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Technical Report

Mechanical and abrasive wear characterization of bidirectional and chopped E-glass fiber reinforced composite materials

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ABSTRACT

Bi-directional and chopped E-glass fiber reinforced epoxy composites are fabricated in five different (15, 20, 25, 30 and 35) wt% in an epoxy resin matrix. The mechanical characterization of these composites is performed. The three body abrasive wear behavior of fabricated composites has been assessed under different operating conditions. Abrasive wear characteristics of these composites are successfully analysed using Taguchi's experimental design scheme and analysis of variance (ANOVA). The results obtained from these experiments are also validated against existing microscopic models of Ratner-Lancaster and Wang. It is observed that quite good linear relationships is held between specific wear rate and reciprocal of ultimate strength and strain at tensile fracture of these composites which is an indicative that the experimental results are in fair agreement with these existing models. Out of all composites fabricated it is found that tensile strength of bi-directional E-glass fiber reinforced composites increases because of interface strength enhancement. Chopped glass fiber reinforced composites are observed to perform better than bi-directional glass fiber reinforced composites under abrasive wear situations. The morphology of worn composite specimens has been examined by scanning electron microscopy (SEM) to understand about dominant wear mechanisms.

1. Introduction

Composites are advanced materials constituting of two or more chemically distinct constituents on a macro-scale, having a distinct interface separating them. One or more discontinuous phases are, therefore, embedded in a continuous phase to form a composite. In most of the situations the discontinuous phase is usually harder and stronger than the continuous phase and is called the *reinforcement*, whereas, the continuous phase is termed as the *matrix*. The matrix material can be metallic, polymeric or can even be ceramic. When the matrix is a polymer, the composite is called polymer matrix composite (PMC). The reinforcing phase can either be fibrous or non-fibrous (particulates) in nature. The fiber reinforced polymers (FRP) consist of fibers of high strength and modulus embedded in or bonded to a matrix with distinct interface between them. In this form, both fibers and matrix retain their physical and chemical identities. In general, fibers are the principal load bearing members while the matrix places them at the desired location and orientation, acts as a load transfer medium between them, and protects them from environmental damages [1].

In past years, because of fairly good strength, low density, and high performance/cost ratios with rapid clean processing, tremendous growth in the developments and applications of fiber reinforced thermo-setting polymer composites such as epoxy, polyester and vinyl ester have been observed. Polymer and their composites are used in variety of industrial applications such as bearing material, rollers, seals, gears, cams, wheels, clutches and transmission belts [2–5]. Therefore, the mechanical and tribological behavior of these materials should be studied systematically.

In the situations where the wear performance in nonlubricated conditions is a key parameter for material selection, polymer composites are used in mechanical components [6,7] and these components are used in various types of wear situations. Among various types of wear, abrasive wear situation occurs in numerous equipments such as vanes and gears, in pumps handling industrial fluids, sewage and abrasive-contaminated water, chute liners abraded by coke, coal and mineral ores; bushes and seals in agricultural and mining equipment, thus have been received increasing attention [8]. Carbon, glass, aramide and graphite fibers are most common fibers used for reinforcement in polymer matrix composites [9–11]. It is evident from the literature that in general, the short fiber reinforcement led to the deterioration in the abrasive wear resistance of the matrix [12] while on the other hand reinforcement of the fabric improved the abrasion resistance of the polymers [13]. That is why the bi-directional fabric reinforcement

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offers a unique solution to the advanced materials in terms of better performance and ease in processing [14]. Three body abrasive wear behavior of polymer composites have been reported by many researchers [15–18]. Stachowiak and Stachowiak [19] while studying the effects of particle characteristics specially shape and hardness on three body abrasive wear of metallic samples, concluded that rounded particles generated round craters and smooth grooves while angular particles produce sharp indents and narrow cutting grooves.

The present work is undertaken for assessing the wear behavior of bi-directional E-glass fiber and chopped E-glass fiber reinforced epoxy composites under abrasive situations. The mechanical characterization of these composites is also performed so as to have an insight about this aspect. An economical and viable experimental strategy based on Taguchi's parameter design has been used to analyse the effect of various parameters and their interactions. This experimental procedure has been successfully applied earlier for solid particle erosion behavior and dry sliding characteristics of polymer–matrix composites [20,21].

2. Experimental details

2.1. Panel preparation

Bi-directional E-glass fiber and chopped E-glass fibers are reinforced separately in epoxy resin to prepare the fiber reinforced composites B_1–B_5 and C_1–C_5. The composition and designation of the composites prepared for this study are listed in Table 1. The fiber material is mixed with Epoxy LY 556 resin in five different percentages (15 wt%, 20 wt%, 25 wt%, 30 wt% and 35 wt%). The fabrication of the composite slabs is done by conventional hand-lay-up technique followed by light compression molding technique. The fibers are mixed thoroughly in the epoxy resin. The low temperature curing epoxy resin and corresponding hardener (HY951) are mixed in a ratio of 10:1 by weight as recommended. The epoxy resin and the hardener are supplied by Ciba Geigy India Ltd. The bidirectional E-glass fiber, chopped E-glass fiber and the epoxy resin possess Young's modulus of 72.5 GPa, 72.5 GPa and 3.42 GPa respectively and a density of 2600 kg m^{-3}, 2500 kg m^{-3} and 1200 kg m^{-3} respectively. Each ply of fiber is of dimension 200×200 mm^2. A wooden mold having dimensions of $210 \times 210 \times 40$ mm^3 is used. A releasing agent (Silicon spray) is used to facilitate easy removal of composites from the mold after curing. The cast of each composite is cured under a load of about 50 kg for 24 h before it is removed from the mold. After this the cast is post cured in the air for another 24 h after removing out of the mold. Specimens of suitable dimensions are cut using a diamond cutter for physical/mechanical characterization and abrasive wear testing. Utmost care has been taken to maintain uniformity and homogeneity of the composites.

Table 1
Designations and detailed compositions of the composites.

Designation	Composition
B1	Epoxy (85 wt%) + bi-directional E-glass fiber (15 wt%)
B2	Epoxy (80 wt%) + bi-directional E-glass fiber (20 wt%)
B3	Epoxy (75 wt%) + bi-directional E-glass fiber (25 wt%)
B4	Epoxy (70 wt%) + bi-directional E-glass fiber (30 wt%)
B5	Epoxy (65 wt%) + bi-directional E-glass fiber (35 wt%)
C1	Epoxy (85 wt%) + chopped E-glass fiber (15 wt%)
C2	Epoxy (80 wt%) + chopped E-glass fiber (20 wt%)
C3	Epoxy (75 wt%) + chopped E-glass fiber (25 wt%)
C4	Epoxy (70 wt%) + chopped E-glass fiber (30 wt%)
C5	Epoxy (65 wt%) + chopped E-glass fiber (35 wt%)

2.2. Abrasive wear test

To evaluate the performance of composites under three body abrasion conditions, wear tests are carried out as per ASTM G 65 [22] using the dry abrasion test rig (TR-50) supplied by DUCOM Ltd. The dry sand/rubber wheel (Dia 228.6 mm, Hardness durometer A-60) abrasion test involves the abrading of test specimen with a grit of controlled size and composition. The abrasive is introduced between test specimen and a rotating wheel with a chlorobutyl rubber tyre. The test specimen is pressed against a rotating wheel at a specified force by means of a lever arm while a controlled flow of grit abrades the test surface. The test duration and force applied by the lever arm is varied. The specimens are weighed before and after the test and loss in mass is recorded. Due to wide difference in material density abrasion are reported on volume loss basis as.

$$W_s = \Delta M / \rho \cdot L \cdot F_N \tag{1}$$

where ΔM is the mass loss in the test duration in grams (gm), ρ is the density of the composite (gm/cm^3), L is the sliding distance (m) and F_N is the normal load (N). The specific wear rate is defined as the volume loss of the specimen per unit sliding distance per unit applied normal load.

2.3. Mechanical characterization

The experimental density of the composites is obtained by the Archimedes principle of weighing small pieces cut from the large composite panel first in air and then in water. Theoretical density of composite is calculated and compared with experimental density in order to calculate void fraction of the composites. Hardness measurement is done using a Rockwell-hardness tester equipped with a steel ball indenter (1/16″) indenter by applying a load of 50 Kgf. The tensile test is performed on flat dog-bone shaped composite specimens as per ASTM D 3039-76 [23] test standards on universal testing machine (UTM) Hounsfield H25KS. The flexural and inter laminar shear strength test is conducted as per ASTM standard D2344-84 [24] using the same UTM. The low velocity instrumented impact tests are carried out on composite specimens. The tests are done as per ASTM D 256 [25] using an impact tester. At the last, the worn surfaces of some selected samples are examined by scanning electron microscope Carl Zeiss NTS GmbH, SUPRA 40VP.

2.4. Experimental design

The Taguchi method is a commonly adopted approach for optimizing design parameters. Taguchi method provides the designer with a systematic and efficient approach for experimentation to determine near optimum settings of design parameters for performance, quality and cost [26–29]. Since experimental procedures are generally expensive and time consuming, the need to satisfy the design objectives with the least number of tests is clearly an important requirement. Exhaustive literature review reveals that parameters viz., RPM, fiber loading, normal load, sliding distance, and abrasive size largely influence the abrasive wear characteristics of polymer composites. Thus, the impact of five parameters are studied using L_{25} (5^6) orthogonal design [30]. The control factors and the parameter settings for wear test (given in Tables 2 and 3) present the selected levels for various control factors. The array chosen in this work is the L_{25} (5^6) which has 25 rows corresponding to the number of tests (24 degrees of freedom) with six columns at five levels, the factors are assigned to the columns.

The plan of the experiments is as follows: the first column is assigned to RPM (A), the second column to Fiber loading (B), the third column to Normal load (C), fourth column to Sliding distance