

Friction behaviour of aluminium composites mixed with carbon fibers with different orientations

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Abstract. The primary goal of this study work it was to distinguish a mixture of materials with enhanced friction and wearing behaviour. The composite materials may be differentiated from alloys; which can contain two more components but are formed naturally through different processes such as casting. The load applied on the specimen during the tests, is playing a very important role regarding friction coefficient and also the wearing speed. Sintered composites are gaining importance because the reinforcement serves to reduce the coefficient of thermal expansion and increase the strength and modulus. The friction tests are carried out, at the room temperature in dry condition, on a pin-on-disc machine. The exponentially decreasing areas form graphs, represented to the curves coefficient of friction, are attributed to the formation of lubricant transfer film and initial polishing surface samples. The influence of the orientation of the carbon fibers on the friction properties in the sintered polymer composites may be studied by the use of both mechanical wear tests by microscopy and through the use of phenomenological models.

1. Introduction

A composite material generally can be defined as a combination of two or more materials which lead to better properties than the individual materials. As opposed to metal alloys it is made a new material, in case of composites each material retains its mechanical, chemical and physical properties [1].

The main components of composite materials are the reinforcement and the matrix. The advantages of composites are high strength and stiffness and low density which allows a reduction in weight of the final piece. Complex assembly consisting of matrix and the reinforcing material provides strength and stiffness, reinforcing material is heavier, stronger and stiffer than the matrix, which can be in the form of fibers or particles [2, 3].

The particles used in composite materials have dimensions that are approximately equal in all directions, can be spherical, flat, or any other regular or irregular geometry. Composite materials with particles tend to be much weaker and less rigid than composites with continuous fibers, but they are cheaper because generally contain less reinforcement material (approx. 45%) [4].

Particle reinforced for the metal matrix composites type have been the most popular over the last two decades. The modern trend for diverse applications of composite materials is to optimize the mechanical properties thereof by heat treatment of metal matrix composites. Now, research is focused mainly on aluminum due to its unique combination of good corrosion resistance, low density and better mechanical properties [5].

An aluminium composites mixed with carbon fibers can be produced by careful selection of the following components: the amount and distribution of reinforcing components (particles and fibers),



the matrix alloy and application. By choosing the appropriate method of manufacture, processing and finishing, as well as reinforcing component form, it's possible to obtain different characteristic profiles even if is used the same composition and amounts of materials [6, 7].

In case of Al-based composites can be observed: a good wetting is necessary to facilitate the fabrication, especially when is used a liquid state technique with low pressure, interfacial reactions between matrix and reinforcement should be very limited, to avoid the degradation of the reinforcement and the formation of new brittle phases and a correct bonding is required to deliver the intended property. For aluminium composite materials reinforced with carbon fibers, wetting may be improved by a chemical reaction with the reinforcement which lowers the interfacial energy [8].

The arrangement or orientation of the fibers relative to one another, the fiber concentration, and the distribution all have a significant influence on the strength and other properties of fiber-reinforced composites. With respect to orientation, two extremes are possible: a parallel alignment of the longitudinal axis of the fibers in a single direction, and a totally random alignment. Continuous fibers are normally aligned, whereas discontinuous fibers may be aligned randomly oriented, or partially oriented. Better overall composite properties are realized when the fiber distribution is uniform [9].

In the literature can be observed that if the reinforcement is strongly bonded with the matrix, wear resistance of composite would improve linearly with increase in reinforcement volume fraction. The matrix will be subjected to more and more wear with increase in the reinforcement content, can consider a balance between these phenomena for developing wear resistant composite material. Aluminium matrix over a range of loads and sliding speeds [10, 11].

2. Experimental aspects

The wear tests were made on three different orientations of fibers on a standard machine of tribology, pin disk type. Counter-disk was made of cast iron with a superficial hardness of 92 HB. The wear rate and friction coefficient decreased exponentially with time of friction and reached a stationary value.

It's required a correct selection of the orientation of reinforced layers in advanced composite materials to provide efficient structural design. Because the strength design requirements are a function of the load direction, fiber orientation and sequence of layers must be correct chosen. It is very difficult during a reparation to replace each damaged layer with a layer with the same orientation and the same material [12].

Reinforced unidirectional fibers can be disposed in a single direction thus the resistance and rigidity is only in the fiber direction. Bidirectional reinforced fibers are arranged in two directions, combining these guidelines have resistance in both directions, but not necessarily in the same concentration. Many composite materials used for aerospace are made from quasi-isotropic materials.

The properties of metallic materials, such as density, modulus of elasticity and thermal expansion, can be substantially modified by their reinforcing particles or fibers. Besides good thermal properties, their low density makes them particularly desirable for aerospace electronics and orbiting space structures.

A special importance from this point of view it has the percentage of reinforcement material used. The use of small additions of graphite (2%), leading to the improvement of the wear characteristics. Increasing the percentage of reinforcement material to about 8%, resulting in reducing of these performances, causing the appearance of a significant softening and hence an increase in the rate of the wear. Were performed determinations on the test specimens from the composites materials with Al matrix and 43% carbon fiber. Table 1 shows the properties that it has the fiber and the matrix. The material was fabricated by bonding technology trough diffusion.

The friction coefficient as a function of wear time for the samples subjected to the different thermal treatments and directions of the fiber follows an exponential curve. The wear mechanism is based on the fact that, while the adhesion between graphite and iron is relatively poor, the aluminium will be transferred to the disk by adhesion. This action leaves fibers without the support of the matrix and thus will break easily. To conduct this work was performed measurements on samples from the Al matrix

composites and carbon fiber 43%, the studies by scanning electron microscopy and electron diffraction showed the presence of reaction zones of fiber-matrix interface.

Table 1. The specific properties of the fiber and metal matrix.

Characteristic	Thornel Fiber P-55	Matrices 201 Al
Diameter	11 μm	-
Tensile strength	1720 MPa	190 MPa
Tensile modulus	380 GPa	71 GPa
Elongation	0.5 %	20 %
Density	2.0 mg/m^3	2.77 mg/m^3

Studies by electron microscopy with streaks and electron diffraction showed the presence of the reaction zone from the fiber-matrix interface. Reaction zones, in case of material found out in receiving state, include the present compounds $\text{Al}_4\text{O}_4\text{C}$, in the case of heat-treated material the intermetallic compounds Al_4C_3 . The thickness of the reaction areas increased with increasing of time and temperature of thermal treatment, leading to improve of the mechanical properties.

The wear samples were prepared mounting them initially in epoxy resin, then wet sandblasting them (with SiC, graining 600) and polishing them with Al_2O_3 (1 and 0.5 μm) in kerosene. After preparation, the epoxy resin was removed with acetone, and the profiles were measured with surface profile-graph.

Tables 2 ÷ 4 shows average speeds of stationary wear and standard deviations obtained from at least five experiments applied to each sample and each fiber orientation. In the case of fibers normal to the plane and the direction of sliding, the speed of the wear decreases with decreasing of the matrix hardness.

Table 2. The effects of the heat treatment on the stationary speed with the wear out of the test samples having the fibers oriented normal to the friction counter-disk.

Material	Wear speed [$(\text{cm}^3/\text{cm}) \times 10^7$]	Hardness (kgf/mm^2)
500°C, 24 h	0.0052±0.0006	55.0
450°C, 24 h	0.0060±0.0007	62.0
545°C, 168 h	0.0067±0.0017	64.6
545°C, 24 h	0.0076±0.0015	68.2
Material – reception	0.0077±0.0011	78.8

Table 3. The effects of the heat treatment on stationary speed of the wear of presented by test samples having the fibers oriented parallel to the sliding direction.

Material	Wear speed [$(\text{cm}^3/\text{cm}) \times 10^7$]	Hardness (kgf/mm^2)
In reception status	0.0070±0.0000	22
450°C, 24 h	0.0095±0.0003	36
545°C, 168 h	0.0141±0.0017	120
500°C, 24 h	0.0157±0.0079	104
545°C, 168 h	0.0168±0.0048	145

The opposite trend, increasing the speed of the wear with decreasing of hardness, was observed in materials with the fibers parallel to the plane of sliding and perpendicular to the direction of sliding. If the fibers were parallel to the direction of sliding has been found a clear correlation between the speed of the wear and the thickness of the reaction zone, the speed of the wear increases with increasing of the reaction zone.

Table 4. The effects of the heat treatment on stationary speed of the wear of presented by test samples having the fibers oriented perpendicular to the sliding direction.

Material	Wear speed $[(\text{cm}^3/\text{cm}) \times 10^7]$	Hardness (kgf/mm^2)
At reception	0.0075 ± 0.0001	78.8
545°C, 24 h	0.0099 ± 0.0011	68.2
545°C, 168 h	0.0123 ± 0.0064	64.6
450°C, 24 h	0.0126 ± 0.0034	62.0
500°C, 24 h	0.0204 ± 0.0070	55.0

3. Results and discussion

The friction coefficient as a function of time the wear of, for samples with different thermal treatment and the fiber directions, and it follows an exponential curve. Figure 1 shows a typical curve of the coefficient of friction as a function of time. Average stationary values and standard deviations presented by coefficient of friction, depending on heat treatment and fiber orientation, are presented in tables 5 ÷ 7.

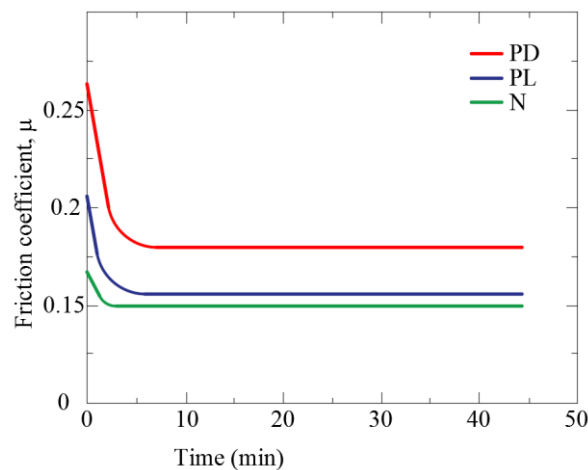


Figure 1. Typical friction coefficient, depending on time and the orientation of the fibers compared to the disk and the sliding direction (samples in a reception stage).

Can be observed that higher values are obtained for the friction coefficients of the material in the reception stage than those of heat treated materials. It seems that the fiber orientation has a more pronounced effect on the friction coefficient than heat treatment. Specific tests applied to the wear surfaces of the samples showed lack transfer of aluminium to the surface.

Exponentially decreasing areas, presented by curves of the wear speed and friction coefficient, are attributed to formation of the transfer of lubricant film and initial polishing surface samples.

In the stage of the stationary wear, when the fibers are parallel to the sliding plane and perpendicular to the direction of sliding, the microscopic investigations showed that the material of

matrix is removed in layers, leaving the fiber more exposed, until the forces of friction creates a moment of rotation outward over the exposed fibers.

Table 5. The effects of the heat treatment on stationary of the wear of presented by test samples having the fibers normal to the friction counter-disk.

Material	Friction coefficient
450°C, 24 h	0.132±0.005
500°C, 24 h	0.142±0.004
545°C, 24 h	0.144±0.004
545°C, 168 h	0.148±0.003
At reception	0.148±0.002

Table 6. The effects of the heat treatment on stationary of the wear of presented by test samples having the fibers parallel to the sliding direction.

Material	Friction coefficient
450°C, 24 h	0.146±0.003
545°C, 168 h	0.149±0.006
At reception	0.152±0.003
545°C, 24 h	0.160±0.008
500°C, 24 h	0.167±0.006

Table 7. The effects of the heat treatment on stationary of the wear of presented by test samples having the fibers perpendicular to the sliding direction.

Material	Friction coefficient
450°C, 24 h	0.136±0.006
545°C, 168 h	0.137±0.016
545°C, 24 h	0.139±0.006
500°C, 24 h	0.146±0.002
At reception	0.175±0.007

The tensions created by moment are normal, fragile interface giving them a little resistant. Also, when propagation, superficial cracks meet the fiber, but, rather to pass through the fiber, propagates around the fibers from the reaction fragile zone, removing layer by layer from the matrix. In both cases, relatively low variations presented by the interface property, resulted from thermal treatments, are insignificant compared to the overall resistance of the fibers to "running outwards" and propagation of cracks in the reaction zone.

Investigation of matrix under-superficial cracks led to the conclusion that the wear from the matrix is made by layering mechanism. As we know, the theory of stratification is based on nucleation and cracks propagation under (and parallel to) the wear surface.

Theorizing in terms of the two processes, the initiation and propagation of cracks, it can be seen that the wear speed presented on the samples wear with fibers perpendicular to the sliding direction

increases with decreasing of hardness. Generally, soft materials have slower crack propagation than harder materials, and harder materials have a higher resistance to crack nucleation. Consequently, when the fiber direction is parallel to the sliding plane and perpendicular to the direction of sliding, we estimate that the wear speed is controlled by the speed of cracks nucleation from the matrix, which, depends on the hardness of the matrix.

If the fibers are parallel to the direction of sliding, it has been observed that the wear of the matrix is also done through the mechanism of stratification. In this case, the under-superficial cracks are propagating parallel to the fibers and do not intersect that, thus contributing significantly less to peel off the fibers.

Obviously, while increasing the thickness of the reaction zone is increased the probability of fracture formation being relieved to be peel off. When detachment occurs, the fibers are removed from the matrix by "pulling out". The mechanism of "pulling out" is expected to be slower than "rolling outwards".

It has been found experimentally, the wear speed measured of the composite with parallel orientation is smaller than to the composite with perpendicular orientation.

In conclusion, if the fibers are parallel to the direction of sliding, factor that controls the wear is the quality of the interfacial reaction zone, which defines the bounding resistance of the fibers to the matrix. It has been shown that the interfacial bounding resistance decreases inversely exponentially as a function of the fiber matrix thickness of the reaction zone.

If the fibers were normal to the plane and the sliding direction, the wear surface appeared smooth than that observed for perpendicular and parallel type tests, where were insignificant rolling and pulling fibers. N-type samples, under-superficial cracks from matrix were propagated perpendicular to the fibers and were diverted along the interface, when they came to the fibers. On the stratification of the matrix between the fibers, the fibers lose the support that break off and are extracted from the matrix.

The factor that controls the wear speed is the speed at which are removed the layers from the matrix between the fibers. Speed of crack propagation is proportional to the hardness of the material; therefore, as shown in table 2, for N-type samples, the wear speed decreases simultaneous with the toughness of matrix.

4. Conclusions

It has been found thus that the wear of the matrix was produced by layering mechanism, for all the directions of the fiber. In the case of normal and perpendicular orientations of the fibers, the speed of wear increased by toughness increasing of the matrix.

In the case of parallel orientation of the fibers, the speed of the wear increased by increasing the thickness of the reaction zone. When the fibers were normal to the plane and the sliding direction, the fiber extraction was minimal.

When the fibers were parallel to the sliding plane and perpendicular to the sliding direction, the rolling of the fiber it was significant outward. When the fibers were parallel to the sliding direction, extracting of the fiber was significant.

The effect that it had fiber orientation on the wear speed was more marked for heat treated materials than for the materials in reception stage.

Could not establish any relationship between matrix hardness but the thickness of the reaction zone and friction coefficients, however, the friction coefficients have had minimum values when the fibers were normal to the friction counter-disk.

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