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Correlation of the tribological behaviors with the mechanical properties of poly-ether-ether-ketones (PEEKs) with different molecular weights and their fiber filled composites

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ABSTRACT

The tribological behaviors of three poly-ether-ether-ketones (PEEKs) with different molecular weights and their SCF (short carbon fiber)/graphite/PTFE (polytetrafluoroethylene) filled composites were examined using a block-on-ring apparatus under dry sliding conditions. Tensile tests, hardness measurements and dynamic mechanical thermal analysis (DMTA) of the PEEK based materials were also performed. The tribological behaviors of PEEK based materials were correlated with their mechanical properties and the tribological mechanisms were discussed based on scanning electron microscope (SEM) inspections of worn surfaces and wear debris. Under a low apparent pressure, a high material ductility seems to reduce the wear rate of pure PEEK through alleviating the microcutting effect exerted by the protruding regions of the counterpart. Under a high pressure, however, a high stiffness seems to improve the wear resistance of pure PEEK by reducing the plastic flow occurring in the PEEK surface layer. After incorporating SCF/graphite/PTFE fillers, the wear rate of PEEK was decreased significantly. Thinning and cracking of SCF are supposed to be the important factors determining the tribological behaviors of the composites.

1. Introduction

Poly-ether-ether-ketone (PEEK) presents the combination of a good tribological performance and a high strength and therefore, it is being widely used as tribomaterial [1]. The tribological performance of PEEK can be improved by incorporating appropriate fillers. The selection of filler types (including the surface modification of certain fillers) and the optimization of their dimensions, contents, and dispersing states constitute most of the efforts on the tribology of PEEK in the last two decades. Many delicate formulations of PEEK composites [2–9], especially the ones with multiple fillers [2,3], were proposed.

Generally, for a single-phase material, the combination of a low surface energy, a high stiffness, and a high toughness results in a good tribological performance, i.e. low friction coefficient and wear rate. The structure of polymeric materials, e.g. molecular weight and crystalline structure, exerts important roles on their properties including tribological performances [1,10]. For example, an increase in PEEK crystallinity leads to a higher material stiffness and a lower ductility. Accordingly, its tribological performance is strongly dependent on the crystallinity.

Compared with a single-phase polymer, the polymer composite presents a more complicated structure–tribology relationship. Generally, the roles of fillers can be summarized into the three following aspects: lubricating effect, improving mechanical properties, e.g. compressive strength and stiffness, and promoting the formation of a homogeneous transfer film. The internal lubricants refer to the materials with a low surface energy, e.g. polytetrafluoroethylene (PTFE), and the layer-structural materials in which the layers are linked by weak Van der Waals bonds, e.g. graphite, MoS_2, etc. A pioneering work was carried out by Voss and Friedrich [11] on short glass and carbon fibers reinforced PEEK composites. The fibers were incorporated into the matrix to increase its creep resistance and compressive strength. Their results indicated that short carbon fiber (SCF) improves the wear resistance of PEEK more effectively than glass fiber. Polymeric material filled with SCF/graphite/PTFE is a successful tribomaterial formulation [12]. The multiple fillers play synthesized roles on improving the tribological performance of polymer. Moreover, such fillers like nanosized particles and internal lubricants might promote the formation of a homogenous transfer film on counterpart surface. The homogenous transfer film was assumed to benefit the tribological performance of the material [7].

Effort on fundamental understanding of tribology is always crucial for the formulation of tribomaterials. Surely, it is of interest to understand how PEEK's mechanical properties affect its tribological behaviors. In this work, the mechanical properties of three

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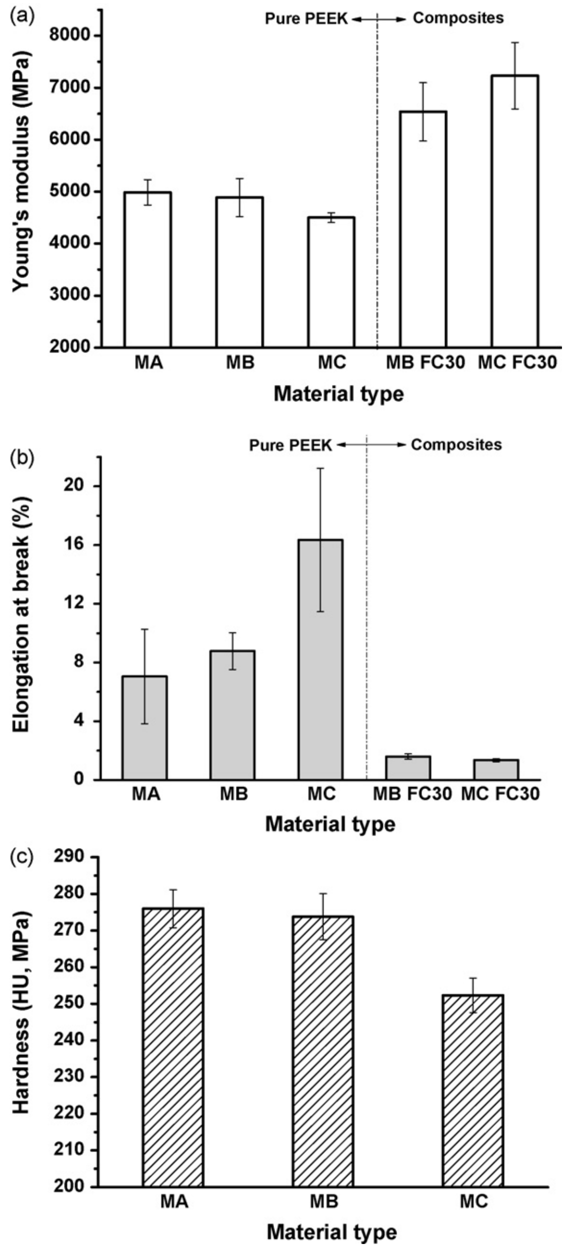

Fig. 1. (a) Young's modulus; (b) elongations at break and (c) universal hardness of studied PEEK based materials.

pure PEEKs and two SCF/graphite/PTFE filled PEEK composites with different matrix molecular weights were characterized. The tribological behaviors of the PEEK materials were examined and correlated with their mechanical properties. The objective of this paper is to describe a comprehensive effort to correlate the tribological behaviors of PEEK materials with their mechanical properties.

2. Experimental

2.1. Materials

Three pure PEEKs referenced in this paper as MA (material A), MB (material B), and MC (material C) and two SCF/graphite/PTFE filled PEEK composites referenced as MB FC30 and MC FC30 were used in this work. MB FC30 and MC FC30 were compounded, respectively from MB and MC with each 10 wt% SCF

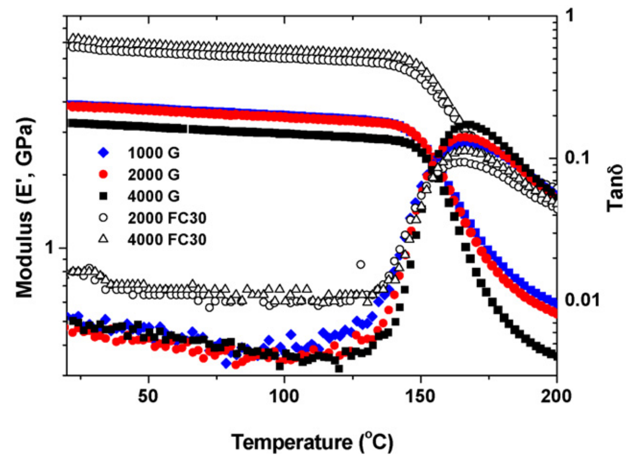

Fig. 2. DMTA results of PEEK based materials in a temperature range from 20 °C to 200 °C.

(9.1 vol%), graphite and PTFE. The molecular weights of the three PEEKs follow the order: MA < MB < MC. Plates were compression molded at 400 °C and slowly cooled to room temperature in the mold. All samples were prepared under the same compression and cooling conditions. Two kinds of plates with dimensions of 100 mm × 80 mm × 4 mm and 100 mm × 80 mm × 2 mm were prepared. The thick plates are employed for tensile and tribological tests while the thin ones are used for dynamic mechanical thermal analysis (DMTA) and hardness measurements. It should be noted that using the same processing parameters, the PEEKs with different molecular weights have different crystallinities: a high molecular weight corresponding to a lower crystallinity [13]. Therefore, the difference of mechanical and tribological properties between the PEEKs in this work should be considered as a result of synthesized effects of molecular weight and crystallinity.

2.2. Tensile test

All tests were performed at room temperature (23 °C) on a Zwick 1474 universal testing machine at a constant crosshead speed of 1 mm/min. The measurements followed DIN EN ISO 527 using dumbbell shaped specimens. The specimens with a 4 mm thickness were machined from the compression molded plates. The displacement of each specimen during tension was accurately measured by an extensometer. All presented data correspond to the averages of five measurements.

2.3. Universal hardness

The measurements of material universal hardness (HU) were performed on a Shimadu DUH-202 dynamic ultramicrohardness tester using a Vickers hardness indenter. The maximum load was 100 mN. The depth of penetration of the indenter tip was measured dynamically when applying and releasing the load and the hardness data were determined by the final depth after releasing the load completely. All presented data are the mean values of 10 measurements.

2.4. Dynamic mechanical thermal analysis (DMTA) test

DMTA tests were performed using a Gabo Qualimeter Explexor with tension configuration. The complex modulus and loss factor of each specimen with a dimension of 50 mm × 12 mm × 2 mm were determined at a constant frequency of 10 Hz. The samples were heated from 20 °C to 200 °C at a rate of 1 °C/min.