NEW TECHNOLOGY IMPROVING THE SERVICE CHARACTERISTICS OF SINTERED SELF-LUBRICATED BEARINGS WITH CONTROLLABLE PORE SIZE

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ABSTRACT

The new technology for improving the service characteristics of sintered self-lubrication bearings was offered. The essence of this technology consists in use the manufacture of sintered bearings organic pore-former with the desired size fractions, which allows to obtain materials with desired porosity and controllable pore size. In addition, in order to reduce the coefficient of friction, used an oil impregnating process, added anti-friction additive - graphite powder. This technology is simple, economically expedient and extends the application of sintered bearings for various nodes of friction.

Keywords: sintered sleeve bearings, controllable pore size, organic pore-former, antifriction addition, self-lubrication effect

1. INTRODUCTION

Porous self lubrication bearings are the most common products produced by powder metallurgy industry. Their main advantage is that their pores, being filled with lubricant, play a role of grease reservoirs, providing the self-lubricating effect [1, 2]. The effect of self-lubrication involves the oil separating from the pores in the local heating of the bearing, which leads to a rapid recovery of the boundary layer of lubricant on the sliding surfaces. The lower porosity of the material leads to the higher temperature increase on the working surface of the bearing. With the increase of the bearing porosity, the oil reserve increases, as it is located in its pores and, consequently, the oil blooms to the work surface with a smaller increase in temperature of the sample [1, 2]. Therefore, the quality of oil impregnating is one of the main factors of safe and continuous operation for porous self lubrication bearings. Most often, the porosity of self lubricated bearings consists of 20-30% [1-5].

However, the growth of porosity is accompanied by a significant decrease of strength properties and impact strength of these materials, as well as the deterioration of their thermal conductivity [1]. In addition, the increasing porosity

deteriorates the wear-in, increases the friction coefficient and, hence, it increases the wear [1, 6]. Therefore, it is necessary to choose the optimal level of porosity, which provides for the concrete operating conditions of the bearing, the required quality of oil impregnating, which is a main factor in a safe and continuous operation of sintered bearings in self-lubricating regime.

According to research [2], a significant effect on the wear resistance of self-lubricated bearings renders the porosity and the size of pores. Larger pores of the material provide more oil to appear on the friction surface. Protrusion of oil from the pores is related to the magnitude of capillary channels formed in the body of the material with intercommunicating pores. The increase in grain size decreases the surface of capillary channels in the material body and, consequently, less amount of oil appears on the surface, for the same relative porosity. During the operating process, this means most oil adsorbed from the pores on the friction surface. Therefore, in boundary friction condition or in self-lubrication regime, it is recommended to use oil impregnated bearings with large pores (200-420 μm), which provide a more sustained recovery of the oil films on the friction surfaces, during the operation process.

For controlling the pores size, a number of techniques was developed, as described in publications [6, 7]: selection of grain size of initial powders (a coarsening of particle size of initial powders increases the pore size), changes in compaction degree of the powder mixtures, selection of the appropriate modes of sintering.

However, the use of techniques described above does not justify itself obtaining products with very small (less than 20 μm) or large pores (200 μm) [6]. Compaction of fine-grained powders always requires the use of lubricants or plasticizers, as fine-grained powders have worse compactability than that charaterizing the coarse powders [2, 8] and the use of large size powders aggravates their sintering and consequently, affects the strength characteristics of the finite products [6, 9]. But the small pores are needed for products such as fine filters, friction and electrical materials and large pores for products such as gaskets, impregnated with bitumen, electrode implants, coarse filters, foams, rigid foams, foam rubbers, gas and foam concretes, porous glass, etc. Therefore, in order to control the pore size in these products, all kinds of pore-formers are used: solid, liquid or gas [10, 11].

For the first time, the use of pore-formers in the production of porous bearings is described in reference [12]. Further development of this direction became in researches given in [13, 14]. In manufacturing bearings with controllable pore size, in these references, ammonium bicarbonate was used as a pore-former. However, there are several reasons that do not allow for using this pore-former in the production of porous sleeve bearings with a controllable pore size, in machine industry:

• ammonium bicarbonate is unstable and decomposes in air, with the release of ammonia, which is a dangerous substance;

• special storage conditions of ammonium bicarbonate are required, as well as additional measures of security personnel employed in the process of sieving pore-former into factions, mixing and compaction of mixtures, as well as during transportation gof reen compacts to the furnace, which significantly increases the cost of the finite products;

• in contact with air, the molecules of ammonium bicarbonate stick together, a natural process of agglomeration is occurred, which causes considerable difficulties in obtaining fraction of pore-former with desired size, after sieving;

• in the process of mixing initial powders with a pore-former (the process takes about 2-3 hours or more), the intensity of its decomposition will increase, making impossible for obtaining products of given size;

• during the decomposition of ammonium bicarbonate, water deposits, so the mixing of the components will be accompanied by an oxidation of the surfaces of metal powders (especially iron), which will lead to a deterioration in the compressibility of the mixture and, consequently, to an increase of compaction pressure and premature wear of the matrix and the punch of the press-form.

In this work, in order to avoid changes of properties for the initial metallic powders by the decomposition products of the pore-former in the mixing process, improving safety and environmental performance of individual stages of the technological cycle of production of sintered bearings with controllable pore size (absence of harmful gases) are required, thus increasing productivity and reducing the cost of a finite product. The sawdust is used as a pore-former, with low ash content after combustion (mainly coniferous trees: larch or pine). In addition, in order to improve the service characteristics of the sintered self-lubricated bearings, used for oilimpregnating, various antifriction additives are added, widespreadly used in automotive, aerospace and engineering industries. These additives are intended to reduce the coefficient of friction and, as a consequence, they also reduce the wear of friction pair. As anti-friction additives in self-lubricating bearings, the use of molybdenum disulfide and graphite is recommended [15]. However, since the molybdenum disulfide is much more expensive than the graphite, then fine-grained powder graphite is economically feasible to use as an oil additive. In the present study, the validity of these assumptions is investigated.

2. EXPERIMENTAL TECHIQUE

The initial materials used in the experimental are iron powder, copper powder and graphite powder. The iron powder particles have an irregular shape with numerous small protrusions. The particles of electrolytic copper powder have a pronounced dendrite structure. The graphite powder particles have a distinct tabular form.

Dried sawdust of pine was used as pore-former in these experiments. The particles of pore-former have an irregular shape. The sieving pore-former into fractions was carried out on a special device model EML 200 digital (Haver & Boecker, Germany). For sieving, sieve series were used, having the mesh sizes: 500 μm, 355 μm, 250 μm, 125 μm, 63 μm and 45 μm.

An analysis of the data in the references of anti-friction materials, working in a mode of self-lubrication in the case of small sliding velocities [1, 16-18] has shown the optimum content of powder mixtures of iron, copper and graphite (Fe=88%, Cu=9%, C = 3%, wt), and the content of pore-former – by volume (9%).

In order to obtain different sizes of pores in the sintered bearings, to the initial powders, the pore-former with different particle sizes was added: less than 45 μm, 45-63 μm, 63-125 μm, 125-250 μm, 250-355 μm and 355-500 μm. Batches weight of powder components were determined based on the weight and porosity of specimens and were calculated according to equation:

$$m_i = m_{mix} \cdot X_i, \qquad (1)$$

where m_{mix} – the weight of powder mixture, g; X_i – the proportional content of components in the mixture.

The weight of samples from Fe-Cu-C was calculated using equation:

$$m_{mix} = V \cdot \rho_{mix} \cdot K_1 \cdot K_2 \cdot K_c, \qquad (2)$$

where ρ_{mix} – the theoretical density of the powder mixture, g/cm^3; K_1 =1.005-1.09 – the coefficient of the powder loss during compaction; K_2 =1.01-1.03 – the coefficient of the powder loss during sintering; V – the volume of the sample (compact), cm^3;

K_C – the coefficient of compact density, determined by the formula:

$$K_C = 1 - \frac{P}{100},$$ (3)

where P – the originally given porosity of the compacts,% (P=18%).

The density of the mixture of Fe-Cu-C was calculated according to equation:

$$\rho_{mix} = \frac{1}{\dfrac{X_{Fe}}{\rho_{Fe}} + \dfrac{X_{Cu}}{\rho_{Cu}} + \dfrac{X_C}{\rho_C}},$$ (4)

where ρ_{Cu} = 8.92 g/cm^3 – the density of copper; X_{Cu} – the proportional content of copper powder in the mixture, by weight; ρ_{Fe} =7.86 g/cm^3 – the density of iron; X_{Fe} – proportional content of iron powder in the mixture by weight; ρ_C =2.253 g/cm^3 – the density of graphite; X_C – the proportional content of graphite powder in the mixture, by weight.

The weight of pore-former in a mixture of Fe-Cu-C-OP was determined according to equation:

$$m_{OP} = V_{OP} \cdot \rho_{OP},$$ (5)

where ρ_{OP} = 0.52 g/cm3 – density of organic pore-former; V_{OP} – pore-former volume in the mixture, cm3.

The volume of pore-former was calculated using equation (here OP – organic pore-former):

$$V_{OP} = V \cdot Y_{OP},$$ (6)

where Y_{SD} =0.09 – the proportional content of pore-former in the mixture (porosity of sintered bearings being 25-27%).

Weight of the mixture system Fe-Cu-C-OP calculated using equation:

$$m_{mix} = m_C + m_{Cu} + m_{Fe} + m_{OP},$$ (7)

where m_C – the weight of graphite in the mixture, g; m_{Cu} – the weight of copper in the mixture, g; m_{Fe} – the weight of iron in the mixture, g; m_{OP} – weight of pore-former in the mixture.

The mixture density from Fe-Cu-C-OP was calculated using equation:

$$\rho'_{mix} = Y_{OP} \cdot \rho_{OP} + 1 \cdot (1 - Y_{OP}) \cdot \rho_{mix}.$$ (8)

Mixing the components of the system Fe-Cu-C-OP was manually performed. In order to improve the homogeneity of the mixtures and reduce dusting of graphite during mixing, 2% kerosene (by weight) was added into the mixture [6, 19]. For all cases, the duration of mixing was 30 minutes. The volume of mixed components consists of 1/3 of the mixing chamber volume. At the end of the mixing process, the mixture was dried in hot air. The drying is necessary for removing the kerosene from the mixtures, because its presence significantly affects the fluidity of the mixtures, which causes difficulties in filling the mixture into the matrix. The obtained mixture of the system Fe-Cu-C-OP visually had a uniform distribution of components.

The compaction of ring samples was carried out by bilateral compaction, with stops without lubrication of the working surfaces of the press-form. The mixture compaction was performed with the help of a hydraulic compression testing machine model PSU-50, with a nominal force of 500 kN, without lubrication of the press-instrument working surfaces.

The compacted samples were sintered in a protective reducing atmosphere (carbon monoxide). According to the recommendations given in [1, 2, 6, 9], the sintering was held at a temperature of 1150°C. The heating rate was about 8-10 C/min. The samples were initially cooled in the furnace to approximately 800 C,

during 2 hours and then in oil. This cooling mode allows for obtaining samples with pearlitic structure and also improves their mechanical properties [6, 20]. It should be noted that in the process of sintering, the pore-former almost completely burned. The ash residue is not more than 0.3-0.5% by mass.

After 10 minutes, the samples were extracted from the cooling bath and placed in a cleaning bath for removing the ash residue from the pores. The process of cleaning was carried out using ultrasonic vibrations, during 45 minutes. After ultrasonic cleaning, the specimens were placed in warmed oil bath (120 C). After cleaning, the samples were impregnated with oil, heated up to $120°C$. To improve the operation properties of sintered samples, used for the oilimpregnating, graphite powder was added (particle size less than 20 microns), 20 grams in one liter of oil. The oilimpregnating process was performed during 2 hours. The specimens were 30 minutes left in a heated oil bath. Then, the samples were cooled in oil at room temperature, during 30 minutes [6]. It should be noted that cooling, cleaning and oilimpregnating of the samples were carried out in oil grade HH-32 (ISO 6743/4-82). According to the recommendation given in [19, 21], this oil has optimum viscosity and lubricity for sintered self-lubricated bearings. Then, the ring samples were calibrated to increase the accuracy of the finite size. The dimensions of the sample after calibration were: outer diameter – 42.4 mm, inner diameter – 28.1 mm, height – 10 mm.

Calibrated samples were cut into four parts and subjected to wear resistance test.

The wear tests of the porous samples were carried out on a universal friction machine model MI - 1M, which simulates the sliding of the shaft on the hub. During the tests, the linear sliding speed and the load were kept constant at 0.67 m/s and 320 N, respectively. Thus, the pressure on the friction surface was 1.8 MPa and the working parameter $p·V = 1.2$ MPa·m/s. The total testing time was 50 hours, which corresponds to the sliding distance of 120 km.

3. RESULTS AND DISCUSSION

The results of the tests on wear resistance of the samples system Fe-Cu-C with different particle size pores are shown in Table 1.

Table 1. Tests results on the resistance of the system samples Fe-Cu–C

Number	Pore size of samples after sintering, μm	Porosity, %	Mass wear, g	Linear wear, μm	Friction coefficient
1	less than 45	26.2	-	-	-
2	45 - 63	26.3	0.209	172.4	0.120
3	63 - 125	26.2	0.117	96.3	0.098
4	125 - 250	26.1	0.075	61.8	0.086
5	250 - 355	26.3	0.131	108.6	0.110
6	355 - 500	26.3	0.26	215.1	0.138

As seen from Table 1, the minimum wear was obtained for the sample with the pore size in the range 125-250 μm. The decrease or increase in the size of pores, from the specified ranges, leads to a deterioration of the antifriction properties. Reducing the pores size leads to increase the surface of the capillary channels formed in the body of compact. As a consequence, most of the oil is adsorbed by the surface capillary channels and has no opportunity to appear on the friction surface, which increases the wear of the samples. The increase of pore size reduces the

strength properties and the carrying capacity of the sintered material. In addition, enlargement of pores deteriorates and increases the wear-in time. It should be noted that the pore size more than 250 μm promotes an intensive projection of oil in the friction zone and from the end surfaces of the specimens. This leads to the rapid loss of the oil and, as a consequence, the loss of anti-friction properties. Besides, Table 1 shows that the sample with pore sizes less than 45 μm was inoperable.

Table 2. Results of test of samples manufactured at different oilimpregnating modes

Component content (% by weight)	Graphite presence in oil	Pore size after sintering, μm	Mass wear, g	Linear wear, μm	Friction coefficient
3%C + 9%Cu + 88%Fe	+	125 > 250	0.075	61.8	0.086
3%C + 9%Cu + 88%Fe	-	125 > 250	0.101	83.4	0.094

Table 3. Results of tests on determining the permissible parameter [p·V]

Load on the sample, N	350	380	410	440	470	500	530
Parameter p·V, MPa·m/s	1.3	1.4	1.5	1.6	1.7	1.8	1.9
Linear wear (μm) / friction coefficient							
	73.4/ 0.098	107.2/ 0.012	145.6/ 0.127	211.6/ 0.141	264./ 0.156	330.5/ 0.173	*
* Inoperable sample							

According to Table 2, the addition of graphite powder in oil helps to reduce the wear of the samples. It is possible that adding graphite powder in oil contributes to a significant increase in the number of structurally free graphite located in the bearing pores. During operation of friction pair, the graphite from the oil appears from the pores and reaches the sliding surface, where it forms layer of graphite and oil that reduces the friction coefficient. In this case, as seen from Table 2, the friction coefficient decreased 1.1 times. With the aim to determine the permissible parameter [p·V], series of experiments at a constant sliding speed (0.67 m/s) and a variable load were performed. It should be noted that the added graphite powder had a high dispersion in oil. For all cases, test time was 50 hours or until the complete loss of operating ability of the specimens. Test results are given in Table 3.

Analysis of the data in Table·3 shows that the loss of operating ability for the self-lubricated bearings occurred when the parameter [p·V] reaches the value of 1.9 MPa·m/s. According to references [1, 4, 6, 18], [p·V] for such material could be 1.6-1.7 MPa m/s. Thus, the control of pores size in manufacturing sintered self-lubricated bearings, as well as an additive to oil anti-friction additives - graphite powder of high dispersion, are improving their service characteristics and can increase the range of workloads and sliding speeds of the friction pair.

4. CONCLUSIONS

1. For self-lubricated sintered bearings, with certain composition and volume porosity, the pore size is an important characteristic, affecting the service characteristics.

2. The use of pore-formers in the manufacture of sintered self-lubricated bearings allows for obtaining materials with controllable pore size, which can operate in a reliable way, under various loading conditions: from self-lubrication mode to fluid friction mode.

3. In order to improve the service characteristics of self-lubricated sintered bearings, oilimpegnating was used and the authors recommend adding graphite powder of high dispersion. This promotes the formation of a colloidal lubrication between interfaced friction surfaces that reduces the friction coefficient and, hence, the wear of friction pair.

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