EFFECT OF STRUCTURE ON THE FRICTIONAL BEHAVIOR OF A COPPER-TITANIUM-CARBIDE COMPOSITE

N. G. Baranov, Yu. N. Semenov, and N. P. Brodnikovskii

As is well known, high wear resistance under dry sliding friction conditions is exhibited by materials with heterogeneous structures composed of both hard and softer, ductile constituents. However, there is as yet no general agreement as regards the optimum size of the hard inclusions [1-4]. In view of this, in the present work a study was made of a model sintered composite material consisting of a copper matrix and titanium carbide inclusions of various sizes.

The method of manufacture adopted enabled parts to be produced where the amount and particle size of the strengthening phase could be varied within wide limits. Because of the absence of chemical reaction between the titanium carbide component and the copper matrix [5], the model was characterized by high thermodynamic stability. Specimens were produced from PMS-1 copper powder to GOST 4960-68 and a titanium carbide powder of the following chemical composition (in %): titanium 79.9, combined carbon 17.6, and free carbon 0.14. The titanium carbide fractions employed - 1/0, 28/20, and 60/40, to GOST 9206-70 - were prepared, using centrifuges, by the sedimentation method.

The copper and titanium carbide* powders were mixed in a VA-100 eddy-bed apparatus [6]. To prevent contamination of the charge and comminution of the titanium carbide grains, mixing was performed in a special PVC container with PVC-coated milling elements. The titanium carbide content was varied from 0 to 20 vol.%. Specimens were pressed under a pressure of 4 tons/cm², pre-sintered for 15 min at 900°C, re-pressed under a pressure of 10 tons/cm², and finally sintered for 2 h at 900°C.

The porosities of specimens were determined by the hydrostatic weighing method.

Wear tests on specimens were carried out, using the apparatus and procedure described in [7], in air at room temperature. The specimens were rings of 40-mm o.d. and 30-mm i.d. The sliding speed was 0.1 m/sec and the load 10 kg/cm². The mating element material was ZhS-6 heat-resisting alloy (a cast Ni-Cr-Mo-W-Al-Ti superalloy) heat treated (by quenching from 1200°C and annealing for 2 h at 1050°C) to HRC 35 hardness. The testing parameters selected ensured the best conditions for revealing the effect of structure on the frictional behavior of the material investigated.

X-ray structural studies were carried out, using copper radiation, in a URS-501 diffractometer. The x-ray diffraction investigation showed that the addition of TiC particles had broadened the lines of copper and increased the parameter of the fcc copper lattice (Table 1). Within the ranges investigated the lattice parameter was apparently unaffected by the concentration and particle size of the strengthening phase.

Examinations of microsections with an MIM-8 microscope demonstrated that the materials investigated had fine-grained microstructures with evenly distributed TiC particles.

The effects of the amount and particle size of the strengthening component on the porosity of parts after re-pressing and final sintering are depicted in Fig. 1a. It will be noted that the porosity of the material grew with decrease in TiC particle size as well as with increase in TiC content.

*The TiC powders were subjected to ovalization in the VA-100 apparatus by a process developed at the Special Design and Technology Office of the Institute of Materials Science, Academy of Sciences of the Ukrainian SSR.

Fig. 1. Variation of porosity (a), specific wear (b), coefficient of friction (c) and hardness (d) with titanium carbide content and grain size. TiC grain size: 1) 1/0; 2) 28/20; 3) 60/40.

TABLE 1. Effect of Titanium Carbide Content and Particle Size on Lattice Parameter of Copper

<table>
<thead>
<tr>
<th>TiC content, vol.%</th>
<th>TiC grain size</th>
<th>Lattice parameter, Å</th>
<th>TiC content, vol.%</th>
<th>TiC grain size</th>
<th>Lattice parameter, Å</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>3.6147</td>
<td>0</td>
<td>1/0</td>
<td>3.6154</td>
</tr>
<tr>
<td>10</td>
<td>1/0</td>
<td>3.6154</td>
<td>10</td>
<td>28/20</td>
<td>3.6154</td>
</tr>
<tr>
<td>10</td>
<td>28/20</td>
<td>3.6154</td>
<td>20</td>
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</table>

Data on the frictional characteristics of the composite are presented in Fig. 1b and c. During the friction experiments on both pure and strengthened copper specimens the following observations were made. In the course of running-in, from the very first few meters of track, intense transfer of copper onto the mating part and seizure occurred. The wear debris consisted of metal particles. Oxidizing wear conditions were reached after sliding for 180-250 m, marking the end of the running-in period. Under these conditions seizure was no longer observed, and specimen wear had decreased by a factor of three to 10 and attained a stable level. The wear products were oxide particles. Under the conditions of steady-state oxidizing wear there was no transfer of copper onto the mating part because the oxide particles prevented direct contact between the elements of the rubbing pair and acted on the mating part surface as an abrasive [8]. The presence of titanium carbide had a pronounced effect on the wear of the mating part. The addition of up to 5-10% of titanium carbide decreased the wear of the mating part from 15 to 2-3 mg/cm²-km, but at higher carbide phase contents the wear began to grow once again.

In Fig. 1d are shown curves of Brinell hardness of specimens, determined with a 5-mm-diameter indenter at a load of 250 kg and a load application time of 30 sec. Over the whole carbide phase concentration range investigated the hardness of specimens grew with decrease in carbide particle size. A change in hardness in composites of this kind is, of course, linked with an elastic constriction mechanism [9].

Comparison of the data on the frictional characteristics and hardness reveals a total lack of correlation between these properties. With growth in particle size over the whole carbide phase content range investigated the wear sharply decreased in spite of a fall in hardness, and consequently under dry sliding friction conditions materials with a coarsely heterogeneous structure proved to be the most efficient. The improvement in wear resistance associated with strengthening with coarse particles was clearly due to the formation of an optimum structure.

Although coarse particles cannot markedly strengthen a material by hindering movement of dislocations, they nevertheless effectively prevent plastic flow of surface layers during rubbing. Here their effect is ap-