FRICITION AND WEAR OF SELF-LUBRICATING BEARING COMPOSITES INCLUDING FULLERENE-LIKE WS₂ AND MOS₂ NANOPARTICLES

L. RAPOPORT ¹, W. LESCHINSKY ¹, Y. FELDMAN ², M. LYOVSKY ¹, Y. VOLOVIK ¹, R. TENNE ²

¹ Holon Academic Institute of Technology, Holon 58102, ISRAEL; e-mail: rapoport@barley.cteh.ac.il
² Weizmann Institute of Science, Rehovot 76100, ISRAEL; e-mail: reshef.tenne@weizmann.ac.il

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1 INTRODUCTION

Modern Powder Metallurgy (P/M) technologies are used to produce low cost high quality bearings and gears with long-term performance and reliability in critical applications (high loads and sliding velocities). One of the main advantages of P/M technology is the possibility to provide controlled porosity for self-lubrication. In order to increase loading parameters of the bearings, solid lubricants like WS₂ and MoS₂ are usually included as additives to powders under sintering. The solid lubricants used are layered materials (e.g., platelets of 2H – MoS₂).

In the past few years, inorganic fullerene-like (e.g., IF) supramolecules of WS₂ and MoS₂ materials with structures closely related to (nested) carbon fullerenes have been synthesized [1, 2]. Recent experiments showed that IF possess lubricating properties superior to those of 2H platelets in a wide range of operating conditions, for example at various concentrations and load/speed ratios [3]. However, the slippery nature of these nanoparticles leads to their fast displacement from the contact area, and consequently the efficacy of their lubrication rapidly vanishes. By confining the IF nanoparticles inside a porous and densified solid matrix, their slow release to the metal surface is expected to alleviate both friction losses and wear, while assuring the mechanical integrity of the composite. It is expected that the creation of densified powder matrix including nanoparticles of a solid lubricant with and without oil allows to develop new powder composites with largely improved mechanical properties.

The results of friction and wear experiments with powder composites were presented recently [4]. The main issue of this work was to develop self-bearing materials impregnated with 2H and IF solid lubricants and to check their friction and wear behaviour.

2 EXPERIMENTAL PROCEDURE

Bronze-graphite, iron-graphite and iron-nickel-graphite composites were chosen as the materials for powder matrices, Table 1. The porous structure was achieved by introducing organic materials (foaming agents). The single heating cycle included sintering of the composites and volatilizing the foaming agents. The first compaction was performed under low pressures. Sintering of the specimens was carried out in a protective hydrogen atmosphere at temperatures of 750 and 1050 °C for the bronze, iron and iron-nickel samples, respectively. Volatilizing of the foaming agents was accomplished by heating the matrix to 550 °C for 30 min in air. A well mixed suspension of the solid lubricant particles in mineral oil was vacuum impregnated into the porous materials. For volatilizing the oil, the samples were dried at T = 150 °C during 24 hours. Subsequently, the samples were recompacted in order to obtain uniform density distribution. The final value of porosity after repressing was about 27…30 % for all studied porous matrixes.

Friction and wear behavior of IF-WS₂ nanoparticles with the sizes close to 120 nm and IF- MoS₂ were compared with commercially available layered WS₂ particles (2H) with average size close to 4 µm.

In order to determine the tribological properties of self-bearing composites, two series of friction experiments were carried out. One of them was the evaluation of the critical load of a transition to seizure. On the other hand the wear rate of powder composite was determined in long-term experiments. The tribological tests were performed at laboratory atmosphere (~50 % humidity) using a ring-block tester at loads of 150-1200 N and sliding velocity of 0.5-1.7 m/s. To prepare the curved metal surface for the measurement, a run-in period of between 10-30 hr was performed, during which the load was slowly increased to 300 N. Intermissions for examination of the bearing surface with optical and scanning electron microscopes (SEM); energy dispersive X-ray spectroscopy (EDS); X-ray photoelectron spectroscopy (XPS), and with tip profiler were made from time to time during the run-in period and in the experiment itself.

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<table>
<thead>
<tr>
<th>Material</th>
<th>Bronze-graphite</th>
<th>Iron-graphite</th>
<th>Iron-nickel graphite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>95.5</td>
<td>48.5</td>
<td></td>
</tr>
<tr>
<td>Cu</td>
<td>86</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>Sn</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ni</td>
<td>4</td>
<td>3</td>
<td>48.5</td>
</tr>
<tr>
<td>Graphite</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Composition of sintered materials, wt%


3 RESULTS

Scanning electron microscopy of powder samples showed non-uniform distribution of 2H platelets on the surface of the metal matrix. This phenomenon occurred due to “glueing” of these particles edge-on to the metal surface through their reactive prismatic faces (\(10 \bar{1} 0\)). The sticking of the prismatic edges of the 2H platelets to the metal surface averts their permeation deep into the metal piece and leads to their accumulation at the metal surface. It is found that this orientation diminishes the efficacy of the tribological action of such particles [4]. Contrarily, the IF nanoparticles are scattered quite randomly in the porous metal matrix due to their slippery nature, Fig 1.

It is established that the impregnation capacity of porous metal matrices with oil-IF suspension is much higher than with 2H-oil suspension.

Bronze-graphite sample, which was oil impregnated and dried (hereafter designated- reference), was studied first. The following values of wear coefficients were obtained under load of 300 N and sliding velocity of 1 m/s, for bronze-graphite; + 2H, and + IF, respectively: \(K_w \times 10^{-10} = 8.9; 3.3; 2\). The friction coefficients were similar for all the samples studied under this load.

It was established that the surface pores of the reference sample are rapidly filled with agglomerated wear particles already under the low load of 300 N. The agglomeration and compaction of the wear particles in the pores led to a formation of smooth surfaces. With load increasing, severe plastic deformation of the surface layers was obtained, Fig. 2. The fast agglomeration and compaction of the wear particles within the pores and the severe plastic deformation of the surface layers led to increasing of the friction coefficient, contact temperature and wear rate. A lot of small pores were preserved on the surface of powdered bronze impregnated with IF under steady friction state, Fig. 3.

With load increasing the detached and trapped wear particles fill the pores, but a fraction of the pores remained opened nevertheless. The accumulation of 2H particles in the pores leads to formation of thin WS2 film on the surface of powder sample. Under low load this film really provides the low friction coefficient and the wear rate, but with load increasing, WS2 film is cracked. The critical load of transition to seizure was essentially higher for sintered materials with IF-WS2. The transition to seizure occurred under \(PV = 950\), while it was 300 and 570 for reference and impregnated with 2H particles, respectively. SEM showed that the transition to seizure for all samples occurred when the pores on the surface were filled by agglomerated wear particles and a smooth surface was obtained.

![Fig. 1: IF nanoparticles impregnated in bronze-graphite matrix](image1)

![Fig. 2: Severe plastic deformation of reference bronze sample](image2)

![Fig. 3: Preservation of pores on the surface of bronze + IF nanoparticles in steady friction state](image3)

Similar values for the friction coefficient and wear rate were observed under low loads (300 N) for the iron and iron-nickel samples with 2H and IF particles impregnated. These parameters were substantially higher for the reference sample under low loads. The efficacy of IF was increased with the load. It was found that part of
the pores for the iron surfaces with 2H and IF are filled with the agglomerated wear particles, while the other pores remain open. However, the number of open pores was appreciably higher for the powdered composite with IF nanoparticles. Tip profiler measurements of the tested samples showed that the surface of the reference iron sample was smoother than the blocks impregnated with either IF or 2H powders. The roughness parameter, \( R_{\text{pp}} \), was 0.25, 1.36 and 1.44 \( \mu \text{m} \) for the reference, IF and 2H lubricated surfaces, respectively.

The effect of the load on the friction coefficient for the iron-nickel samples is shown in Fig. 4. The critical point for the transition to seizure was 700 N for the block impregnated with IF, while it was 475 N for the sample impregnated with 2H-WS\(_2\) particles. Examination of the SEM images along the tribological tests provides a qualitative assessment of the pore feeling phenomenon. During the transition to seizure a large fraction of the pores become closed and smooth surfaces are formed.

Friction and wear of sintered materials can be considered on the basis of a third body phenomenon [5-7]. The lose wear particles at the metal interface can participate in the friction process as a lubricant. When third body presents detached and trapped wear particles in the case of friction with reference porous sample, the severe plastic deformation of surface layers occurs and the great wear particles are delaminated. It is believed that the roll shape of IF nanoparticles provide the easier shear both as between first and third bodies and inside of third body (between wear particles).

2H particles were found to be edge-on glued to the underlying metal surface through their reactive prismatic faces (10 1 0) [4]. The sticking (“gluing”) of the prismatic edges of the 2H platelets to the metal surface averts their permeation deep into the metal piece and leads to their accumulation at the metal surface. The accumulation of 2H particles in the pores leads to formation of thin WS\(_2\) film on the surface of powder sample. Under low load this film really provides the low friction coefficient and the wear rate, but with load increasing, WS\(_2\) film is cracked and the tribological properties are diminished.

4 DISCUSSION

It was established that the steady friction state is associated with the formation and elimination of agglomerated wear particles from the pores. The pores are filled by agglomerated and compacted wear particles during a short time. With a following loading the pores are closed and smooth surface of powdered block is covered by the adhered wear particles that leads to formation of rough surface. It is supposed that the IF nanoparticles limit the adhesion between the wear particles and the surface of pores and thus allows to preserve the equilibrium between filling and elimination of wear particles from the pores in the steady friction. The small pores filling by IF provide the support of high loads under friction of powdered IF impregnated samples. At the same time the preservation of IF nanoparticles in the contact facilitates the shear of the lubrication film and thus it improves greatly the friction properties of contact under high load.

The impregnation of IF nanoparticles into the pores allows to improve all the tribological properties as friction coefficient, wear rate and the critical load of a transition to seizure.

Decreasing the friction coefficient with IF is determined apparently by the following effects:

1. the slow release and furnishing of nanoparticles from open pores to contact preserve straight contact of first bodies.

2. the sliding/rolling of IF in the boundary with first bodies and between wear particles inside of third body facilitate the shear of lubrication film.

3. the limitation of the adhesion of agglomerated wear particles in the pores allows to preserve the open pores on the contact surface with a loading.

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5 CONCLUSION

The effect of load on friction, wear and the transition to seizure for powdered bronze-graphite, iron-graphite and iron-nickel-graphite composites impregnated with oil, 2H and IF lubricant has been studied. It was found that the impregnation of IF into the pores allows to improve the tribological properties of the powdered composites in comparison to application of 2H-WS\(_2\) solid lubricant. The transition to seizure is determined by the adhesion of wear particles when all pores on the surface are practically closed that limits a furnishing of solid lubricant to the contact surface.

The main advantages of IF is in slow release and furnishing of nanoparticles from the open pores, sliding/rolling of IF between rubbing surfaces and in limitation of the adhesion of agglomerated wear particles in the pores. The model of third body was used in order to explain the effect of wear particles, oil and solid lubricant particles on friction and wear behavior of powdered composites.
6 REFERENCES