ORIGINAL PAPER

ASSESSMENTS ON THE FRICTION AND WEAR BEHAVIOR OF SOME POLYMERIC MATERIALS USED IN SLIDING CONTACTS

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Abstract. *The effects of friction on polymeric materials are quite difficult to explain due to the micro and macroscopic interactions of the friction coupling surfaces, which slide over each other. The friction and wear behavior of surfaces in sliding motion can be considered important design criteria. By adding different concentrations of reinforcing agent to the base material, the tribological performance of surfaces in sliding motion can be obtained. The experimental study was carried out on a pin-on-disc type tribological stand under dry friction conditions. The friction and wear behavior was analyzed for two base materials (PTFE and PA66) and the same glass fiber reinforced materials (PTFE + 25% fiber-glass and PA66+GF30). The tests were carried out at different sliding speeds and loading forces,* v_1*=0.20 m/s,* v_2*=0.50 m/s,* v_3*=0.75 m/s and loading forces,* F_{n1}*=1.0 N,* F_{n2}*=2.5 N,* F_{n3}*=5.0 N over a friction length of 5000 mm. Research has shown that the coefficient of friction decreases with increasing loading force. Tests have shown that a high value of the friction coefficient does not mean a high wear rate, the wear rate values are between* 10^{-12} *and* 10^{-15} m^2*/N. TheL(1) presences of the reinforcing agent in the base material have a significant importance on the friction and wear behavior under the action of operating factors (load, sliding speed).*

Keywords: *polymeric materials; polytetrafluoroethylene; polyamide PA66; the friction tests; tribological behavior.*

1. INTRODUCTION

Due to the high tribo-mechanical properties, high corrosion resistance, ease of manufacturing and low costs, the use of polymeric materials in industrial applications is increasing [1]. Studying the phenomena that generate friction and wear of polymeric materials is important for their tribological behavior.

The phenomenon of friction occurs as a result of the sliding resistance of one solid body in contact with another [2-4]. The wear of materials with industrial applications represents the damage of a surface in sliding motion compared to the counterpart, the phenomenon being that the wear is a consequence of the friction process [2, 4-8]. Friction and wear represent the response of surfaces in motion under the action of exploitation factors, not being properties of the materials [4].

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In the specialized literature [2, 3, 6, 7, 9, 10-14, 17-20] it is shown that the main mechanisms that generate friction in the case of polymers are the adhesion and deformation of the two materials in contact. Adhesion is characterized by a transfer of material from one surface to another. The deformation mechanism is characteristic of visco-elastic materials and involves energy dissipation in the contact area between the surfaces.

During sliding, an elasto-plastic deformation of the asperities occurs due to hysteresis losses. According to this theory, the total frictional force is equal to the force required to shear the adherent junctions and the force required for the elasto-plastic deformation of the asperities [3-5, 14-17].

During the sliding of the surfaces, local sticking of the tips of the asperities can occur. The breaking of these microjunctions formed in the real areas of contact between the surfaces, is due to the appearance of the shearing force [2, 3, 5, 6, 9, 10, 17]. These forces are dependent on the shear strength of the two materials. Following the breaking of the microjunctions, a release of material occurs, usually the softest (the polymer), which adheres to the surface of the counterpart, made of a material with greater hardness. This is how material is transferred from one surface to another, according to Fig. 1. [3] Initially, a polymer film is created on the top of the asperities of the metal surface (Fig.1.a). In the next phase, the gaps between the peaks of the asperities are filled (Fig. 1.b), after which the last phase of forming a continuous layer deposited on the metal surface follows (Fig. 1.c).

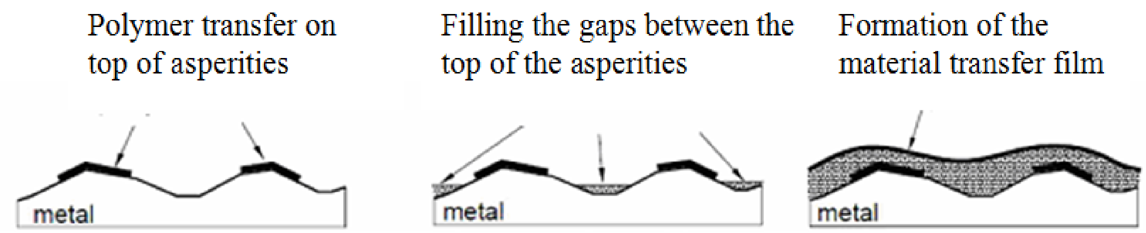

Figure 1. Modeling the transfer process of a polymeric material on a metallic surface [14].

The microscopic analysis highlights the appearance of a deformation component (hysteresis) in the elastic limit of the material, as a result of material friction. In the case of some metals, the fraction of energy lost in the elastic limit is less than 1%, and for viscoelastic materials such as elastomers, it can be much higher. [3] At the initial moment of sliding of the surfaces, the softer material is deformed, and elastic deformation energy appears. Most of this elastic energy is subsequently released, and a small part is lost as heat as a result of elastic hysteresis losses. Fig. 2 represents the transfer mechanism of this energy for a hard, spherical asperity sliding over a polymer surface.

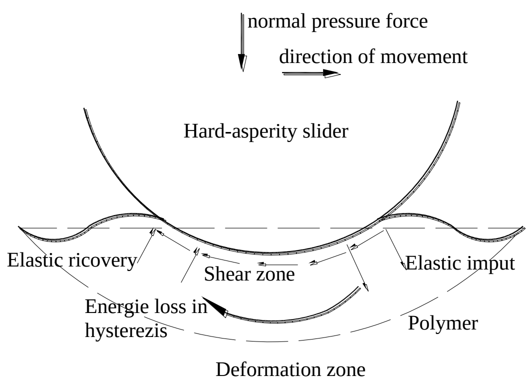

Figure 2. Sliding of a rough, hard sphere over a polymer [3].

The energy resulting from the deformation can be found before and after the opening. If the two energies were equal, then the sliding force would be zero. This energy loss, called hysteresis loss, occurs during the deformation and relaxation of the polymer material. This is related to the possibility of the material to store energy, to its deformation properties, to the sliding conditions, as well as to the mechanical properties [4].

2. MATERIALS AND METHODS

2.1. MATERIALS

The analyzed materials were: polytetrafluoroethylene (PTFE) is a high-performance plastic material with multiple tribological characteristics of low friction, self-lubrication, low density and chemically neutral. PTFE is an excellent solid lubricant with a high wear rate under normal friction conditions [1, 6, 9, 10, 21-25]. In order to achieve a better friction behavior, tests were done on composite materials [6, 9, 23-29]. The study on friction behavior was carried out by carrying out some comparative tests between the simple PTFE material and a PTFE composite reinforced with 25% glass fiber. The specialized literature indicates high compression and good wear properties in the PTFE composite material with glass fiber. The percentage of fiber can vary between 5% and 40% fact that leads to an increase in resistance to compression and small deformation under load.

Polyamide PA66 is a plastic material with high rigidity, hardness, abrasion resistance, low friction properties and thermal dimensional stability. This provides excellent performance especially in preserving the mechanical properties at high temperatures [30-32]. A comparative analysis with the PA66 material was made for polyamide 66 reinforced with glass fiber PA66+GF30. The composite exhibits high mechanical strength, creep resistance and dimensional stability.

The materials subjected to tribological analyzes were purchased commercially, in bar form and machined by turning. The physico-mechanical properties of the materials under analysis are presented in Table 1.

Table 1. The physico-mechanical characteristics [28-32]

Property	Units of measure	PTFE	PTFE+25% glass	PA66	PA66+GF30
Density	kg/m^3	2.17·10^3	2.20·10^3	1.14·10^3	1.29·10^3
Tensile strength	MPa	30–33	16–18	23–25	25–28
Elongation	%	300	220	150–300	150–280
Coefficient of thermal expansion	10^{-5}°C	12	8	15	3
Max/min work temperature	°C	–200/+250	–160/+200	–30/+100	–30/+120
Thermal conductivity	W/mK	0.46	0.48	0.29	0.36
Hardness	Shore D	55	65	81	84.6

2.2. THE EXPERIMENTAL PART

The friction tests were performed on a pin-on-disc tribometer [20]. The scheme of the operating principle is presented in figure 3. The pin made of polymeric material is in permanent, perpendicular contact on the rotating horizontal disc (from E335 according to SR EN10025). The pin has a diameter of 10 mm and a height of 70 mm and the disc has a diameter of 120 mm with thickness of 6 mm processed with a roughness of R_a = 0.05 – 0.1 µm. The sliding speed can be varied by changing the placement position of the pin on the disc (r_{min}…r_{max}) or by changing the speed of the disc by means of a speed variator.

The experimental tests were carried out in dry friction mode, at ambient temperature 20°C and a relative humidity in the range of 50-60%. The samples (pin/disc) were cleaned and degreased before testing. Five tests were performed for the same values of the experimental parameters.

According to the specialized literature [4, 8, 9, 11, 18, 21, 23, 24] and taking into account the possible applications of the materials under analysis, the following test parameters were selected: for the sliding speed: $v_1=0.20$ *m/s*, $v_2=0.50$ *m/s*, $v_3=0.75$ *m/s* for the applied load representing the normal forces: $F_{n1}=1.0$ *N*, $F_{n2}=2.5$ *N*, $F_{n3}=5.0$ *N*. The sliding distance for each test performed was L=5000 mm. It was sought that the experimental tests be as close as possible to the industrial operating conditions so that there is a real picture of the tribological behavior of these materials. To assess the wear rate, the samples were weighed on an analytical balance before and after each test.

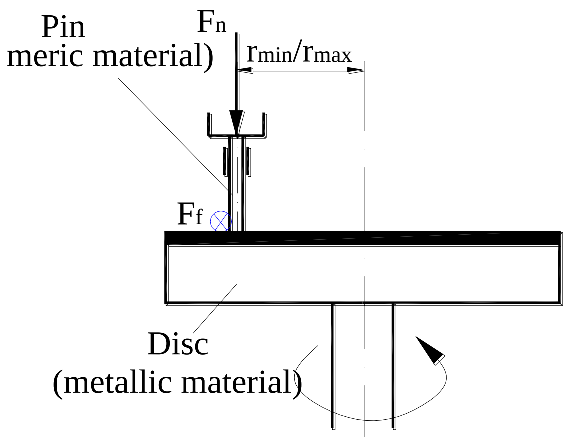

Figure 3. Functional scheme of the pin/disc tribological stand

2.3. EVALUATION OF FRICTION AND WEAR OF POLYMERIC MATERIALS

For the composites tested under the mentioned experimental conditions, the coefficient of friction and the wear rate were analyzed:

- the coefficient of friction which represents the ratio between the normal pressure force F_n [N] and the friction force F_f [N]:

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

- the specific wear rate is defined as the volume of wear lost (V [m^3]) for an applied normal load F_n [N] and the sliding distance L_f [m]

$$K_{sp} = \frac{V}{F_n \cdot L_f} \left[\frac{m^3}{N \cdot m} \right] \qquad (2)$$

where $V = m / \rho$: m mass of material lost due to friction [kg]; ρ material density [kg/m^3].

3. RESULTS AND DISCUSSION

3.1. RESULTS

Experimental research has indicated that the coefficient of friction varies differently with normal load and sliding speed. Figs. 4-5 show the evolution of the friction coefficient with sliding duration for the 4 materials as a function of the sliding speed and the normal pressing load on the pin. The experimental data represented in Fig. 4 were determined for a sliding speed of v_1*=0.20 m/s* and a normal compressive force of F_{n1}*=1.0 N*. Fig. 5 shows the evolution of the friction coefficient for the same sliding speed v_1*=0.20 m/s* but for a normal pressing force on the pin of F_{n3}*=5.0 N*. For the same sliding speed and friction length, the coefficient of friction increases with increasing loading force. The friction coefficient shows two stages of evolution for the four materials. In the first stage there is an increase in the coefficient of friction, after which there is a period of stagnation, and in the second part of the sliding distance we have a decrease and a stabilization of its values.

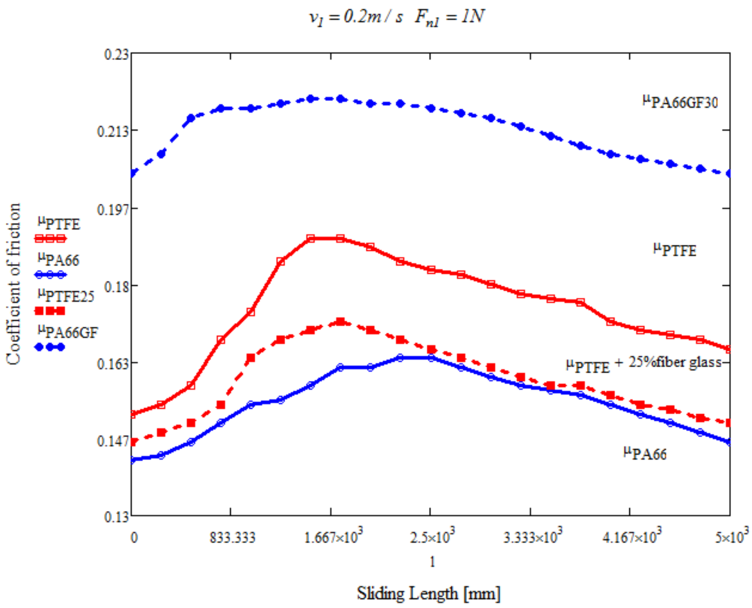

Figure 4. The variation of the coefficient of friction for the four materials for the sliding speed of v_1*=0.20 m/s* and normal compressive force of F_{n1}*=1.0 N*.

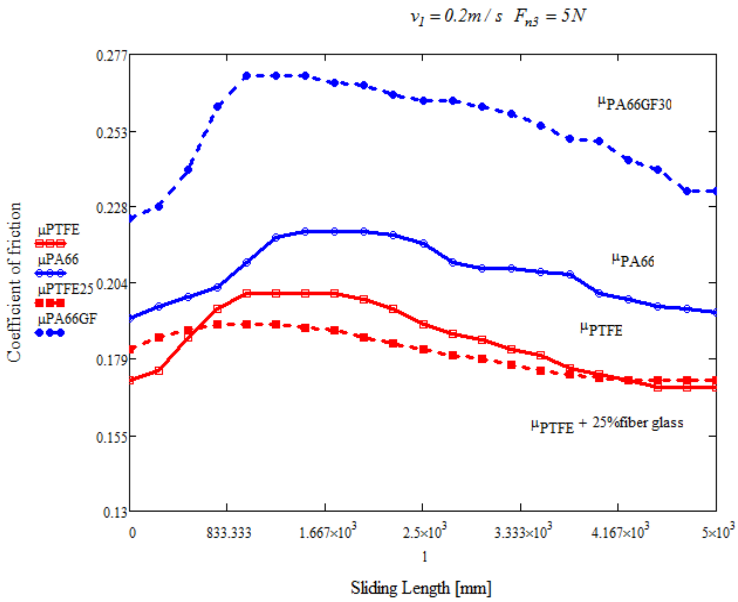

Figure 5. The variation of the coefficient of friction for the four materials for the sliding speed of v_1=0.20 m/s and normal pressing force on the pin of F_{n3}=5.0 N.

The explanation of this phenomenon would be that in the first part of the contact between the surfaces in motion, the real friction surface increases by breaking the tips of the asperities in contact. The material transfer occurs as a result of the breaking of the tips of the asperities, due to the detachment of the soft material (the polymer) that adheres to the surface of the counterpart (the metallic material). Due to the transfer of material and the stabilization of the real contact area, in the second stage there is a uniformization of the value of the coefficient of friction. In the case of materials with glass addition, the increase in the coefficient of friction is faster due to the greater shearing tendency of the tips of the asperities, in the second part the decrease is somewhat slower.

Figs. 6-8 show the coefficient of friction values for the tested materials as a function of speed and loading force, under dry friction conditions. The experimental values of the variation of the friction coefficient with sliding speed and loading force are similar to those given in the literature [2, 4, 6, 8, 9, 11, 14, 19, 21, 23, 26].

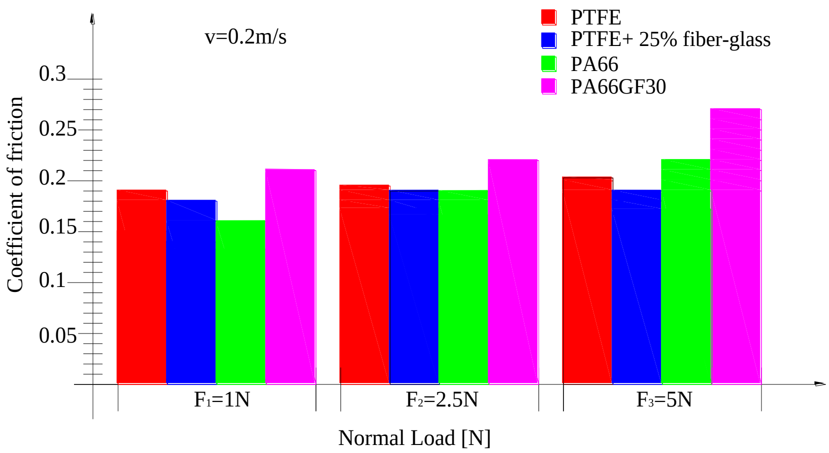

Figure 6. The variation of the coefficient of friction for the four materials for the sliding speed of v_1=0.20 m/s and the three values of the normal pressing force F_{n1}=1.0 N, F_{n2}=2.5 N, F_{n3}=5.0 N.

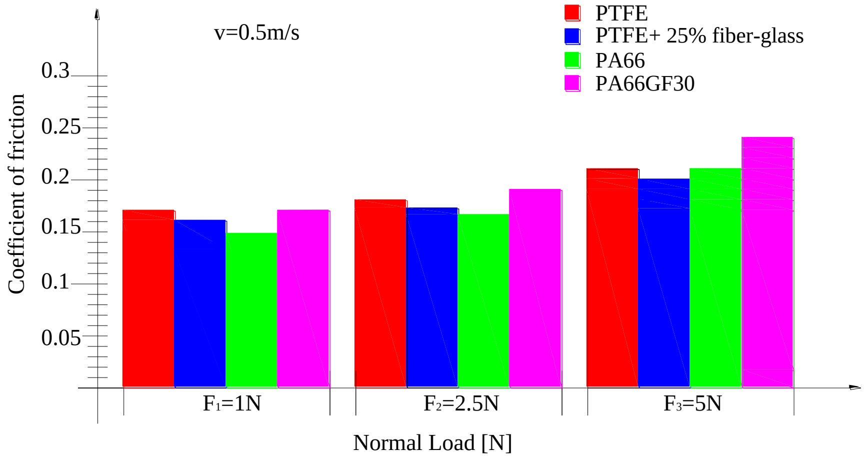

Figure 7. The variation of the coefficient of friction for the four materials for the sliding speed of $v_1=0.50$ *m/s* **and the three values of the normal pressing force** $F_{n1}=1.0$ **N,** $F_{n2}=2.5$ **N,** $F_{n3}=5.0$ **N.**

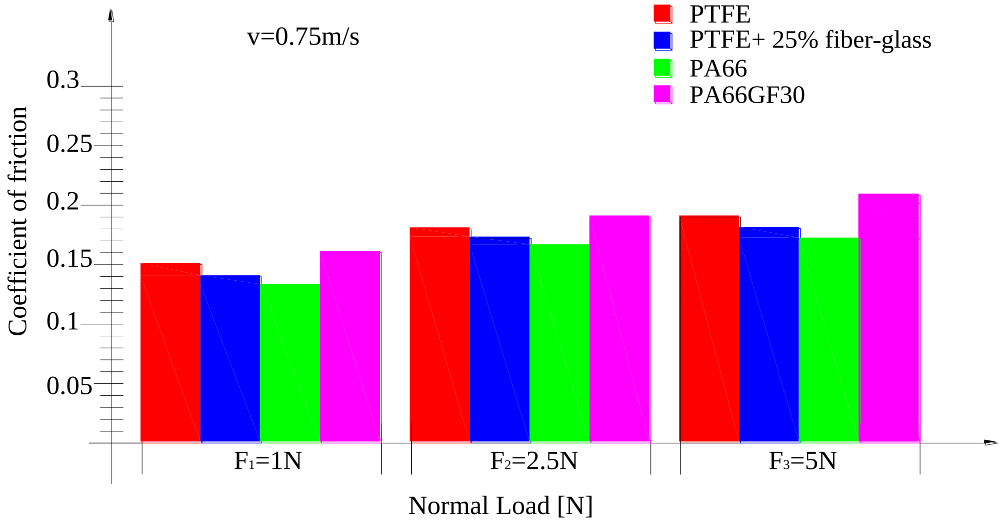

Figure 8. The variation of the coefficient of friction for the four materials for the sliding speed of $v_1=0.75$ *m/s* **and the three values of the normal pressing force** $F_{n1}=1.0$ **N,** $F_{n2}=2.5$ **N,** $F_{n3}=5.0$ **N.**

The graphical representation shows the decrease of the coefficient of friction with the sliding speed and its increase with the loading force. For PTFE+ 25% glass, the friction coefficient values are lower than those of the base material (pure PTFE), and PA66+GF30 has a higher friction coefficient than that of the PA66 base material. The material PA66+GF30 is not recommended in sliding contacts, where a low friction coefficient is usually desired.

Figs. 9-10 show the wear rates for the tested materials as a function of loading force and sliding speed. The experimental values of the wear rate are similar to those found in the specialized literature [2, 4, 6, 8, 9, 11, 14, 19, 21, 23, 26, 33-36].

Fig. 9 shows the wear rate as a function of the three pin loading forces for the test friction length at the sliding speed of $v_1=0.75$ *m/s*. It is observed that the wear rate increases with the increase of the loading force. PTFE+25% glass has the lowest rate of wear and PTFE the highest. Due to the hardness conferred by the glass fibers, the PA66+GF30 material has a high coefficient of friction and a low wear rate.

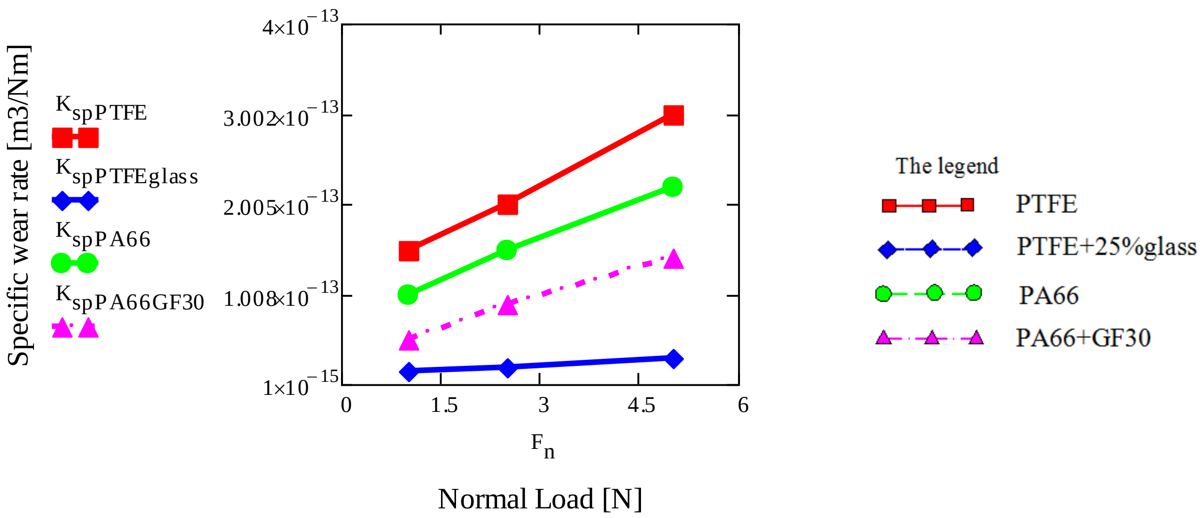

Figure 9. Variation of wear rate for tested materials as a function of normal loading force for a speed

Fig. 10 shows the wear rate as a function of the sliding speed for a pin loading force of $F_{n1}=1.0$ *N*. The wear rate increases with the sliding speed, its value being lower compared to the increase in the wear rate as a function of the loading force. Pure PTFE and PA66 materials have a faster increase in wear rate with sliding speed.

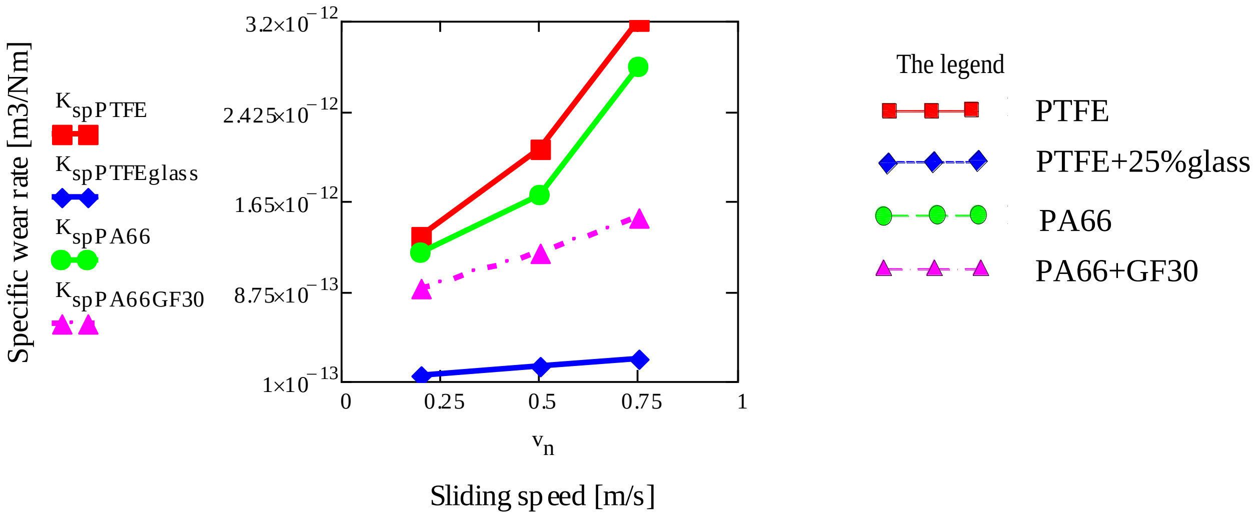

Figure 10. Variation of wear rate for tested materials as a function of sliding speed for a pin loading force

4. CONCLUSIONS

The experimental studies carried out highlighted the tribological performances of pure PTFE, PTFE + 25% glass fiber, PA66 and a composite thereof PA66+GF30. The evolution of the friction coefficient and the wear rate under the action of the sliding speed was analyzed the evolution of the friction coefficient and the wear rate under the action of the sliding speed

(v_1=0.20 m/s, v_2=0.50 m/s, v_3=0.75 m/s) and the pin loading force (F_{n1}=1.0 N, F_{n2}=2.5 N, F_{n3}=5.0 N) for a friction length of L=5000 mm, under dry friction conditions.

Based on research from the specialized literature, the main mechanisms that generate friction in the case of polymers were explained. The obtained experimental results correspond to the research found in the specialized literature. They can be used in the future to design the various components of mechanical tribosystems.

The experimental analyzes highlighted the fact that:

- the friction and wear behavior of the material couplings is strongly influenced by the working parameters (loading force, sliding speed, sliding distance).
- the friction coefficient is different depending on the material combination, the highest value being PA66+GF30;
- under the same test conditions of pure PTFE, PTFE +25% glass fiber, PA66 shows a better coefficient of friction compared to PA66+GF30;
- increasing the sliding distance and load of the pin, leads to the loss of material mass;
- a small value of the coefficient of friction does not necessarily mean a small wear;
- the wear rate is higher for pure materials (PTFE and PA66) compared to glass-reinforced composite materials (PTFE + 25% glass fiber and PA66+GF30);
- the wear rate is dependent on the loading force.
- the presence of reinforcing agents improves the tribological performance of composite materials.

The experimental parameters were chosen taking into account the industrial operating conditions so that there is a more realistic picture of the tribological behavior of these materials.

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