EFFECT OF PARTICLE SIZE OF COPPER POWER ON MECHANICAL AND TRIBOLOGICAL PROPERTIES OF SEMI-CARBONIZED COPPER/PHENOLIC RESIN-BASE SEMI-METALLIC FRICTION MATERIALS

1Hsun-Yu Lin, 1Yi-Fang Kuo, 2Kuo-Jung Lee, 1Jiin-Huey Chern Lin, and 1Chien-Ping Ju

1Department of Materials Science and Engineering, National Cheng-Kung University, Tainan, Taiwan.
2Department of Materials Science and Engineering, I-Shou University, Kaohsiung, Taiwan

Introduction

Semi-metallic friction material generally contains more than half (by weight) of metallic powders, which are mixed in and reinforce one or several binder resins. With such advantages as less sensitivity to temperature, better speed stability, better mechanical and tribological performance, as well as little environmental pollution, semi-metallic friction material has now largely replaced asbestos-based friction material and has found widespread usage in clutch/brake material as well as little environmental pollution, semi-metallic friction material, thermal decomposition or liquescence of phenolic resin due to frictional heating can cause semi-metallic friction material to fade away (a phenomenon of friction decline with operation time) [1,2].

An earlier study [3,4] indicated that carbonized semi-metallic friction materials show far better high temperature heat/oxidation resistance than non-carbonized semi-metallic friction materials, especially for high energy/high temperature tribological applications. Reported in the present study is the study of the effect of particle size of copper powder on mechanical and tribological properties of semi-carbonized copper/phenolic resin-base semi-metallic friction materials.

Experimental

The copper/phenolic resin-based friction material used for this study was prepared by dry-mixing the pure copper powder and phenolic resin powder, and followed by hot-pressing the mixture at 180°C for 10 min under a pressure of 390 MPa. Three different particle sizes of pure copper powder (0.5, 50, and 420 μm) were selected for this study. The novalac type phenolic powder has a grain size of 200 mesh (about 65 μm) and a softening temperature of 95–110°C. A resin content of 50 vol% (12 wt%) was used in this work. Before carbonization, the green compacts were post-cured in an air furnace at 180°C for 1 hr. During post-curing, methylene and aminomethylene bonds were formed into a three-dimensional infusible molecule, leading to good high-temperature performance, excellent mechanical properties and dimensional stability of the resin. After post-curing, the samples were heat-treated/carbonized in a furnace in a nitrogen atmosphere at 950°C for 5 hr.

The compressive strength of each sample was determined using a desk-top mechanical tester (Shimadzu AGS-500D, Kyoto, Japan) at a cross-head speed of 1.0mm/ min in line with ASTM D695 standard. The tribological performance of the material was evaluated by constant speed (500 rpm) slide testing under a load of 1MPa according to CNS 2586 standard method. A CNS 2472 cast iron disk (GC25) was used as the counter-face material. All tests were performed at ambient temperature in the atmosphere. The friction force, from which the friction coefficient can be calculated, was determined from the output of a strain gauge mounted on the arm of which the pin is attached. The sliding-induced weight loss and the reduction in thickness of each sample were measured using an electronic balance (GM-1502, Sartorus, Germany) and a digital micrometer (APB-1D, Mitutoyo, Japan), respectively. The surface morphology/chemistry of samples was characterized using a scanning electron microscope (SEM) (Hitachi, SU1500, Japan) equipped with an energy dispersive spectrometer (EDS).

Results and Discussion

As mentioned earlier, three different particle sizes of pure copper powder, 0.5 μm (designated “CuS”), 50 μm (designated “CuM”), and 420 μm (designated “CuL”), were selected for the study of particle size effect on mechanical and tribological properties of the present friction materials.

The compressive strength and toughness values of the composite samples are demonstrated in table 1. As indicated in table 1, the compressive strength values of composite samples CuS and CuM (126.3 MPa and 131.7 MPa, respectively) are higher than composite sample CuL (95.0 MPa). The toughness values of the composite samples increase with the particle size of the specimens.

When copper/phenolic resin-based materials were carbonized at high temperatures, copper powder was sintered together. The small copper powder with a higher surface area was more easily sintered than the large copper powder, which explains why CuS and CuM show higher compressive strength values than CuL. The formation of resin char during carbonization process is considered to restrain the sintering process.

The weight loss and thickness loss data of composite samples are demonstrated in table 2. As indicated in table 2, the weight loss and thickness loss values of composite samples decrease with particle size of the samples. It is interesting to
note that the variation in weight/thickness loss of the samples is more related to its toughness than strength.

The surface morphology/chemistry of composite samples is demonstrated in fig. 2. As indicated in fig. 2(a), the CuS surface shows that the copper particles had been sintered into large particles with carbon adhering on the interface and within pores among the particles. As indicated in fig. 2(b), the CuM surface shows that the copper particle is bonded tightly. As indicated in fig. 2(c), the CuL surface shows that copper particles is non-uniformly distributed with carbon filling the gaps among the particles.

**Table. 1** Compressive strength and toughness of composite samples.

<table>
<thead>
<tr>
<th></th>
<th>Compressive strength (MPa)</th>
<th>Toughness (MJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CuS</td>
<td>126.3±17.3</td>
<td>38.49±11.49</td>
</tr>
<tr>
<td>CuM</td>
<td>131.7±10.1</td>
<td>54.44±15.09</td>
</tr>
<tr>
<td>CuL</td>
<td>95.0±9.2</td>
<td>65.59±29.79</td>
</tr>
</tbody>
</table>

**Table. 2** Weight loss and thickness loss of composite samples.

<table>
<thead>
<tr>
<th></th>
<th>Weight loss (g)</th>
<th>Thickness loss (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CuS</td>
<td>0.98±0.19</td>
<td>0.26±0.08</td>
</tr>
<tr>
<td>CuM</td>
<td>0.53±0.08</td>
<td>0.15±0.01</td>
</tr>
<tr>
<td>CuL</td>
<td>0.18±0.05</td>
<td>0.05±0.01</td>
</tr>
</tbody>
</table>

**Conclusions**

The smaller copper powder with a higher surface area was more effectively sintered than the large copper powder. The compressive strength values of composite samples CuS and CuM are higher than composite sample CuL. The toughness values of the composite samples increase with the particle size. CuM demonstrates the highest strength and COF among all three materials. The variation in COF has a similar trend to that in compressive strength. The variation in weight/thickness loss of the samples is more related to its toughness than strength.

**Acknowledgment.**

The authors would like to acknowledge National Science Council of R.O.C. for the support for this research under Contract No. NSC97-2221-E-006-020-MY2.

**References**