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WEAVE OF POLYETHERIMIDE WITH CARBON FABRIC COMPOSITES IN ADHESIVE WEAR

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Abstract— **Bi-directionally (BD) reinforced composites enjoy the combination of benefits of best possible enhancement in mechanical properties in two directions, enhanced tribo-performance, ease in processing, etc. Polyetherimide (PEI) is a promising specialty thermoplastic polymer with very good mechanical and thermal properties. 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.). Polyacrylonitrile (PAN) based high strength carbon fabric (plain weave) reinforced polyetherimide (PEI) composites were fabricated using impregnation technique by selecting 55 vol.% contents of carbon fabric. These bidirectional (BD) composites were evaluated for their tribological behavior in adhesive wear mode. Tests were conducted at various operating parameters such as load, velocity and orientation of fabric with respect to the sliding plane. Wear mechanism studies by SEM supported the observed wear performance of composites.**

Keywords: Carbon fabric reinforced composites, BD composites, Polyetherimide BD composites, Tribology of composites, Dry wear and friction of composites.

I. INTRODUCTION

Fabric/textile reinforced polymer composites exhibit very good mechanical strength properties in both longitudinal as well as transverse directions. Fabrics are easy to handle while compression molding of the composite as compared to non-woven or continuous fibers. The unique advantage of fabrics as a reinforcement lies in their ability to drape or conform to curved surfaces without wrinkling. In case of polymer matrix composites (PMCs), carbon, graphite, glass, Aramid fabrics, etc., are the most commonly used fabrics that have immense potential in tribo-applications in automotive and aircraft industry as well [1–3]. Carbon fabric (CF) not only offers maximum extent of strength enhancement, it also increases the thermal conductivity of the composite which is very important from tribo-point of view. The rapid dissipation of frictional heat produced at the asperity contacts protects the matrix from excessive degradation and helps in the retention of performance properties to a great extent. Furthermore, in general, carbon fibers help in imparting additional lubricity because of layer lattice structure of graphite, which is a building unit of carbon fiber [4]. 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 [1,2,4]. 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]. Polyetherimide (PEI) is a high performance, high temperature (Tm ~380–400 ◦C) versatile polymer that possesses good tribological properties. PEI based composites have shown even better strength and tribological properties in various wear modes. Hence, in order to explore the potential of such composites, a series of CF-PEI composites were developed in the laboratory with varying contents of CF, weave and processing techniques. These composites were evaluated for strength and tribo-performance in various wear modes such as fretting [9, 17], abrasive [10, 18], erosive [11, 19] and adhesive

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[20].However, the influence of contents of CF on triboperformance in adhesive wear was not reported which forms the objective of this paper. The results on this aspect are reported in this paper.

II. EXPERIMENTAL

2.1. Fabrication of composites

The PEI material (ULTEM 1000) in a granular form was supplied by GE plastics USA. The three types of weaves of carbon fabric (PAN based-high strength), viz. P (plain weave), T (twill weave) and S (satin 4-H) (Fig. 1) were procured from Fibre Glast Ltd., USA. The properties of fabrics were studied in the laboratory. These composites were prepared by an impregnation technique followed by compression molding. The plies (280mm×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 the disturbance in weave and followed by drying in oven for 2 h at 100 ◦C in a stretched condition. These 20 prepregs were then stacked in the mould carefully to avoid misalignment. A mould release agent, PTFE coated glass fabric was placed on the top and bottom of stacked prepregs. The mould was then heated so that a temperature of 385–390 ◦C was attained within 2 h. The prepregs were then compression molded at this temperature at an applied pressure of 7.35MPa. During the total compression time of 20 min two intermittent breathings (each of 2 s) were applied to expel the residual solvent if any. The composites were allowed to cool in ambience under same pressure (7.35MPa). It was then cut with the help of diamond cutter as per requirements.

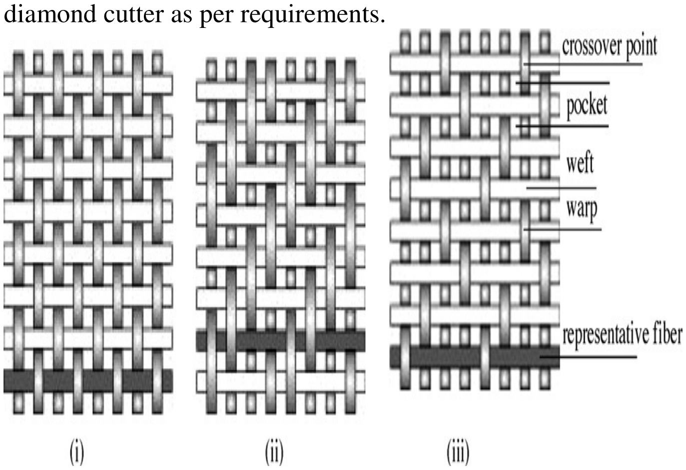

Fig:1. Schematic showing different weave patterns: (i) plain, (ii) twill and (iii) satin (4-H)

Table 1: General properties of various weaves (www.netcomposites.com) of fabric

Property	Plain	Twill	Satin
Stability	Good	Acceptable	Poor
Drape	Poor	Good	Excellent
Porosity	Acceptable	Good	Excellent
Smoothness	Poor	Acceptable	Excellent
Balance	Good	Good	Poor
Symmetrical	Excellent	Acceptable	Very poor
Crimp	Poor	Acceptable	Excellent

2.2. Characterization of the composites

The CF-PEI composites containing plain, twill and satin 4H weave of CF (55 vol. % and 65 wt. %) and designated as P, T and S, respectively were characterized for various properties as per standards (Table 2). Their composition was determined using Soxhlett apparatus and dichloromethane as solvent by boiling for 36 h at 40 ˚C.

Table 2: Details of the composition and properties of fabricated composites[20]

Composites	PEIa	P	T	S
Density(kg/m3) (ASTM D 792)	1270	1550	1530	1540
Tensile strength (MPa) ASTM 6	105	535	888	575
Tensile modulus (GPa) ASTM 638	03	73	106	76
Elongation at break (%) (ASTM 638)	60	0.54	0.08	0.32
Toughness (MPa) (ASTM 638)	–	3.8	2.2	2.8
Flexural strength (MPa) (ASTM 790)	150	589	51	832
Flexural modulus (GPa) (ASTM 790)	3.3	40	54	46
Inter laminar shear strength (MPa) (ASTM 2344)	–	49	66	63

Properties of PEI as per supplier's data.

2.3. Adhesive wear studies

In case of sliding against smooth metallic surface generally dominant wear mode is adhesive wear. Studies in multi-pass and dry condition were conducted on a single pin-on-disc machine in which pin of composite slid against rotating disc of mild steel. The details of this machine fabricated specially for studying composites in severe operating conditions are discussed elsewhere [14]. Prior to the experiment, polymer pin (10mm×10mm×3–4 mm) was slide against a rough disc of mild steel for uniform contact. This disc was then replaced with the experimental disc with *R*a values in the range 0.1–0.2μm. The fabric in the composite was parallel to the sliding plane and warp fibers were parallel to the sliding direction unless specified.
The specific wear rate was calculated using the equation,
$K0\ (m^3/Nm) = \Delta m/\rho L d$
where Δm is the weight loss in kg, ρ the density in kg/m3, L the load in N and d the sliding distance in m.The operating

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parameters were: velocity, 1 m/s and variable load (150, 170, 190 N); sliding time, 2 h and sliding distance, 7.3 km.

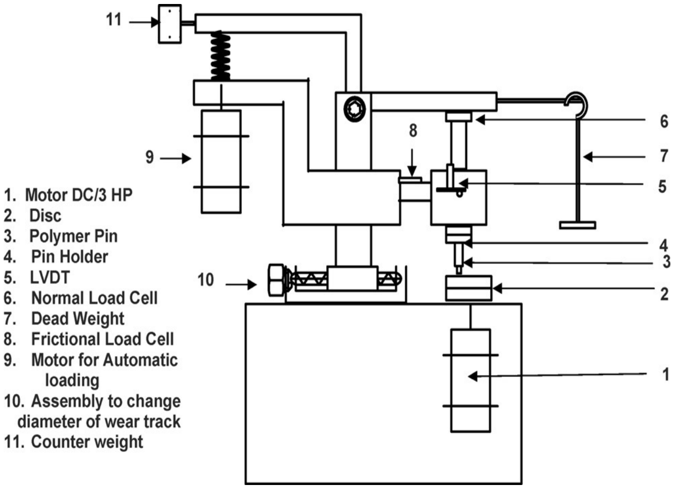

Fig. 2. Schematic showing the pin on disc machine.

III. Results and Discussion

Histograms in Figs. 3 and 4 show the coefficient of friction (μ) and specific wear rates (*K*o) of the composites under various loads in adhesive wear. As seen from Table 2, significant enhancement in all the strength properties of PEI except elongation was observed due to CF reinforcement. The performance of the composites was in the order: *C*T >*CS* >*C*P for all properties except toughness where the order was reverse. Twill weave proved most efficient in imparting highest strength properties to the composites as compared to other weaves.

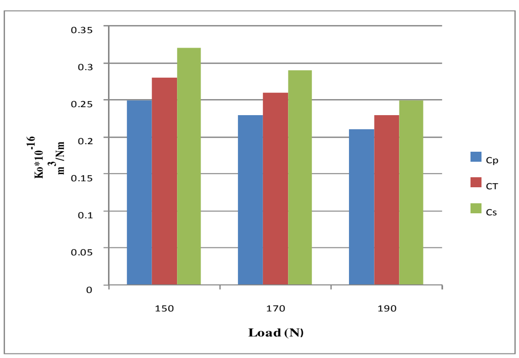

Fig: 3. Friction coefficient under various loads for composites in adhesive wear

As seen from Figs. 3 and 4, the friction performance and specific wear rate (*K*o) of the composites under selected loads showed the following trends: *CS* > *C*P > *C*T .*C*T showed *K*o in the range 10^{-16} m^3/Nm at 150 N. With increase in load, specific wear rate increased appreciably which is in tune with the general observation in case of fiber reinforced composites in the literature. When load increases, extent of frictional heat apart from mechanical stresses also increases which lead to increase in the extent of fiber breakage (micro-cracking, micro-cutting and pulverization of fibers followed by peeling off or pulling out of fibrous debris) that increases disproportionately leading to increase in specific wear rate (wear rate per unit load). This was observed in SEM studies of the composites.

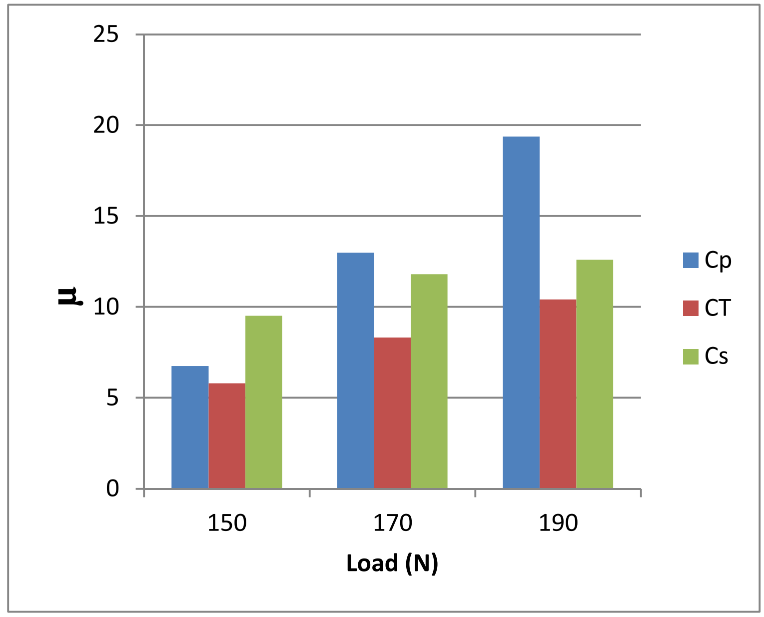

Fig: 4. Specific wear rate (*K*o) under various loads for selected composites in adhesive wear mode

SEM

Scanning electron micrographs (SEM) of worn surfaces are collected in Figs. 5–7.

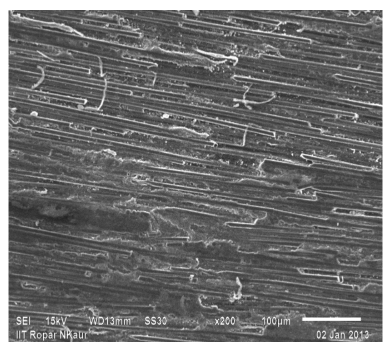

Fig: 5. Scanning electron micrographs of worn surface speed 1m/s & load 150 N

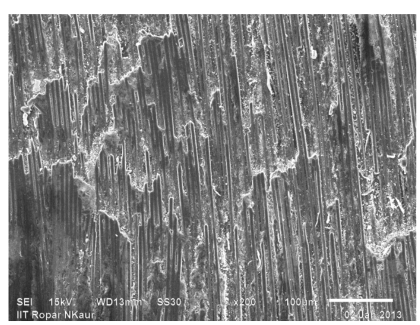

Fig: 6. Scanning electron micrographs of worn surface speed 1m/s & load 170 N

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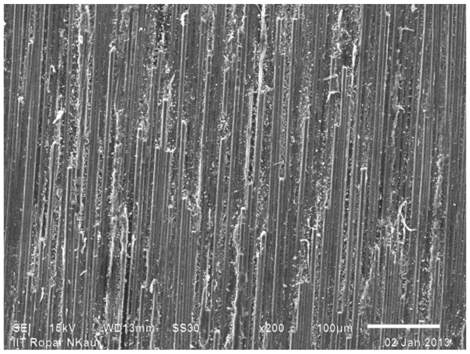

Fig: 7. Scanning electron micrographs of worn surface speed 1m/s & load 170 N

IV. CONCLUSIONS

Based on the studies on three composites of PEI containing 55 vol.% of carbon fabric of three different weaves, viz. plain, twill and satin, it was concluded that the weave of fabric influenced both strength and tribological performance significantly. The selected operating parameter, viz. load affected wears performance substantially. The specific wear rate increased with load in adhesive wear mode. The Performance in sliding wear mode against smooth metal surface: *C*T >*C*P >*C*S.

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