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The role of internal friction in the process of energy dissipation during PTFE composite sliding against steel

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Abstract

The state of strain varies in a polymer material during sliding against steel. The reasons for this are, among other things, imperfections of shape of the surface of the contacting steel element and the oscillatory character of the friction force. The viscoelastic nature of polymer materials (considerable internal friction) means that under such conditions a certain amount of friction energy is dissipated in the form of heat inside these materials, contributing to their heating up. For this reason the internal friction for selected PTFE composites has been investigated, as well as the temperature distribution on the surface of PTFE samples sliding against steel under dry friction conditions. It was observed (using a thermovision system) that the highest temperature occurred inside the polymer material, at some distance from the friction surface. That testifies to the generation of heat during friction, not only on the contact surface of the sliding materials but also inside the polymer material. Both thermovision investigations and computations demonstrated the essential role that internal friction plays in polymer materials during their sliding against metals.

Keywords: Friction heat; Temperature distribution; Internal friction; PTFE composites

1. Introduction

High-molecular polymers, including PTFE and its composites, exhibit viscoelastic properties. This means that they can be considered in certain conditions as a very thick non-Newtonian fluid, which is characterised among other things by viscosity, i.e. internal friction. When a polymer is being deformed, some motion of the molecular chains or their parts occurs, which has associated with it a jump over a potential energy barrier [1,2]. This results in the dissipation of a part of the strain energy, termed internal friction (damping). Investigations carried out for elastomers (rubber) [1,3] as well as for metals and ceramics [4] have proved that during a cyclic deformation heating up takes place. The amount of energy dissipated in the form of heat depends primarily on the frequency and the amplitude of the strains as well as on the value of the loss modulus, which describes the internal friction in those materials.

During sliding cyclic deformation of the materials occurs. This is mainly due to deviations of the contact surface shape, tolerance of machining (waviness, roughness, run out of the rotating element) as well as from the oscillatory character of the friction force itself [4–6]. In the case of a metal–polymer pair, as a result of the difference in the rigidity (modulus of elasticity) of the contacting materials, the polymer material is the first to undergo strain. That is why the heat of friction will be generated not only on the surface of the sliding pair, but also in the bulk of the rubbing polymer material, as a result of internal friction. These additional heat sources inside the polymer material could be a reason for the development of a region of increased temperature inside the polymer material, at some distance from the surface of friction [7].

A similar phenomenon, which has been presented among others by Shpenkov [8], has been observed in metals in the

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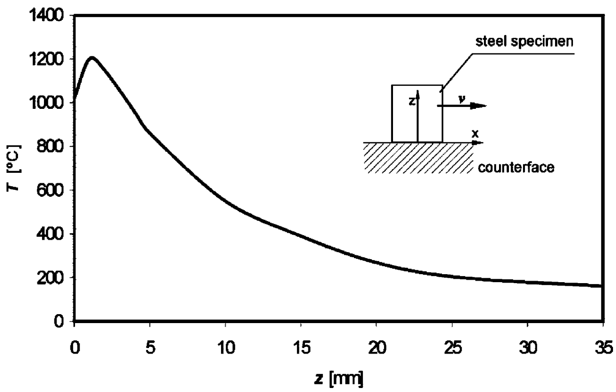

Fig. 1. Temperature T in the bulk of rubbing steel specimen vs. distance z from nominal contact surface in normal direction (sliding time: 20 s) [11].

initial period of their friction. He investigated the distribution of temperature in steel elements during friction. He carried out the measurements by means of thermocouples, which were placed both on the surface and inside of the steel element. The results of those measurements confirmed that in the initial period of friction the temperature of the steel inside was considerably higher than on the surface itself, the difference of temperature could reach even 250 °C. Shpenkov also found out that the place where the maximum temperature occurred inside the steel element could be 1.5 mm from the surface. Similar observations concerning the temperature distribution in the upper layers of metals during friction were presented by Piljavskij [9] and Abdel-Aal [10,11]. They found that in the initial period of friction, at substantial distances from the contact surface, the temperature was higher than on the contact surface (Fig. 1). In Abdel-Aal's opinion this results from the presence of internal heat sources connected with plastic strains occurring under the surface of friction.

2. The effect of internal friction on the rise of temperature connected with heat generation in PTFE composite bulk

To confirm the role of internal friction in the process of heat generation in the bulk of polymer materials and investigations of the temperature distribution on the external surface of polymer samples during cyclic compression were carried out. The samples were made from PTFE composites of various heat conductivity: TK25 (PTFE + 25 wt.% carbon) and TSt40 (PTFE + 40 wt.% stainless steel AISI 316L). The samples were in the form of plates of the following dimensions: 30 mm high, 20 mm wide, and 4 mm thick. Testing was conducted using the MTS 858 Mini Bionix machine. The samples were loaded with a compression force in such a way that the stresses occurring in them were of fluctuating (unilaterally variable) character. The compression frequency amounted to 10–15 Hz whereas the strain amplitude was 0.5–1%. The strain amplitude and frequency values were chosen on the basis of the average values of the strain occurring in polymer sliding bearings or seals, in contact with the surface of shafts. It should be mentioned that, according to Ref. [12], the material strains in seals made from a PTFE composite could reach about 2%.

Observations of the temperature distribution of a polymer sample subjected to cyclic strain were made using an AGEMA Thermovision® 550 camera. The camera measures the infrared (IR) radiation coming from an examined object with a resolution better than 0.1 °C and makes it possible to get a coloured picture of high resolution (320 × 240 pixels). A single pixel in the registered picture corresponded to an actual square-shaped area of the side length of 0.1–0.2 mm (depending on the distance of the camera from the object under investigation). Calibration was carried out in agreement with the procedure described in the instructions for use of the thermovision camera.

It was found during the measurements that after a lapse of ca. 300 s the temperature on the surface of the sample stabilizes and so equilibrium of the heat generated inside the sample with the environment is achieved. Some examples of the results of the observation of the temperature field on the surface of the samples made from the tested composites are presented in Fig. 2. The clear increase of temperature observed on the surface of the samples during a cyclic compression testifies to a considerable dissipation of energy in the form of heat, due to internal friction. The recorded temperature rise at a selected point on the surface of the middle part of the sample in relation to the ambient temperature was for the TK25 composite $\Delta T = 8.3\,°C$, whereas for the TSt40 composite $\Delta T = 6.3\,°C$.

3. Determination of the amount of energy dissipated owing to internal friction

During this study of temperature distribution on the surface of polymer samples under cyclic compression, the compressive force value and the sample deformation were also recorded. These quantities were used to calculate the relevant stresses and strains. Fig. 3a presents an example of stress and strain variations for the TK25 composite as a function of time. The measurements were carried out under fluctuating compression (the strain amplitude $\varepsilon_0 = 0.6\%$ and strain frequency $\omega = 10$ Hz) at an ambient temperature $T_0 = 24\,°C$. The hysteresis loop σ–ε (Fig. 3b) obtained under the above-described conditions testifies to a considerable dissipation of energy in this material: manifestation of internal friction.

The results of this study made it also possible to determine the value of the mechanical loss factor $\tan\delta$, and of the loss modulus E''. These quantities, under the above conditions of research, are:

(a) composite TK25: $\tan\delta = 0.161$, $E'' = 210$ MPa,
(b) composite TSt40: $\tan\delta = 0.170$, $E'' = 150$ MPa.

The values of the loss modulus E'' obtained can be used to determine the amount of the dissipated energy. Assuming that the dissipated energy is totally converted into heat, this