Considerations regarding the volume fraction influence on the wear behavior of the fiber reinforced composite systems

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Abstract. This paper contains an analysis of the factors that have an influence on the tribological characteristics of the composite material sintered with metal matrix reinforced with carbon fibers. These composites are used generally if it's needed the wear resistant materials, whereas these composites have high specific strength in conjunction with a good corrosion resistance at low densities and some self-lubricating properties. Through the knowledge of the better tribological properties of the materials and their behavior to wear, can be generated by dry and the wet friction. Thus, where necessary the use of high temperature resistant material with low friction between the elements, carbon fiber composite materials are very suitable because they have: mechanical strength and good ductility, melting temperature on the higher values, higher electrical and thermal conductivity, lower wear speed and lower friction forces. For this purpose, this paper also contains an experimental program based on the evidence of formaldehyde resin made from fiber reinforced Cu-carbon with the aim to specifically determine the volume of fibers fraction for the consolidation of the composite material. In order to determine the friction coefficient and the wear rates of the various fiber reinforced polymer mixtures of carbon have been used special devices with needle-type with steel disc. These tests were conducted in the atmosphere at the room temperature without external lubrication study taking into consideration the sliding different speeds with constant loading task.

1. Introduction

Today the composite materials are specifically created with the most appropriate micro- and macro-structural compositions, to correspond for the particular requirements in terms of mechanical strength, stiffness, low density, dimensional stability, thermal and chemical fatigue resistance, to the shock and the wear, insulating properties, aesthetics and, not ultimately, the economic imperatives [1].

In recent decades, have been produced and used such of material in various activity fields, from the household items to the components of spacecraft or nuclear plants. Due to increased consumer demands, the entire industry presents "facilitate syndrome" that has generated such materials, lighter machinery, less energy consumption, less pollution, greater comfort. The composite materials meet these demands and therefore the future studies predict a true "exhibitor" of these materials after the third millennium [2-4].

Currently, the polymeric composite materials and metal shows a special scientific interest and technically speaking justifying both the development of research in this area and the production of these materials, which is why the subject of this paper is the reaction to is the abrasive wear and their behaviour [5].

Fiber composites are the most important, and various composite is composed in principle of a macromolecular compound comprising a reinforcing agent or filler in fiber form hard, stiff and brittle.

The matrix serves to transmit the force of the fibers ensuring the ductility and toughness of the composite fibers, while the fibers carrying much of the applied force. The metals used as the matrix are inducing in the composite material to the essential properties for machinability, corrosion resistance, electrical and thermal conductivity and, in particular mechanical strength. When the macromolecular compound is a thermoplastic polymer or thermosetting, the matrix is called polymer, the basic characteristic of the resulting compound costing through the very high report strength / weight [6-8].
2. Tribological evaluation of the composite materials

The set of experiments conducted were focused on the creating of the composite materials with short fiber reinforced with carbon fiber texture for tribological evaluation of polymer composites with different volume fractions. Yielding data from these preliminary experiments are presented in Figure 1. We can see that depending on the type of resin used, the influence on the re-polymerization temperature, which leads to a change in the composite materials polymerization.

2.1. Experiments to obtain polymer composites with solid state

In these experiments tests were performed by making a polymer composite material reinforced with short carbon fibers, using the polymers in the solid state. The formulations used in these tests are shown in Table 1.

| No. | Test type | Resin | Fiber volume | Graphite Addition |
|-----|-----------|-------|--------------|------------------|
| 1.  | TA1       | 14.81 | 22.24        | 62.95            |
| 2.  | TA2       | 12.81 | 28.62        | 68.57            |

There has been also investigation by scanning electron microscopy on the samples are subject to wear, in order to elucidate the wear process.

The tests were performed at low sliding speed (\(v = 7.2\) mm/s) or greater (\(v = 40.8\) mm/s) keeping the constant value of the loading \(N = 8\) daN, the coefficient of friction values is shown in table 2 and figure 1.

| No. | Tested type | Fiber percent, % | Friction coefficient \(v = 7.2\) mm/s | Friction coefficient \(v = 40.8\) mm/s |
|-----|-------------|------------------|---------------------------------------|---------------------------------------|
| 1.  | TA1         | 22.24            | 0.18                                  | 0.192                                 |
| 2.  | TA2         | 28.62            | 0.22                                  | 0.232                                 |

![Figure 1](image.png)

**Figure 1.** The friction coefficient graphs at sliding speed:

a. \(v = 7.2\) mm/s; b. \(v = 40.8\) mm/s and at constant load \(N = 8\) daN

Basically, a wear process can be described as a phenomenon of propagation of cracks, these cracks lead to the formation of the very fine particles in the mass of composite material. If we refer to the carbon-fiber-reinforced polymers, can easily notice some differences in the mechanism of wear, which is connected in particular from metallic fibers in the matrix. We conclude that the phenomenon of wear composite materials studied is dependent on several factors:
• matrix wear;
• wear sliding of the fibers;
• wear cracking of the fibers;
• wear separation in the fiber matrix.

In case of the short fiber reinforced polymer composites, characteristic are the traces of wear and spraying fibers in the matrix material. The presence of fibers tends to inhibit the formation of large chips of matrix material, by accumulating layers of polymer material sheared. These mechanisms are more likely in case of oriented fibers [9,10].

Figure 2. Flow chart for the production of sintered carbon fiber polymer composites.
Figure 3 shows the wear tests of the different surfaces of polymer composite materials with short carbon fibers by scanning electron microscopy analysis (carbon fiber: 22.24%).

2.1.1. Conducted experiments on obtaining of polymer composite materials reinforced with short carbon fiber

In these experiments were taken, samples of the composite with epoxy matrix and short carbon fibers. Table 3 shows the types of formulations presentation of the samples, as well as the specific conditions for implementing access of the types of material [11].

Table 3. Formulations of the composite materials with bicomponent epoxy resin and short carbon fibers.

| No. | Test type | Fortifying % | Fiber percent % | Resin ALEPOX type | Hardening conditions |
|-----|-----------|--------------|------------------|------------------|---------------------|
| 1   | TB1       | DEDA-12      | 27.9             | IV               | Could               |
| 2   | TB2       | DEDA-12      | 20.8             | V                | Could               |
| 3   | TB3       | DEDA-12      | 28.4             | VI               | Could               |
| 4   | TB4       | DEDA-12      | 28.1             | 0                | Could               |
| 5   | TB5       | DEDA-12      | 24.6             | 5                | Could               |

Table 4. The friction coefficient values at the sliding speed of \( v = 7.2 \) mm/s and 40.8 mm/s and constant load charging \( N = 8 \) daN.

| No. | Tested type | Fiber percent, % | Friction coefficient \( v = 7.2 \) mm/s | Friction coefficient \( v = 40.8 \) mm/s |
|-----|-------------|------------------|----------------------------------------|----------------------------------------|
| 1   | TB1         | 27.9             | 0.24                                   | 0.25                                   |
| 2   | TB2         | 20.8             | 0.22                                   | 0.24                                   |
| 3   | TB3         | 28.4             | 0.27                                   | 0.27                                   |
| 4   | TB4         | 28.1             | 0.25                                   | 0.23                                   |
| 5   | TB5         | 24.6             | 0.28                                   | 0.26                                   |
Electron microscopy investigations have revealed, in this case, a particular behavior to friction tests generated by the presence of short fibers, and the polymerized areas of the epoxy resin. Thus, Figure 4 shows the surface microscopy under test wear of the TB4 specimen polymerized stage. It’s highlighted the trend of fibers stretching before their breaking and resin areas have the appearance of molten zone. Loose particles are observed during the test of wear and captured areas of the molten resin. These statements are supported and appearances before the test specimen surface wear (Figure 4).

2.2. Tribological evaluation of the Cu matrix composites reinforced with short carbon fiber with different volume fractions.

Table 5. Constituents of the consolidated powder mixes.

| No. | Mixture            | A  | B  |
|-----|--------------------|----|----|
| 1   | Cu (%)             | 95.2| 97.6|
| 2   | Carbon fibre (%)   | 4.8 | 2.4 |

The measurements regarding the relative density are presented in table 5. The relative density is defined as the average of the densities measured relative to the theoretical values for each mixture. It is noted that sample B has the highest relative density from the entire analysed and consolidated samples specific feature.

Table 6. Variation of the friction coefficient and composite sample wear.

| No. | Load (N) | Friction coefficient |
|-----|----------|----------------------|
| 1   | 4.46     | 0.120                |
| 2   | 8.92     | 0.207                |
| 3   | 13.40    | 0.133                |

The above presented results demonstrate the fact that the new method of powders consolidation, high energy and high speed is suitable for the production of parts with a good tribological behaviour, from mixture of copper and carbon fibers.

3. Conclusion

How can we found in this paper for applications of high temperature and a low friction, carbon Cu-fibers composites are suitable materials for a lot of applications which satisfy the planning requirements. That’s including the mechanical strength of these materials with good ductility, to have a higher melting temperature and a higher thermal and electrical conductivity and also a lower friction and a lower speed of the wear. The tests on this paper were performed at low sliding speed value (v = 7.2 mm/s) or a greater sliding speed value (v = 40.8 mm/s) keeping the constant value of the loading N = 8 daN.
To determine the friction coefficient and the wear rates of the various mixtures polymer, with carbon fiber and Cu-carbon fiber has been used a test apparatus needle type on the steel disc, the tests was carried out in air, without external lubrication, at the room temperature for different values of sliding velocities and constant loading tasks.

If we made a comparison with the pure copper, the wear resistance of the composites obtained by copper and carbon fibers is greatly improved. Can be observed when the percentage of carbon fibres increases, the friction coefficient simultaneously with wear mass loss decreases but the hardness of the microstructure increases. With increasing of the load and rotating speed, leads to an increase of friction coefficient and wear mass loss, correspondingly.

4. References

[1] Yentl Swolfsa, Jia Shia, Yannick Meertena, Peter Hineb, Ian Wardb, Ignaas Verpoest, Larissa Gorbatikha 2015 The importance of bonding in intralayer carbon fibre/self-reinforced polypropylene hybrid composites, Composites Part A: Applied Science and Manufacturing Volume 76 299–308

[2] Kenneth Kanayo Alaneme, Benjamin Ufuoma Odoni 2016, Mechanical properties, wear and corrosion behavior of copper matrix composites reinforced with steel machining chips, Engineering Science and Technology, an International Journal, Volume 19 1593-1599

[3] L. Rodriguez-Tembleque, M.H. Aliabadi 2016 Numerical simulation of fretting wear in fiber-reinforced composite materials, Engineering Fracture Mechanics, Volume 168 13–27

[4] Po-Ching Yeh, Po-Yu Chang, Justin Wang, Jenn-Ming Yang, Peter H. Wu, Ming C. Liu 2012 Bearing strength of commingled boron/glass fiber reinforced aluminum laminate, Volume 94 3160-3173

[5] Libo Yan, Nawawi Chouw, Liang Huang, Bohumil Kasal 2016 Effect of alkali treatment on microstructure and mechanical properties of coir fibres, coir fibre reinforced polymer composites and reinforced-cementitious composites, Volume 112 168–182

[6] C. E. Correa, S. Betancourt, A. Vázquez, P. Gañan 2015, Wear resistance and friction behavior of thermoset matrix reinforced with Musaceae fiber bundles, Tribology International, Volume 87 57-64

[7] Chawla K.K. 2005 High-Performance Fiber Reinforcements in Composites, Journal of Minerals, Metals & Materials 47

[8] Davim, J.P., Marques, N., Baptista, A.M. 2001 Effect of carbon fibre reinforcement in the frictional behaviour in a water lubricated environment, Wear, Elsevier Sc. 251 1100-1104

[9] F. Zhaoa, G. Lia, W. Österleb, I. Häuslerb, G. Zhanga, T Wanga, Q Wang 2016 Tribological investigations of glass fiber reinforced epoxy composites under oil lubrication conditions, Tribology International, 103 208–217

[10] Dutta, I. Peterson, K.A., Park, C. 2003 Interfacial Creep in Multi-Component Material Systems, Journal of Minerals, Metals & Materials, January 38-43

[11] M.R. Sanjay, G.R. Arpitha, B. Yogesha 2015 Study on Mechanical Properties of Natural - Glass Fibre Reinforced Polymer Hybrid Composites: A Review, Materials Today 2 4–5