Evaluation of the tribological properties of a magnesium alloy of the Mg-Ca system depending on the structure of the material under study

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Abstract. The paper presents the results of a study of the tribological characteristics of the contact of the tool steel of composition Fe-18W-4Cr-1.2V with a magnesium alloy of the Mg-Ca system, strengthened by SPD using the method of ECAP. It has been established that the SPD processing of a magnesium alloy, due to an increase in strength as a result of the grain structure refinement, makes it possible to significantly reduce the integral value of the friction coefficient in the moving friction contact. In addition, the SPD processing of the material under study leads to a decrease in the molecular component of the friction coefficient.

1. Introduction
In modern mechanical engineering, in particular in friction units, one of the ways to reduce the weight of vehicles is to apply light alloys with enhanced mechanical properties. Magnesium is interesting for use as a structural material due to the attractive strength-to-weight ratio that exceeds the one for aluminum and other light metals and alloys [1-3]. The high damping capacity of magnesium alloys allows using them effectively to manufacture automobile and aircraft wheels, various components for motor-and-tractor and aerospace engineering, rollers for cargo conveyors [4, 5] etc. Severe plastic deformation (SPD) can effectively increase the strength of bulk metals due to the fabrication of an ultrafine-grained structure in them [6, 7]. SPD techniques can be considered as alternative techniques to dispersion strengthening of composite materials. However, the tribological behavior of ultrafine grain magnesium alloys is studied insufficiently for application in friction units [8, 9].

This study presents the results of determining the integral value of the coefficient of friction and its molecular component. In addition, a comparative assessment of the strength of adhesive bonds and the molecular component of the friction coefficient of a magnesium alloy of the Mg-1%Ca composition, hardened as a result of SPD by the equal channel angular pressing (ECAP) method in sliding tribological contact with tool steel of composition Fe-18W-4Cr-1.2V is given. The material of the counter-body - tool steel - was selected because of its high wear resistance to maximize the elimination of errors during tribological tests.

2. Experimental procedure and materials
In comparative tests, the composition of the magnesium Mg-1% Ca alloy was used in the initial
(coarse-grained) state and after two passes of ECAP.

Tribological tests were carried out on the friction machine “Timken”. Figure 1 presents the machine and the processing scheme.

Testing of the initial and dispersion-strengthened materials was conducted under a normal load of 10 N and 50 N and a disk rotation speed of 250 min⁻¹ and 1000 min⁻¹, the slip distance was 1650 m in all the tests.

The friction coefficient \( f \) was calculated according to the formula:

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

where \( F \) – the friction force, N; \( P \) – the normal loading force, N.

Figure 1. Friction machine “Timken” (a) and testing scheme (b): 1 – tested sample (magnesium alloy of the composition Mg-1% Ca); 2 – rotating steel disk (tool steel of the composition Fe-18W-4Cr-1.2V).

Figure 2 presents the ECAP scheme that was chosen for strain hardening of the initial material [10].

Figure 2. ECAP scheme.

The employed scheme allows achieving high degrees of accumulated strain as a result of shear in the conjugating channels. In this case, the angle between the conjugating channels \( \phi \) was 120°.

Studies on the evaluation of the adhesive bond shear strength and the molecular component of the friction coefficient were carried out on the one-ball friction machine at temperatures of 20, 150 and 300°C according to the scheme shown in figure 3 [11].
Adhesive bond shear strength ($\tau_n$) and adhesive (molecular) component of the friction coefficient ($f_m$) were determined by the method presented in [11].

3. Results of experiments and their discussion

Figure 4 presents graphs with the results of tribological tests according to the “block-disk” scheme (figure 1).

![Figure 4](image)

Figures 4. Change in the integral value of the coefficient of friction depending on the microstructure of a magnesium alloy of the composition Mg-1%Ca: 1 - fine-grained after SPD treatment by ECAP; 2 - coarse-grained after annealing.

It can be seen from the graph that the friction coefficient is higher for the studied material in the coarse-grained state after annealing than for the fine-grained after two cycles of SPD processing by ECAP throughout the entire test period. Moreover, the coefficient of friction of a material with a fine-grained structure varies slightly depending on the test time. In order to explain these results, let us consider the data received with the help of the one-ball friction machine.

Figure 5 demonstrates that the dependence of the adhesive bond shear strength $\tau_n$ on the normal pressure $p$, is described by the binomial dependence:

$$\tau_n = \tau_o + \beta p$$  \hspace{1cm} (2)

where $\tau_o$ – adhesive bond shear strength without normal loading force; $\beta$ – piezoefficient.

![Figure 5](image)

Figure 5. The dependence of the adhesive bond shear strength on the normal pressure in the contact with tool steel of the composition Fe-18W-4Cr-1.2V: (a) - Mg-1%Ca in the initial state; (b) Mg-1%Ca after two ECAP passes.
The molecular constituent of the friction coefficient $f_m$ can be defined as:

$$f_m = \frac{\tau_n}{p_r} = \frac{\tau_n}{p_r} + \beta$$

(3)

It is seen from formula (3) that the molecular component of the friction coefficient increases when the normal pressure $p_r$ decreases.

A decrease in the slip rate reduces the temperature of the friction contact, which, according to the data in figure 6, enhances the molecular component $f_m$ and the total friction coefficient $f$.

The experimental data given in figures 5 and 6 testify to the fact that the deformation treatment of the initial magnesium alloy provides a lower value of the adhesive constituent of the friction coefficient with a high bearing capacity of the frictional contact [12].

4. Conclusion

On the basis of the conducted research, it was established that the magnesium alloy of the composition Mg-1%Ca can be effectively strengthened by severe plastic deformation using the equal-channel angular pressing technique. The deformed material significantly improves the tribological properties in the moving friction contact and there is a decrease in both the integral value of the friction coefficient and its molecular component. In this case, an increase in the bearing capacity of the frictional contact is observed. Thus, the use of a magnesium alloy after ECAP in friction units is quite promising.

References

[1] Harrington W C 1994 Metal matrix composites applications Mechanical properties of Metallic Composites ed S Ochiai (New York: Mercel-Dekker) pp 759–73
[2] Kaczmar J W, Pietrzak K, Wlosinski W 2000 J. Mater. Process. Technol. 106 58
[3] Yeong Y M 2000 Influence of Types of Reinforcements on Properties of Magnesium Alloy (Eng. Thesis) (National University of Singapore)
[4] Galdin N M 1989 Color Casting: Reference Book (Moscow: Mashinostroenie) [in Russian]
[5] Reshetov D N 1995 Mechanical Engineering. Vehicle Components. Structural Strength. Friction, Wear, Lubrication Vol IV-1 (Moscow: Mashinostroenie) [in Russian]
[6] Valiev R Z and Alexandrov I V 2007 Bulk Nanostructured Metallic Materials: Processing, Structure and Properties (Moscow: Akademkniga) [in Russian]
[7] Valiev R Z, Estrin Y, Horita Z, Langdon T G, Zehetbauer M J and Zhu Y T 2006 JOM 58(4) 33
[8] Huang S-J and Liu H-W 2003 The Chinese Journal of Mechanics 19(2) 57
[9] Sinha S K, Reddy S U and Gupta M 2006 Tribology International 39 184
[10] Valiev R Z 2006 Rossiyskiye Nanotechnologii 1(1-2) 208 [in Russian]
[11] Shuster L Sh 1999 Adhesive Interaction of Metallic Solids (Ufa: Gilem) [in Russian]
[12] Semenov V I, Shuster L Sh, Chertovskikh S V and Raab G I 2005 Trenie i Iznos 26 74 [in Russian]