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Friction and wear of PEEK in continuous sliding and unidirectional scratch tests

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ABSTRACT

Friction and wear of a commercially available polyetheretherketone were investigated by two different testing approaches, namely the standard pin-on-disc (POD) configuration and an unidirectional pin-on-flat (POF) scratch test, in a wide range of pv-products from 0.001 to 8 MPa m/s under dry sliding condition. It was found that the steady state friction coefficient gained from POD tests slightly decreases with increasing sliding velocity from 0.1 to 1 m/s, further increase in the velocity to 4 m/s results in an obvious raise of the friction coefficient. It is assumed that this increase can be attributed to the high interfacial temperature induced strong adhesion between PEEK surface and steel counterbody. No obvious difference of the friction coefficients between POD and POF tests is noted in the studied range. With respect to the wear rate, the wear rate measured from POD increases with monotonously increasing velocity. Possible reasons for these observations are discussed based on the analysis of the worn surfaces of polymer samples and transfer films formed on the steel counterface as well as the investigations on the thermal characteristics of different tribo-systems.

1. Introduction

Due to their light weight potential, excellent self-lubricant ability and design flexibility, polymeric materials are increasingly applied where friction and wear are crucial issues, such as in bearings and sealing components. Polyetheretherketone (PEEK) is a high performance material which is widely used as tribo-material. Its basic friction and wear properties and the correlation between tribological behaviour and other material properties have been systematically studied. For example, the influence of different load conditions on friction and wear of PEEK against steel counterparts [1,2] and the correlation of tribological properties with mechanical properties of PEEKs with different molecular weights [3] have been reported. Parallel to this progress, the understanding of wear of polymers has been improved by experiments with fabricated surface textures on the steel counterface, based on which Wang et al. [4] concluded that the transfer of polymer material contributed to adhesive wear. There is still a lack of studies comparing tests in different configurations and at different length scales, whose results could help to reduce the experimental expenses of qualifying the PEEK tribo-materials for industrial applications. Generally, a fundamental understanding of the friction and wear mechanisms in polymeric materials based on tests in different configurations addressing different length scales is highly desirable.

On the macroscopic scale, friction and wear properties of PEEK and its composites in contact with steel counterparts have been studied using various testing approaches such as a block-on-ring (BOR) test with standard specimens [5], fretting experiments [6], a bent-plate-on-ring test with a U-shaped PEEK-coated metallic substrate [7], or rolling contacts [8,9]. On the microscopic scale, single-asperity friction and wear of PEEK was systematically investigated by Pei et al. [10] using diamond stylus in scratch tests. It was reported that the scratch friction coefficient decreased in repeated strokes and approached a stable value after several scratches. The scratch initiation and the resulting damage patterns were found to be strongly dependent on the tip geometry in single-asperity scratching.

These investigations demonstrate that different aspects of the tribological properties are addressed in specific testing approaches at macroscopic and microscopic scales. Systematic studies on the effects of scale and of the testing procedure are sparse. Burris and co-workers [11] studied PEEK components with compositionally graded PEEK/PTFE

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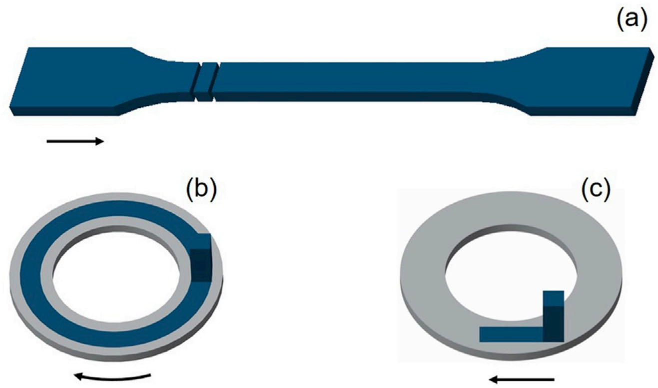

Fig. 1. Schematic illustration of (a) the preparation of tribological testing samples from injection molded plaques, (b) pin-on-disc test and (c) pin-on-flat unidirectional test. The arrow in (a) indicates the injection molding direction and the arrows in (b) and (c) indicate the sliding and scratching direction.

surfaces in contact with steel counterparts by reciprocating pin-on-disc, rotating pin-on-disc, and thruster washer approaches. They showed how friction and wear results depend on the testing methods. Malucelli and co-workers reported comparable data for friction coefficient and wear rates in three different sliding wear tests, namely pin-on-disc, thruster washer, and reciprocating sliding [12]. There is no general scaling law which would allow to directly explain friction and wear of polymeric materials by constitute contributions of microscopic processes. The tribological properties of polymeric materials are rather interdepend on several factors, i.e. pressure and velocity as well as the thermal characteristics in the tribo-system. The interfacial temperature is an important factor in friction and wear phenomena of polymers. Mbarek and co-workers [13] showed how friction and wear properties depend on the interfacial temperature generated by frictional heat. Analysis of the molecular structure of wear debris [14] and examination of the decomposition products during severe polymer wear using mass spectroscopy [15] have revealed that the temperature at the interface between polymer sample and steel counterpart reached the polymer melting temperature. The temperature variation was found to be closely related to a change in wear mechanisms [16]. In order to connect the technological relevance of macroscopic sliding tests with the insight into mechanics provided by microscopic single-asperity scratching experiments, we studied the tribological properties of PEEK in an unidirectional pin-on-flat configuration using a scratch tester at a speed of several millimeters per second and compared the results with those from continuous sliding wear tests in this work. We correlate friction and wear results of the different testing approaches and discuss similarities and differences in terms of wear mechanisms and thermal characteristics.

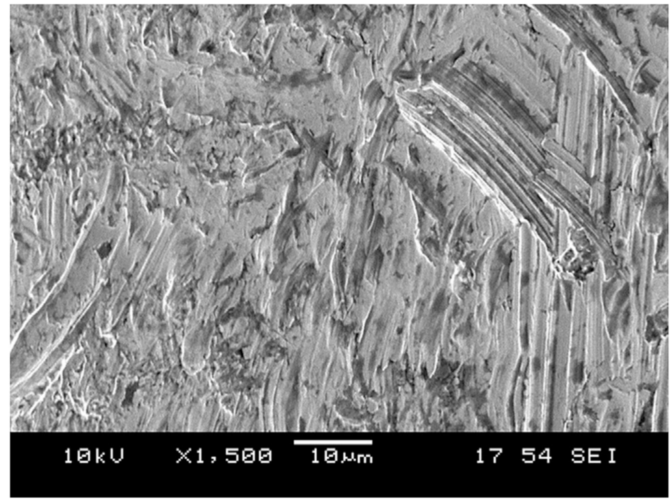

Fig. 3. Surface morphology of the as-received steel counterbody.

2. Material and testing methods

A commercially available polyetheretherketone, VESTAKEEP® 2000G from Evonik Industries AG, Germany, was tested due to its high potential for the tribological applications under dry sliding condition. Its mechanical and thermal properties were reported in an earlier study [17]. The samples were milled from injection molded standard tensile testing specimens supplied by Evonik Industries AG. The geometry of the sample is $4 \times 4x10\ mm^3$ and the nominal contact area in tribological tests is $4 \times 4\ mm^2$. The sliding and unidirectional scratching direction is parallel to the injection molding flow direction (cf. Fig. 1a). During the sliding wear experiment, the steel disc rotates continuously until the end of the test (cf. Fig. 1b). By contrast, in the unidirectional test the polymer sample scratches linearly against the steel disc (cf. Fig. 1c). After each cycle, the specimen is moved back to the start position.

Sliding wear tests were conducted on a self-constructed POD apparatus based on a commercial available tribometer according to ASTM D3702 (cf. Fig. 2a) at room temperature (21 °C). A schematic introduction and the setup of the POD apparatus are shown in Figs. 1b and 2a. The load was applied by a pneumatic cylinder and the normal and friction force were measured by a biaxial load cell. The counterpart was commercially available axial needle bearing washer (100Cr6) with an outside diameter of 42 mm, which was purchased from Schaeffler Technologies AG & Co. KG, Germany. The surface morphology of the steel counterpart is shown in Fig. 3. Asperities were randomly distributed and the average surface roughness R_a of the disc was ≈0.2 µm, which was measured by using a 3D confocal microscope from NanoFocus AG. The disc was used as received without further treatment. The sliding wear tests were carried out in a wide range of test conditions, i.e. the apparent

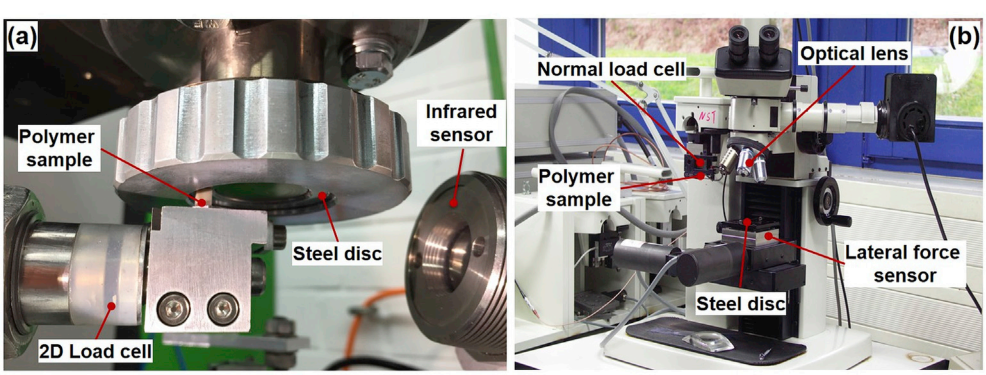

Fig. 2. Experimental setup of (a) POD apparatus and (b) scratch tester.