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Ball-on-flat reciprocating test to evaluate dry sliding wear behaviour of reinforced polymer composites

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Abstract. This paper presents the results of the tribological investigations on polymeric composite materials reinforced with Cu, Zn, Sn, SiO_2 and MoS_2 microparticles, used for repairing metal parts made of brass and bronze. The tested material were: three composite materials (products of the company Diamant Metallplastic GmbH, Germany): Multimetall Messing (used for repair of brass parts), Multimetall Bronze (used for repair of bronze parts) and Moglice (for brass and bronze parts). The testing was conducted in dry conditions, in ball on flat configuration, by reciprocating method, on the CETR UMT-2 tribometer (Bruker Corporation) at normal loads 20, 30, 40 and 50N, over a sliding distance of 100m. The paper presents studies of the variations of the friction coefficient, linear wear, volumetric wear parameters, profilometric studies with SEM surface morphologies of the wear tracks. The researches allowed the classification of materials according to their tribological behaviour and the results recommend the tested reinforced composite materials as good candidates for repairing metal parts made of brass or bronzes.

1. Introduction

Due to their good mechanical properties (mechanical strength, stiffness, hardness, low density, etc.), polymer composites are successfully used in many industry sectors such as automotive industry, naval industry, aerospace, machine manufacturing and others [1, 2, 3]. The advantages of these materials recommend their use in the maintenance and repair activities of parts and equipment in various economic sectors.

For the tribological characterization of these materials, they are tested in the laboratory in a *ball-on-flat test configuration in reciprocating* sliding [4, 5, 6, 7]. In the cited papers, the authors studied the variation of the friction coefficient and the structure and topography of the used surfaces by modifying certain test parameters like loading forces, sliding distance and/or time, frequency.

The paper describes the results obtained through comparative analysis of three polymeric composites, as they were discussed previously [8, 9, 10, 11].

2. Experimental procedure

2.1. Materials characterization

The materials used for research purpose are provided by Diamant Metallplastic GmbH, Germany [12]: 1. Multimetall Messing, code SAC, used for repairing brass parts; 2. Multimetall Bronze, code SBC, used for repairing bronze parts; 3. Moglice, code SMC, composite material used to repair brass and bronze parts.

The composite materials SAC and SBC are epoxy matrix reinforced with Cu, Zn, Sn particles, and various allotropic forms of SiO_2 and belongs to Multimetall category [12].

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The composite material SMC is an epoxy matrix reinforced with particles of cristobalite (αSiO_2) and molybdenum disulfide (MoS_2) [12].

These composites are recommended for the repair of surface defects such as cracks, holes executed incorrectly, pinching or squeezing, etc.

The counterpart was a steel ball (AISI 52100 GCr15, grade like SKF), Φ6, HV 946, surface roughness $R_a \approx 0.06$ µm.

The main mechanical characteristics of the composites materials [12] are shown in Table 1 and 2.

Table 1. The main mechanical characteristics of the composites materials

Material code	E-Modulus DIN 53457 [MPa]	Tensile Strength [MPa]	Compressive Strength [MPa]	Bending Strength [MPa]	Shear Strength [MPa]	Hardness [Shore D]
SAC	5800	63	155	95	35	87-89
SBC	5800	62	155	79.5	16.5	86
SMC	10400	-	120	66	-	88

Table 2. The main mechanical characteristics of the composites materials

Material code	Impact Strength [MPa]	Surface Pressure [MPa]	Specific Weight [g/cm^3]	Temperature Resistance permanent [˚C]	Temperature Resistance temporary [˚C]
SAC	4.8	-	1.6	-32 to +160	-
SBC	5.4	-	2.2	-32 to +160	+350
SMC		12.5	1.7	-20 to +60	-40 to +125

For all tested samples, the following average values of roughness (R_a) were determined: SAC - Ra=1.42 µm, SBC – Ra=1.81 µm and SMC – Ra=0.97 µm.

The composite is obtained by mixing two components. We obtain a putty that is applied on specially prepared metallic surfaces. After drying (4 ... 30 hours), the composite materials are machined. The test samples for composite materials were thus obtained. All samples for both composite materials had the final dimensions Φ76x7.

2.2. Experimental setup and procedures

The testing was conducted on the tribotester CETR UMT-2 (Bruker Corporation) at room temperature (20÷26°C) and relative humidity conditions of 50-60%. Dry sliding reciprocating tests were conducted in accordance with ASTM G133-05 standard. Testing parameters were: the stroke - 5mm, duration - 475 min, the sliding distance – 100 m and normal loading forces: 20, 30, 40 and 50N.

Before performing the tests, the samples were degreased with organic solvent and then dried with hot air at 50°C.

In order to study the intensity and type of the wear process, it is often used the profiometric analysis of the wear tracks. The acquisition of the digital profiles for all samples was done with a laser profilometer (µSCAN, ® NanoFocus) and they were processed with the software SPIP 6.2.6 (™ Image Metrology, Hørsholm

For each wear track, three cross sections were obtained as shown in Figure 1: on the center of the track (profile "m") and at the 2 mm distance on both side of the track (profile "i" and profile "e").

For the wear evaluation by profilometry, the area of cross-sections measured from the highest peaks adjacent to the track and the lower part of the profile was used.

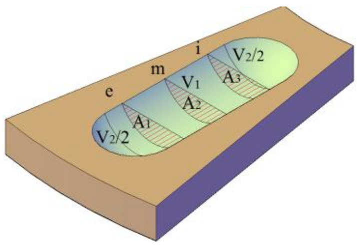
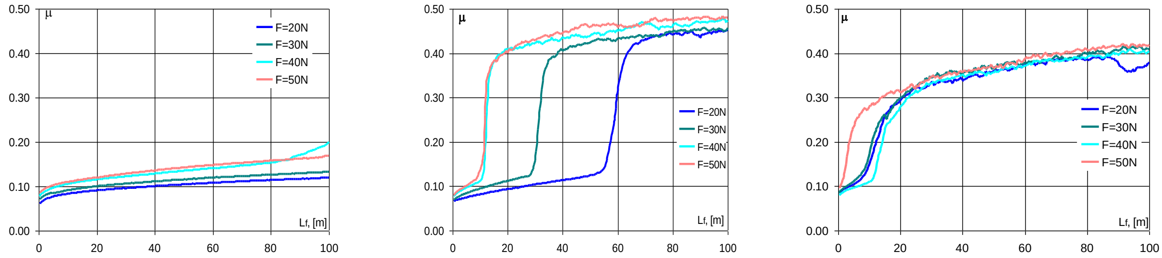


Figure 1. Graphical modeling of wear tracks [11]

3. Results and discussion

Figure 2 shows friction coefficient variation graphs for all studied materials and for the four loading forces according to the sliding distance. The values for COF were acquired at a frequency of 10 values per second.



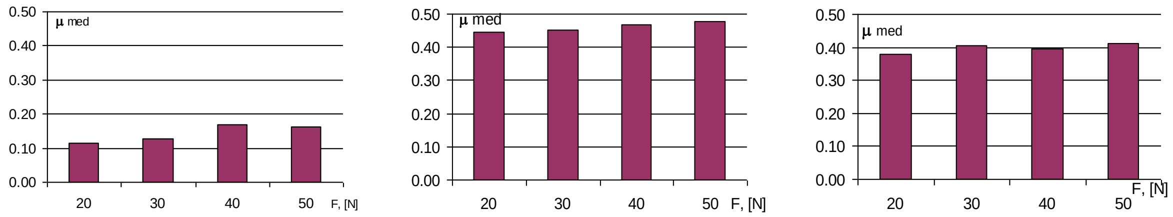
a) b) c)

Figure 2. Variation of the coefficient of friction for: a) composite (code SAC) [8]; b) composite (code SBC) [11]; c) Moglice (code SMC) [10]

Relative to composite materials the following is noticed:

- the friction coefficient increases with increasing load force (Figure 1a, 1c, 1e);
- there are three stages for all loading forces to composites SBC and SMC (Figure 1c, 1e): in first stage (from 10 m to 55m for composite code SBC and 0 to 10m for moglice) COF increases slowly; in the second stage COF increases very rapidly, and in the third stage a slow increase can be detected ;
- the length of the first stage (for SBC and SMC composite materials) decreases with the increase of the loading force;
- in step 3 of the friction coefficient for SBC and SMC composite materials shows instability;
- at SAC composite material, the friction coefficient features a steady and stable growth.

Figure 3 illustrates the graphs of the average friction coefficient for all samples and all loading forces. The friction coefficient was calculated with the values acquired over the last 25 m of the sliding distance.



a) b) c)

Figure 3. Variation of the average coefficient of friction for:
a) composite (code SAC) [8]; b) composite (code SBC) [10]; c) Moglice (code SMC) [11]

It can be seen in Figure 3 that the smallest values of the average coefficient of friction are in the composite code SAC (Figure 3a); the other two composites have close values in terms of the average friction coefficient.

Figure 4 shows the variation graphs of the wear depth according to the distance for the four load forces. The following is noticed:

- low values for linear wear on SAC composite compared to other materials;
- small values for linear wear also occur in the SMC composite;
- different behaviour: on the brass composite, in the initial phase there is a marked increase, followed by a linear increase with a very low slope; in the other two composites, the linear wear has a small increase at first, followed by a significant increase; higher values are observed in the bronze composite.

Volumetric wear parameters considered for characterizing the intensity of wear are: the wear volume (V), the wear intensity (I_v) and the specific wear rate (k):

- the volume of wear (V) [11]:

$$V = A \cdot s \tag{1}$$

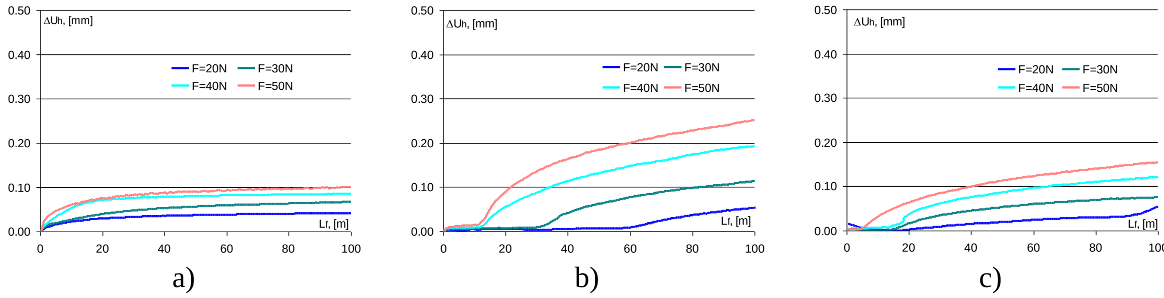


Figure 4. Variation of linear wear depth (F=20, 30, 40 and 50N, L_f=100m):
a) composite (code SAC) [8]; b) composite (code SBC) [11]; c) Moglice (code SMC) [10]

- the volumetric wear intensity (I_v) [13, 14]:

$$I_v = \frac{V}{L_f} \tag{2}$$

- the specific rate of wear (k) [14]:

$$k = \frac{V}{F \cdot L_f} \tag{3}$$

where:

A - average cross-sectional area of wear track, mm^2;
s - length of the stroke, mm;
L_f – sliding distance of friction, m;
F – normal force load, N.

The average cross-sectional area of the wear tracks was calculated with:

$$A = \sum_{i=1}^{3} A_i \tag{4}$$

The Evolution of volumetric wear parameters is shown in Fig. 5. From this figure we can see:
- the composite material code SAC has the lowest values of volumetric wear parameters;
- all the volumetric parameters of the composite material for brass have a linear growth trend;
- the bronze composite has the highest values of the volumetric wear parameters;
- the composite moglice, compared to metallic materials in terms of volume wear parameters, seems to be a good material for refurbishing both brass and bronze parts.

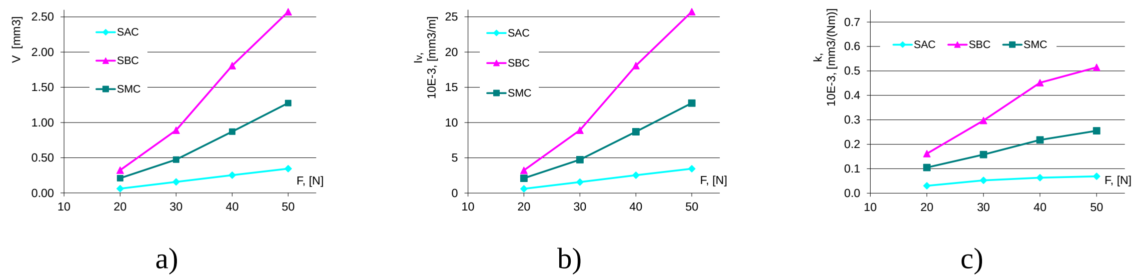


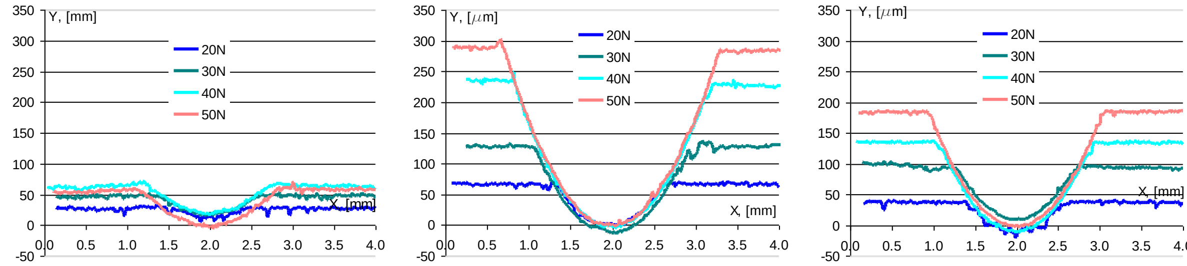
Figure 5. Variation of volumetric wear parameters:
a) the wear volume (V); b) the wear intensity (I_v); c) the specific wear rate (k).

Figure 6 presents the most representative 2D profiles of the cross-section of the wear traces for each material according to the normal load force values.

It can be noticed :

- The rough appearance of the 2D profile shapes for brass composite material (Figure 6a) can be caused by the reinforcement particles unused during the test;
- The composite material moglice has 2D profiles (Figure 6c) as an order of magnitude of the width and depth of the wear parameter between the composite material cod SAC and the other materials. At

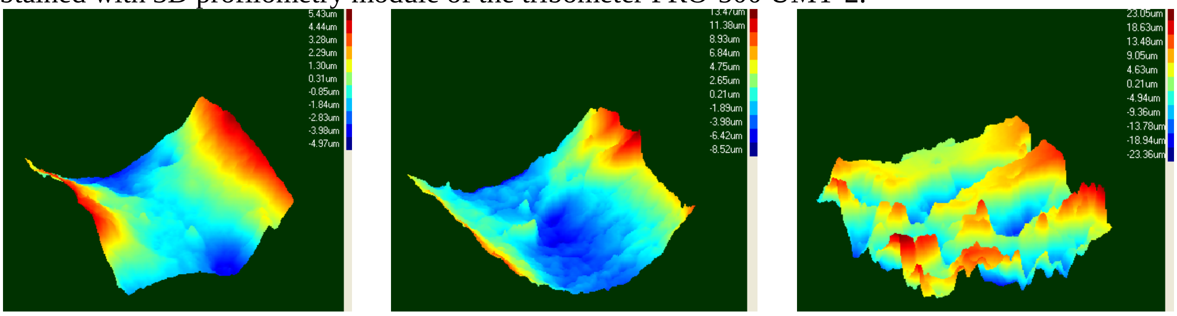
the moglice composite, for the 20 N test force, the same rough profile of the profile as the SAC composite is observed.



a) b) c)

Figure 6. Digital roughness profiles (2D) for the loading forces 20÷40N:
a) composite (code SAC) [10]; b) composite (code SBC) [13]; c) Moglice (code SMC) [12]

Figure 7 presents the 3D plots (scanning area: 0,5x0,5 mm) for the composite materials. Images were obtained with 3D profilometry module of the tribometer PRO-500 UMT-2.

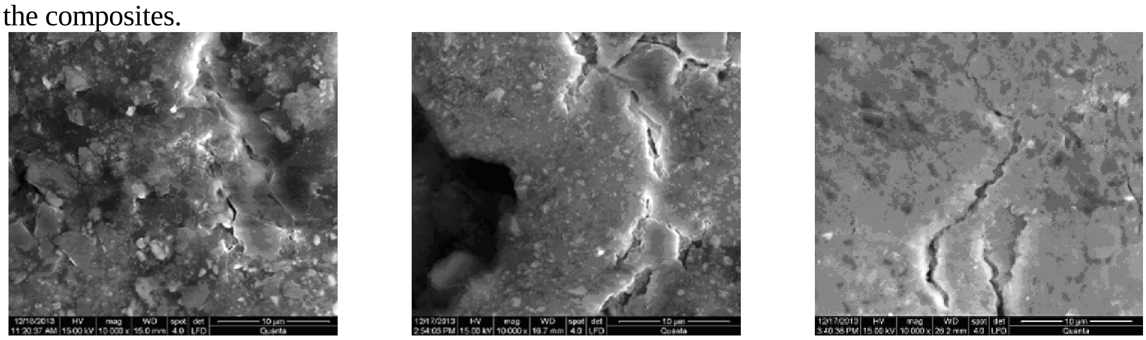


a) b) c)

Figure 7. Details of the wear track for loading force 30N, by the profilometric module of the tribotester CETR-UMT-2: a) composite (code SAC) [11]; b) composite (code SBC); c) Moglice (code SMC)

In Figure 7, it can be seen a gouges on the worn surface as an effect of adhesive wear when the microparticles are pulled away and removed from the surface to be rubbed. No abrasion wear is observed.

Evidence of wear phenomena results from the study of the wear traces with the Quanta 200 electronic microscope. The images are shown in Figure 8. The SEM images obtained at the 10000x magnification scale show cracks at the material grain boundary as well as bonding of the material onto the worn surface of the composites.



a) b) c)

Figure 8. SEM surface morphologies by the Quanta 200 electronic microscope (x10000):
a) composite (code SAC), F=40N; b) composite (code SBC), F=50N; c) Moglice (code SMC), F=20N

4. Conclusions

The purpose of this research was to make a comparison of the tribological behavior of three composite materials used in the repair of brass and bronze metal parts.

The results of testing composite materials with microparticles in dry friction reciprocating ball-on-flat conditions show the following:

1. The composite brass material has the lowest values for wear parameters such as: friction coefficient, linear wear depth and volumetric wear parameters (the cross sectional area, the volumetric wear, the volumetric wear intensity and the specific wear rate);
2. The moglice composite has good tribological characteristics and can be used successfully in reconditioning brass and bronze parts;
3. Adhesive wear is the dominant wear process for all three composite materials;

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