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Recommendations for h-BN loading and service temperature to achieve low friction coefficient and wear rate for thermal-sprayed PEEK coatings

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ABSTRACT

This work investigated the friction and wear characteristics of poly(ether-ether-ketone) (PEEK) with and without addition of hexagonal boron nitride (h-BN), which was prepared by coating PEEK on carbon steel substrate via flame spray coating technique. The coatings were then tested at different temperatures (30, 100, 200 and 300 °C) by ball-on-disc sliding wear test; 100 and 200 °C were found to be suitable service temperatures to obtain low friction and wear rate for PEEK coatings. No chemical or structural changes of PEEK were observed at the temperature range used in this work. The results indicated that h-BN could be used as a wear and friction reducer for PEEK coatings under optimum loading and service temperature. The loading of h-BN at 2 wt% was sufficient for improving the wear resistance, with reduced friction coefficients. The testing temperature exhibited a more pronounced effect on the friction and wear characteristics of PEEK coatings as compared to the effect of h-BN addition.

1. Introduction

Thermal spray coating for polymer material is a process where polymer particles are melted and sprayed onto the substrate surface at high velocity, and the molten polymer particles flow, spread onto the substrate surface before cooling. There have been several thermal spray coating techniques, such as, flame spraying, high velocity oxy-fuel coating spraying (HVOF), and plasma spraying. Recently, the thermal spray coating has been used for many engineering polymers including polyetherimide (PEI), fluoropolymer PVDF, polyamide-12, and poly(ether-ether-ketone) (PEEK) for tribological properties, chemical resistivity and corrosion protections [1–3]. Poly(ether-ether-ketone) (PEEK) is considered a high-performance engineering polymer showing excellent wear resistance with low coefficient of friction and a biomaterial in medical applications [4]. The main applications for PEEK related to tribology are bearings, bushings, rollers, pressure discs, piston rings and sealing rings, gears, and cookware. The effects of metal, ceramic fillers on the wear rate and friction coefficient of PEEK-based composites have been studied by many researchers [5,6]. At room temperature, the tribological properties of PEEK can be improved by mixing with some reinforcing or self-lubricating materials [5], such materials including Graphene, Tungsten disulfide (WS_2) and carbon nanotube (CNT). It has been found that these materials have significant effects on friction and wear properties of PEEK. Moreover, a mixture of two solid lubricants (graphite and h-BN) in polymer exhibited relatively good wear resistance and low friction in adhesive wear mode as a result of self-lubricating effect from h-BN structure [6].

In general, the tribological performance of PEEK drops under elevated temperature [7]; this has led to investigations into improving such performance by incorporating a wide range of additives [8,9], such as carbon nanotubes (CNT), nano-montmorillonite (MMT), rigid fillers and fibers, titanium dioxide (TiO_2), zinc sulfide (ZnS) and graphite. The friction coefficient and wear rate of the PEEK and PEEK composites have been found to decrease when tested at temperatures above the glass transition temperature (T_g; around 143 °C). According to a previous report [10], PEEK can have an operating temperature of up to 250 °C. If this is the case, the wear resistance performance of PEEK would inevitably decrease at higher temperatures. To date, few studies have been conducted on the tribological performance of PEEK at high temperatures (around 250 °C). Hence, investigation of the friction and wear characteristics of PEEK under highly elevated temperatures (up to 300 °C, which is close to its melting temperature, T_m) has become one of our primary research goals. Moreover, our previous work [11] on the tribological properties of PEEK filled with hexagonal boron nitride (h-BN), which is known as a solid lubricant for high-temperature applications, suggested that the addition of h-BN at 8 wt% could improve the wear resistance, with a reduced friction coefficient at room temperature. In addition to PEEK, polyimide (PI) and polyetherimide (PEI) can also be regarded as high-performance polymers for tribological applications under room and elevated temperatures when properly

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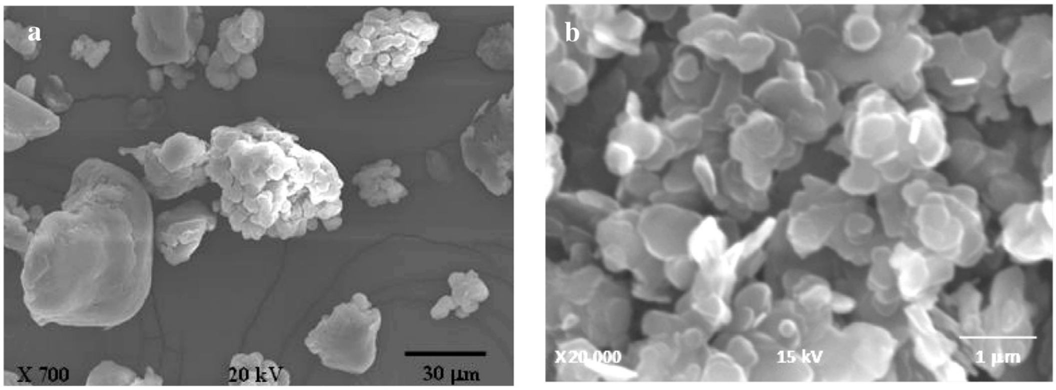

Fig. 1. Powder morphology of PEEK and h-BN powders: (a) PEEK and (b) 0.5 µm particle size of h-BN.

blended with reinforcing additives [12,13]. Chang et al. [12] improved the tribological properties of PEI loaded with short carbon fibers (SCF), graphite flakes, and TiO_2 and ZnS particles under sliding wear testing at room and elevated temperatures. It was found that SCF and graphite could greatly increase the wear resistance and load-carrying capacity, whereas TiO_2 and ZnS particles reduced friction with increasing temperature as a result of changing particle movement from sliding to rolling patterns. Dong et al. [13] found that carbon fibers (CF) could decrease the specific wear rate, with an increase in friction coefficient, of polyimide (PI) at low temperatures (room temperature to 140 °C) and could greatly improve the wear resistance and friction coefficient at high temperatures (180–260 °C) due to the transfer films and graphitization promotion of CF additive. Therefore, PEEK, PEI and PI composites show great promise for tribological applications, with excellent self-lubricating and anti-wear properties at elevated temperatures.

A review of recent literature found that studies on the addition of h-BN in polymers for improving their tribological applications have been very rare; moreover, no published works are available on the tribological properties of h-BN/PEEK composites tested at elevated temperatures. Therefore, the present work aimed to investigate the tribological performance of PEEK at very high testing temperatures (referred to as the service temperature of PEEK products during use) of up to 300 °C, and with various contents of h-BN powder as a reinforcing additive. Only a limited amount of information on these issues has been found in the literature, since h-BN is usually used for metal-based composites in processes such as metalworking and for sealing materials in aircraft engines, and the tribological data for PEEK are mostly available for temperatures below 200 °C [10].

2. Experimental

2.1. Sample preparation

PEEK powder (150PF grade, size distribution 0.2 to 200 µm and average size 48 µm) from Victrex (Lancashire, UK) and h-BN powder (average particle size of 0.5 µm) from M K Impex (Mississauga, Ontario, Canada) were used as raw materials. The morphologies of h-BN and PEEK powders are shown in Fig. 1a and b, respectively. The PEEK powder was rounded in shape while the h-BN particles were flakey in shape. PEEK was mixed with different loadings of h-BN (2, 4, 6 and 8 wt%) in ethanol solvent under an ultrasonic bath at a frequency of 50 Hz for 15 min. As-mixed composite particles were dried at 80 °C in an oven for 6 h. The h-BN/PEEK composites were sprayed on a low-carbon steel substrate, 25.4 mm in diameter and 5 mm in thickness, by flame spray process (DJ 1400; Sulzer Metco, Winterthur, Switzerland). The coating thickness was about 250 µm. The spraying parameters used are described in our previous report [11]. Fig. 2 shows the cross-sections of the h-BN/PEEK composite coating for low (Fig. 2a) and high (Fig. 2b) magnifications. It was found that the h-BN particles were well-distributed within the PEEK coating. In order to ensure the same amount of h-BN in PEEK after the coating process, the amount of h-BN after the calcination of h-BN/PEEK composite coating was measured and compared with the added h-BN before the coating process.

2.2. Thermal and structural stability and hardness of PEEK and h-BN/PEEK composites

The thermal and structural stability of PEEK and h-BN/PEEK composite coatings was investigated using various techniques, i.e. differential

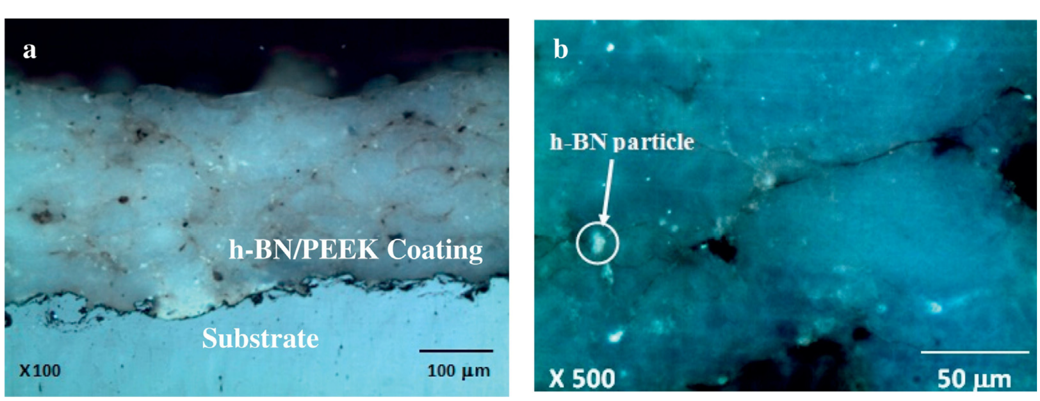

Fig. 2. Cross-sections of 8 wt% h-BN/PEEK composite coating: (a) low (×100) magnification and (b) high (×500) magnification.