PTFE Composites and Water Lubrication.
II. Surface Characterization

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Surface characterization of PTFE composites in the case of water lubrication is discussed. Methods for analysis of surface quality are shortly presented. The study of the effect of wear is based on Abbott-Firestone curves which provide many advantages. Roughness studies were performed by the help of digital profilometer applied on PTFE samples. The surface quality study points out the statistical character of the information concerning the profile of composites with polymeric matrix.

Keywords: PTFE, surface quality, Abbott-Firestone curves, water lubrication

Many specialists underlined the difficulty of analysing the parameters of functioning surfaces, both for 2D but also for 3D [3,4,10]. It was noticed that parameters as Ra do not have a direct functional significance but they are easy to calculate and therefore they are included in any soft for profile parameters. ISO 12085 and ISO 4287 help engineers to introduce many profile parameters in order to characterise in a better way the functionality of surfaces, both after manufacturing processes and service periods. These parameters become criteria for maintaining or removing an element from a tribosystem. Thus, functional characterisation relates surface topography to engineering application directly.

Utility of Abbott-Firestone curve in tribological evaluation of a surface becomes evident when studying surfaces of same material but obtained with different technologies: these surfaces may have the same Ra but different Abbott-Firestone curves [5,7,8]. The reasons of these differences may be: different shapes of the asperities, their distribution on height but also their spacing ranges. Studying these curves after functionning on laboratory models reveals some specific tendencies that may be correlated with other tribological parameters as wear and friction coefficient [7,11], and they may recommend range of load, speed or combination of them for actual applications.

One of the advantages offered by Abbott-Firestone curves is that it simulates the effects of wear or running-in, giving information on material and void volumes of the surface topography, on damaging rate of the superficial layer, on bearing capacity and fluid retention capacity of the studied materials.

Analysis of surface quality

Roughness studies were performed by the help of digital profilometer Surtronic3+ and soft Talyprof (Taylor Hobson ®). Measurement settings were: profile parameters (table 1) calculated on the entire profile length (4mm), use of the Gaussian filter, the cut-off length 0.8 mm. For plotting Abbott-Firestone curves the raw profiles were used. Figure 1 presents a set of shoes after testing and the code of zones where the profiles were recorded. Figure 4 presents typical profiles for some of the tested materials (see Part I of the paper).

The initial surfaces of the tested materials are characterized by roughness parameters having similar magnitude (fig. 5-10, for F=0).

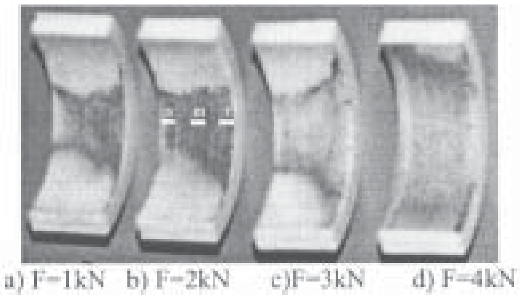

Fig. 1 Tested shoes made of PTFE + 15% glass fibbers [10] after sliding in water in open circuit (sliding speed of 2.5m/s) . White segments represent the zone for recording the roughness profile and their codes

Table 1

Symbol	Significance and relationships
Ra	Arithmetic mean of the departures of the profile from the mean line (fig. 5)
Rt	Maximum peak to valley height (total height) of the profile in the assessment length (fig. 6)
Rq	Root mean square average roughness (fig. 7)
Rsk	Skewness (fig. 8)
Rku	Kurtosis (fig. 9)
RSm	Mean spacing between profile peaks at the mean line, measured over the assessment length (fig. 10)
ΔH	the distance between two tp%
tp (%)	the bearing ratio at a given depth

The lowest values of Ra, grouped in more narrow intervals are obtained for polymer and for the composite with highest content of glass fibbers (40%). However, the tribological behaviour (here expressed by low wear, see Part I of the paper) is obtained for the composites with average fibber concentration (15 and 25%, respectively). This profile parameter does not seem to be related to load and wear, and becomes sensitively different only for the limit of the fibber concentration interval.

At the end of testing time (necessary for sliding 10500m), Rt was diminished very much for the composite with 25% glass fibbers, under load greater than 1kN. For F=1kN, the tribolayer is not very well compressed and the roller acts like a fine-cutting tool. At greater load, even if wear increases, the surface profile remains smooth. It seems to

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bear a wearing process with micro-cutting, smoothing and compression of the superficial layer [5,7].

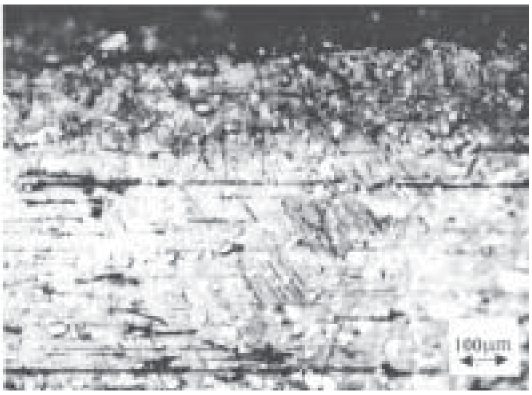

Fig. 2 View of the edge of the loaded zone of the shoe (coded a, fig. 1) for the composite PTFE +20% glass fibbers + 5% carbon, after sliding in water at v=3m/s and average pressure p=4.6MPa

Microscope studies shows wear traces in the sliding direction (they are more obvious) but also, finer traces towards lateral edges of the contact (fig. 2). They may be the result of forced evacuation of water and fine wear particles in the lateral direction. This combination of traces may explain the large range for profile parameters characterizing the polymer (fig. 5-fig.10), even for Abbott-Firestone curves (figs. 3, 11).

For the composite with 40% glass fibbers, even if Rt is decreasing very much (fig. 7), the wear points out that a glass concentration of 40% is not favourable to applications involving sliding under water lubrication roughness parameters being similar to those obtained for composite with lower concentrations.

The range of each parameter seems to be similar for composites with glass fibber, the range being smaller for PTFE, under loads of 2…4kN. Although the parameters Ra, Rt, Rq for PTFE are lower in the range 2…3kN, suggesting a smother surface, the tribological behaviour is poor for this load range. Thus these parameters may be considered as “false friends” as they could not be related to the tribological behaviour.

Comparing the data obtained for each zone of the shoe, one may notice that the parameters characterizing the lateral zone (noted with a and f are not similar, suggesting different local sliding regimes, the values for m zone being less spread. This is the zone where the probability of having complete water film is greater.

Comparing Rt for initial surfaces to those obtained after sliding, one may notice that this parameter has a sharp tendency to diminish even if there are some values similar to the initial ones (only for PTFE, fig. 7). The conclusion would be that wear takes place in the tribolayer limited by Rt. This remark may be confirmed or not by wear graphics.

The range for Rsk is similar for all composite but smaller for the composite with 40% glass fibber.

Rku has the same tendency but with a larger spread range for the polymer.

Both Rku and Rsk describe a good surface for sliding but none of them could give information about the fact that the tribolayer are new or not.

RSm varies more for the PTFE and less when the fibber concentration increases.

The influence of powder seems to be rather small, except higher value for Ra and Rt in case of the composite with MoS_2. For the composites with powder (carbon + graphite) the parameters, except RSm, the values are grouped in narrow ranges, with some extreme values out of these ranges, suggesting a greater probability for local perturbations.

Rsk is basically a measure of the profile symmetry about the mean line. A peaky surface has positive skewness, a scrathy or a porous one tends to have negative skewness. If the spikes are almost simmetrically disposed, however the numerical values Rsk tends to zero, i.e. the surface has a symmetric height distribution. For a symmetric distribution of heights, Rsk may be negative, if the distribution has a longer tail at the lower side of the mean line or positive if the distribution has a longer tail at the upper side of the mean line [4]. Surfaces with greater negative values (-2…-4) because of a few peaks flattening are specially wanted for the lubricant retention [6]. A comparatively large negative Rsk (<-1) may be found in surfaces such as ground and honed surface. Conversely, a comparatively large positive Rsk (>1) may indicate the presence of a few spikes on the surface that could quickly wear away in contact with other surface [4].

In general, the presence of a small number of asperities outliers on a surface will not significantly influence the functional performance of the surface. However, in this case, the computation of the skewness may be significantly influenced, illustratting that Rsk is unstable if it is used for indicating functional properties of the surfaces [3,4,6].

When Rsk tends to zero, Rku is a more useful parameter, as it can distinguish between predominantly bumpy [3,4] or a spiky surfaces. The kurtosis is often measured relative to value 3, since it corresponds to the Rku of a gaussian distribution. Values smaller than 3 show that there is a well spread distribution within Rt. A value greater than 3 indicates greater frequency of the distribution closer to the mean line. Increase of Rku value, for the same surface, could be a sign of significant surface wear.

Therefore using a combination of Rsk and Rku parameters, it may be possible to identify surfaces that will

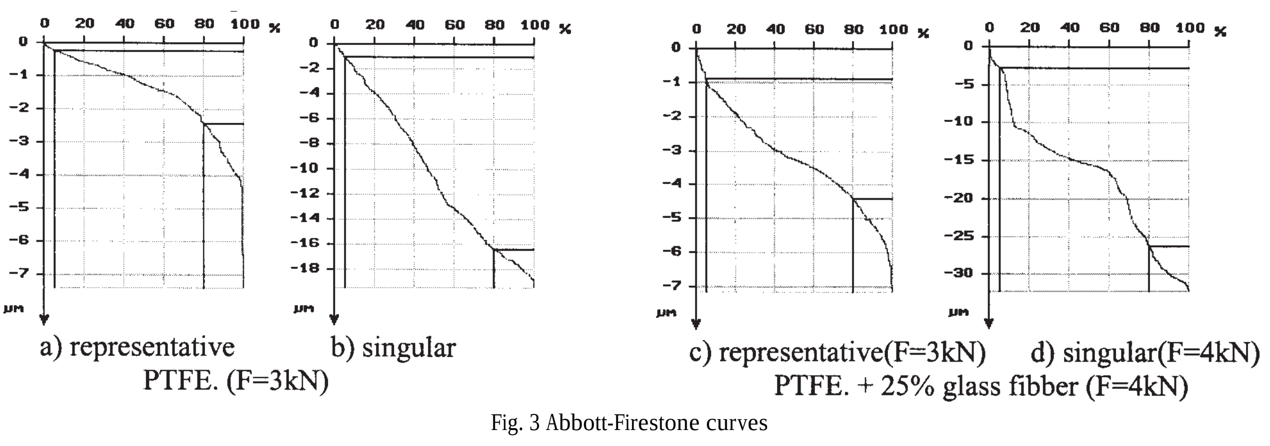

Fig. 3 Abbott-Firestone curves

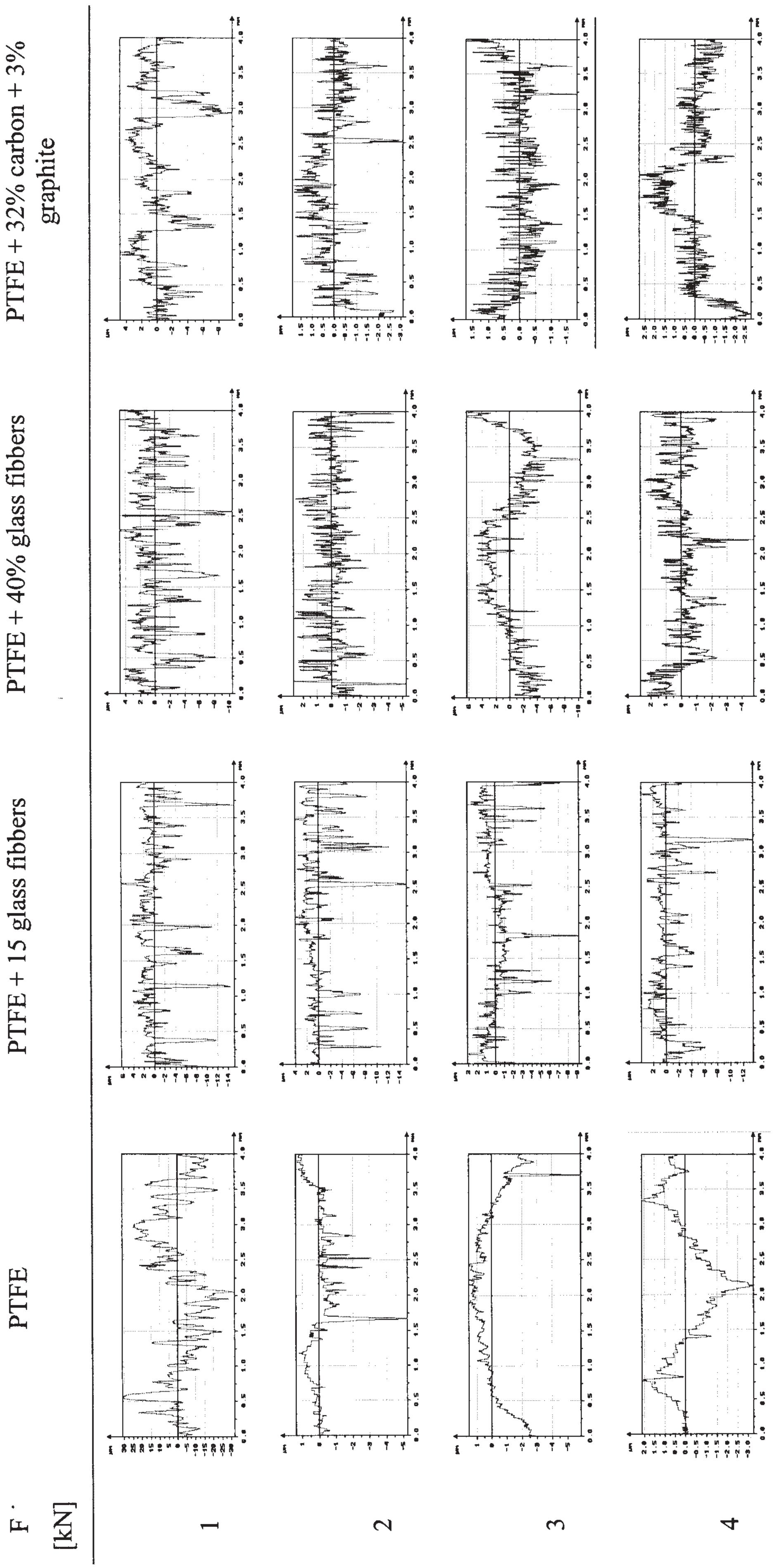

Fig. 4 Typical profiles for the zone coded with m, for some of the tested materials, after sliding in water at 2.5m/s

behave better, especially those with flat top and deep valleys. Skewness and kurtosis are more sensitive to changes in profile shape than Ra and Rq. This makes them capable of analysing wear experiments [6]. In particular, a surface having positive skewness could be expected to undergo severe changes in the skewness value when running in.

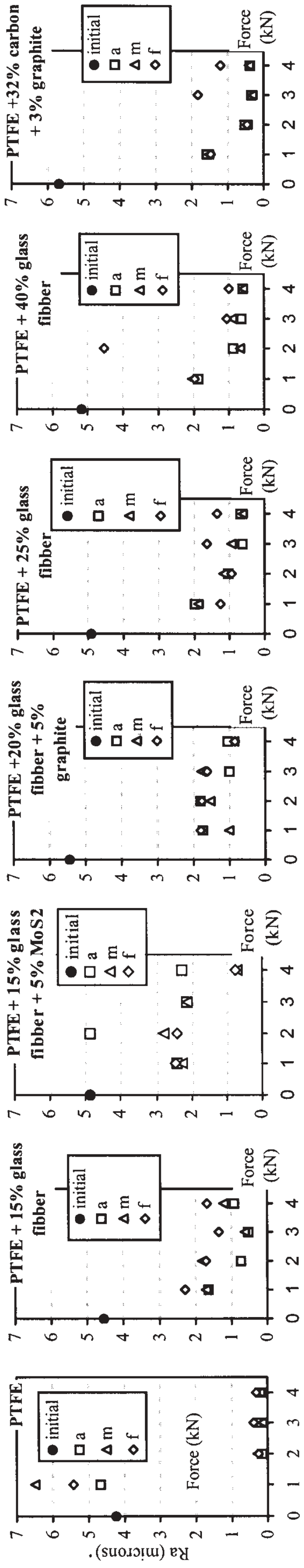

Fig. 5. Parameter Ra after sliding in water at v=2.5m/s

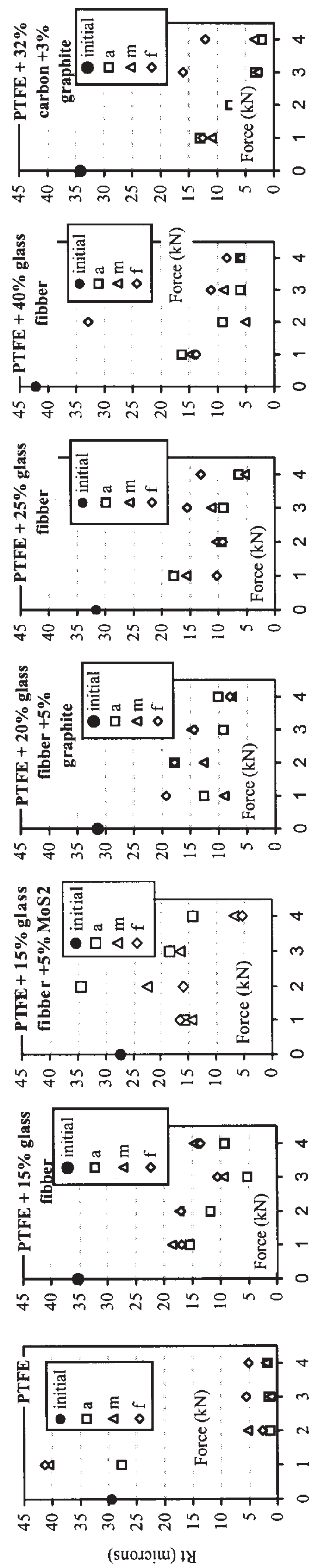

Fig. 6. Parameter Rt after sliding in water at v=2.5m/s

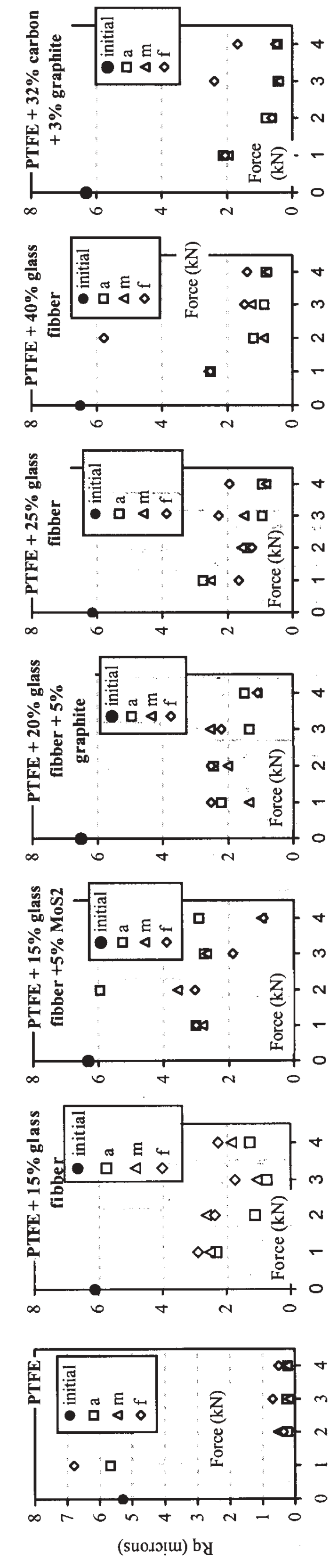

Fig. 7. Parameter Rq after sliding in water at v=2.5m/s

Abbot-Firestone Curves

Studying the Abbott-Firestone curves on laboratory models after functioning reveals specific tendencies that may be correlated with tribological parameters as wear and friction coefficient, and they may recommend the range of load, speed or combination of them for actual applications.

For this study were chosen bearing ratios of 5% and 80%, these values being imposed by practical considerations [4,5,7]. The authors considered representative Abbott curves those that seem to be similar in 80% of the recorded profiles and singular those with very different shapes as presented in figure 3b and d.

Both ADF (amplitude distribution function) and Abbott-Firestone curves show that composites with average glass fibber concentration have a good retaining capacity of the fluids (fig. 3, a and c), confirmed by the long middle level with low slope characterising the curves and also by a tail for the ADF under the mean line of the profile.

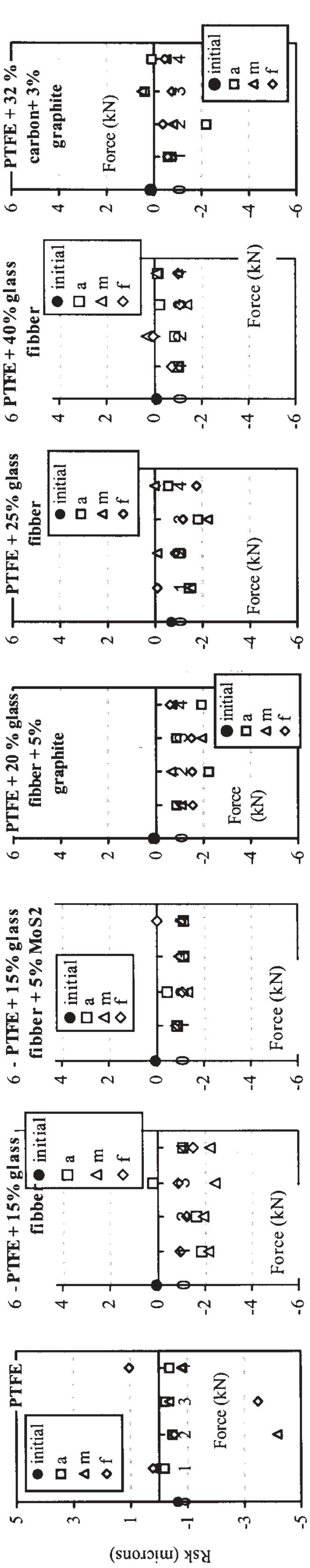

Fig. 8. Parameter Rsk after sliding in water at v=2.5m/s

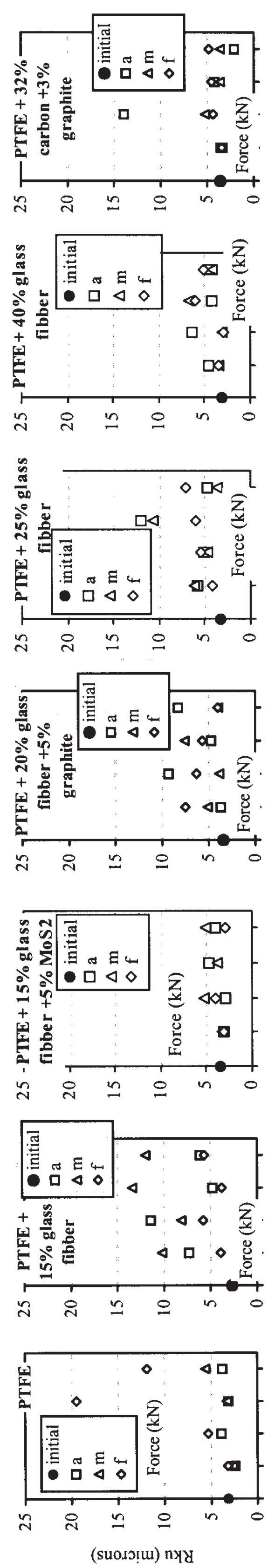

Fig. 9. Parameter Rku after sliding in water at v=2.5m/s

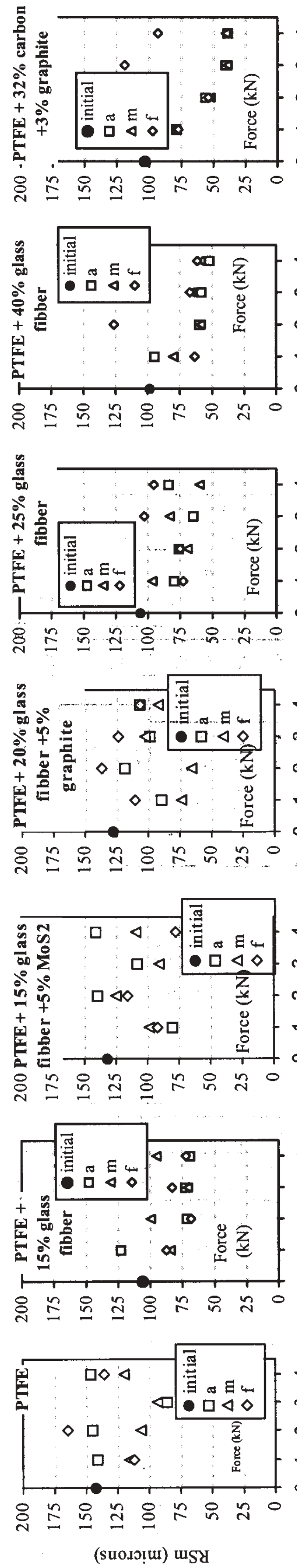

Fig. 10. Parameter RSm after sliding in water at v=2.5m/s

Even if composite with 40% glass fibbers has a lower middle level of the Abbott-Firestone curves, this may be explained by the great number of points on the profile, having medium height. Roughness core for this composite is very consistent (fig. 11d) showing a middle zone much larger as compared to the other composites. It is from this zone that material is detached as fibber + polymer aggregates and this composite has the greatest value of wear. Therefore it is not recommended for similar applications.

Analysing the values for wear (presented in Part I. Tribological Characterisation) there are obviously two tendencies for the tested materials. The increased wear of materials situated at the concentration limits (0, 40% glass fibber, respectively) and the relative low values and less dependent on load for the composites with average concentration (15 and 25%, respectively), may be explained as follows: at moderate fibber concentration the superficial layer changes its topography only in the peak and core zones but for extreme concentrations a new working

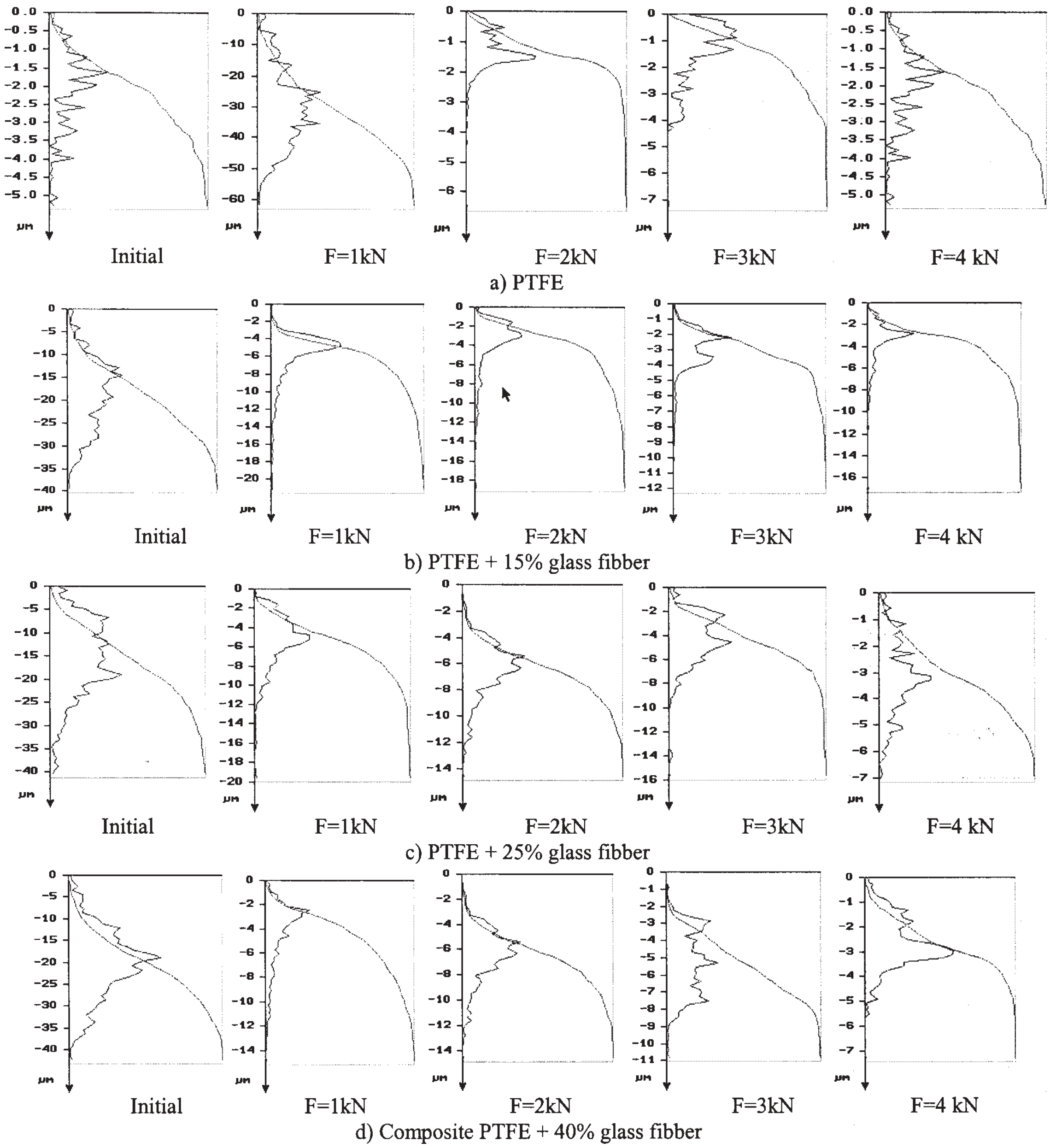

Fig. 11. Typical Abbott-Firestone curves for the PTFE + glass fibber composites

Table 2

Fibber concentra-tion	Force	tp5%	tp80%	h_{max}	$\frac{\Delta H}{h_{max}}$ *	$\frac{tp5\%}{h_{max}}$	$\frac{tp80\%}{h_{max}}$	$\frac{h_{max} - tp80\%}{h_{max}}$
%	kN		microns					
	0	4.02	20.18	33.4	0.483	0.120	0.604	0.395
	1	9.3	42.08	63	0.520	0.147	0.667	0.332
0	2	0.36	1.78	6.63	0.214	0.054	0.268	0.731
	3	0.24	2.46	7.42	0.299	0.032	0.331	0.668
	4	0.57	3.1	5.38	0.470	0.105	0.576	0.423
	0	6.56	26.52	40.3	0.495	0.162	0.576	0.423
	1	3.31	7.97	21.6	0.215	0.153	0.368	0.631
15	2	1.29	5.39	19.3	0.212	0.066	0.279	0.720
	3	1.33	4.81	12.4	0.280	0.107	0.387	0.612
	4	1.35	5.3	17.4	0.399	0.077	0.304	0.695
	0	4.21	22.74	41.2	0.449	0.107	0.304	0.448
	1	1.8	7.78	28	0.213	0.064	0.277	0.722
25	2	3.56	8.05	14.9	0.301	0.023	0.540	0.459
	3	1.46	6.12	16	0.291	0.091	0.382	0.617
	4	0.89	4.42	7.16	0.493	0.124	0.617	0.382
	0	7.51	27.35	43.2	0.459	0.173	0.633	0.366
	1	1.42	6.63	15.2	0.342	0.093	0.436	0.565
40	2	0.84	3.37	7.91	0.319	0.106	0.426	0.573
	3	2.69	7.21	11	0.410	0.121	0.655	0.344
	4	0.97	3.41	7.44	0.327	0.130	0.458	0.541

*ΔH = tp80%-tp5% (microns).

surface appears, that could be situated under the initial profile.

Typical values of Abbott-Firestone parameters are given in table 2. Initial profile is given for F=0. The parameter variations are quite insignificant. It is difficult to appreciate if the profiles are totally new (obtained by detaching wear particles) or only partially destroyed.

Conclusions

The surface quality study points out the statistical character of the information concerning the profile of composites with polymeric matrix. For the same shoe, in a narrow zone, Abbott-Firestone curves may characterize a typical functioning surface or a local perturbation due to wear particles detaching, solid particle embedding or wear traces caused by the steel roller. The problem is to establish a methodology for separating the two categories.

For PTFE, at a load F=1kN the steel roller act like a micro-cutting tool, the superficial layer being insufficiently compressed and the polymer bands are easy to be detached. A better quality of the initial surface as a result of pressing technology is due to a greater forming pressure than the average pressure in functioning under F=1kN (corresponding to an average pressure p=0.76MPa).

Dimensionless parameters related to Abbott-Firestone curves, as $\Delta H/h_{max}$, $(h_{max}\text{-tp80\%})/h_{max}$ etc., may provide information on the fluid retaining capacity and wear resistance. It may be noticed the tendency of having deep and narrow valleys for the zone of the Abbott-Firestone curve between tp80% and h_{max}. Bearing ratio tp5% is similar for all tested materials, having a slightly tendency of decreasing with load. There is an obvious tendency to be larger for materials situated at the limits of glass fibber concentration (0% and 40%, respectively) (table 2).

The very low values of the friction coefficient obtained for all tested materials at a sliding speed of v=2.5m/s indicates a very great probability of forming a total or partial water film [7]. Its generation is facilitated also by water infiltration in the profile valleys, especially in narrow and deep ones.

Pressing technology and low load produce, for PTFE surfaces, profiles with deeper maximum valleys. The tendency of light decreasing of Rt for composites with 15…25% glass fibbers as a function of loading, may reflect the possibility of increasing the load.

For polymeric composites, the study of the profile parameters has to be correlated to one or a set of tribological parameters in order to use the result for optimization either of the composite or the functioning regime.

Thus, the methodology of quantification of the surface quality for the polymeric composites may be different from those for the metallic ones. It is the specialist's task to establish how distortional the curve could be as compared to the typical ones, also established based on his experience and test data .

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