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DEVELOPMENT OF NANOSTRUCTURING TECHNIQUE TO PRODUCE PM - PARTS WITH IMPROVED TRIBOLOGICAL PROPERTIES

H. WIŚNIEWSKA-WEINERT, V. LESHCHYNSKY*
Ł. KĘDZIA and J. OZWONIAREK
Metal Forming Institute
Jana Pawla II Str. No 14, 61-139 Poznan, POLAND
e-mail: kedzia@inop.poznan.pl

M. IGNATIEV
Moscow Institute of Electronic Technique
Moscow, RUSSIA

E. KOVALEV
A.A. Baikov's Institute of Metallurgy and Material Science
Moscow, RUSSIA

The authors of the article present nanoparticles impregnation technique developed at the Metal Forming Institute (Poznan) for the production of sintered powder parts characterised by a low friction coefficient at high temperatures. The powder forging of the precision high performance structural components is of great importance to achieve a definite material density. This study is focused on deformation of PM- parts, e.g., sleeve bearing during precision cold forging. The results relate to sleeve bearing fabricated by the method of forging powder parts impregnated with mixtures of oil and specially developed nanoparticles with desired solid lubricating properties. A proper strain distribution during plastic deformation of particulate material was achieved by optimizing technological parameters. The results of a tribological examination of impregnated PM – parts were evaluated to optimize tribological properties of nanocomposites.

Key words: powder bearing, solid lubricant, nanoparticles, friction coefficient.

1. Introduction

Wear of bearings can be reduced by reducing the friction between the moving components. This also eliminates the need for a heavy, complex and expensive cooling and lubricant systems in engines and other machines. Thus, self lubricating powder components have attracted great attention. Advanced PM technologies have been used to produce low cost high quality bearings and gears with long-term performance and reliability in critical applications (high loads and sliding velocities, high temperatures). Self-lubricated porous bearings, such as sintered bearings which are impregnated with oils and solid lubricant (Leshchynsky *et al*., 2002), are extensively used in various industrial applications. However, an effective and carefully controlled impregnation of porous bearings with various types of lubricant and its additives is still a challenge. Some problems exist in MoS_2 particles due to its platelet shape and high quantities of the particles in a liquid-particle suspension. The second problem is that it is difficult to develop dry porous bearings that are effective in high temperature friction.

Therefore, the use of solid lubricants in the cases of dry friction and boundary lubrication is expected to substantially improve the contact conditions by film generation. A solid lubricant composite impregnated and anchored in the open porosity is introduced (Rao *et al*., 1999) and the solid film lubricant is shown to be

* To whom correspondence should be addressed

stable up to temperatures of about $370^{0}C$ (Rao *et al.*, 1999). This work is aimed at studying the surface modification technology of the sliding bearings with various solid lubricants and the bearing friction properties at the operation temperatures up to $300^{0}C$.

2. Experimental procedure

The experiments were conducted using Ni80Cr20 powder (AMETEK) particle size of $80-120\mu m$. The main characteristics of the technology operations are summarized in Tab.1. The powder compaction and forging of rings (outer diameter-*20.2mm*, inner diameter-*14.3mm*, height-*10mm*) were carried out using the special tooling installed in the test machine. After compaction and deformation, the density of compact was measured by Archimedes's method. Tribology tests were performed with a ring-on-shaft tester with a steel shaft of hardness of 45HRC. Energy Dispersive Analysis and Scanning Electron Microscopy were conducted before and after the friction tests.

Table 1. Technology operations parameters.

<table>
<tr><th>Operation</th><th colspan="2">Main parameters</th></tr>
<tr><td>Preparation of the mixture</td><td colspan="2">Powder composition on the base of -Ni80Cr20 powder</td></tr>
<tr><td rowspan="2">Ring Compaction</td><td>Mass</td><td>$m=10.1^{+0.02}g$</td></tr>
<tr><td>Porosity</td><td>*24%*</td></tr>
<tr><td rowspan="3">Sintering</td><td>Atmosphere</td><td>Vacuum</td></tr>
<tr><td>Time</td><td>*0,5h*</td></tr>
<tr><td>Temperature</td><td>$1120^{0}C$</td></tr>
<tr><td rowspan="4">Vacuum vibro impregnation</td><td>Time</td><td>*1h*</td></tr>
<tr><td rowspan="3">Impregnation mixture</td><td>A - MoS_2 +oil</td></tr>
<tr><td>B - WS_2 +oil</td></tr>
<tr><td>C - $MoS_2+Cr_2O_3$ +Graphite+oil</td></tr>
<tr><td rowspan="3">Drying</td><td>Number of cycles</td><td>1-8</td></tr>
<tr><td>Temperature</td><td>$100^{0}C$ start of drying
$250^{0}C$ temperature of drying</td></tr>
<tr><td>Time</td><td>$1h/250^{0}C$</td></tr>
<tr><td rowspan="2">Surface Deformation</td><td>Strain</td><td>*20%*</td></tr>
<tr><td>Porosity of surface layer</td><td>*14-16%*</td></tr>
<tr><td>Tribology tests</td><td colspan="2">Ring-on-shaft test were made with load *100N* at $20^{0}C$ and $300^{0}C$</td></tr>
</table>

3. Results and discussion

3.1. Impregnation

The experimental results are presented in Fig.1. The results demonstrate that vibrations facilitate penetration of solid lubricant particles into a porous network. The type of impregnating mixture influences the kinetics of a carrier oil evaporation (Fig.1b). In the case of impregnating oil containing graphite, the evaporation rate is maximized, implying that it is more effective to apply the complex impregnating mixtures than applying MoS_2 +oil. The time dependence of evaporation rate reveals about a regular diffusion kinetic for all impregnating compositions. It allows a prediction of the content of oil or other carrier liquid in the pores of bearing.

a) b)

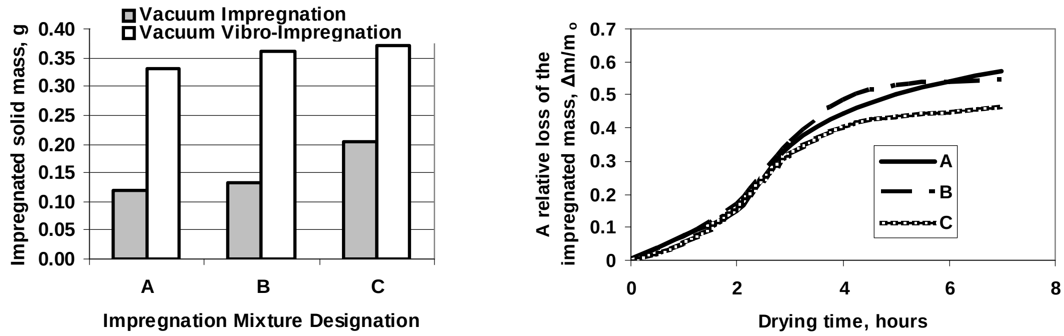


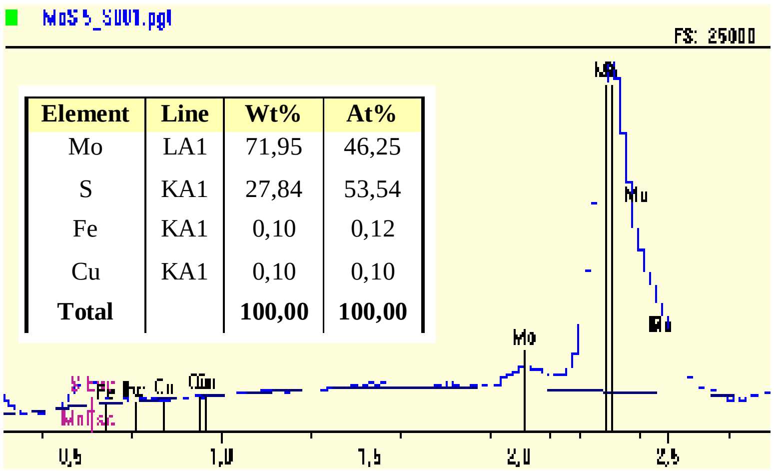
Fig.1. Comparison of impregnated masses (a) and kinetics of drying process (b) for impregnation compositions listed in the Tab.1.

3.2. Surface deformation

The aim of forging and surface deformation operations is to identify the relation between pore and solid material areas at a sliding surface of a porous bearing. Powder forging was realized according to (Wiśniewska-Weinert *et al*., 2002) and drawing internal diameters with MoS_2 was done to obtain the surface porosity of *15-18%* and to generate additional solid lubricant film.

The last operation results in the creation of continuous MoS_2 solid lubricant film. The data shown in Fig.2 proves this statement. Based on these results, it is clear that the surface deformation results in generation of MoS_2 nano-sheets (Fig.2b) which comprise about *7%* of surface area.

a)



Element	Line	Wt%	At%
Mo	LA1	71,95	46,25
S	KA1	27,84	53,54
Fe	KA1	0,10	0,12
Cu	KA1	0,10	0,10
Total		**100,00**	**100,00**

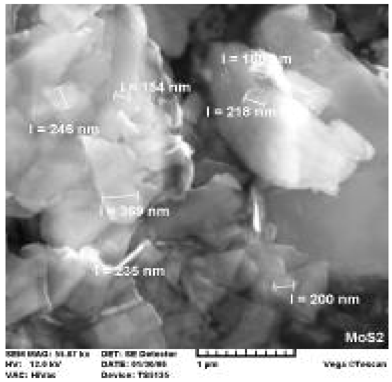


Fig.2. EDS analysis (a) and SEM image (b) of surface after drawing.

3.3. Tribology

Friction test results (Fig.3) show that mixed lubrication in really dry test conditions was successfully achieved without any oil added on the sliding interface for the MoS_2 (case 1) and WS2 (case 2). An example of friction curve for high temperature (case 3) clearly shows the stable friction regime for only *80,000* cycles. However, even in this case, we observed that the impregnation mixture *C* has a beneficial lubrication effect on the friction coefficient. We believe that the low hardness of the ring results in low durability of this friction pair, and this effect will be taken into account in further research.

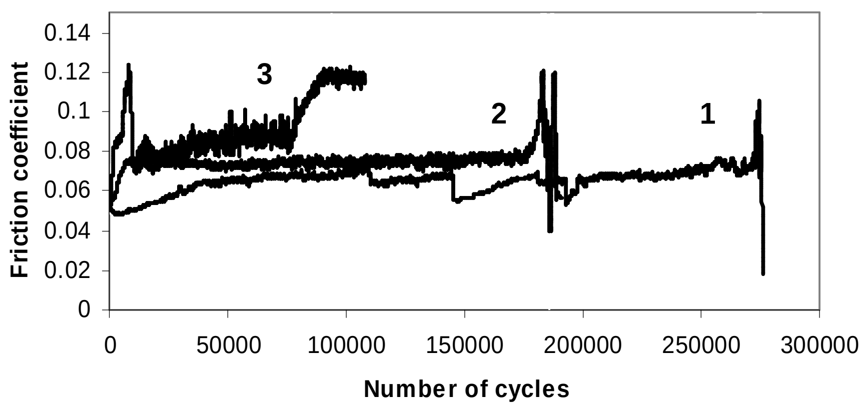


Fig.3. Tribology test results 1-impregnation mixture A, $T = 20^0 C$; 2-impregnation mixture B, $T = 20^0 C$; 3-impregnation mixture C, $T = 270^0 C$.

SEM examination of the structure topography after the friction test as shown in Fig.4 shows that a pore closure occurs in the areas of high contact loads (Fig.4a). It is because of a softening material due to heat generated at the friction contact. The distance between pores greatly influences friction conditions because the pores are the main source for solid lubricant film generation. The solid lubricant film is relatively soft because of the layered structure of the lubricant. However, it is important to consolidate solid lubricant film's grip on the surface. Thus, the surface deformation is a very important technology step. The solid lubricant film areas are shown in Fig.4b.

a) b)

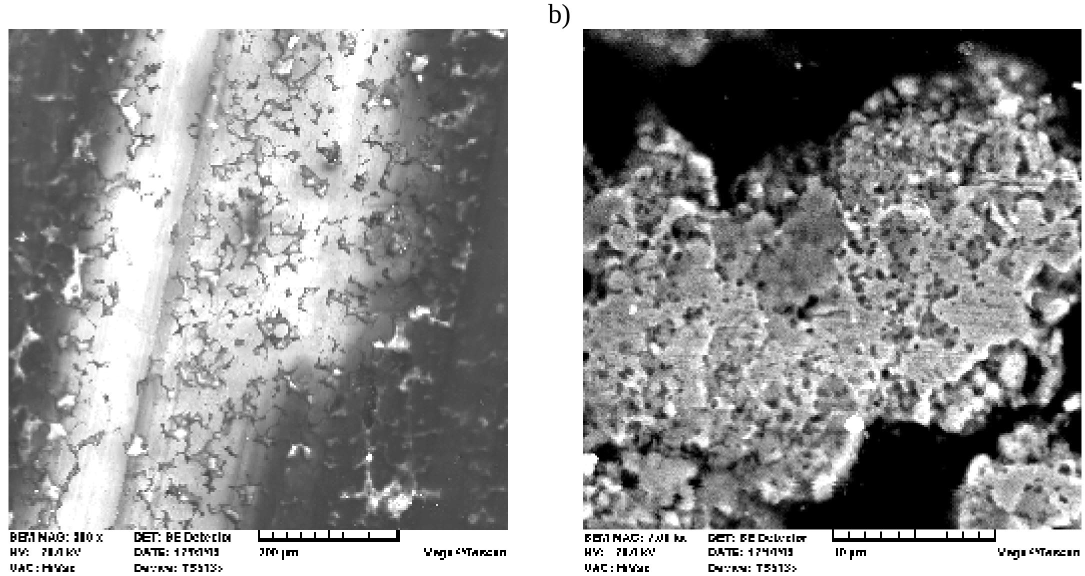


Fig.4. SEM images of sample impregnated with composition A after friction test with regime 1 (Fig.3): area of sliding with open and closed pores (a); high magnification image of solid surface (b).

4. Conclusion

The complex PM surface deformation technology with vibratory impregnation was developed for solid lubricant embedded bearings.

Solid lubricant films generated at the interface “shaft-impregnated bearing” were found to be effective in boundary and mixed lubrication regime both at ambient and high temperatures.

Some features of the surface porous structure were found to influence friction properties governed by the generation of a solid lubricant film in spite of the absence of liquid.

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