Surface morphology of bearing sleeves made of PM bronze and their properties

INTRODUCTION

In technologies of production of self-greasing bearings the porous framework is saturated with a liquid grease or grease material particles are introduced in the base powder. PM bronze or iron is used as material for bearing bases made with the use of powder metallurgy method [1]. The PM bronze sintering kinetics was described in paper [2]. A special group of bearings are bearings operating under increased temperature. They require special hard greases suitable for such conditions and resistant to oxidation. Results obtained on steel sinters [3] indicate that solid grease mixtures composed of micro-particles and nanoparticles in the quantity of 7-15% and size of 50-200 nm constitute an effective grease both under the ambient temperature and increased temperature. The grease is introduced, with the use of a pressure method, in the form of a solid grease suspension into the porous structure of the sinter, which leads to a formation of a thin layer of grease film on the internal surface of the sleeve [4, 5]. Paper [6] presents the results of tests on bronze sinters to be used for bearings. The influence of unit pressing pressure on the density, mechanical properties of bronze sinters and surface morphology has also been developed. This paper specifies the sinter properties in the form of sleeves for infiltration with the use of MoS2 nanoparticles assuming parameters of their production specified in the paper [6].

OBJECTIVE

The objective of the test included the assessment of the surface condition and mechanical properties of sleeves made of PM bronze after such operations as sintering, calibration and calibration with densification.

- The tests made on the sleeve included:
  - determination of the density depending on the technological process conducted,
  - observation of the surface condition with the use of a scanning electron microscope (SEM),
  - tests on mechanical properties of sleeve during a technological compression test,
  - delivery of an experimental self-greasing bearing with its surface layer modified by MoS2 particles and tribological tests.

CHARACTERISTICS OF THE MATERIAL TO BE TESTED

The tests were performed on samples made of Bromix powder in the form of sleeves and in various stages of production, i.e. after:

- pressing and sintering,
- pressing, sintering and calibration,
- pressing, sintering, calibration and calibration with densification.

Samples with the weight of 29.9 g and size of ø29/ø24.5×22.7 mm, were cold-pressed under the unit pressure of 400 MPa. Such samples were then sintered in the dissociated ammonia atmosphere: 10 minutes in the temperature of 610°C and then 20 minutes in the temperature of 920°C. After sintering some of the samples had their internal diameters calibrated. Following the calibration the density was 6.70 g/cm3 (Tab. 1). Some of the calibrated samples were also calibrated and densified with the use of unit pressure of 300 MPa. As a result of such operations, samples were obtained with the height of 17 mm and average density of 7.08 g/cm³.

SLEEVE TESTS

The sleeve surface after calibration and calibration with cold densification

The condition of the sleeve surface was observed after calibration of internal surface and calibration with densification. The surface condition was documented as regards selected locations of the front surface as well as internal and external surface of the sleeve. The tests were conducted with the use of Hitachi S-3500N scanning microscope. The results of the observations of the surface after calibration are presented in Figure 1, and after calibration with densification in Figure 2.

Mechanical properties of the sleeve

The radial compression test was conducted on the sleeve placed between flat boards and under load set as presented in Figure 3. During loading, the force was measured as a function of the path of deformation expressed by an absolute change of the sleeve diameter (Δd). On the basis of the tests, the relation of F/h to Δd was determined, where the respective values were arrived at: F – force, h – height of the sleeve, d – ring diameter. Figure 4 presents the changes of the F/h relative force in relation to Δd absolute deformation during the compression of the sleeve. As a measure of the yield strength of these materials, for comparative purposes the F/y force corresponding to permanent deformation of the sleeve in relation to the material height was assumed. Table 2 presents the measured parameters and determined values of F/y and angle of inclination.

<table>
<thead>
<tr>
<th>Material</th>
<th>Density, g/cm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample</td>
<td>Mean</td>
</tr>
<tr>
<td>Calibrated sample</td>
<td>6.72</td>
</tr>
<tr>
<td>Calibrated and densificated sample</td>
<td>7.07</td>
</tr>
<tr>
<td>6.69</td>
<td>6.69</td>
</tr>
<tr>
<td>7.08</td>
<td>7.08</td>
</tr>
</tbody>
</table>

Table 1. Results of density measurements of samples following calibration and calibration with densification

Tabela 1. Wyniki pomiarów gęstości próbek po kalibracji i po kalibracji z dogęszczaniem

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tangent of a straight section in the compression curve that is a measure of Young modulus.

Samples to be bent were cut out of the sleeve parallel to their axis. Such samples were bent in three points after calibration and calibration with densification. The distance between supports was 14 mm. The bending strength values are presented in Table 3.

Tribological tests of the self-greasing bearing with its surface layer modified with MoS₂.

The technological process of production of pilot sleeves was conducted in accordance with established parameters using the following operations: pressing, sintering in the atmosphere of dissociated ammonia, calibration, modification of the surface layer and calibration with densification.
After calibration, the sleeves are subject to modification of the surface layer with the use of a composite mixture with a 20% content of MoS2 submicrometric powder and PC-2 pressure equipment (developed by the Metal Forming Institute). PC-2 chamber generates a pressure of 30 MPa, which allows an infiltration of the open porous structure of the sleeve with sulfide nanoparticles (Fig. 5, 6).

A thin layer of grease film is created on the internal surface of the sleeve in the form of sulfide aggregate made of microparticles and nanoparticles of the size of 50÷200 nm. (Fig. 7a, b). Following the modification of the surface layer, the sleeves were calibrated with densification. The pores were measured with the use of Eclipse light microscope on the sleeve surface following the calibration (Fig. 8a) and the calibration with densification (Fig. 8b). Results of the pore measurements are presented in Table 4.

Friction and wear tests

The tribological tests for the sleeve-roll friction pair were conducted in the Laboratory of Surface Engineering and Tribology at INOP in Poznań with the use of TWT-500N high-temperature tribological tester. The tests covered sleeves made of Bromix powder and cooperating with a roll made of 100Cr6 hot-machined steel with the hardness of 51÷52 HRC. The tests covered the sleeve with its surface layer modified with MoS2 submicrometric particles as well as a comparative test without modification of the surface layer.

The friction and wear tests were realized in the following conditions: the temperature of 300°C, roll rotating speed of 60 rev/min,

Table 2. Results of the radial compression test of the sleeve

<table>
<thead>
<tr>
<th>Material</th>
<th>No. of sample</th>
<th>Dimensions</th>
<th>$F$, N</th>
<th>$\sigma_g$, MPa</th>
<th>$\sigma_g$, MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calibrated sample</td>
<td>1</td>
<td>5.40, 2.76</td>
<td>303.80</td>
<td>621</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>3.70, 2.76</td>
<td>178.20</td>
<td>531</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>3.60, 2.76</td>
<td>241.40</td>
<td>740</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>4.80, 2.76</td>
<td>250.80</td>
<td>575</td>
<td></td>
</tr>
<tr>
<td>Calibrated and densificated sample</td>
<td>1</td>
<td>5.25, 2.90</td>
<td>368.90</td>
<td>712</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>3.25, 2.90</td>
<td>211.80</td>
<td>651</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>5.50, 2.90</td>
<td>433.90</td>
<td>788</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>2.40, 2.90</td>
<td>169.80</td>
<td>707</td>
<td></td>
</tr>
</tbody>
</table>

For after calibration, the sleeves are subject to modification of the surface layer with the use of a composite mixture with a 20% content of MoS2, submicrometric powder and PC-2 pressure equipment (developed by the Metal Forming Institute). PC-2 chamber generates a pressure of 30 MPa, which allows an infiltration of the open porous structure of the sleeve with sulfide nanoparticles (Fig. 5, 6). A thin layer of grease film is created on the internal surface of the sleeve in the form of sulfide aggregate made of microparticles and nanoparticles of the size of 50÷200 nm. (Fig. 7a, b). Following the modification of the surface layer, the sleeves were calibrated with densification.

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The friction and wear tests were realized in the following conditions: the temperature of 300°C, roll rotating speed of 60 rev/min,
variable load from 50 to 300 N. The load of the friction pair was changed every 7200 cycles (revolutions). The friction and wear coefficients of the friction pair were determined on the basis of a change of the roll and sleeve weight. Figure 9 presents the results of the friction and wear tests. Table 5 presents the mass wear of individual friction elements and Figure 10 presents the percentage wear and tear.

SUMMARY

Calibration and calibration with densification lead to an increase in the density of the sinter as a result of such operations and change of the surface morphology. The calibration mainly leads to changes on the internal surface of the sleeve and calibration with densification leads to changes on the front, internal and external surface. The changes are characterized by decreased pores as well as narrowing of the measurement tolerances of products.

The tests on mechanical properties were made as a part of the technological compression tests of the sleeve and bending tests of the sleeve samples cut out of the sleeve parallel to their axis. The parameters of evaluation of the properties in the radial compression test included: relative force corresponding to yield strength ($F$) related to the sample height ($h$) and angle of inclination ($\alpha$) of the
Fig. 8. The structure, on which pores were measured: a) the sleeve after calibration, b) the sleeve after calibration with densification

Rys. 8. Struktura, na których wykonano pomiary wielkości porów: a) tuleja po kalibrowaniu, b) tuleja po kalibrowaniu z dogęszczaniem

Fig. 9. The value of the friction coefficient for the sleeve: a)÷c) with the modified surface layer, d) without modification

Rys. 9. Wartość współczynnika tarcia dla tulei: a)÷c) z modyfikowaną warstwą wierzchnią, d) bez modyfikacji

Table 5. Change of weight of the friction pairs

<table>
<thead>
<tr>
<th>No. of friction pair</th>
<th>Mass of the sleeve g</th>
<th>Mass of the shaft g</th>
<th>Weight loss g</th>
<th>Wear %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before test</td>
<td>After test</td>
<td>Before test</td>
<td>After test</td>
<td></td>
</tr>
<tr>
<td>1 32.7465</td>
<td>32.6285</td>
<td>64.01325</td>
<td>64.013</td>
<td>0.11615</td>
</tr>
<tr>
<td>2 32.9798</td>
<td>32.949</td>
<td>64.1904</td>
<td>64.19</td>
<td>0.0308</td>
</tr>
<tr>
<td>3 33.0275</td>
<td>32.9818</td>
<td>64.1576</td>
<td>64.157</td>
<td>0.0457</td>
</tr>
<tr>
<td>4 32.65315</td>
<td>32.4556</td>
<td>61.4016</td>
<td>61.3961</td>
<td>0.19755</td>
</tr>
</tbody>
</table>

straight section within the yield range on the compression curve. For sintered and calibrated materials it was $F/h = 22-36$ N/mm and after calibration with densification $29-45$ N/mm for the compression speed of 5 mm/minute. The angle ($\alpha$) of the straight section within the yield deformation was $89.10-89.50^\circ$ for calibrated sinters and $89.10-89.70^\circ$ for sinters that were calibrated and densified. Apart from the condition of the material, the values of $F/h$ and $\alpha$ depend on the density of the material. They indicate a favourable impact of the calibration and calibration with densification onto the characteristics of the obtained materials. In the bending of the samples cut out of the sleeve in three points the average bending strength was 617 MPa and after calibration with densification it reached 712 MPa.
After calibration the sleeves were subject to surface layer modification. The sinters were characterized by the density of 6.70 g/cm$^3$ and pore measurements of 25÷134 μm. The modification of the surface layer was made with the use of MoS$_2$ powder with manometric structure. As SEM observations showed in turns, sulfide nanoparticles penetrate the porous structure of the sinter and a thin layer of a greasing film is formed on the internal surface. After modification of the surface layer, calibration with densification was conducted on the sleeves.

The friction and wear tests conducted on the sleeves made is possible to determine a friction and mass wear coefficient for the friction pairs. The tests were made in the temperature of 300°C and with variable load. The friction coefficient for the sleeve with its surface modified was from 0.04 to 0.06. To compare, the friction coefficient for the sleeve without a greasing film was 0.1. In all cases during the first stage a period of running-in of the friction pair system was observed, following which, the process was characterized by a stable course. No seizure symptoms were observed.

**CONCLUSIONS**

The conducted tests enable formulating the following conclusions:
- calibration and densification at the height of the sample cause changes in the surface morphology of sintered products. Calibration mainly causes changes in the internal surface of the sleeve and calibration with densification causes changes in the front, external and internal surface,
- radial compression tests of the sleeve as well as three-point bending tests showed a favourable impact of calibration and calibration with densification onto characteristics of the produced materials. The values of $F_o$ and $h$ depend on the condition and density of the material,
- the three-point bending test confirmed the existence of a trend for change in properties of the material during radial compression. The average bending strength for the material after calibration was 617 MPa and after calibration with densification 712 MPa,
- the modification of the surface layer of the sleeve with the use of MoS$_2$ sulfide nanoparticles has an impact on their strength and leads to a decrease of the friction coefficient,
- the friction coefficient for the sleeve with its surface layer modified was characterized by a stable course and amounted to 0.04 to 0.06. For the sleeve without a greasing film the friction coefficient value was 0.1. The mass wear of the sleeve with its surface layer modified is lesser and ranges between 0.09-0.35%.

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**REFERENCES**