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Optimization of weave of carbon fabric for best combination of strength and tribo-performance of polyetherimide composites in adhesive wear mode

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Abstract

Studies are focused on the composites using carbon fabric (CF) as a reinforcement and high performance thermoplastic polyetherimide (PEI) as a matrix. Based on impregnation technique three composites viz. P, T and S were fabricated using three different weaves viz. plain (P′), twill (T′) and satin 4H (S′), respectively, keeping the fabric content constant (55% by vol.). Apart from evaluating physical and mechanical properties of these composites, friction and wear performance in dry adhesive wear mode was investigated on a pin-on-disc machine under various loads at room temperature as well as at high temperature (90 °C) against mild steel disc. It was observed that the CF reinforcement proved significantly beneficial for enhancing strength and modulus properties. These properties of the composites followed the order; $T \gg S > P$ while friction and wear performance followed an order; $T > P > S$. Thus, twill weave proved to be the most suitable for best possible combination of strength, modulus and tribo-performance. SEM studies on worn pin surfaces proved helpful in understanding wear mechanisms.

Keywords: Carbon fabric reinforced composites; BD composites; Plain, twill and satin weave; Polyetherimide BD composites; Tribology of composites

1. Introduction

Fabric/bidirectional (BD) reinforcement shows excellent promise for developing polymer matrix composites (PMCs) because of the multiple advantages. Fabric reinforced polymer composites have very good mechanical strength properties in both longitudinal as well as transverse directions. Fabrics are easy to handle while compression molding of the composite. The unique advantage of fabrics as a reinforcement lies in their ability to drape or conform to curved surfaces without wrinkling. Fabrics of carbon (CF), graphite (GrF), glass (GF), aramid (AF), etc. are most commonly used for developing PMCs that have immense potential in tribological applications in numerous industries especially in aircraft industry [1–3]. Among these, CF not only offers maximum extent of strength enhancement, but also increases the thermal conductivity which is very important from tribological point of view. The rapid dissipation of frictional heat produced at the asperity contacts protects the matrix effectively from degradation and helps in the retention of all performance properties considerably. Furthermore, in general, carbon fibers help in imparting additional lubricity because of layer-lattice structure [4]. In spite of these facts, available literature on the tribology of BD composites [5] reveals that approximately only 30% literature pertains to the carbon/graphite fabric reinforced composites. Most of these studies are focused on the composites based on thermoset resins and pertain to the influence of different fabrics such as CF, GF or AF on wear performance. Papers published on the tribo-composites based on thermoplastic polymers such as Polyetheretherketone (PEEK) reinforced with CF, GF and AF in adhesive [6,13,14], abrasive and fretting-fatigue wear modes on the other hand are very few [6–14].

The multiple functions of the matrix include stabilizing the fiber in compression (providing lateral support), translating the fiber properties into the laminate, minimizing damage due to impact by exhibiting plastic deformation, and providing out-of plane properties to the laminate. High performance thermoplastics such as PEEK, polyethersulphone (PES), polyetherimide

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Table 1a
Characteristic properties of various weaves of fabric [5]

Property	P′ (plain)	T′ (twill)	S′ (satin)
Stability	Good	Acceptable	Poor
Drape[a]	Poor	Good	Very good
Porosity	Acceptable	Good	Very good
Smoothness	Poor	Acceptable	Very good
Symmetrical	Very good	Acceptable	Very poor
Rigidity	Highest	Higher	High

[a] The ability of a fabric to conform to a complex surface.

Table 1b
Properties of three weaves of carbon fabric evaluated in the laboratory [5]

Carbon fabric	P′ (plain)	T′ (twill)	S′ (satin 4H)
Density (kg/m^3)	1850	1850	1850
Area (kg/m^2)	1960	1980	1930
Tow[a]	3K	3K	3K
Tex	20	22	19
Denier	185	198	171
Crimp (%)	0.64	0.70	0.30
Count	28	26	31
Warp/inch[b]	12	16	14
Weft/inch[b]	12	16	14
Thickness (m)	0.0034	0.0034	0.0036
Bending length (m)	0.072	0.059	0.05
Tensile strength (MPa)	0.3	0.147	0.12
Elongation (%)	1.25	1.85	1.52

[a] Supplier's data.
[b] It is defined as the number of fibers per square inch of the fabric. It is measured by using a lens. Through the lens (area 1 cm^2) the warp or weft fibers are counted and said to be warp/inch and weft/inch.

(PEI), etc. nowadays have become the most favored matrices because of high thermal stability, their easy processablity, recyclability, unlimited shelf life, better strength properties, resistance to fatigue, cracking, etc. In this scenario, it was thought worthwhile to develop composites of carbon fabric (CF) and PEI and explore their potential in tribological applications. PEI is known to have very good combination of performance properties such as high strength (tensile strength 105 MPa, flexural strength 150 MPa) and modulus (tensile modulus 3 GPa and flexural modulus 3.3 GPa), thermal ($T_g \sim 215\,^\circ$C, heat distortion temperature $\sim$200 °C and melting point 380–390 °C), which renders it a most promising thermoplastic matrix to develop tribo-composites. Initial studies were carried out to examine their tribological performance in fretting, abrasive and erosive wear modes [7–11]. However, tribological evaluation in adhesive wear mode assumes significance in view of applications such as bearings, slides, bushes, etc. in un-lubricated conditions. In the case of BD composites, parameters such as amount and weave of CF, fiber–matrix adhesion, type of resin, orientation of fabric with respect to loading direction, etc. are critical to the performance of composites. Amongst all these parameters, weave of fabric is crucial in controlling the properties of the composites and components. The characteristics of weaves form a strong basis for their selection as a reinforcement as seen in Table 1a because of the particular arrangement of fibers in each weave. Since various properties of weave as shown in Table 1a affect mechanical properties of the composites, it is expected that tribological properties will also be influenced. Designing of a composite with optimized properties depends on various parameters of weave. For example, if satin weave is selected for fabricating composite, which will be the most suitable for complex structure because of its best drape, its role on mechanical and tribological properties, however, has to be investigated. The influence of weave can be highlighted only if the composites contain same amount of resin. Such studies, however, are not available in the literature. Hence, this subject was taken up in this research work and results on adhesive wear performance are reported in subsequent sections.

2. Experimental

2.1. Fabrication of composites

GE plastic USA supplied the PEI material (ULTEM 1000) in a granular form. The carbon fabric used as reinforcement was procured from fiber Glast Ltd. USA. Three types of weave of carbon fabric (properties studied in the laboratory and are given in Table 1b) viz. P′ (plain weave), T′ (twill weave) and S′ (satin 4H) (Fig. 1) were selected to study the influence of weave on the strength properties and adhesive wear behavior. These composites were prepared by an impregnation technique followed by compression molding. The plies (280 mm × 260 mm) were cut from the carbon fabric roll and the open strands from all the four sides were sealed with a PTFE coated glass fabric tape to avoid the fiber misalignment. Dichloromethane was used as a solvent to prepare the solution of PEI (25 wt.-wt.%). These plies were immersed for 12 h individually in the containers filled with viscous solution of PEI. The container was sealed to avoid evaporation of solvent, which was required for wetting of fiber strands with the PEI solution. The plies were taken out carefully to avoid

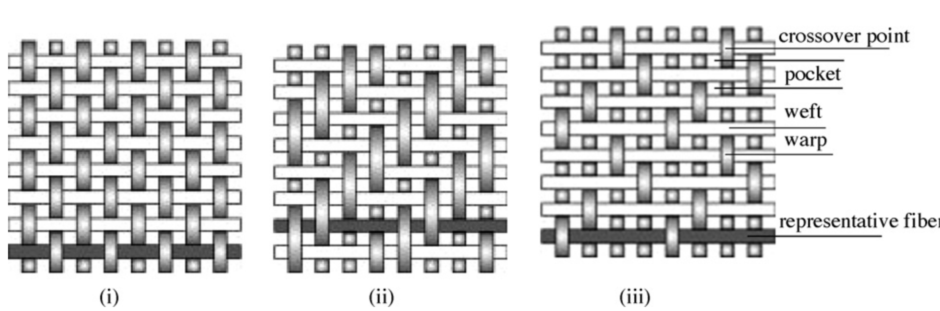

Fig. 1. Schematic showing different weave patterns of (i) plain, (ii) twill and (iii) satin (4H) (blank represent warp while shaded represents weft).