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Tribological Behavior of a Thermoplastic Material Under the Action of a Conic Penetrator in Sliding Movement

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Abstract. *Knowing how to deform the Turcite thermoplastic material under the action of conical penetrators is a means of obtaining information on the processing of the counterpart (made from a metal material with higher hardness) with which it comes into contact. The paper aims to theoretically determine the depth of penetration of the thermoplastic material under the action of some conical penetrators and to establish the coefficient of static and kinetic friction under the action of these penetrators. The proposed model will be validated experimentally on a tribological stand made for this purpose.*

Keywords*: penetration depth, conical penetrators, coefficient of static and kinetic friction for plastics*

1.Introduction

The friction couplings used in technical applications use a variety of materials that must fit mechanically, thermally, and chemically during operation.

In technical applications, the characterization of materials in terms of compatibility of the coefficients of friction or the properties of resistance to deformation and scratching are some of the indicators to be considered when choosing the materials of the friction torque.

The Various studies on this topic [1-11] illustrate that polymeric (thermoplastic) materials have a wide range of scratch deformation characteristics under the action of conical penetrators, compared to metallic or ceramic materials.

Because the nature of material deformation in any actual deterioration process depends on several contact variables (shape and size of roughness, normal load, sliding speed), a model for deterministic investigation was proposed, varying only some of the geometric parameters of a penetrable conical shape (from - a harder material - cast iron) in contact with a polymeric composite material.

Theoretical model

In the vast field of mechanical demands that any thermoplastic material can withstand, the scratching phenomenon is one of the most important. The way the material deforms under the action of a sliding cone-shaped penetrator is considered a characteristic of the material.

In the proposed model, a rigid conical-shaped penetrator [12, 13] (Figure 1) is considered, which scratches the flat surface of the softer material.

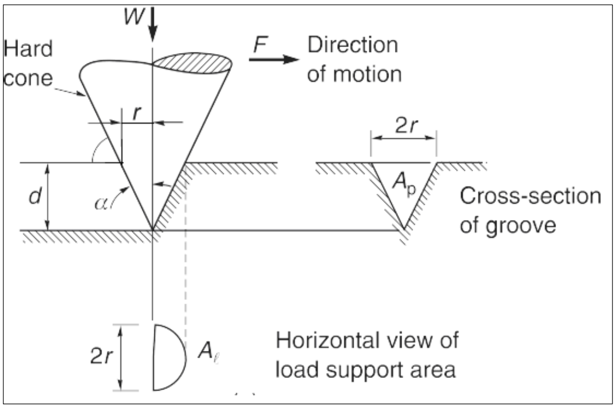

Figure 1. The geometric characteristics of the rigid conical penetrator [12]

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For a scratch element, which slides without friction on a surface with lower hardness, the penetration depth (δ) can be evaluated based on the Tresca criterion (of maximum tangential stresses) [1, 13] as:

$$r = \left(\frac{F}{\pi \sigma_c (1+\psi)} \right)^{1/2} \tag{1}$$

where: σ_c - the flow pressure of the softer material;
ψ - the angle of the sliding lines;
F- friction force.

If we consider that the volume of deformed material is constant the angle of the sliding lines (ψ) can be determined from [1, 12, and 13]:

$$\cos(2\alpha - \psi) = \frac{\cos\psi}{1+\sin\psi} \tag{2}$$

With these considerations, the expression of static penetration:

$$\delta = r \cdot ctg\,\alpha = \left(\frac{F}{\pi \sigma_c (1+\psi)} \right)^{1/2} \cdot ctg\,\alpha\ . \tag{3}$$

In the case of plastics not only the way of penetration and deformation of the material is different that of the metallic materials, but also the evolution of the coefficient of friction. It was found that the Coefficient of friction for a couple of materials has a varied distribution depending on the sliding speed of the kinematic couple surfaces [14, 15]. Thus, it was found that the Amontons-Coulomb friction laws [12-15] are not respected, the coefficient of friction tends to decrease with increasing load or if the geometric surface is small.

It can be established that in the field of plastic deformations the contact areas of the two materials (according to Figure 1) are:

- longitudinal section:

$$A_l = \frac{\pi \cdot r^2}{2} \tag{4}$$

- cross section:

$$A_c = \frac{1}{2} \cdot 2r \cdot \delta = r^2 \cdot ctg\,\alpha \tag{5}$$

Based on the coefficient of friction defined by the expression Amonton-Coulomb coefficient of friction that is defined by the force of friction (F_f) and normal force to push (F_n):

$$\mu = \frac{F_f}{F_n} \tag{6}$$

Then we can write that the coefficient of static friction is:

$$\mu_s = \frac{A_c \cdot \sigma_c}{A_l \cdot \sigma_c} = \frac{2}{\pi} ctg\,\alpha \tag{7}$$

where: σ_c is the flow pressure of the softer material.

In Figure 2 is show the evolution coefficient of friction according to the theoretical model based on the semi angle cone (10°…60°). Its decrease is noticed with the increase of the penetration half.

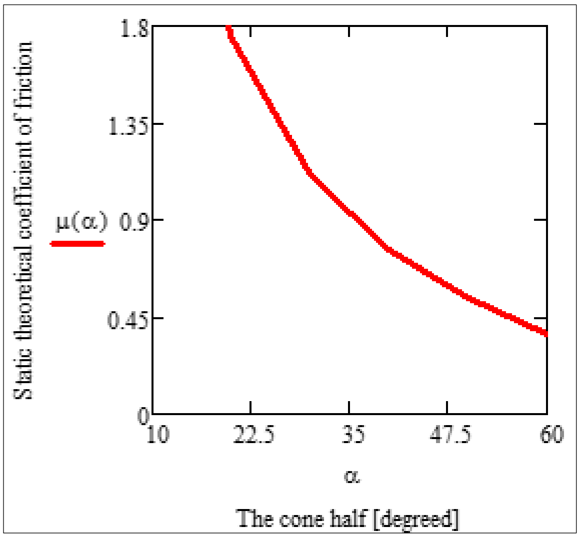

Figure 2. Evolution predicted coefficient of friction Depending on the half cone angle (10°…60°)

2. Materials and methods

Selection of materials

Applying thermoplastic materials in various fields of technology is increasingly obvious due to their ability to withstand high mechanical and thermal. Also, these materials are recognized for their good properties related to wear resistance, vibration absorption capacity, are less sensitive to changing operating conditions, etc.

The material under study is a Slydway Turcite B material with a bronze fill. Turcite is a high performance engineered thermoplastic material, for use as plain, linear and wear-ring bearing elements. The characteristics of Turcite are: very low friction for reduced power loss, low wear for long life, excellent chemical resistance/fluid compatibility, no stick-slip for positional accuracy/control, good specific bearing loads, unlimited shelf life, absorbs vibration during machining [16]. The main mechanical characteristics of the material used Turcit B Slydway are shown in Table 1.

Table 1 . The main mechanical characteristics of the Turcite B

Mechanical properties	Measurement units	Features
Tensile strength	MPa	13.8
Hardness	Shore D	50-60
Thermal conductivity at 20°C	W/m K	0.8
Modulus of elasticity at 20°C	N/mm^2	1000
Linear coefficient of expansion	1/K	$6\ 10^{-5}$

Used for plating machine tool guides or in the case of sliding bearings this material comes in contact with steel or cast iron surfaces. In practice, hardnesses of approx., 60 HRC for steel and approx. 240 HB for cast iron have been found to be effective.

In the proposed experiment it is considered that on the test tube made of thermoplastic material Turcite of thickness 3 mm slides conical shaped samples from cast iron.

Tribological experiments

Experiments were conducted on friction tribological stand type pin on disk that pin was made into a cone at different angles [17]. For the validation of the proposed theoretical model, 3 conical cast iron samples were used, which were processed with the semi-angles of the cone $\alpha_1=10^o$, $\alpha_2=20^o$, $\alpha_3=30^o$, $\alpha_4=45^o$, $\alpha_5=60^o$. The defects of the tapered pins were 12μm/radius. The tests were made in dry friction conditions, samples were cleaned and degreased. To determine the deformation of the thermoplastic material, the conical specimens were loaded with the normal loads F_1=0.1N, F_2=1N, F_3=2N, F_4=5N. For each load, 3 similar tests were performed for which the penetration depth was measured. Figure 3 shows the evolution of the theoretical and experimental penetration depth for the four loads. Theoretical and experimental data processing was performed using software Matchad.

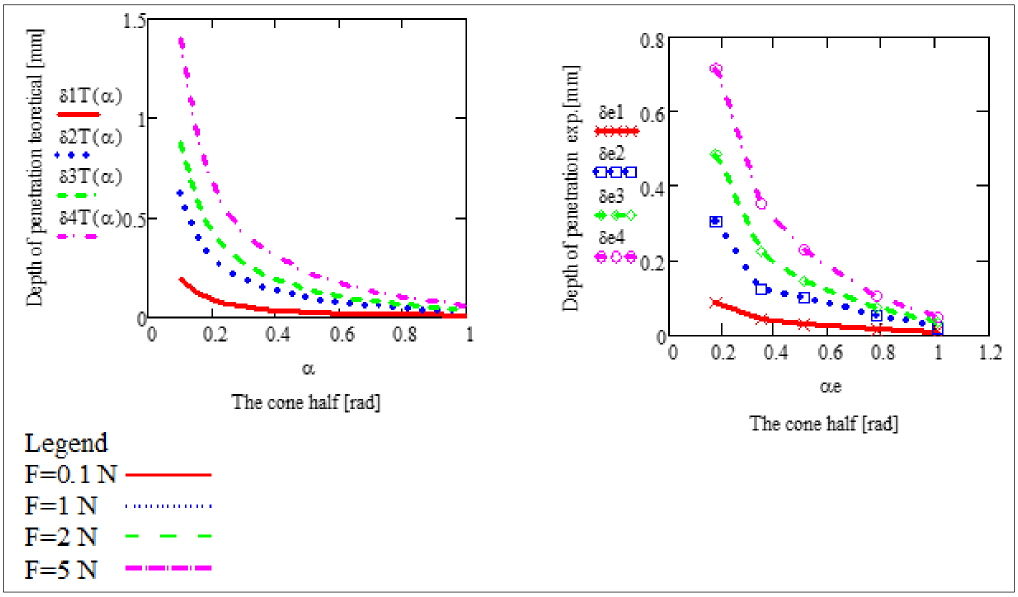

Figure 3. The evolution of theoretical and experimental penetration depth depending on the angle (half angle) of the conical penetrator and the loading force

In the field of low sliding speeds, stick-slip movement may occur. Phenomenologically, the most widely accepted cause for the stick-slip phenomenon is that static friction exceeds kinetic friction or, the coefficient of friction decreases rapidly at low speeds. A stick-slip friction measuring device was used to determine the static friction coefficient.

On the test stand, the coefficient of static friction for the four loading forces was determined at a slip speed of ν_1=0.1mm/s. Figure 4 shows the evolution of the coefficient of static friction with the normal loading force applied to the conical penetrator for the sliding speed ν_1=0.1mm/s.

The coefficient of kinetic friction was determined to stand tribological [17], each conical penetrator according to the charge F_2=1N at a sliding speed and power ν_1=1.25m/s, ν_2=3.75m/s, ν_3=5m/s, ν_4=10mm/s. The variation of the sliding speed was made with the help of a frequency converter connected to at drive motor. Figure 5 shows the evolution of the coefficient of kinetic friction for the experimental data presented.

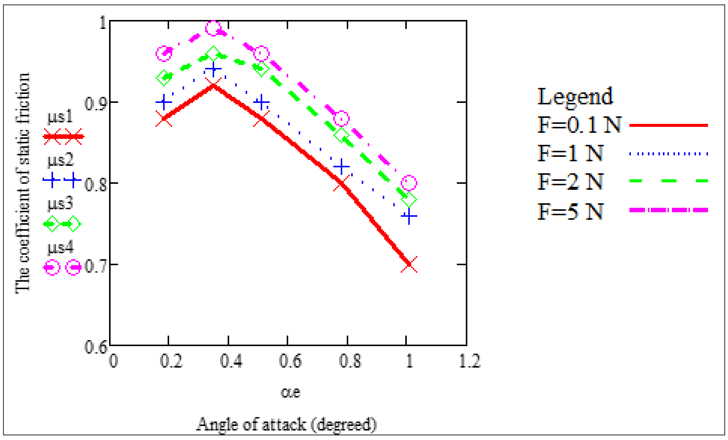

Figure 4. Evolution of the coefficient of static friction with the normal force applied to the conical penetrator at the slip speed ν_1=0.1mm/s

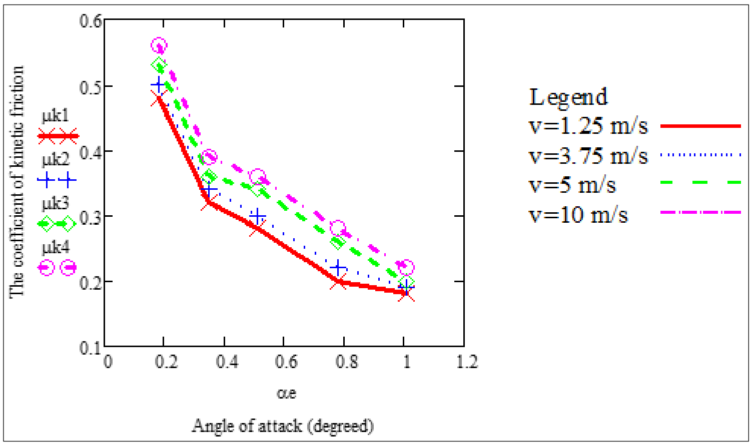

Figure 5. Evolution of the coefficient of kinetic friction for Turcite depending on the shape of the penetrator for a Loading F_2=1N and sliding speeds de v_1, v_2, v_3, v_4

3. Results and discussions

Under slip conditions, the analysis of wear and the response mode of the analyzed material pair (plastic/cast iron) requires careful analysis in order to determine the parameters that affect the deterioration of the surfaces. The visco-elastic character of the thermoplastic materials influences the processing and analysis of the experimental results [13, 18-20].

From the analysis of the theoretical model it is found that the penetration depth of the thermoplastic material is dependent on the characteristics of the material (flow resistance) and the penetrator half-angle.

The difference between the theoretical and experimental penetration depth values is noticeable only for the small semi angles of the penetrator, this can be explained by the elasticity properties of the material, assuming that the friction is absent at the moment of penetration. For higher values of the semi-penetrator angle, it is noted that the differences are small.

It is found both theoretically and experimentally that the penetration depth increases with increasing load and decreases with increasing semi-penetrator angle. This is due to the size of the contact surface and the pressure exerted by the conical penetrator.

At small values of the semi-angle of the penetrator, it is appreciated that the deformations of the soft material are higher, which also leads to values of the higher coefficients of friction. The explanations given are related to the viscoelastic properties of the polymer.

In the case of the coefficient of friction the differences are significant. In the case of the theoretical model, the coefficient of static friction decreases with the increase of the semi angle of the cone, so with the increase of the contact surface area. In the case of the coefficient of static friction, we notice an increase of its value for small semi-angles and a decrease of it with the increase of the semi-angle, which is due to the thinning property of the thermoplastic material.

The differences between theoretical and experimental values is due to the fact that the theoretical model is the coefficient of friction only on the size of the angle of the conical indenter.

In reality, other parameters such as the characteristics of the material and its hardening properties intervene during the sliding between the friction torques.

It is found that the higher the penetration angle, the lower the values of the coefficient of static friction.

This can provide information on the importance of how the hard surface is machined to achieve less friction between the materials in contact.

The values of the coefficient of kinetic friction increase with the increase of the sliding speed and decrease with the increase of the semi-angle of the penetrator, this is due to the deformation mode of the contacted asperities (elastic, elasto-plastic and plastic).

In experiments the variant of dry friction was adopted because the Turcite material is slightly hygroscopic. A limited, mixed lubrication of the material couple could influence the experimental results obtained.

4. Conclusions

The use of thermoplastic materials when making bearings and slide guides is increasingly evident due to the multiple tribological properties. The couple of materials chosen for the bearing (steel/thermoplastic material, cast iron/thermoplastic material) and its way of processing have a decisive role in the smooth functioning of the coupling in terms of wear. Processing of the harder material with roughness with a high penetration angle can lead to less wear of the thermoplastic material.Since the thermoplastic materials deform quite easily under the action of an abrasive particle or the surface asperities with which it comes in contact, an analysis in this regard is required.

Following the analysis, it can be concluded that if a material deforms less under the action of a conical penetrator, with a larger semi-angle, then the material of the counterpart with which the thermoplastic material comes in contact must be finer processed (with lower roughness). This does not mean, however, that the surface must be glossy, because in the case of frictional couples operating in a limited or mixed lubrication regime then the lubricant would no longer adhere to the surfaces of the joint.

At the same time, the lower the surface roughness of the harder material, the lower coefficient of friction is, which leads to a lower wear of the joint. In the literature it has been shown that there is an optimal range of the value of the roughness parameters for which the polymer has a good wear behavior. A penetration angle of $70^0...80^0$ causes the values of the coefficient of friction to decrease, the scratching phenomenon to be much reduced and to predominate an adhesion wear of the thermoplastic material [1,5,6, 18-20].

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