PTFE Composites and Water Lubrication
I. Tribogical Characterisation

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This paper presents experimental results on tribological behaviour of some composites with PTFE matrix under water lubrication. The experimental work pointed out particular processes taking place in the superficial layers of the tested composites. The results were plotted in order to underline the existence of an optimal regime for a system with given geometry, materials and lubrication conditions. The composites with PTFE matrix have an optimal composition as concerning the adding materials concentration that gives better tribologiocal behaviour, including low friction coefficient and wear. For instance the composites with PTFE matrix and glass fibber have this optimal concentration range of 10...30%. There are presented maps for these two tribological parameters in order to reveal the importance of the sliding regime parameters as normal force and the sliding speed. The tests also underline that water lubrication could be o solution for sliding bearing taking into account the interest of scientists for environment protection.

Keywords: tribological behaviour, composites , glass fibber, water lubrication

Water lubrication

As compared to conventional lubricants, water has uncontested advantages: a rapid evacuation of heat generated in contact, friendly for the environment and very low price. Water is a promising solution especially because of its non-polluting impact on environment and investigations were intensified for introducing water as a satisfactory lubricant in industrial applications [6, 7, 14, 28, 30].

There were developed several models, involving EHD, TEHD or micro-EHD theories sustaining that, under certain conditions (including materials, load, speed), water and water fluids may generate a bearing film, this being continuous or partial in the contact, depending on the actual conditions the system is functioning under [8, 14, 21, 23, 25, 28, 29].

There was intensified the research on materials resisting in water (including ceramics, cermets, polymers and composites with polymeric matrix and adding materials as fibbers and powders) and water based-fluids (including emulsions, glycols) having a reduced lubrication capacity, in order to obtain at least a satisfactory behaviour, especially for a mixt regime, the most plausible to exist in the water lubricated tribosystems or at startings or stoppings when the dry regime even very short could damage the both surfaces if the materials are not carefully selected [1, 6, 30].

Designing a tribological test

Tribological tests play an important part in selecting materials of triboelements and lubricants. They are useful if they point out specific processes that will be controlled with great probability, in the actual tribosystem. [1, 4, 12, 13, 19]. A tribological study implies, of course, the friction coefficient and some wear parameters but it has to explain the processes taking place within the triboelemets and to offer solutions for increasing the durability and the performances of the system based on the tribological investigation.

For classification the testing methods are divided into different categories. The gradation of testing procedures corresponds to a step-by-step reduction and modification of the tribosystem. Here, the classification is done into 6 categories, according to the below-mentioned criteria according to DIN 50322 [34]:

- service and service-related tests with real groups of components or constructions or real machines or equipment:

I - service (field) tests,

II - tests on the rig with the total system,

III - rig tests with partial systems or component groups,

- tests using model systems with simplified or with scaled-down components of simple test units:

IV - tests with unchanged or scaled down components,

V - tests with similar stresses on model units,

VI - tests with simplified test models

When testing sliding bearings, the research has the advantage of maintaining the geometry of the tested system, the involved materials, including lubricant but the problem is the scale of the tested model [4, 8, 10]. Large model, dimensionally closer to the actual ones offer the advantage of a more predictable behaviour of the actual system but unable to study the processes within the superficial layers with sufficient accuracy and they could interact in very complicated ways. Smaller models give the opportunity to identify and monitor tribological processes in a more clearing way and to develop solutions

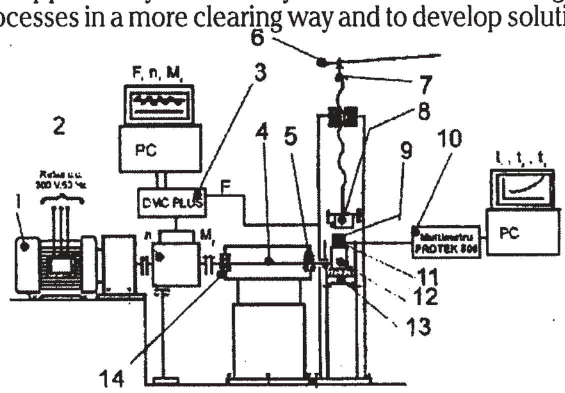

Fig. 1. Testing machine for roller-shoe tribomodels
1 – moto-variator 2 – torque transducer, 3 – dynamic acquisition system, 4 – shaft, 5 – rolling bearing, 6 – rotating arm, 7 – loading screw, 8 – force transducer, 9 – shoe support, 10 – temperature measuring device, 11 – shoe, 12 – roller, 13 – double walls for lubricant cooling, 14 – rolling bearing

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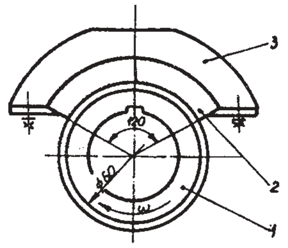


Fig. 2 Tribomodel
1 – stainless steel roller, 2 – shoe,
3 – rigid support

for optimising the actual systems. How far will go the research in simplifying the model is actual a state of art including experience and theory.

Laboratory test were generally done on small tribomodels for material couple steel – polymer, too often on pin-on-disc rigs, the parameters being unuseful for real applications (small loads and speeds). These researches have the benefit of evidencing the particular processes within the superficial layer for these material couples [5, 9, 19, 25, 33]. Due to the methodology and the imposed parameters (including geometry, speed, load) for the test with water lubrication, the research done by this paper's authors is useful for practical application and could recommend ranges for functioning parameters based on laboratory data.

The differences among the mathematical and experimental tests are also due to the subject aproach. In statical systems (without kinetic friction), many parameters may be considered as constants, for instance, the materials'strength, the temperature etc. In a tribological process the parameters have a dynamic evolution, are interactioning, the mathematical functions that describe their behaviour being complex. This dynamic aspect of the mechanical properties has a tremendious influence on the tribosystem evolution.

Many specialists began the study of material tribological behaviour directly on tribomodels, followed by the development of a mathematical model [1-4, 18, 27, 32].

Figure 1 presents the stand used for testing the composites [25]. In order to emphasise the changes taking place into the superficial layers during the transitory regimes of loading/unloading, but also during the stable regime of each test, the experimental data (rotational speed, applied normal force and friction moment) were monitored by the help of a dynamic acquisition system DMCplus (®Hottinger). The torque transducer was type T30 FN 200 (®Hottinger).

The tribomodel was shoe – roller (fig. 2) and the tested materials were

- stainless steel for the rollers, having ~40±3HRC, surface quality Ra=0.6...1.2mm.
- composites with PTFE and PTFE matrix for the shoes. The composites may be divided into two groups: with short fibbers [2, 3] and with powders [4], (carbon, graphite, bronze).
- water as lubricant, in open circuit.

In order to point out that tribological performance could not be related to mechanical properties as elongation and strength limit, figure 4 presents the characteristics of the tested materials used for manufacturing the shoes [35]. Hardness is similar for all tested materials but the tribological behaviour varies in a large range. The traction limit is lower for the composites PTFE + 40% glass fibbers, PTFE + 23% carbon + 2% graphite and PTFE + 32% carbon + 3% graphite but tribologically they behaves differently taking into discussion the wear and friction processes.

Polymers have poor mechanical and tribological behaviour and specialists try to improve them by adding different kind of other materials (fibber, powder, solid lubricants etc.) [2, 5, 7, 13, 15, 16, 26, 33].

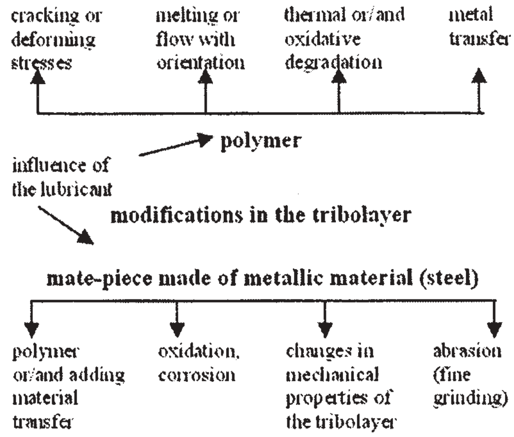


Fig. 3.

It is important to study the particular processes occurring within the tribolayer of such materials for maximising the effect of some desired ones and for minimising those accelerating wear and decreasing the system durability.

Figure 3 presents modifications of the superficial layer for polymers and composites with polymer matrix [7, 15, 25, 30, 32]. Often, the molecular chains are cut-off, reducing the molecular weight. These light-molecular components make the tribolayer to become more plastic. As for semicrystalline polymers, including PTFE and high-density polyethylene, sliding produces an orientation of the molecular chains [3, 9, 20, 27, 33] on a depth of ~10mn to several hundred microns.

Lubricant and environment (temperature and chemical agents especially) may also change the superficial layers during system exploitation. For instance, water forces the micro-cracks when its pressure is oscillating [23]. Both lubricant and environment may initiate and support local changes of composition and structures, not dangerous at macro-scale but strong enough to locally weaken the tribolayer. A higher thermal field may accelerate these processes, especially when lubricant is missing. Other processes characterising the metallic and polymers surfaces in contact are interactions with tenso-active agents, with free radicals and ions (especially when dealing with emulsions, water or special mix of lubricants).

Tested materials are commercially available from CEPROINV Focşani, Romania and some of their mechanical characteristics are given in table 1. PTFE will be the comparing level for all these tested composites.

The tribomodel (fig. 2) makes possible an average pressure characterising an actual bearing, as the contact angle is very rarely more than a=120°, as chosen for the shoe. Roller was changed for each tested material and regime.

Results and discussions on the tribological behaviour of tested materials

The testing methodology is based on [4, 15, 16]. A tribological characterisation will include the evolution of friction coefficient and one or maybe more wear parameters, allowing the selection of favourable regimes for the actual application. From a tribological point of view favourable means a reduced friction coefficient, a minimum wear and maintenance of the system functioning parameters in admissible ranges [1, 17, 25, 27], a classification of the tested materials for journals, taking into account tribological criteria [4, 7], optimization of the material content (matrix and adding materials), this study dealing with the optimization of glass fibber or powder concentration when using a PTFE matrix. (fig. 11) [2, 3, 24, 25]. One may notice the wear reduce in the range of the concentration of 15...25% glass fibber.

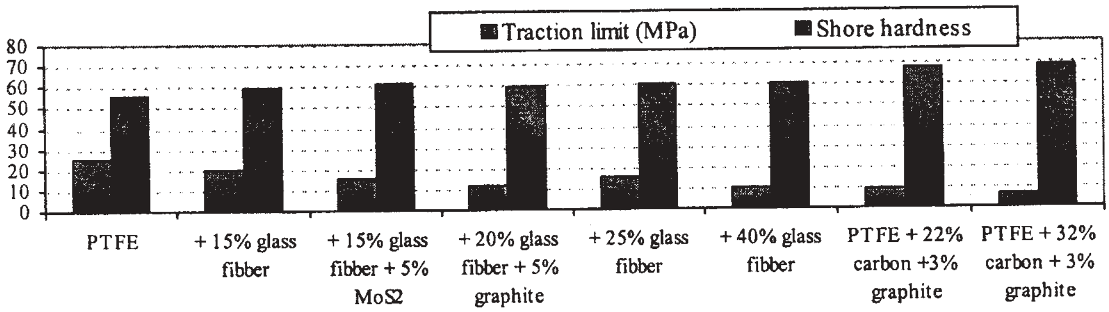


Fig. 4 [35]

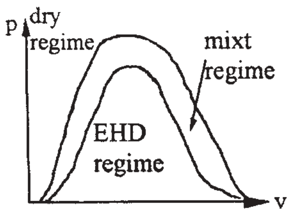


Fig. 5

Friction

Stribeck curve is well known in the literature [6, 8, 18] but a similar plot when using composite with plastic matrix has a different aspect: the regime with complete water film is an island surrounding by a zone with mixt regime, larger or narrower, depending on the material of the journal and on the scale of the bearing (fig. 5).

The data analysis for the friction coefficient suggest that this tribological parameter is more accurate describe if the is given the range of this evolution and not a single value, as there is still given in many catalogues [33].

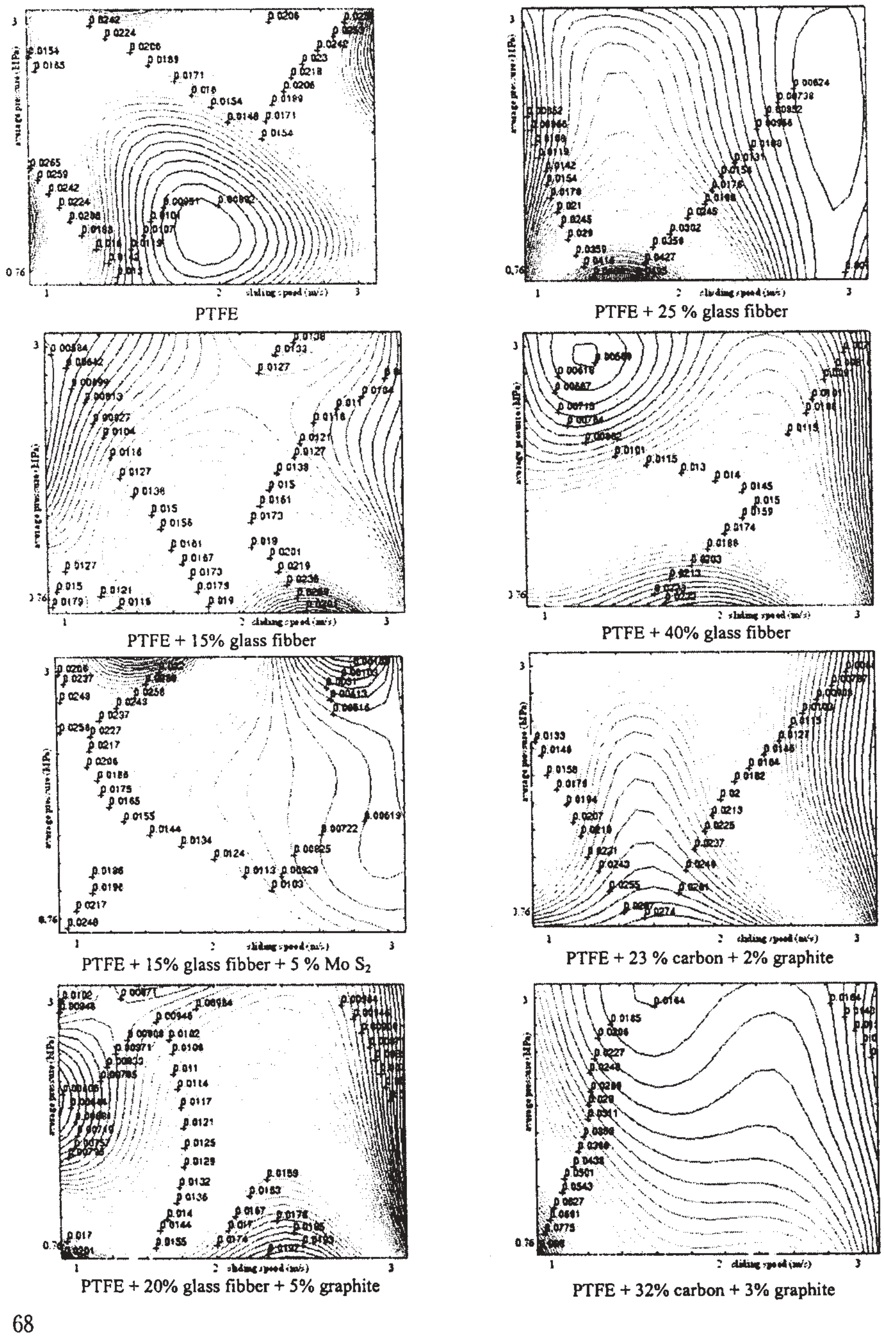
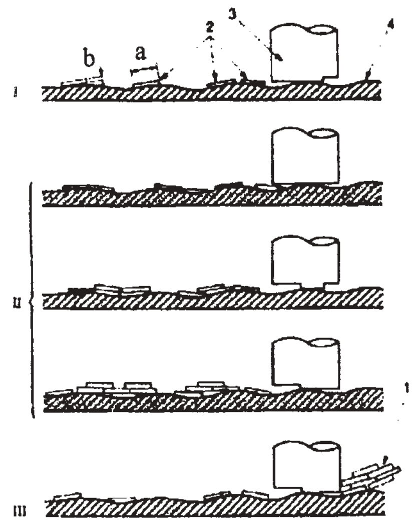


Fig. 6. Friction coefficient map, as function of average pressure and sliding speed



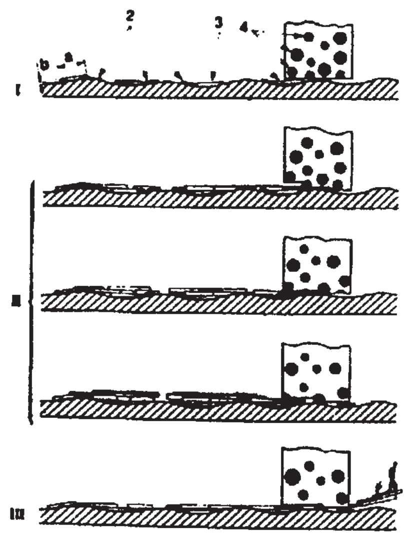
Model for adhesive wear of the composite made of PTFE and short glass fibbers a) dry sliding, b) higher speed, c) water lubrication and high speed [11]

a) low sliding speed and dry regime

b) low sliding speet under water lubricantion

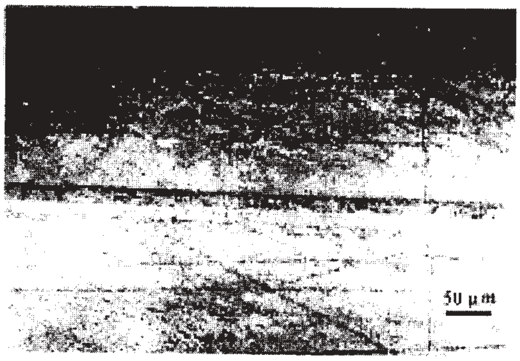
c) higher sliding speed under water lubrication

1 – Wear particle generated by overlapped slides of PTFE and it has the tendency of being rolled even before the total detachment; 2 – slides of PTFE transferred on the mating surface; 3 – pin made of PTFE; 4 – initial profile of the metallic surface [25]

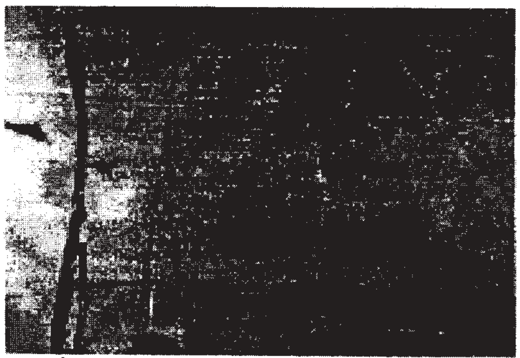


Model for adhesive wear of composite made of PTFE and powder, sliding on a surface with low chemical reactivity: 1 – wear particle detached by sliding and rolling, 2 – micro-slides of PTFE, 3 – slides deposed on the first transferred ones, 4- adding material [11]

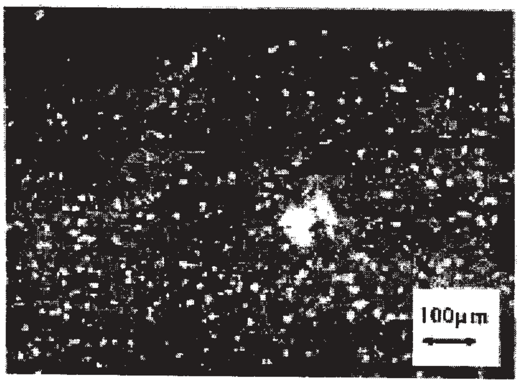
Fig. 7. Adhesive wear and transfer mechanism for PTFE and PTFE composites



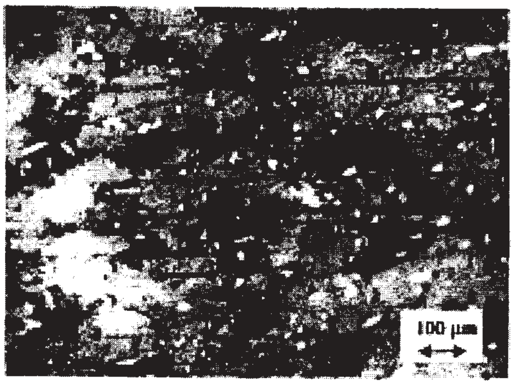
a) PTFE surface with wear traces (F=3kN)



b) PTFE surface with wear traces (F=3kN)



c) PTFE + 15% glass fibber



d) PTFE + 40 % glass fibber

Fig. 8 Wear traces on the shoes after sliding in water against steel

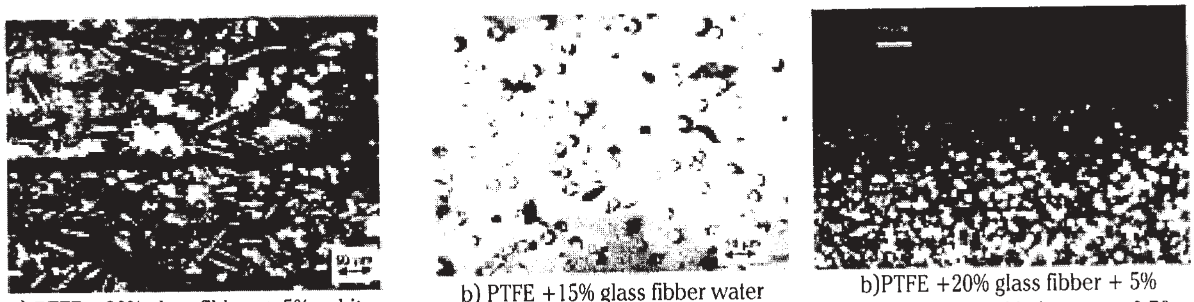
The maps of the friction coefficient that are presented in figure 6 suggest they represent only a part of a typical map as given in figure 5.

For the shoe made of polymer the minimum value is obtained for approximately p=1MPa and v=2m/s. For the composite with 25% glass fibbers this value is characteristic for a sliding speed greater (~2.5...3m/s) but for a larger range of average pressure, but a greater concentration (40%) moves this minimum value of the friction coefficient to lower speeds and higher pressures. taking into account the maps for the powder composites it seems they develop this minimum at higher speeds and loads and further investigation is needed.

Processes within the superficial layers and wear

The investigations on the superficial layer allow establishing the processes taking place in the superficial layer under water lubrication:

- evolution of the constituent concentration and optimization of the glass fibber concentration or of the powder (graphite and carbon), confirming the theoretical models or the tendencies noticed in [1, 13].

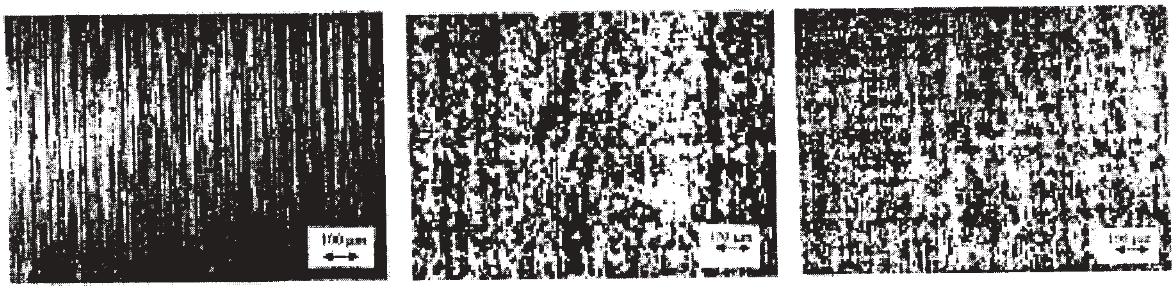


a) PTFE +20% glass fibber + 5% aphite, after dry friction at p= 0.76 MPa

b) PTFE +15% glass fibber water lubrication, v ~ 1m/s and p=3.6 MPa

b)PTFE +20% glass fibber + 5% aphite, after dry friction at p= 0.76 MPa

Fig. 9 Tribolayers of the composites with PTFE matrix after sliding [25]



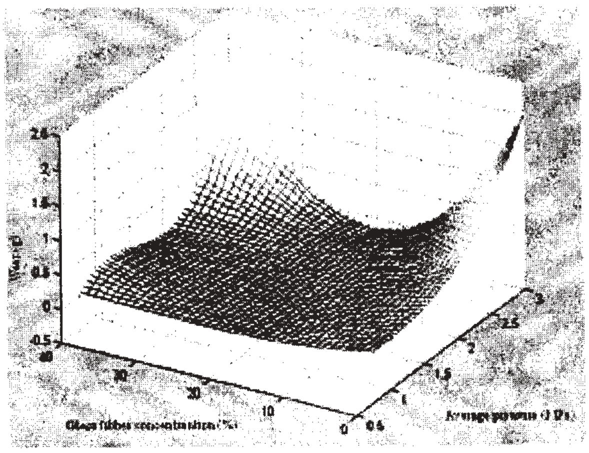


Fig. 11. Influence of the fibber concentration and of the average pressure on the wear of the shoe, for v=2.5m/s, after 10500m of sliding in water in open circuit

- fragmentation and orientation processes, changes in the crystallinity degree of the polymer, by the help of the microscopic and X-ray investigations X [9, 25];
- wear and transfer processes on both triboelements [29] (fig.9, fig. 10), that being also analysed in [3, 7, 15, 22, 31, 32].

The data obtained for wear may be grouped into two categories: those for the composites with glass fibbers and those for the powder ones. The first ones have a very reduces wear as compared to the polymer but the second group is characterized by negative wear meaning that the tribolayers of these materials may capture water drops or solid particles from water for the tested sliding distance of 10500m. For them a further investigation is needed because it is necessary to know how take place the detachment from the tribolayers: in small particles or in aggregates.

Figure 11 presents a 3D diagram of wear in order to underline the good tribological behaviour of the composites with moderate glass fibber concentration. Wear was measured as a mass loss of each shoe after sliding in water. The wear plot was calculated using a cubic spline interpolation in 2D space.

It is obvious that the polymer has the highest wear intensity and therefore it is not recommended for actual applications involving range of load and speed as tested here. For F=1kN (average pressure p=0.176MPa) all composites have the wear in a narrow interval but for F=3...4kN (p=2.31 ...3.08MPa) the composite with 40% glass fibbers has a wear similar in shape and values to PTFE.

Composites with 25% and 40% glass fibbers and the powder composites have a negative wear, obtained as the process of retaining water, solid particles in the tribolayer is still dominant but it is very probable to have a similar behaviour (with positive wear) as the composite with 15% glass fibber, if the test would be continued. So the sliding distance may be increased for getting more accurate information even if standards accept for sliding tests a sliding distance of 1500m.

Table 1

WEAR (g) FOR SOME OF THE TESTED COMPOSITES, FOR v=2.5m/s, after 10500m OF SLIDING IN WATER IN OPEN CIRCUIT

Material	Load (average pressure)			
	1kN (0.77MPa)	2kN (1.54MPa)	3 kN (2.31MPa)	4 kN (3.08MPa)
PTFE	0.917	1.175	2.4	3.011
PTFE + 23% carbon + 2% graphite	-0.3013	-0.3956	-0.3345	-0.1596
PTFE + 32% carbon + 3% graphite	-0.19913	-0.18113	-0.908	-0.7582
PTFE + 15% glass fibber + 5% MoS_2	0.00196	0.0294	0.0095	0.0285
PTFE + 20% glass fibber + 5% graphite	0.009	-0.0011	-0.0032	-0.0049

As pointed out by Bahadur and Blanchet [1, 2, 3], for every type of composite with polymeric matrix there is an optimum range for fibber (mass) percentage. For the composites with PTFE matrix and glass fibber this range seems to be 10...30%.

Table 1 contains wear data about the powder composites. It also contains wear data about the composites with both glass fibber and powder, but for the tested conditions it is obvious that these combinations do not differ too much as concerning the tribological behaviour so, the selection criteria will include the price.

PTFE wear is very severe, non-applicable for the regime presented in figure 11, but for composites with 15...25% glass fibbers wear is reduced by more than ten. For a composite with a high concentration of glass fibbers (40%), wear behaviour is good only for small average pressures; under higher pressures the wear becomes similar to the polymeric material, but the involved processes may differ as compared to the polymer: wear is intensified by dislocating aggregates of PTFE + fibbers and not by tearing bands of polymers from the shoe surfaces.

Conclusions

Actual industrial systems have to be designed taking into account, from the beginning, a particular regime of functioning, especially for water lubrication ones.

These experimental studies pointed out particular processes characterizing water lubrication and journals made of polymer and composite with polymer matrix. Each of the tested materials has optimal ranges for speed, load, constituent concentration.

The tribological tests reveal processes that are hard to be theoretically modeled as for instance the fibber agglomeration within the superficial layer of the composite with polymeric matrix.

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