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Carbon fabric reinforced polyetherimide composites: Influence of weave of fabric and processing parameters on performance properties and erosive wear

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Abstract

Woven carbon fabric reinforced (55 vol.%) polyetherimide (PEI) composites were fabricated using three types of weaves viz. plain (P), twill (T), and satin-4 H (S) by impregnation technique. Three more similar composites were fabricated with film technique to study the influence of both, weave of fabric and processing technique on the performance properties of the total seven composites including neat PEI. The composites were evaluated for physical and mechanical properties along with erosion wear behavior studied in identical conditions. In almost all properties viz. tensile strength (TS), modulus (TM), elongation to break (*e*), flexural strength and modulus, interlaminar shear strength (ILSS), etc., film technique proved far inferior to impregnation technique because of improper wetting of fiber strands, as evidenced by SEM studies. CF reinforcement enhanced all the properties of PEI manifold except elongation to break. None of the weaves proved best performer in all the mechanical properties. In case of erosive wear studies, plain weave composite proved slightly better than satin weave composite. Composite with twill weave proved poorest performer. In case of film technique, however, trends were different where plain weave composite proved poorest and satin proved best. Efforts were made to correlate various strength properties with wear resistance W_R. The factor (elongation × toughness) showed fairly good correlation with W_R. SEM studies were conducted to understand wear mechanisms.

Keywords: Erosive wear; Carbon fabric reinforced polyetherimide composites; Plain; Twill and satin weave; Fiber reinforced composites; Mechanical properties of composite

1. Introduction

Fabric reinforced polymer composites exhibit bi-directional (BD) strength properties that make them a favored class of materials for a wide range of applications where the uni-directionally (UD) reinforced fiber composites fail to deliver the desired results. Another special feature of such reinforcement is their ability to drape or conform to curved surfaces without wrinkling. By combinations of different fibers in weft and warp or employing different weaves, composites of tailored properties can be fabricated. Carbon fiber (CF) reinforced composites are used in aircraft industries since more than five decades and this was initiated from trim tabs, rudders, spoilers, doors, etc. [1]. BD composites in aircraft industries were dominated by CF–epoxy system till recently CF–polyetheretherketone (PEEK) (a thermoplastic; TP) proved more advantageous than epoxy (thermoset) CF system in terms of severity of damage during impact of low energy by particles apart from their infinite shelf life. Thus, TPs are today's most favored matrix. Such composites compete with Al–Cu alloys and Al–Li alloys in the aircraft industry [1]. However, hardly anything is reported on other TPs-specialty polymers in this regard.

In applications such as radomes, aircraft structures, pipelines, etc., where erosive wear is highly dominating, the engineering material is expected not only to provide high specific strength but also resistance to wear and damage. A lot of papers are available in the literature, which deals with the erosive wear behavior of short and long fiber reinforced polymer composites [2–7]. However, not much is reported on the erosive wear behavior of fabric reinforced polymer composites [3,6]. Few papers available report on the effect of operating parameters like angle of impingement and impact velocity on the erosion

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resistance of glass/epoxy, glass/phenolics, and graphite/epoxy composites. For instance in the case of Aramid and graphite fabric reinforced composite, it has been reported that the latter exhibits lower erosion resistance than the former. The maximum wear rate was observed at an angle of impingement of 90° for graphite composite, indicating brittle-type erosion behavior, while Aramid composite exhibited wear maxima in the range of 34–45°, indicating semi-ductile failure behavior [6]. In a recent paper, authors have reported on the influence of carbon fabric contents in PEI on erosive wear performance with a view to find an optimum amount of fabric for best combination of mechanical properties and erosive wear resistance (W_R) [8]. However, nothing has been reported on the influence of the type of weave pattern on erosion resistance of fabric reinforced composites in which weave of fabric plays a very important role in deciding mechanical properties of composites. Table 1a compiles some features of the three weaves viz. plain, twill and satin that offers a good platform for tailoring of composites for various tribo-applications. In spite of this, not much is reported on this aspect except in the case of abrasive wear performance of the same composites by the authors [9]. Moreover, no paper could be available that report on the influence of processing technique on wear behavior. Hence, in this paper carbon fabric polyetherimide composites were fabricated with three different weave patterns of fabric and two different processing techniques. The results on strength properties and performance in erosive wear mode are presented in the subsequent sections.

2. Experimental

2.1. Fabrication of composites

GE plastics USA supplied the PEI material (ULTEM 1000) in a granular form and sheet form while films of PEI were supplied by Westlake Pvt. Ltd., USA. The carbon fabric used as reinforcement was procured from Fiber Glast Ltd. USA. Carbon fabrics of three different weaves viz. plain weave (P), twill weave (T) and satin weave-4 harness (S) as shown in Fig. 1 were selected. The properties of these fabrics were studied in the laboratory and are compiled in Tables 1a and 1b.

In the case of impregnation technique (I), a fixed concentration of fabric (55 vol.% or 65 wt.%) was selected to develop three composites (IP_{55}, IT_{55} and IS_{55}), while for film technique (F) it was 52 vol.% (FP_{52}, FT_{52} and FS_{52}). In case of I-technique, the plies (280 mm × 260 mm) were cut from the carbon fabric roll

Table 1a
Characteristic properties of various weaves of fabric [12]

Property	Plain	Twill	Satin
Good stability	Good	Acceptable	Poor
Good drape	Poor	Good	Excellent
Low porosity	Acceptable	Good	Excellent
Smoothness	Poor	Acceptable	Excellent
Balance	Good	Good	Poor
Symmetrical	Excellent	Acceptable	Very poor
Low crimp	Poor	Acceptable	Excellent

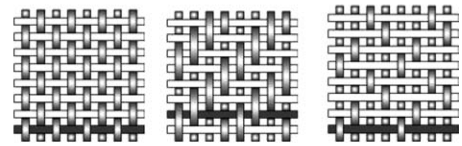

Fig. 1. Schematic showing different weave patterns: (i) plain (one weft over one warp), (ii) twill (two warp over two weft), (iii) satin (4 H) (one warp over three weft).

Table 1b
Properties of three weaves of carbon fabric measured in the laboratory

Carbon fabric	Plain	Twill	Satin (4 H)
Density (g/cm^3)	1.85	1.85	1.85
Area (g/cm^2)	196	198	193
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/in.	12	16	14
Weft/in.	12	16	14
Thickness (cm)	0.34	0.34	0.36
Bending length (cm)	7.2	5.9	5.0
Tensile strength (MPa)	0.3	0.147	0.12
Elongation%	1.25	1.85	1.52

[a] Supplier's data.

and the open strands from all the four sides were sealed with a PTFE coated glass fabric tape to avoid the fiber misalignment. Dichloromethane (CH_2Cl_2) was used as a solvent to prepare the solutions of PEI. These plies were immersed individually in separate containers filled with viscous solution of PEI for 12 h. The containers were properly sealed to avoid evaporation of solvent, which was required for adequate wetting of fiber strands with the PEI solution. The plies were taken out carefully to avoid the misalignment in weave and followed by drying in oven for 2 h at 100 °C in a stretched condition. These prepregs (20, 20, 20, in case of impregnation technique) respectively to attain the desired thickness in the range of 3–3.5 mm) were then stacked in the mould carefully to avoid misalignment. PTFE coated glass fabric was placed on the top and bottom of the stacked prepregs. During compression molding, the mould was heated to attain the temperature in the range of 385–390 °C within 2 h. The prepregs were then compression molded at this temperature at an applied pressure of 7.35 MPa.[1] During the total compression time of 20 min at high temperature four intermittent breathings (each of 2 s) were given to expel the possible residual solvent. During breathings, temperature of the composite dropped by 3 °C, which was regained immediately. It did not have any adverse effect on the viscosity of PEI melt.

The composites were allowed to cool under natural conditions under same pressure 7.35 MPa. The test specimens were cut from the composites with the help of diamond cutter as per required standards for mechanical and tribological testing.

[1] Composites were moulded based on optimization of processing temperature and pressure as reported in our earlier work [10].