Research Regarding the Evolution of Friction Coefficient in a Friction Torque Like a Plastic Material / Steel for Different Parameters

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Explaining the phenomena occurring at the level of relative friction surfaces has become increasingly complex and often contradictory. Research over time has shown that the friction coefficient for a friction coupler is not a constant magnitude, as Amonton-Coulomb has stated, its values being dependent on a multitude of factors (normal load, slip rate, the nature of the material, the state of lubrication, etc.). The laws of the two are considered to be valid only under conditions of dry rubbing and elastic deformation of the surfaces in contact. The present paper proposes in the first part a study on the theoretical expression of the coefficient of friction. The experimental part of the paper highlights the variation of the coefficient of friction with the speed, loading and processing of the contact surface. It was made on a tribological stand of pin / disc type, and the coupler used was polymeric material called Turcit (for disc) / general purpose steel (for pine).

Keywords: sliding motion, friction coefficient, friction area, operating conditions

The friction couplers used in the machine construction use a wide range of materials that have to meet the thermal and mechanical stresses specific to machine building. Generating the frictional force at the contact surfaces in a friction coupler results from elastic, elastoplastic or plastic deformations of the contacting peaks [1, 2, 3]. Each interaction of asperities will contribute to the friction force, its magnitude being a sum of the individual forces of asperity contacts.

Research on the evolution of friction coefficient over time for a sliding friction clutch implies the existence of at most 6 stages [4,5];

- the first stage in which the asperities of the surfaces come into contact and begin to deform, is a stage in which nothing spectacular happens, the coefficient of friction having a relatively constant value;
- Stage II occurs due to the adhesion of the materials in contact when the friction coefficient increases; at this stage, if the operating conditions (pressure, speed, lack of lubricant) are tougher, wear particles which are entrained in interstitium and which increase the coefficient of friction may occur;
- stage III; the abrasive particles resulting from the plastic deformations of the peaks of the asperity or the accidental external penetration of the abrasive particles can lead to a significant increase of the coefficient of friction;
- Stage IV; the grip between the couple materials maintains the coefficient of friction constant. At this stage the asperities continue to deform and new rusty surfaces can be created by delamination. The coefficient of friction can remain at the same value without any further changes in its value or other stages to follow;
- Stage V occurs when the hardness difference is significant, hard asperities form a fine surface on the element with lower hardness, which does not cause deformation of the asperity. Under these conditions, the coefficient of friction may decrease as a result of the stabilization of the peaks of the asperity peaks;
- Stage VI can occur only after the occurrence of stage V when the less hard surface becomes bright and the value of the coefficient of friction can remain constant at the value of the previous stage. The evolution of the friction coefficient, as presented, depends on the chosen material couple, the loading conditions, the lubrication state, the surface treatment mode, etc. Clerico [5], in his studies, determined that friction coefficient values for the friction behavior of the polyamide / metal coupling are higher in the first few hours of operation when it can increase to 0.65 after which it stabilizes at a value of 0 42. The explanations given are related to the visco-elastic properties of the polymer.

Tribological research related to the friction processes in kinematic couples has indicated that in the relative movement between the elements of any coupling, the value of the friction coefficient is not an intrinsic magnitude but varies according to different parameters. The fact that the coefficient of friction is an intrinsic size was confirmed only for a certain speed line, contact pressures, lubrication state, etc., under the elastic deformation of the contacting materials [3, 4, 6].

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The paper proposes a theoretical study on the friction coefficient size and an experimental part that makes it clear that this coefficient varies with different parameters (pressure, slip speed).

For the experimental part a pin-disc friction coupler is used in which the material of the disc is made of a polymeric material called Turcit (66 Shore D hardness) and the pin (the pin) is generally rolled steel (hardness HB 490 ... 610 N / mm^2).

Theoretical study

In the specialized literature, the friction of polymeric materials is explained in terms of friction adhesion theory. However, when comparing metallic materials, there are three differences that relate to the following aspects [7]:

- the friction laws of Amontons-Coulomb are not respected exactly, noting that the coefficient of friction tends to decrease with increasing load; it also tends to decrease if the geometric contact surface is small;
- another aspect refers to the fact that if the friction surfaces are left in contact under load, the actual contact area may increase over time due to creep, and the friction at start may also increase;
- The friction can change with the slip rate due to the viscoelastic properties of the polymer, and the most obvious changes occur as a result of frictional heating.

The concepts and hypotheses stated over time on the expression of the friction coefficient have been found to be valid only in the field of elastic deformations of the material. Research has shown that the value of the friction coefficient is a number given by the ratio of the frictional force (F_f) to the normal pressing force (F_n).

$$\mu = \frac{F_f}{F_n} \tag{1}$$

It is known that the frictional force is due to the interaction (elastic, plastic) between the asperities of the two materials of the coupling or the climbing of the asperities of one surface on the other.

When the surfaces of the friction joint are loaded with a certain force, the contact of the surfaces is made only on the ends of the asperities, so that the real area of contact is given by the number and size of the points of the asperities in contact. The response of a material of a frictional coupling under the action of the operating factors is characterized by the state of deformations when the state of stresses is known, including the state of these breaking stresses.

The tips of the asperities, during the displacement of the surfaces of the joint, may deform elastic, elasto-plastic or plastic. The plastic deformation of the asperite peaks occurs, according to Bawden and Tabor's theory of microjunctions [1-8], as a result of the breakdown of the cold microspheres that form between the asperite peaks. They consider that the process of forming these welding bridges and their breaking is a repetitive phenomenon throughout the entire period of movement of the joint. The time at which the welding and breaking of the welding bridges takes place is by the order of one-thirds of a second.

In this hypothesis, the friction force is the force required to shear the peaks of the asperities in contact:

$$F_f = A_r \cdot \tau_f \tag{2}$$

where: τ_f is the breaking tension by shearing the peaks of the asperities

A_r isthe actual contact area given by the peaks of the asperities.

For a material that passes from the elastic deformations field to the plastic one of the asperities the normal pressing force will be:

$$F_n = A_r \cdot \sigma_c \tag{3}$$

where: σ_c is the flow pressure of the softest material between the two

By replacing the second and third relations in the first relation, the expression of the friction coefficient becomes:

$$\mu = \frac{\tau_f}{\sigma_c} \tag{4}$$

The flow pressure of the (softer) material is as close to the hardness of the material (HB) [1, 4, 6], which leads to.

$$\sigma_c = \frac{HB}{3} \tag{5}$$

Under these conditions, the expression of the coefficient of friction for plastics is:

$$\mu = \frac{3\tau_f}{HB} \tag{6}$$

The equation (6) is in agreement with many preliminary experimental results [1, 6].

The theoretical study presented shows that the coefficient of friction is a number that depends only on the mechanical properties of the softer material of the two. Under normal conditions of temperature and humidity, for many materials, the coefficient of friction is about 0.2 ... 0.5. The values of the friction coefficient can be much higher when the surfaces are not contaminated with oxide films or in the case of extreme sliding speeds.

In the specialized literature there are numerous opinions regarding the evolution of the friction coefficient with different parameters. Barlow [8], studying the frictional behavior of the polymer / steel coupling, establishes for the friction coefficient values of 0.1 ... 0.28, in the presence of a lubricant. He appreciates an increase in the value of the friction coefficient with the increase of the sliding speed between the surfaces of the friction joint.

Watanabe et al [7-10], highlight the increase of the coefficient of friction with the increase of the normal load. Lancaster [10,11] found that the coefficient of friction decreased withthe roughness of the metal surfaces.

Experimental part

The evaluation of the effective friction coefficient was performed on a tribological stand of pine / disk type friction [10,11,14]. The diagram of the operating principle is shown in figure 1. On the surface of the disk is placed Turcit polymeric material, in thickness of 3 mm. The pin made of OL 42 has a cylindrical shape with a diameter of 10 mm and is placed on the surface of the disc. The surface of laying of the pine was realized by different processes of processing by cutting (turning and grinding). The sliding speed of the pine can be varied by changing the position of the disk or by changing the speed of the disk by means of a speed inverter.

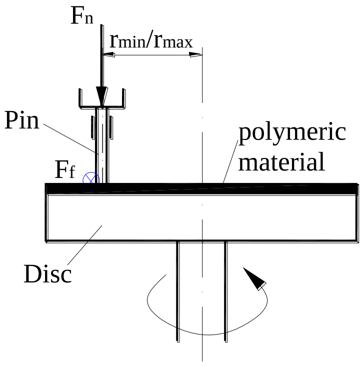

Fig. 1. Pin / disk stand layout

There is no lubricant between the contacted surfaces (pin / disc) (the friction is dry) because it was found that the presence of the lubricant can clog the pores of the thermoplastic material and thus the value of the friction coefficient can be changed.

To achieve the experimental part the pine is loaded through some weights, the value of the normal force with which it presses the disk being $F_{n1} = 0{,}5N$, $F_{n2} = 1N$, $F_{n3} = 5N$, $F_{n4} = 10N$. For each of the loads of the pine the speed of rotation of the disk is varied. The evaluation of the coefficient of friction on the test stand was made as an average of 3 measurements of the coefficient of friction during each test.

Figure 2 shows the evolution of the friction coefficient with slip speed for the four loads of the pin. There is an increase in the coefficient of friction with the speed after which a decrease occurs and a stabilization of the value.

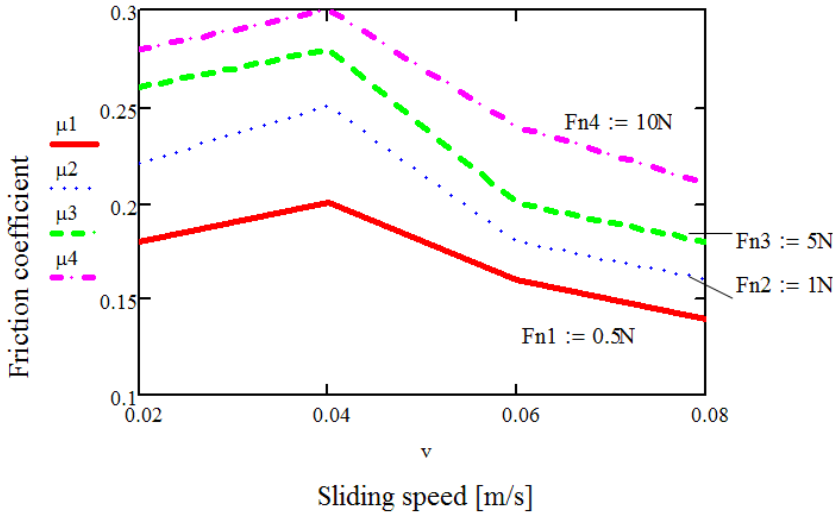

Fig.2. Evolution of the friction coefficient with sliding speed for different loads
$(F_{n1}, F_{n2}, F_{n3}, F_{n4})$

Figure 3 shows the evolution of the friction coefficient with the normal force for different sliding speeds.($v_1 = 0.02 m/s; v_2 = 0.08 m/s$).

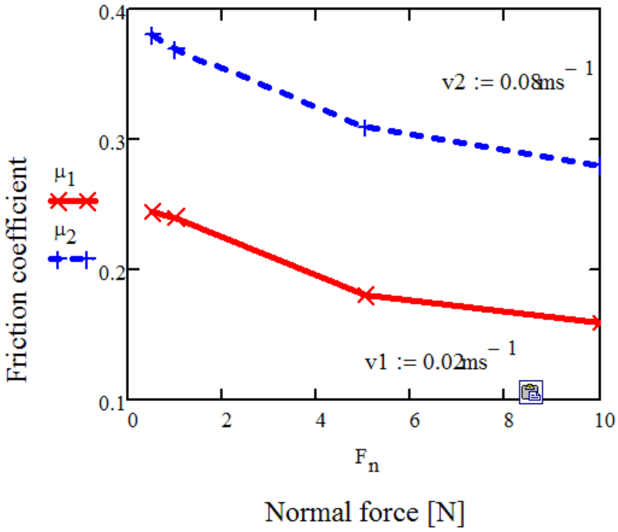

Fig. 3. Evolution of the friction coefficient with the normal force for different sliding speeds (v_1, v_2)

It is noted that the size of the friction coefficient decreases with the increase of the sliding speed.

From a tribological point of view it has been found that the surface processing mode also plays an important role in the functioning of the friction joint. In order to highlight the variation of the coefficient of friction with the roughness, the front surface of the pine (which rubs on the thermoplastic material), was processed by two cutting procedures:

- a turning process, and the roughness was measured: $R_a = 3.2$ µm;
- a rectification process, and the roughness was measured: $R_a = 0.8$ µm.

Thus the pin was loaded with a normal force : F_{n2} = 1N at a sliding speed v_1=0.02 m/ s and allowed to run for a period of 60 minutes. The friction coefficient was evaluated after every 10 minutes. The results of the measurements are shown in Figure 4.

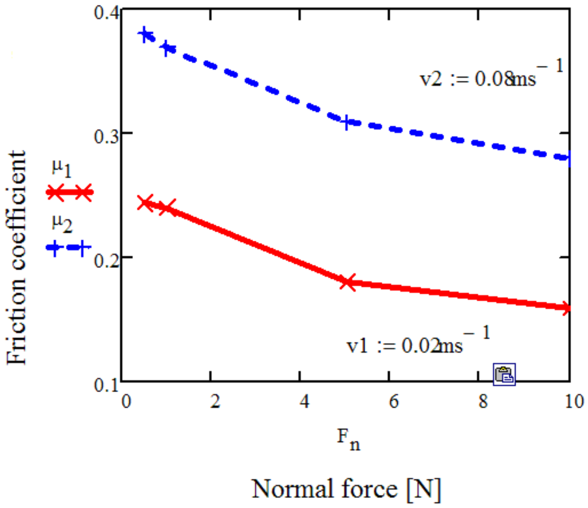

Fig. 4. Evolution of the coefficient of friction according to the roughness of the pine surface

It is noteworthy that for finer processed surfaces the values of the coefficient of friction increase slightly, whereas in the case of rough surfaces a decrease of the coefficient of friction takes place after which its value begins to increase. This is explained by the adhesion of the surfaces and the elastoplastic deformations of the contact asperities and at the same time the modification of the real contact area.

Conclusions

Research on the coefficient of friction has shown that the Amonton-Coulomb laws are not validated under conditions of variation of the loading parameters of a frictional coupling. We can say with certainty that the coefficient of friction is not independent of speed and pressure as they believed [14-16]. The laws established by them proved to be valid only in case of dry rubbing and under the elastic deformations of the asperities of the surfaces in contact, in slip motion.

In the case of dry friction, the variation of the frictional force and the friction coefficient according to the working parameters (pressure, sliding speed, etc.) could not be included in a mathematical relation, due to the complexity of the phenomenon. In this context, experimental determinations are needed to determine the friction force or friction coefficient.

Thus, from the analysis of the experimental results obtained, the following conclusions can be drawn:

- the coefficient of friction has values in a wide range, between 0.15 and 0.4;

- the variation of the coefficient of friction theoretically for different pairs of materials is explained on the basis of the mechanical resistance of the softer material of the friction joint;

- it can be appreciated that the values of the coefficient of friction obtained experimentally (at small loads when the deformations of the asperities are in the elastic domain) are close in value to those obtained theoretically. If the experimental values are greater than the theoretical ones, the explanation is given by the increase of the real area of contact due to the pressing force and implicitly by friction. If the experimental values are lower than the theoretical values, the explanation is given by the different adhesion of the materials in the formation of the microjunctions. This adhesion is mainly due to the difference in hardness of the contact materials (the polymer material is softer than the steel).

- the coefficient of friction in the operation of a frictional coupling is variable and depends on the operating conditions - pressure, relative speed of sliding, mode of surface processing, etc .;

- the variation of the decrease and increase of the coefficient of friction with the load can be explained by the run-in period to which any friction couple is subjected, until the uniformity of the asperities of the contact surfaces;

- at higher loads of the friction joint, the crushed layer is destroyed and entails the increase of the friction coefficient;

If we analyze the two basic laws initially enunciated by Amonton in 1699 according to which: Law 1 - friction is independent of the apparent area of contact of the bodies in contact; Law 2 - the friction force is proportional to the normal load between the two bodies in contact, the following observations can be made:

- the first law is easily justified by the presented theoretical model in which it was seen that the value of the friction coefficient depends only on the mechanical characteristics of the softer material of the two couplings;

- the second law is true only if the contact between the tips of the asperities is totally plastic and the actual contact area no longer depends on the topography of the surface.

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