[\frac{\text{ad} \mu \text{s} \sigma}{N}\right]^2 - q_\phi} . \tag{16}
\]

Keeping in mind \( \beta_u + \beta_o + \beta_v = 1 \) and considering (12) and (13), we obtain

\[
\beta_y = 1 - \frac{q_\phi}{q_u} = \frac{0.5 T_p \omega d^2 q \left[\frac{\text{ad} \mu \text{s} \sigma}{N}\right]^2 - q_\phi}{0.5 T_p \omega d^2 q \left[\frac{\text{ad} \mu \text{s} \sigma}{N}\right]^2} . \tag{17}
\]

5.Conclusion
According to the results of the analysis and preliminary calculations, the values of the limit wear of the shaft and sliding bearings of the planetary turning mechanisms of crawler tractors, as well as the permissible values of the limit gap between them have been determined. The limit value of the clearance is determined taking into account the misalignment of the sun gear, leading to the rotation of the sleeve of the sliding bearings. By comparing the obtained calculation results with the limit clearance value, it is possible to determine the service life of plain bearings, as well as other parts of the planetary swing mechanism.

References
[1] Antsiferov V N Perspective materials and technologies of powder metallurgy. Perm, PSTU, 2014. 109
[2] Bal'shin M.Yu. Scientific foundations of powder metallurgy and fiber metallurgy. M .: Metallurgy. 2011. 336
[3] Dovydenkov V A Research and creation of a composition based on metal powders, their oxides and carbon for obtaining shaped blanks with desired properties. Abstract of dissertation for the degree of Doctor of Technical Sciences. Moscow: 2009. 32
[4] Panov V S, Narva V K, Dubyniko L V Production technology and properties of sintered materials and products from them. Laboratory praktukum. M .: MISIS. 2007. 103
[5] Sorokin V K, Shmelev L S Production technologies and equipment for the production of powder and composite materials and products. Nizhny Novgorod. NSTU. 2011. 184
[6] Shvedkov E L and other Dictionary-reference book on powder metallurgy. Kiev. Naukov-Dumka. 2011 270
[7] Neikova O P, Naboychenko S S, Dowson G Hondbook of non Ferrous Metal Powders. Technologies and Applications. Amsterdam. Elsever. 2009. 616
[8] Boukria O, El Hadrami E M, Sultanova Sh, Safarov J, Leriche F, Aït-Kaddour A 2020 Foods, (9)6, 724
[9] Boukria O, El Hadrami E M, Boudalia S, Safarov J, Leriche F, Aït-Kaddour A 2020 Foods (9)9, 1309
[10] Boukria O, El Hadrami E M, Sameen A, Sahar A, Khan S, Safarov J, Sultanova Sh, Leriche F and Aït-Kaddour A 2020 Foods, 9(11) 1722
[11] Safarov J E, Sultanova Sh A, Dadayev G T and Zulpanov Sh U 2021 IOP Conf. Series: Materials Science and Engineering. Dynamics of Technical Systems (DTS 2020) 1029 1-11
[12] Safarov J, Khujakulov A, Sultanova Sh, Khujakulov U and Sunil Verma 2020 E3S Web of Conferences: Rudenko International Conference “Methodological problems in reliability study of large energy systems” (RSES 2020) 216 1-5
[13] Sultanova Sh, Safarov J, Usenov A, Raxmanova T 2020 E3S Web of Conferences: Rudenko International Conference “Methodological problems in reliability study of large energy systems” (RSES 2020) 216 1-5
[14] Safarov J E, Sultanova Sh A, Dadayev G T and Samandarov D I 2019 International Journal of Innovative Technology and Exploring Engineering 9(1) 4562-4565
[15] Safarov J E, Sultanova Sh A and Dadayev G T 2020 Energetika. Proc. CIS Higher Educ. Inst. and Power Eng. Assoc. 63(2) 174–192
[16] Safarov J E, Sultanova Sh A, Dadayev G T and Samandarov D I 2019 International Journal of Innovative Technology and Exploring Engineering. 9(1) 3765-3768