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Sliding tribological properties of untreated and PIII-treated PETP

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ABSTRACT

Poly(ethylene terephthalate) (PETP) was treated by plasma immersion ion implantation (PIII or PI^3) in nitrogen. The surface changes were characterised by XPS and water contact-angle measurements. Sliding tribological properties of untreated and nitrogen PIII-treated PETP against conventional low carbon structural steel S235 were studied under dry and water-lubricated conditions by a pin-on-disc tribometer.

XPS results suggested the evolution of surface composition and bonding towards those of amorphous hydrogenated carbon-nitride. Water contact-angle decreased implying increased surface wettability. At a very low *Pv* factor (0.0075 MPa m s^{-1}) for the nitrogen PIII-treated PETP the dry friction coefficient was smaller than, while the lubricated friction coefficient was similar to, the corresponding value of the untreated variant. At higher *Pv* factors (near 0.1 MPa m s^{-1}), however, both the dry and lubricated friction coefficients were higher for the treated sample than for the untreated variant, suggesting an increased adhesion component of friction for the nitrogen PIII-treated PETP in this region.

1. Introduction

Poly(ethylene terephthalate) (PETP) is widely used in the industry. The production of synthetic fibers, containers of beverage, food and various liquids, machine parts in the mechanical industry, components for precision engineering and medical implant devices are well known applications. PETP machine parts in the mechanical industry are exposed to friction, thus the modification of the tribological properties of PETP is an important issue.

Plasma immersion ion implantation (PIII or PI^3, called also plasma-based ion implantation) and its deposition variant have been applied to improve its surface barrier [1–3], hydrophobic [4], electrical [5], bacterial repellence [6,7] and blood platelet adhesion [8] properties. Recently we observed a significant increase of resistance to microabrasive wear [9] of nitrogen PIII-treated PETP in a test applying multiple scratches over the same track. In this work we studied the sliding tribological properties of nitrogen PIII-treated PETP by a pin-on-disc tribometer as a function of sliding distance, with various loads and sliding velocities, under dry and water-lubricated conditions.

2. Experimental

Poly(ethylene terephthalate) (PETP) of the type Docapet (Ensinger), virgin grade was used, from which discs of 10 mm diameter and 2 mm thickness were machined. These were polished with SiC paper (grit number P1200 and P4000) and then with felt sheet.

Several PETP samples were treated simultaneously, in the same run by nitrogen plasma immersion ion implantation (PIII). A high voltage pulser of ANSTO (Australia) was applied. The base pressure was about 5×10^{-5} Pa. High purity (4N5) N_2 was used with a flow rate = 20 cm^3 min^{-1} (STP), pressure = 3×10^{-1} Pa, power = 75 W. An accelerating voltage of 30 kV, ion fluence of 4×10^{17} cm^{-2} and fluence rate of 3×10^{13} cm^{-2} s^{-1} were applied.

XPS studies were performed by a Kratos XSAM800 equipment. Mg $K\alpha_{1,2}$ radiation and fixed analyser transmission mode (80 and 40 eV pass energies for widescan and detailed spectra) were used. The spectra were referenced to the C 1s line (binding energy, BE = 285.0 eV) of the hydrocarbon type carbon. Data acquisition and processing, were performed with the Kratos Vision 2 program.

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Table 1
Overview of the wear test categories of DIN 50322.

Category	Type of testing	Test system
I.	Field or bench testing	Field test with real machine
II.		Bench test with real machine
III.		Bench test with units
IV.	Laboratory testing	Original elements or sample testing
V.		Sample testing with modelled conditions
VI.		Simplified sample testing under simplified conditions

Water contact-angle measurements were done by the static sessile drop method, applying the SEE System apparatus (Advex Instruments) and distilled water, at 23 °C.

For tribological studies the pin-on-disc module of the dynamic tribotester of SZIU was applied. The measurements were carried out according to the VI. wear test category of the German standard DIN 50322 (Table 1) [10]. The schemes of the test arrangement can be seen in Fig. 1a and b. In comparative tests distilled water was added dropwise into the contact zone, with a drop volume = 10 μl and drop frequency = 2 min^{-1}. The temperature close to contact was measured by a thermocouple situated inside the sample, at 1 mm distance from the contact zone.

3. Results and discussion

3.1. Surface characterisation

According to the XPS measurements, the surface composition and bonding of PETP was strongly altered as a result of N PIII-treatment. The spectral changes have been discussed in our previous paper [9]. The elemental composition changed from the values of C 72 at% (theory: C 71 at%), O 28 at% (theory: O 29 at%), characteristic for the untreated sample, to C 67 at%, O 18 at% and N 15 at%. In addition, the bulk plasmon loss energy E_p for the C 1s peak increased from 21.7 to 23.7 eV upon treatment. These results suggest an evolution of the surface composition and bonding towards those of amorphous hydrogenated carbon-nitride [11] type material upon nitrogen PIII-treatment of PETP.

The water contact-angle of untreated PETP was 80.4°, while for its PIII-treated variant it decreased to 74.6°, reflecting an increase in surface wettability.

3.2. Pin-on-disc tribotests under dry conditions

At first, the early stage of the sliding tribological behaviour of dry untreated and PIII-treated PETP was studied. A comparative tribological test was performed with the pin-on-disc tribometer on the untreated and PIII-treated samples under the conditions of low sliding velocity (v = 0.025 m s^{-1}) and low load (P = 0.3 MPa), resulting in a very low Pv factor (0.0075 MPa m s^{-1}). Fig. 2 shows the results, including the evolution of the friction coefficient μ, the depth change caused by deformation plus wear d, and the sample temperature close to contact surface T, as a function of sliding distance l. It can be clearly seen that μ became smaller for the PIII-treated surface than was for the untreated one. Practically no deformation was observed for the untreated sample. (The observed undulations can be attributed to mechanical vibrations of the measuring system.) A definite deformation was, however, observed for the PIII-treated sample, which can be explained by the previously found [9] decrease of elastic modulus from E_0 = 3.56 ± 0.11 GPa of the untreated, to E_{tr} = 2.88 ± 0.16 GPa of the PIII-treated surface layer. The temperature close to the contact surface was slightly higher for the PIII-treated sample. In view of its decreased friction, this can be explained by the smaller thermal conductivity of the layered surface structure created [12].

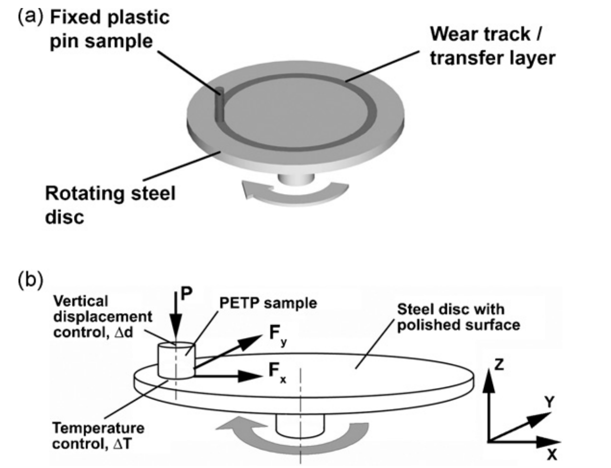

Fig. 1. (a) Layout of the pin-on-disc tribometer. (b) Controlled values for data processing.

Fig. 3 shows the results of tribological tests under the conditions of higher sliding velocity (v = 0.05 m s^{-1}) and stepwise increase of load from P = 0.5 to 1 and 2 MPa. These conditions correspond to Pv factors of 0.025, 0.05 and 0.1 MPa m s^{-1}, respectively. It can be seen that μ for the untreated sample—after a running-in period of approximately 20 m of sliding distance—became stabilised below 0.4 under the load of 0.5 MPa. It remained fairly constant under 1 MPa, but tended to increase under 2 MPa. The corresponding value of d increased stepwise, following the stepwise increase of load. The sample temperature increased throughout the test, especially at the end of test.

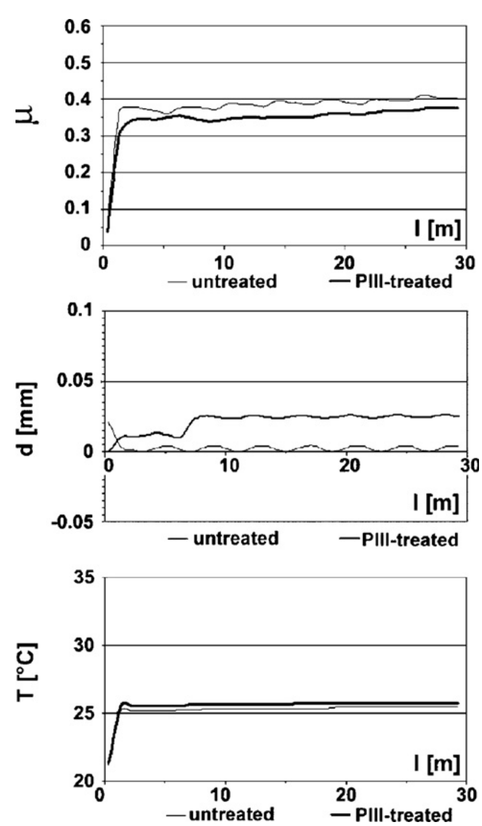

Fig. 2. Tribological properties of dry untreated and PIII-treated PETP as a function of sliding distance (P = 0.3 MPa, v = 0.025 m s^{-1}).