Wear Assessment of Polymer Composite Filled with Metal Particles through Ball-on-Flat Reciprocating Test

VIRGIL ILIUTA[1], ADRIANA PREDA[2], GABRIEL ANDREI[1], IULIAN BIRSAN[1]
[1] " Dunărea de Jos" University of Galaţi, 47 Domneasca Str., 800008, Galaţi, Romania
[2] UZINSIDER SA Galati, 2 Smârdan Str., 800701, Galaţi, Romania

In this study the results of the dry wear tests of composite material used to repair brass made parts are presented. The material belongs to Multimetall Messing category. It has a polymer matrix reinforced with Cu, Zn, Sn particles, and various allotropic forms of silicon dioxide (SiO_2). This composite material was tribologically tested in dry friction reciprocating conditions, in ball-on-flat configuration, using the tribometer CETR-UMT-2. The counterpiece was a steel ball. The tests were performed at normal loads of 20, 30, 40 and 50N, over a distance of 100 m, at an average sliding speed of 3.5 mm/s, at room temperature and relative humidity of 50-60% . The results of the analysis were compared with the similar ones obtained under the same conditions for brass.

Keywords: composite material, brass, wear track, profilometer, tribometer, reciprocating, ball-on-flat

Composite materials are characterized by remarkable properties, such as: stiffness, mechanical strength, wear resistance, low density, wettability. Due to the properties mentioned above, these materials are used in automotive industry, aviation and other fields, in order to replace metal parts [1- 4].

The addition of metal fillers in polymer composites improves mechanical strength and wear behaviour.

In order to study the composite materials' tribological properties, several laboratory tests were conducted in different tribological and kinematic conditions, such as: *ball-on-flat test configuration in reciprocating* sliding [5-9]). Previous studies mentioned above, describe the variation of coefficient of friction, wear parameters and worn surface topography, depending on load, frequency, sliding distance and/or time. For studying the wear intesity, profilometric analysis is commonly used for analyzing the wear tracks.

Results on the behaviour of polymer composites are presented in the papers [10-12]. Also, the topography of wear tracks were studied in the works [13-16].

Experimental part

Materials and methods

The following composite specimens were subject to tribological investigations: 1. composite material (code SAC) used for reconditioning of brass made parts and 2. high strength brass (grade like SAE 430B). The composite material [17] was produced in Germany and belongs to Multimetall Messing category. It has a polymer matrix reinforced with Cu, Zn, Sn particles and various allotropic forms of SiO_2. The composite material results by mixing two components. The obtained putty was applied on the machined surface of the specimen.

After drying (approx. 24 h), the sample's surface was machined, resulting the following roughness parameters: R_a=1.42, R_q=2.48, R_t=23.09, R_{sk}=-2.69 and R_{ku}=15.07. The final dimensions of the samples were: ∅76×7.

The counterpart was a steel ball (AISI 52100 GCr15, grade like SKF), with a hardness of 80HRC, a diameter of 6 mm, and a surface roughness R_a of about 0.06 μm.

The mechanical properties of the composite are [17]: Young's modulus - 5800 N/mm², tensile strength - 63 N/mm², compressive strength - 155 N/mm² and 84-86 Shore Hardness.

For the brass (code SA) the following mechanical properties are determined: tensile strength R_m=723 N/mm², yield strength $R_{p0,2}$=420 N/mm², elongation A5=14% and hardness 236 HB. Roughness parameters of brass were: R_a=0.14, R_q=0.19, R_t=1.84, R_{sk}=-0.15 and R_{ku}=5.35.

Dry sliding wear tests were done using a ball-on-flat reciprocating UMT-2 tribometer (USA) at room temperature (20÷26°C) and relative humidity of 50-60%. Testing parameters were: the sliding distance – 100 m, the reciprocating friction stroke was 5 mm and the test duration - 475 min. For the study, the load applied to the sample was: 20, 30, 40 and 50 N.

Before testing, the samples were degreased with an organic solvent and dried with hot air at the temperature of 50 °C.

The wear tracks were examined and analyzed using scanning electronic microscopy (SEM) and laser profilometer and wear parameters were calculated: the wear volume and specific wear rate.

Profilometric analysis was used for evaluating the wear process intensity and the kind of wear process.

Digital profiles acquired with a laser profilometer (μSCAN, ® NanoFocus) and processed with the software SPIP 6.2.6 (TM Image Metrology, Horsholm). The complex analysis of the worn surfaces was performed with the 2D digital profiles of the surface topography. For each wear track, three cross-sectional profiles were acquired, as follows (fig. 1): on the center of the track (profile "m") and at the 2 mm distance on both side of the track (profile "e" and profile "i").

The volume of worn material (according to ASTM 133-05) used for tribological analysis is situated on the cylindrical side (V_1) of the wear track, and it was calculated using the following equation [18]:

$$V_1 = A_w \cdot c \qquad (1)$$

where the average area (A_w) of the wear track is:

$$A_w = \sum_{i=1}^{3} A_i \qquad (2)$$

* email: virgil.iliuta@ugal.ro; Tel. 0763 113 625

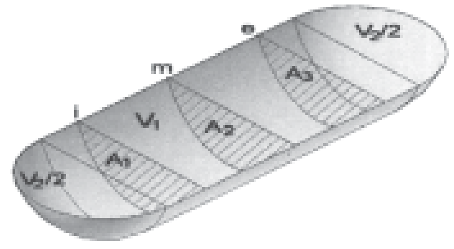

Fig. 1. Geometric model of wear trace

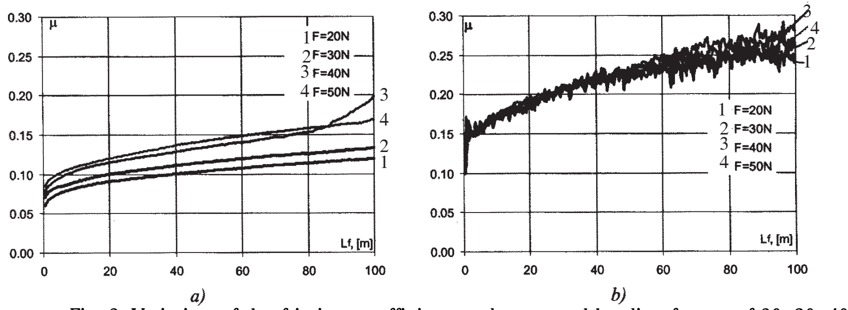

Fig. 2. Variation of the friction coefficient under normal loading forces of 20, 30, 40 and 50N and sliding distance L_f=100 m: a) composite material (SAC); b) brass (SA)

The specific wear rate (k) was calculated using the equation [19, 20]:

$$k = \frac{V_1}{F \cdot L_f} \qquad (3)$$

where the following notations were used:

c – stroke, [mm];

A_i - cross-sectional area, [mm^2];

F – loading force, [N];

L_f - sliding distance, [m].

The results of the tribological analysis were compared with the similar ones obtained under the same conditions for a brass specimen.

Results and discussions

In the figures 2÷5 are shown the results obtained for the studied materials: the coefficient of friction, the average coefficient of friction, the liniar wear, 2D wear tracks profile and the specific wear rate. Considering the composite material, once the value of the loading force increases, the friction coefficient gains greater values, comparing to the metallic material (fig. 2). When talking about the metallic material, greater variations of the friction coefficient appear once the friction distance increases (fig. 2a).

The average friction coefficient was obtained by making an average for those values obtained on the last 25 m of the friction distance.

The values for the average friction coefficient are significantly lower comparing to the ones of the composite material (fig. 3); in the case of the metallic material, the values belonging to the four forces are almost even (fig. 3b).

In the case of the composite material, linear wear (fig. 4a) is characterized by low values, comparing to those belonging to the metallic material. After a significant increase at the beginning (up to 20 m), the linear wear is described by a small increase. In the case of brass, the linear wear is increasing constantly for all the friction distance (fig. 4b).

In figure 5 the profiles (2D) are presented for both materials: the composite material (code SAC) and brass (code SA). We can see significantly lower values for the

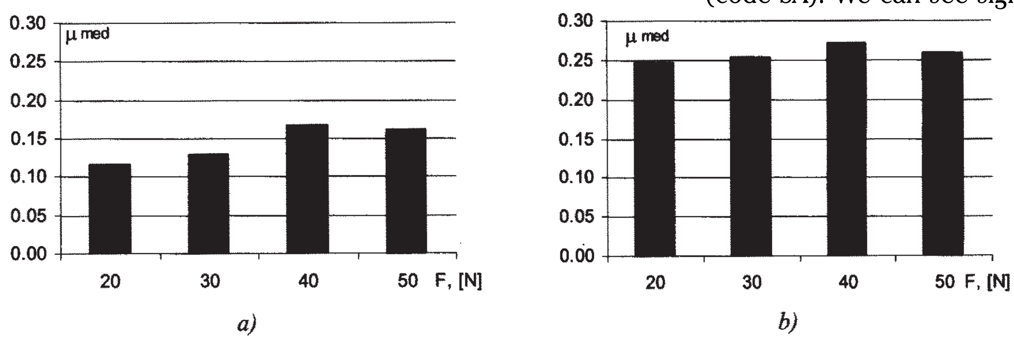

Fig. 3.Variation of the average coefficient of friction under normal loading forces of 20, 30, 40 and 50N, and L_f=100m: a) composite material (SAC); b) brass (SA)

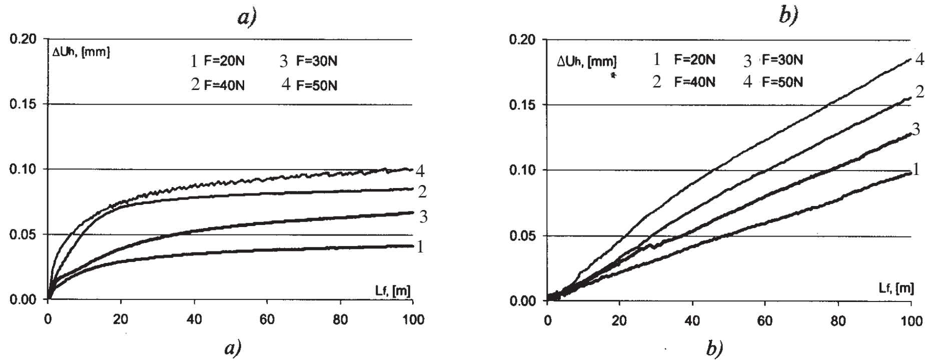

Fig. 4. Variation of the linear wear under normal loading forces of 20, 30, 40 and 50N, and L_f=100m: a) composite material (SAC); b) brass (SA)

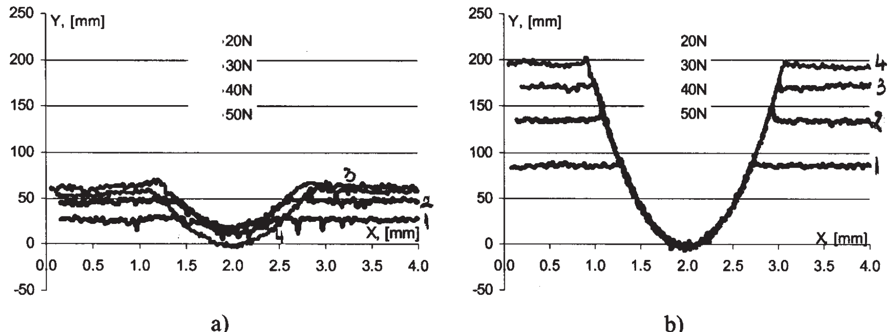

Fig. 5. 2D profiles for the loading forces 20,30,40 and 50N and L_f=100m: a)composite material (SAC); b) brass (SA)

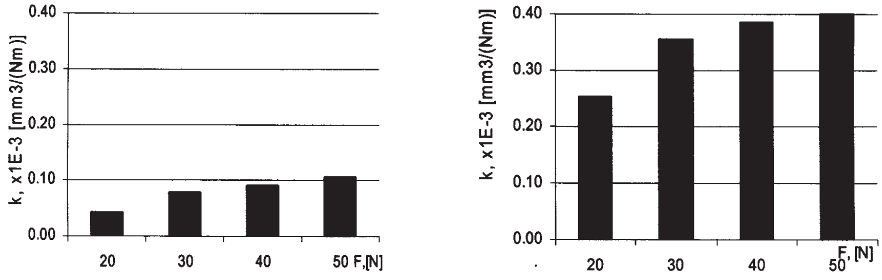

Fig. 6. Variation of the specific wear rate under normal loading forces of 20, 30, 40 and 50N, and sliding distance L_f=100m: a) composite material (SAC); b) brass (SA)

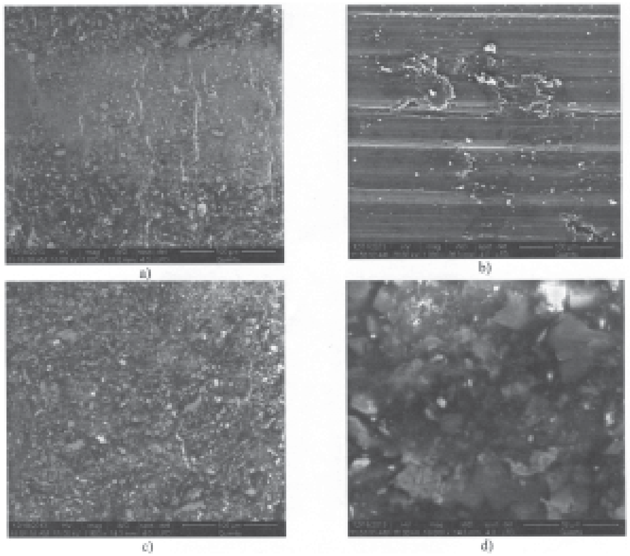

Fig. 7. SEM images of the wear track after reciprocating dry sliding test: a)composite material (SAC, 1000×), at load of 40N; b) brass (SA), at load of 40N; c) composite for brass (SAC, 1000×), at load of 50N; d) composite for brass (SAC, 10000×), at load of 50N

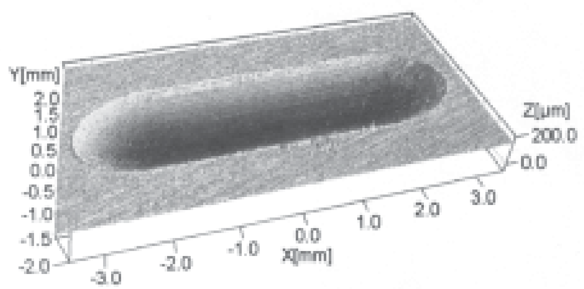

Fig. 8. 3D virtual image of composite for brass at load of 40N

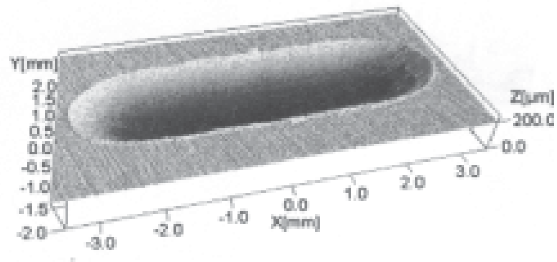

Fig. 9.. 3D virtual image of composite for brass at load of 50N

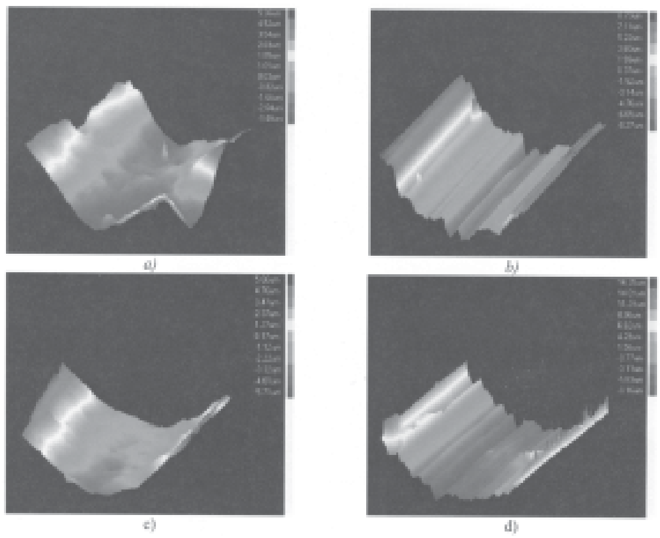

Fig. 10. Typical details of the wear track for the loading force 40N and L_f=100m: a)composite material(SAC); b) brass (SA); c) 3D virtual image of the composite for brass at load of 50 N; d) 3D image of the brass for 50 N

depth and wear track width in the case of composite material, when comparing to the metallic one.

The specific wear rate (fig. 6) for the composite material has much lower values than those of the brass. By increasing the force, the specific wear ratio tends to decrease for both materials.

SEM images of the wear track of composite material and metallic material at the load of 40 N and reciprocating dry sliding test are shown in figure 7.

In the case of composite material, it can be noticed the presence of metallic particles into polymer matrix (fig.7a). The image does not reveal scratches, furrows or other defects. As for the metallic material, it can be observed scratches and grooves along the sliding direction, microcracks and pores, material peeling and adhesion (fig. 7b).

Measurements on Nanofocus instrument allowed to plot 3D virtual images of worn traces after wear test (figs. 8 and 9).

Figure 10 present the typical 3D plots (scanning area: 0.5 x 0.5 mm) for the composite material and for brass.

By looking at figure 10a, we can see that the wear track in the case of composite material, have small smooth gaps. These gaps together with the shape of the 2D profiles that belong to the wear tracks (fig. 5a), lead to the following conclusion: the adhesive wear is a dominant process, when it comes to the composite material. For the metallic material, brass, figure 10b shows fine scratches and furrows, and also microscopic gouges, which leads to the following conclusion: the most common kind of wear is the abrasion one.

Conclusions

The aim of this research was a comparative study of the tribological behaviour of two materials, a composite material and a brass.

The friction coefficient and the average friction coefficient have much lower values for composite material (SAC), comparing to the metallic material, the brass (SA).

The parameters of wear: the linear wear the specific wear rate are significantly larger for the brass, especially for the specific wear rate.

Based on the visual observations and 3D image acquisitions performed using the profilometric module of the CETR-UMT-2 tribometer, it seems that the abrasion wear dominates in the case of metallic material, the brass (code SA). In the case of composite material, the adhesive wear has a significant presence, as the 3D images reveal for the wear tracks (fig. 10 a).

Analyzing the tribological parameters presented in figures 2÷7 and 10 one could observe the better wear behaviour of the composite material compared to the brass, in dry friction reciprocating ball-on-flat test conditions.

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