Study of the Tribological Behavior of a Pin on Disc Type of Contact

S. Djebali, S. Larbi, A. Bilek

***Abstract*—**The present work aims at contributing to the study of the complex phenomenon of wear of pin on disc contact in dry sliding friction between two material couples (bronze/steel and unsaturated polyester virgin and charged with graphite powder/steel). The work consists of the determination of the coefficient of friction, the study of the influence of the tribological parameters on this coefficient and the determination of the mass loss and the wear rate of the pin. This study is also widened to the highlighting of the influence of the addition of graphite powder on the tribological properties of the polymer constituting the pin. The experiments are carried out on a pin-disc type tribometer that we have designed and manufactured. Tests are conducted according to the standards DIN 50321 and DIN EN 50324. The discs are made of annealed XC48 steel and quenched and tempered XC48 steel. The main results are described here after. The increase of the normal load and the sliding speed causes the increase of the friction coefficient, whereas the increase of the percentage of graphite and the hardness of the disc surface contributes to its reduction. The mass loss also increases with the normal load. The influence of the normal load on the friction coefficient is more significant than that of the sliding speed. The effect of the sliding speed decreases for large speed values. The increase of the amount of graphite powder leads to a decrease of the coefficient of friction, the mass loss and the wear rate. The addition of graphite to the UP resin is beneficial; it plays the role of solid lubricant.

***Keywords*—**Friction coefficients, mass loss, wear rate, bronze, polyester, graphite.

I. Introduction

THE wear is one of the major causes of the materials' degradation and losses of mechanical performances of the equipments. It has a direct impact on the reliability and the longevity of the mechanisms. Wear by sliding depends on several tribological parameters which are interdependent such as the normal load (F_N), the sliding speed (V), the material hardness, the geometrical and physical state of surfaces, the coatings, the lubricants…

Bronze is very much used in the mechanical engineering for its interesting tribological characteristics. Polymers and composites are integrated in many industrial applications because of their advantageous properties (high specific strength, good corrosion resistance …). In order to improve tribological properties of the polymers, solid lubricants are added to the polymer matrix. These solid lubricants generally develop a protective film against wear by severe abrasion of the reinforcements and the matrices. Micro and nano lubricating particles such as graphite, TiO_2, SiO_2, ZrO_2 have been successfully used to reduce the coefficient of friction and the wear rate of polymers [1], [2] and reinforced polymers [3]-[5].

In this paper, we present experimental results of the normal load, the sliding speed and micro-hardness influences on the friction coefficient in the bronze on steel contact and experimental results of the effect of the normal load, the sliding speed and the addition of graphite powder on the tribological properties of the unsaturated polyester UP.

II. Experimental Conditions

A. Specimens Material

The discs are made of XC48 steel. To change their surface hardness, they have undergone heat treatment (quenching and tempering at 250 °C and quenching and tempering at 500 °C). The Vickers hardness of the disc surfaces are Hv224 for annealed state, Hv338 for quenched and tempered at 500 °C state and Hv524 for quenched and tempered at 250 °C state.

The pins are of bronze, virgin unsaturated polyester, and unsaturated polyester charged with graphite powder (0% G, 1% G and 2% G).

B. Geometry of Discs and Pins

The bronze pins are machined in bars of square section 6mm x 6 mm. Polyester pins are made by cutting and milling plates molded in virgin unsaturated polyester and unsaturated polyester charged with various mass percentages of a commercial graphite powder (%G) which did not undergo any chemical treatment. For the molding of the plates, three mixtures are prepared (Resin + hardener and Resin + hardener + graphite 1 or 2%). These mixtures are homogenized then poured in moulds. The polymerization takes 24h at room temperature.

C. Tests Conditions

For virgin unsaturated polyester pin and charged unsaturated polyester pin, the tests are performed under four loads (F_N=8 N, F_N=13.5 N, F_N=17.5 N and F_N=22.5 N) at three different speeds (V=0.08 m/s, V=0.32 m/s and V=0.63 m/s) for the three compositions of the pin (polyester virgin, polyester+1% graphite, polyester+2% graphite).

For bronze pin the tests are performed under four loads (F_N=22 N, F_N=45 N, F_N=68 N and F_N=90 N) and three different speeds (V=0.08 m/s, V=0.32 m/s and V=0.89 m/s) for the three states of XC48 steel (annealing, quenching and

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tempering at 250 °C, quenching and tempering at 500 °C).

The test duration is about 2000 seconds and each test is repeated three times. The tests are conducted at room temperature (25 °C).

III. Experimental Device

The tests are carried out on a vertical tribometer of pin on disc type that we have designed and manufactured. This device allows studying the friction and wear of couples of materials. Its principle consists in applying a vertical load (4) to a pin (2) in contact with a rotating disc (3). During rubbing a strain gauge sensor (5) records simultaneously and without interference the values of the tangential force F_T and the normal load F_N. The normal force is measured by gauges J_1 and J_3 and the tangential force by gauges J_2 and J_4 (Fig. 3). The variation of the linear velocity is obtained by changing the radius of the sliding track of the pin on the disc. The device is provided with a compensation system with dead loads (7) which ensures the resetting of the measurement system. The rotation of the disc (3) is generated by an electrical motor (8) of a power of 220 W rotating at 1400 tr/min.

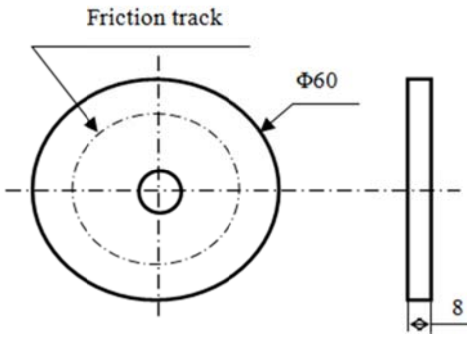


Fig. 1 Disc

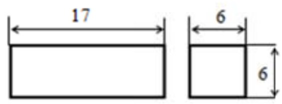


Fig. 2 Pin

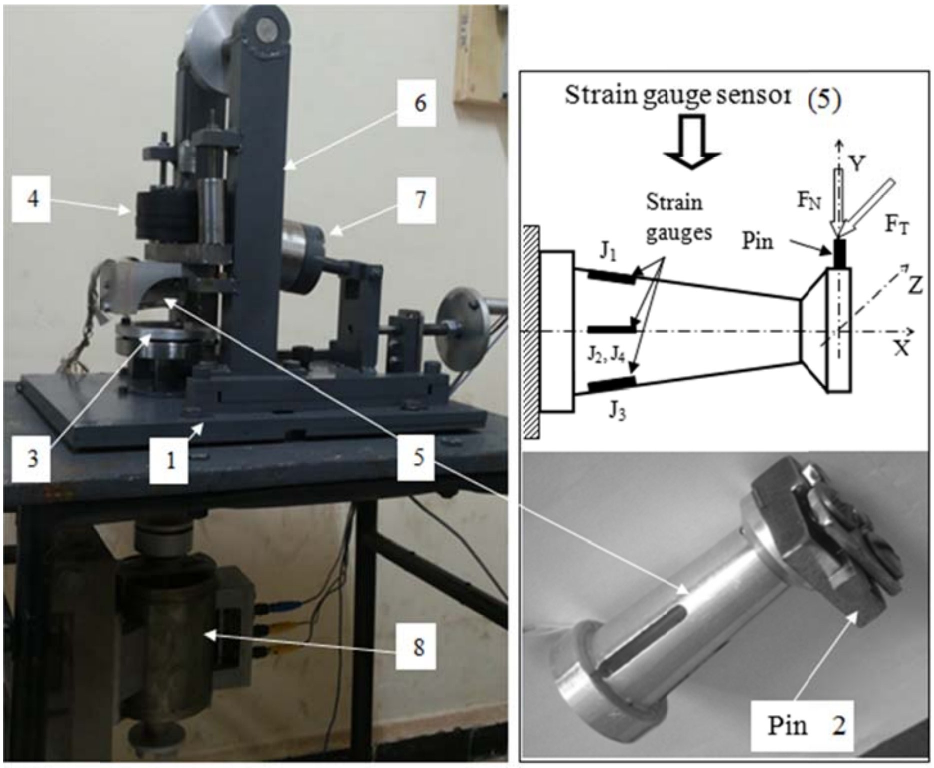


Fig. 3 View of tribometer

IV. Results and Discussions

A. Determination of the Friction Coefficient

From the measurements recorded during the tests, we plot the curves of the normal force $F_N(t)$ and the tangential force of friction $F_T(t)$ versus time. For illustration, an example of these curves is presented on Figs. 4 and 5 (curves relative to a bronze on steel contact). The curve giving the evolution of the coefficient of friction versus time *f(t)* (Fig. 6) is deduced from the curves F_N(t) and F_T(t). It is obtained by the ratio $F_T(t)/F_N(t)$.

We note that the normal load is practically constant throughout the test (Fig. 4) and the tangential force of friction (Fig. 5) undergoes a significant increase over a short period (200 s) followed by a low increase for the remainder of the test, which lasts 1700 to 2000 seconds. As for the tangential force, the coefficient of friction presents a short phase of fast increase followed by one long period during which it increases slightly before stabilizing at a certain value (Fig. 6). This value, which is in fact the characteristic value of the coefficient of friction `*f*' appears, according to the test, between 1700 and 2000 s. The same behaviour of variation of $f(t)$ is observed for the bronze/steel and polyester/steel contacts.

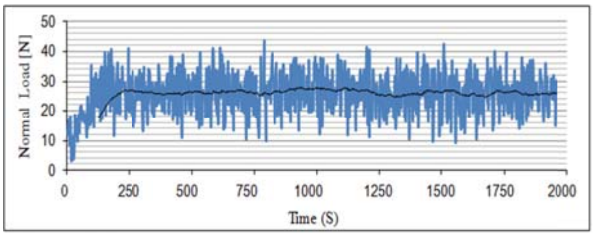


Fig. 4 Normal load versus time $F_N(t)$

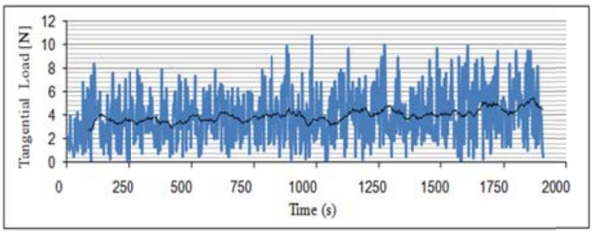


Fig. 5 Tangential load versus time $F_T(t)$

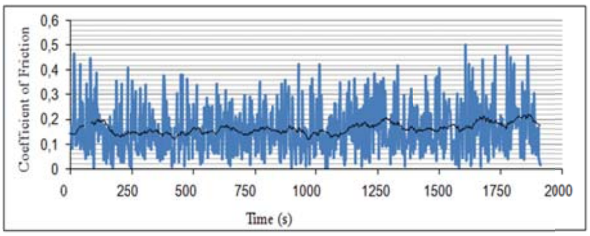


Fig. 6 Coefficient of friction versus time $f(t)$

B. Influence of Normal Load, Sliding Speed and Hardness on the Friction Coefficient for Bronze-Steel Contact

The evolution of the average friction coefficient according to the hardness, speed and normal force is shown in Fig. 7. Some observations can be made:

- The friction coefficient increases with the increase of speed for the low values of the normal load (F_N=22 N and F_N=45 N). For the other two loads (F_N=63 N and F_N=90 N), we observe a random variation of the coefficient of friction as a function of speed except for the case of the steel discs having undergone a quenching and tempering at 250 °C in which the coefficient of friction increases with the sliding speed for all the normal loads considered.
- For low speeds (V=0.08 m/s and V=0.32 m/s) the coefficient of friction increases with the normal load. For V=0.89 m/s the variation of the normal load has practically no effect on the coefficient of friction.
- For low values of the normal load (F_N=22 N and F_N=45 N) and the sliding speed (V=0.08 m/s and V=0.32 m/s), variations between the values of the coefficient of friction are important. Increasing F_N reduces the influence of speed on the friction coefficient.
- The coefficient of friction decreases with increasing hardness. Note however that the decrease is more important in the case of low speeds (V=0.08 m/s and V=0.32 m/s).

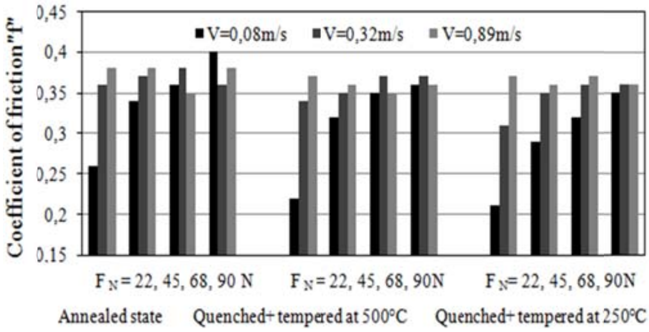


Fig. 7 Evolution of the friction coefficient as a function of the hardness, the normal load and the sliding speed

C. Influence of Normal Load, Sliding Speed and Graphite Content on the Friction Coefficient

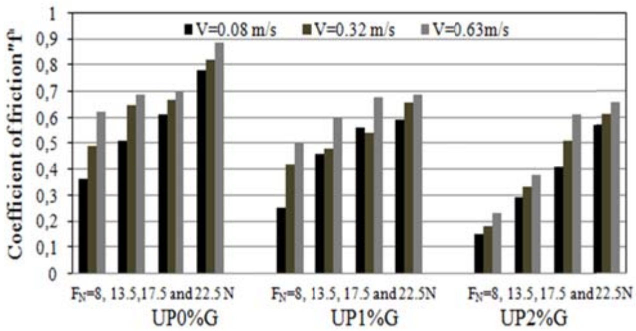


Fig. 8 Evolution of the friction coefficient as a function of the normal load, the sliding speed and the graphite content

Fig. 8 shows values of the coefficient of friction obtained with three materials combinations (Steel XC48/UP 0% G, Steel XC48/UP 1% G and Steel XC48/UP 2% G) for different sliding speeds and normal loads. We used the XC48 steel disc quenched and tempered at 250 °C for which we have obtained the highest value of surface hardness (Hv524). Analysis of the results reveals that:

- The coefficient of friction increases with increase in the speed and the normal load. For dry friction, the increase in normal load causes an increase of the contact area which leads to an increase of the coefficient of friction. The same observation can be made when the velocity increases. This behavior is reported by other authors [1], [3], [6].
- For the same load and the same speed, the coefficient of friction is the lowest in the case of contact with charged resin pins than with that of the virgin resin pins. The coefficient of friction decreases with the increase of the graphite content.

- The coefficient of friction is higher than that obtained with the bronze pin. With the polyester pins, contrary to the bronze pins, we observe a clear increase in the friction coefficient according to the normal load and the sliding speed.

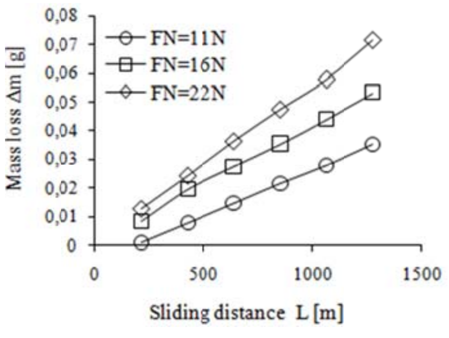
D. Evolution of the Mass Loss and the Wear Rate as a Function of the Normal Load and the Graphite Content

For the three studied compositions, the mass loss '*Δm*' increases linearly with the sliding distance '*L*'. For the great values of the normal load, the slope of the curve describing the variation of the mass loss according to the sliding length seems to increase; it is the sign of a strong abrasion (Fig. 9). The wear rate '*K*' also increases with the sliding distance and the normal load. '*K*' is calculated by:

$$k = \Delta V / F_N L = \Delta m / \rho F_N L$$

where '*ΔV*' is the volume loss, 'F_N' is the normal load, '*L*' is the sliding distance, '*Δm*' the mass loss, and '*ρ*' the density.

The addition of graphite reduces the mass loss and the wear rate. Indeed, the mass loss and the wear rate decrease with the increase of the graphite content (Figs. 9 and 10). Graphite is a good solid lubricant; this explains the contribution to the reduction of the coefficient of friction, the mass loss and the wear rate. The same behavior is already observed in the case of much of polymers and composites [1], [4], [7]. The addition of graphite to unsaturated polyester improves the tribological properties of this last.



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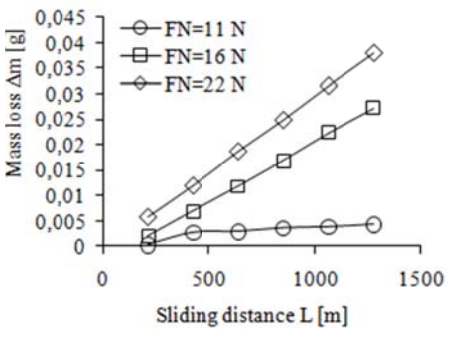

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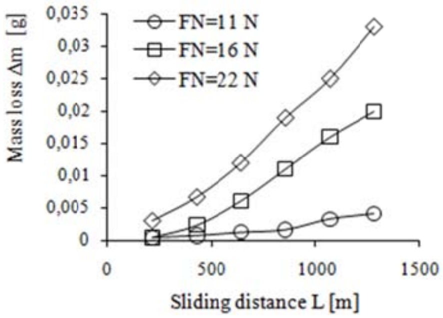

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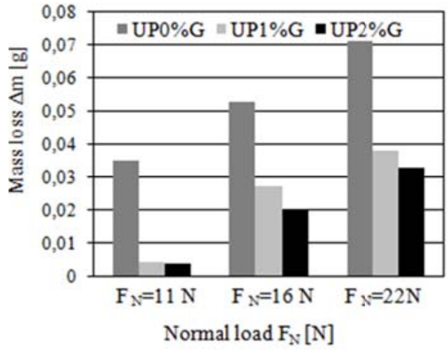
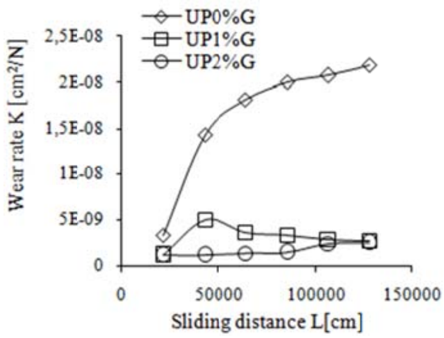


(d)

Fig. 9 Mass loss vs. normal load and graphite content at V=0.32 m/s, (a) Mass loss vs. sliding distance for UP 0% G, (b) Mass loss vs. sliding distance for UP 1% G, (c) Mass loss vs. sliding distance for UP 2% G, (d) Mass loss vs. normal load for different % G



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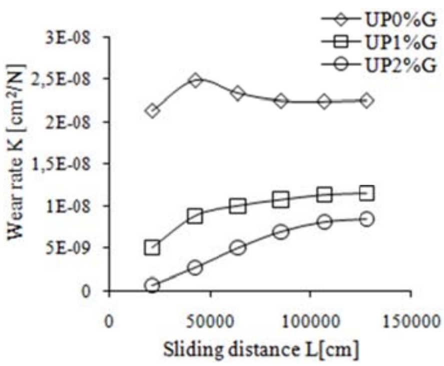

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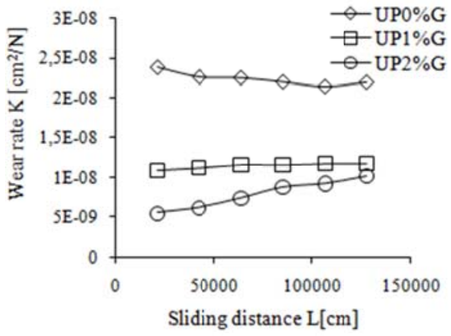

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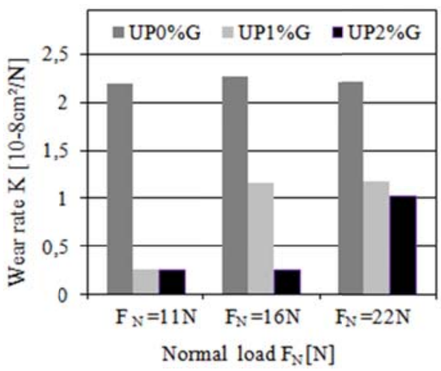

(d)

Fig. 10 Wear rate vs. normal load and graphite content at V=0.32 m/s, (a) Wear rate vs. sliding distance for F_N=11 N, (b) Wear rate vs. sliding distance for F_N=16 N, (c) Wear rate vs. sliding distance for F_N=22 N, (d) Wear rate vs. normal load for different % G

V. CONCLUSION

During testing, we observed wear particles detached from the pin. Some of them remain stuck on the disc sliding track. The wear mechanism activated is that by the abrasion.

Mainly, the increase of the normal load and the sliding speed causes the increase of the coefficient of friction, the mass loss and the wear rate whereas the hardness and the graphite percentage increase contributes to their decrease. More significant is the normal force; more the real contact area increases. The force required to shear the interfacial junctions is thus more important; this explains the high values of the coefficient of friction, the mass loss, and the wear rate. However, it should be noted that in the case of bronze pins the effect of speed on the coefficient of friction clearly appears only at the low speeds. Indeed, for high speeds, the increase of the normal load and the hardness of the disc surface practically do not have an influence on the coefficient of friction.

The graphite addition to the resin is beneficial; indeed, as shown by the results, the values of the coefficient of friction, the mass loss, and the wear rate are minimal for the polyester charged with 2% graphite for the three considered loads. Given these results, we can say that the graphite effectively played the role of solid lubricant. Our results agree reasonably well with those of other authors [1], [3], [4], [7]-[9].

Finally, we think that it is relevant to extend the present study to the graphite contents higher than 2% and especially complete this work by the characterization of the mechanical properties of polyester charged to evaluate the impact of the addition of graphite on its mechanical characteristics (Young's modulus, elastic limit, breaking strength).

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