Thermal processes during friction and wearing of medium carbon steel after plasma electrolytic processing

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Abstract. The thermal state of a frictional contact with varying normal loads and sliding speeds of a friction pair after plasma electrolytic processing is considered. It is shown that an increase in the temperature of the frictional contact decreases the coefficient of friction, and the wear rate of the tribointerface increases with an increase in the temperature of the frictional contact.

1. Introduction

Plasma electrolytic processing is a promising method of high-speed modification of metals and alloys by changing their chemical composition, structure and properties in the surface layer, as evidenced by a noticeable increase in publications [1, 2].

Quenching, carburizing, nitriding, nitrocarburizing, boriding and sulfiding by the electrolytic-plasma method provide high wear resistance of modified steels and alloys [3, 4]. However, the tribological processes during friction of steels after plasma electrolytic processing are insufficiently studied, since most authors practically do not vary the conditions of friction tests.

The thermal state of a frictional contact is one of the defining parameters of its reliability and durability. Knowledge of the thermal dynamics of friction and wear will make it possible to select the optimal combination of friction pairs after plasma electrolytic processing for given operating conditions. In this work, an experimental study and mathematical modelling of the friction contact temperature at different sliding speeds of the sample along the counter-body and different normal loads was carried out.

2. Materials and methods

Cylindrical samples of medium carbon steel (0.45 wt.% C) 10 mm in diameter and 10 mm in height were subjected to anodic plasma electrolytic nitriding followed by plasma electrolytic polishing. An aqueous solution of ammonium chloride (15 wt.%) and ammonium nitrate (5 wt%) was used for the anodic plasma electrolytic nitriding. The samples were saturated with nitrogen at 850 °C for 5 min with subsequent quenching in the same electrolyte. An aqueous solution of ammonium chloride (3 wt.%) was used for the plasma electrolytic polishing. Polishing was carried out at a voltage of 300 V for 1 min. The solution temperature was 80 °C.

Dry wear testing was carried out against a high carbon alloy steel plate (60 HRC) 2 mm in thick (figure 1). The ratio of the current contact area to the area of the entire friction trace (overlap
The normal load and the frictional moment were measured using beam-type strain gauges. The normal load was varied by changing the air pressure in the pneumatic cylinder. This solution allows you to smoothly regulate the normal load within the specified limits. The control of the electric motor, air compressor, solenoid valves and the collection of information from the strain gauges were carried out using a microcontroller with the transfer of the measurement results to a personal computer. The tests were carried out with normal loads of 10, 20, 30, 40, 50, 60, 70 N and sliding speeds of 0.311, 0.933, 1.555, 2.07, 2.695, 3.32, 3.836, 5.184 m/s.

The microgeometry characteristics of the surface of the friction tracks were investigated using a TP-200 profilometer. The friction contact temperature was measured on the friction track directly at the exit from the friction contact zone using a digital infrared thermometer MLX90614ESF-DCI.

To find the theoretical value of the friction contact temperature, a system of standard heat conductivity equations for the sample and the counter-body was solved. At the initial time, the temperatures of the sample and the counter-body are equal. There is no temperature difference in the contact area. The heat generated at the frictional contact is distributed between the sample and the counter-body (figure 1):

$$\lambda_1 \frac{\partial T_1}{\partial z_1} + \lambda_2 \frac{\partial T_2}{\partial z_2} = -q,$$

where $\lambda_1$ and $\lambda_2$ are the thermal conductivity of the sample and the counter-body, $q$ is the intensity of heat release:

$$q = \mu N v,$$

where $\mu$ is the friction coefficient, $N$ is the normal load, $v$ is the sliding speed of the sample along the counter-body. The Newton-Richmann law describes heat transfer with the environment. The contact area of microprotrusions of a rough surface is considered circular and is determined by the Hertz formula. The system of the described equations is solved numerically.

The release of heat at the frictional contact during friction is due to the deformation of the material. The Greenwood-Williamson criterion, determines the type of deformation:

$$K_p = \frac{\Theta}{HB} \sqrt{\frac{R_p}{r}},$$

where $\Theta$ is the reduced modulus of elasticity, $R_p$ is the smoothing height of the rough profile, $r$ is the radius of microroughness determined by modeling the protrusions with bodies of double curvature.
3. Results and discussion
For all normal loads and sliding speeds, fatigue wear occurs at boundary friction and plastic contact, according to the Greenwood-Williamson criterion (3).

An increase in the frictional contact temperature reduces the force of resistance to relative sliding, and hence the shear stresses at the sample-counter-body interface. As a result, the friction coefficient decreases with increasing temperature (figure 2). The theoretical dependences adequately describe the effect of the frictional contact temperature on the friction coefficient, but give overestimated temperature values by 10-15% in comparison with the experimental ones.

Wear rate of both the sample and the counter-body increases with an increase in the frictional contact temperature (figure 3).

An increase in the normal load (figure 4) increases the ratio of penetration to the radius of a single protrusion on the rough surfaces of the friction pair. Therefore, an increase in the normal load leads to an increase in the involvement of the surface volumes of the sample in plastic deformation, and the amount of heat released during friction increases and the friction contact temperature increases.

4. Conclusions
According to the obtained experimental and theoretical dependences, an increase in the frictional contact temperature lowers the friction coefficient. The wear rate in a tribointerface increases with an increase in the frictional contact temperature.
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References
[1] Belkin P N, Yerokhin A L and Kusmanov S A 2016 Surf. Coat. Technol. 307 1194–218
[2] Lin N, Xie R, Zhou P, Zou J, Ma Y, Wang Z, Han P, Wang Z, Tang B and Tian W 2016 Surf. Rev. Lett. 23 1630002
[3] Rastkar A R and Shokri B 2012 Surf. Interface Anal. 44 342–51
[4] Zarchi M K, Shariat M H, Dehghan S A and Solhjoo S 2013 J. Mater. Res. Technol. 2 213–20