TRIBOLOGY OF COMPOSITE MATERIALS ON THE BASIS OF MAGNESIUM ALLOY WITH POWDER FILLER OF SiC

Semenov V.I.\textsuperscript{a}, Shuster L.Sh.\textsuperscript{a}, Chertovskikh C.V.\textsuperscript{a}, Jeng Y.-R.\textsuperscript{b}, Huang S.-J.\textsuperscript{b}, Dao Y.-Zh.\textsuperscript{b}, Hwang S.-J.\textsuperscript{c}

\textsuperscript{a}Ufa State Aviation Technical University, Russia
\textsuperscript{b}National Chung Cheng University, Taiwan
\textsuperscript{c}National Formosa University, Taiwan

Abstract: The work presents the investigation results of the contact tribological parameters of a tool steel with a metal composite material on the basis of magnesium containing a fine-dispersed powder filler of SiC. It was determined that the friction coefficient has lower values at a higher normal load. That can be explained by a decrease in the molecular component of the friction coefficient due to advanced normal pressure in relation to tangential stresses in a contact zone. During the examination of wear rate it was noted that the smallest wearing of composite materials is observed at lower normal loads on the contact surface. At the same time there is a general tendency towards a decrease in the magnitude of wear both with increasing the particle size of the powder filler of SiC and the volume of the powder filler.

KEY WORDS: metal composite material; powder filler; silicon carbide; friction coefficient; frictional constraint; strength of adhesive shear bonds; wear rate.

I. Introduction

In modern engineering, in particular, in tribology application, the use of light alloys with a high complex of mechanical properties is one of the methods for reducing machine weight. The use of magnesium as a structural material is a good method and it is determined by an excellent correlation as strength/weight that is better than Al and many other light metals and alloys [1-3]. The magnesium strength can be increased without a significant change of density because of adding into it a small amount of the dispersed powder filler of silicone carbide. During this process there were obtained satisfactory results [3-5]. High damping capacity of the magnesium alloys make it possible to use them efficiently for producing wheels, various products of automotive and aerospace engineering, rollers of load tracks [6], etc. However, these materials have low wear resistance [7]. Wear resistance can be increased by means of an enhancement in the material strength because of adding the dispersed powder fillers in the magnesium alloys. In recent years, there has been conducted intensive research of matrix composite materials on the basis of magnesium [8, 9] containing micro-particles of silicone carbide. These investigations are of great interest for tribology as a subject of research with a view to producing friction units out of the composite materials. The given investigation presents the results of determination of wear rate, integral quantity of the friction coefficient, and also its molecular components depending on the content of the powder filler of silicone carbide.
II. Methods and materials

The magnesium alloy AZ91D composed of:
89.89%Mg – 9.0%Al – 0.68%Zn – 0.13%Mn
was used as a basic material in the investigations. In comparison tests there were
used matrix composite materials containing a dispersed powder filler of SiC. Table 1 presents
the versions of the composite materials distinguished by a degree of dispersion and a
quantity of the added powder of SiC.

Table 1. Versions of composite materials used in
the research

<table>
<thead>
<tr>
<th>Composition</th>
<th>Mean size of SiC particles, μm</th>
<th>Amount of powder in the volume of alloy, % by wt</th>
</tr>
</thead>
<tbody>
<tr>
<td>AZ91D</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>AZ91D + SiC</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>AZ91D + SiC</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>AZ91D + SiC</td>
<td>11</td>
<td>6</td>
</tr>
<tr>
<td>AZ91D + SiC</td>
<td>15</td>
<td>3</td>
</tr>
</tbody>
</table>

In the process of carrying out the tests there
were recorded a frictional force \(F\), mean bulk
temperature of the composite element of the friction couple \(T_b\) and a magnitude of the
linear wear of the composite sample \(\Delta h\).

The wear of the discs produced out of tool
steel SKD11 (85.21% Fe - 11.6% Cr - 1.48%
C) that are tempered to the hardness of
HRC58...65 was ignored because of its small
quantity as compared to the wear of the test
samples.

After the tests there was made a calculation of
the friction coefficient \((\mu)\) by the formulation:

\[
\mu = \frac{F}{P},
\]

where: \(F\) – frictional force, \(N\); \(P\) – normal load, \(N\).

According to the formulation (4) there was
determined the magnitude of the wear rate \((J)\):

\[
J = \frac{\Delta h}{L},
\]

where: \(\Delta h\) – wear rate, (linear wear) or height
of the layer removed, m; \(L\) – slip distance, m.

The investigations estimating the molecular
component of the friction coefficient were
carried out according to the scheme that is
presented in Fig. 2 [10].

Fig. 2. Test pattern for determening the
molecular component of the friction
coefficient: 1 – indenter; 2 – test specimens

Shear strength \(\tau_n\) is determined from the
correlation:

\[
\tau_n = 0.75 \cdot \frac{M}{\pi \cdot \frac{d_{1,2}^3}{2}},
\]

where \(d_{1,2}\) – diameters of imprints on the test
specimens.

Adhesive component of the friction coefficient
is determined as follows:

\[
f_M = \frac{\tau_n}{P_t},
\]
where
\[ p = \frac{P}{\pi \cdot \left(\frac{d_{12}}{2}\right)^2} \]

III Comparative evaluation of the friction coefficient «AZ91D + SiC – SKD11»

The diagrams with the results of tribological tests are presented in Fig. 3 and 4.

The analysis of the diagrams of dependences «Friction coefficient – filler particles size» (Fig. 3) and «friction coefficient – a filler volume» (Fig. 4) shows the fact that under other equal conditions a normal load in a contact zone influences mostly the change of the friction coefficient. Moreover, the friction coefficient increases while the normal load decreases. The diagrams show that the particles size of SiC influences the change of the friction coefficient in the conditions of smaller normal load more than at great values of the load.

Fig. 3. Friction coefficient dependence on particle size of silicone carbide

Fig. 4. Friction coefficient dependence on the volume of powder filler

Lower values of the friction coefficient are observed with increasing the rate of the relative slip. That can be explained by failure of adhesive bridge bonds (molecular interaction) in the investigated friction couple.

The reduction of the friction coefficient with increasing the normal load can be explained by the results of estimation of the adhesive shear bonds strength. Fig. 5 presents the dependence \( \tau_n = f(p_r) \) that indicates the fact that an increase of the normal pressure considerably advance an increase of the adhesive shear bonds strength. That indicates the fact that the molecular component of the friction coefficient decreases [11]. Besides, an additive effect of the friction coefficient decrease can be obtained due to temperature growth and localized formation of fusible eutectics (Mg – Al). Moreover, judging by the nature of the curves change on the diagrams (Fig. 3 and 4), the powder filler of SiC doesn’t influence considerably the friction coefficient decrease. At the same time an increase of the normal pressure and the presence of the dispersed particles of the abrasive powder of SiC can make for the temperature growth in the contact zone.

IV Wear examination

The results of the composite materials wear on the basis of the magnesium alloy AZ91D with the powder filler of SiC are presented in Fig. 6 and 7.

The presented diagrams show a complex behavior of the wear rate depending on the particles size and volume of the powder filler.
of SiC and also the conditions of the test operations.

Fig. 6. Dependence of wear rate on the particles size of SiC

Fig. 7. Dependence of wear rate on the volume of the powder filler

As it is shown in the presented diagrams, the smaller wear of the composite materials is observed on the contact surface at low normal loads. Moreover, there is a general tendency for the wear rate decrease both with increasing the particles size of the filler of SiC and with increasing the volume of the powder filler. That can be explained by the fact that the particles of the filler of SiC have higher hardness as compared to the steel and they make for glazing the contact surface of the steel disc because of an abrasive effect.

One can suppose that the wear rate decrease also deals with an increase of the composite materials hardness on the contact surface. That can occur as a result of dispersed and strain strengthening of the composite materials surface coatings.

V Conclusion

On the basis of the conducted investigations in the friction couples «composite materials – steel» it was determined the following:

1. There was determined a decrease in the friction coefficient with increasing the normal load and the speed of the relative slip. That occurs because of the reduction of the molecular component of the friction coefficient and the possible appearance of a liquid phase during the melting of the fusible eutectics composing of Mg - Al as a result of frictional heating. In this case the boundary friction is close to the hydrodynamic one;

2. The wear rate value has a general tendency for reduction with increasing the particles size and the amount of the powder filler of SiC. The wear decrease can be explained by an increase in the hardness of the composite materials. That takes place as a result of dispersed and strain strengthening of the composite materials surface coatings.

Literature


The work was performed within the framework of the project No. 95-2811-E-194-001, supported by NSC, Taiwan.