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Design and development of high performance tribo-composites based on synergism in two solid lubricants

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ABSTRACT

The paper presents on the synergistic effect of two solid lubricants viz. thermo-graphite (TG) and hexa boron nitride (hBN – white graphite) in the composites when performance was evaluated in adhesive (against smooth mild steel disc) and in abrasive (against SiC paper) wear modes. The basic composition of matrix PEK (polyether ketone) (50%) and short glass fibers (30%) was kept constant and composites were designed with increasing amount of hBN (0, 5, 10, 15 and 20%) with simultaneous decrease of TG (20, 15, 10, 5 and 0). The composites were characterized for mechanical and tribological properties (in adhesive and abrasive wear modes). It was observed that the composites showed very good tribo-potential (very low wear rate and low friction) in adhesive wear mode. However, any of the SLs did not show great potential when included in isolation. Both showed synergism when existed in the composite in combination. The optimum amount was wear mode specific. For adhesive wear mode 15% TG and 5% hBN worked best while for abrasive wear mode 10% of each worked best. Overall TG proved better choice than hBN. Natural graphite proved superior to TG in adhesive wear mode, while trend was opposite for abrasive wear mode. The Lancaster–Ratner factor was observed to be responsible for controlling wear behavior.

1. Introduction

A family of Poly aryl ether ketones (PAEKs) consists of members such as PEK (poly ether ketone), PEEK (poly ether ether ketone), PEKK (poly ether ketone ketone), PEEKK (poly ether ether ketone ketone) and PEKEKK (poly ether ketone ether ketone ketone), which differ in a ratio of ketone to ether, which mainly affects glass transition temperature (T_g), melting point (Tm), thermal stability and processability of the polymers as shown in Table 1 [1,2]. Higher amount of ketone group results in rigidity of chain and hence higher T_g and Tm. These semi-crystalline aromatic thermoplastic polymers have been the most sought engineering polymers in the recent decades since they exhibit special features such as; high mechanical strength and its retention even at elevated temperatures to a significant level, very good resistance to chemicals and radiation, abrasion and wear; low moisture absorption, good impact strength, low tendency to creep, apart from good tribological properties (generally in the composite form) etc. [1,2]. Amongst these, PEEK is the most explored polymer for developing tribo-composites [3–9] as compared to others [10–17]. Recently commercialized Poly aryl ether ketone (PAEK) though has superior property profile to PEEK, very few papers are available on exploration of its tribo-potential in a composite form [18–27]. Gan et al. [20] studied tribology of on mica filled PAEK composites, with a theme to investigate effect of treatment of mica particles. In a recent review article by Pascual et al. [28] a lot is reported on nano-composites of PAEK, but not on tribological investigations. For efficient tribo-composites, however, reinforcement in a polymer with various fibers along with right kind of lubricants in right combination and in right amount is necessary. In our recent work [21] while studying comparative aspects of PEEK and PAEK, it was reported that both exhibited high μ (0.4–0.45) but low specific wear rate ($K_0 \approx 10^{-14}$ m^3/Nm). PAEK was slightly superior to PEEK in severe operating conditions. When PAEK was reinforced with either short CF (10%) or short GF (30%) and solid lubricated with various combinations of two solid lubricants (SLs) viz. PTFE, hBN

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Table 1
Variation in Tm, and T_g with the ether–ketone relation [2].

Ether/Ketone ratio	Ketone/Ether ratio	Tm (^{0}C)	T_g (^{0}C)	polymer
0.5	2.5	390	190	PEKK
0.75	1.5	375	175	PEKEKK
1	1	365	165	PEK
1	1	360	160	PEEKK
1.5	0.75	345	145	PEEKEK
2	0.5	335	135	PEEK
3	0.3	320	118	PEEEK

and natural graphite, excellent tribo-potential was observed ($K_0 \approx 1–2 \times 10^{-16}$ m^3/Nm and $\mu \approx 0.04$). In successive work [24] on systematic efforts on only one SL viz. hBN (10%) in five different sizes including nano-size in PAEK reinforced with short CF (10%), it was reported that inclusion of CF reduced the wear rate drastically. However, inclusion of hBN affected it adversely, although friction reduced significantly. This indicated that only one SL (hBN) was not adequate for efficient tribo-composites. Hence, it was thought of using combination of two SLs (viz. graphite and hBN) in different proportions and to investigate if any synergism exists [30]. Since thermo-graphite (TG) is recently commercialized graphite with higher conductivity, it was selected as a lubricant in combination with hBN [29]. The tribo-investigations of these composites with increasing amount of hBN (0, 5, 10, 15 and 20%) along with decreasing amount of TG (20, 15, 10, 5 and 0%) are reported in this paper.

2. Experimental details

2.1. Selection of polymer, fibers and solid lubricants and development of composites

A series of composites was designed based on Polyaryletherketone (PAEK) as a matrix (50% by wt), short glass fibers (GF) (30% by wt.) as a reinforcement and combination of two graphites viz. white graphite (hBN) and thermo-graphite (TG) in various amounts (total 20% by wt.) as solid lubricants. One more special composite was developed to investigate the comparative potential of TG and natural graphite (NG). This composite contained 10% NG and 10% hBN so that it can be compared with a composite containing 10% TG and 10% hBN.

2.1.1. Selection of a polymer

Poly aryl ether ketone (PAEK) under trade name G-PAEK 1200P was supplied by Gharda Chemicals Limited, Mumbai, in powder form. The specifications are shown in Table 2.

2.1.2. Selection of fibers

Short glass fibers (GF) with average diameter of 10–11 μm and length of 3–4 mm were procured from Nippon Electric Glass (Malaysia). Fig. 1a shows the SEM micrograph of a fiber.

2.1.3. Selection of solid lubricants

Hexa boron nitride (hBN) particles of (size range 3–15 μm) under the trade name PW grade were supplied by Zibo Jonye Ceramic Technologies Co., Ltd, China. The particles have platy crystal structure having average particle size distribution between 3 and 15 μm. SEM micrograph of a particle is shown in Fig 1b.

A recently commercialized Thermo-graphite (Timrex Graphite C-therm-011) was supplied by Imerys, Switzerland and SEM micrograph is shown in Fig 1c.

Table 3 assembles the designations and details of the developed composites with constant amount of parent composition (50% of PAEK and 30% short GF).

2.2. Development of composites

The composites were manufactured at Gharda Chemicals LTD, Mumbai. The compounding of GF/TG/hBN filled PAEK reinforced with GF was done in a twin-screw-extruder. Homogeneous mixing of powdery ingredients before extrusion is necessary for developing a good composite. Employing ultrasonic sound energy (probe-sonication) to de-agglomerate nano-particles is a standard accepted method. In our earlier work [23], however, same technique was used for both nano and micron sized particles to mix with the matrix particles more efficiently. It was proved that employing probe sonication method in liquid medium for uniform dispersion of powders (filler and matrix) was beneficial from the tribo-performance point of view but not from strength point of view. On the contrary, other method of mechanical mixing in high speed mixer led to higher strength but lower tribo-performance. Hence, in this paper probe sonication method was selected for homogenization of powdery fillers with resin particles (all micrometer sizes) in liquid medium.

Chrom Tech Probe Sonicator was used for dispersing the particles of SLs and PAEK in a suspension form using acetone as a

Table 2
Properties of thermoplastic Poly aryl-ether ketone (PAEK) [23,24].

Properties	PAEK
Density at 23 °C in g/cm^3	1.30
Crystallinity (%)	40
Glass transition temperature (T_g) in °C	152–154
Melting temperature (Tm) in °C	370–372
Processing temp. (°C)	400
Tensile strength (MPa)	105
Tensile modulus (GPa)	4.2
Tensile elongation (%)	10–15
Flexural strength (MPa)	185–190
Flexural modulus (GPa)	4.1
Flexural elongation (%)	10–15
Impact strength (J/M)	55
Maximum service temp. (°C)	280
Heat distortion temp. HDT (°C)	167