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ANALYSIS OF MECHANICAL AND TRIBOLOGICAL PROPERTY OF COMPOSITE BANANA FIBER

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Abstract: Solid particle erosion of polymer composites is a complex surface damage process, strongly affected by material properties and operational conditions. The present research work is undertaken to study the development, characterization and erosion wear performance of two different categories of fibers when reinforced in polymers. One of the two fiber is well known synthetic fiber i.e. glass fiber which is commercially used by many industries and the other fiber will be a natural fiber i.e. banana fiber which will be the new attempt in the present investigation. In both the above cases matrix material will remain epoxy.

From the performed experiments it can be seen that a banana fiber can successfully replace the glass fiber as far as wear performance in concerned, as the study indicates that erosion wear performance of banana fiber based composites is better than that of the glass fiber reinforced composites. Banana fiber is also having a very low specific gravity, so their composites show very low density as compared to glass fiber reinforced composites. From other mechanical characterization it can be said that, in strength point of view, banana fiber-epoxy composites are not very much behind its counterparts glass fiber-epoxy composites.

Keywords :- Solid particle, polymer composites, banana fiber reinforced, mechanical properties, glass fiber, glass fiber-epoxy

INTRODUCTION

Background and Motivation

1Apart from various thermal and mechanical applications, composites are often used as engineering as well as structural components functioning in hostile workplaces where they are subjected to different wear situations. Wear is defined as the damage to a solid surface usually involving progressive loss of materials, owing to relative motion between the surface and a contacting substance or substances [1]. It is a material response to the external stimulus and can be mechanical or chemical in nature. The effect of wear on the reliability of industrial components is recognized to be very high.

In view of the wide range of applications of composites as materials for wear related applications, systematic and comprehensive study of mechanical and wear (tribological) behavior of existing and new class of composites becomes important both from scientific as well as commercial angles.

Types of Composite Materials

Broadly, composite materials can be classified into three groups on the basis of matrix material. They are:

a) Metal Matrix Composites (MMC)
b) Ceramic Matrix Composites (CMC)
c) Polymer Matrix Composites (PMC)

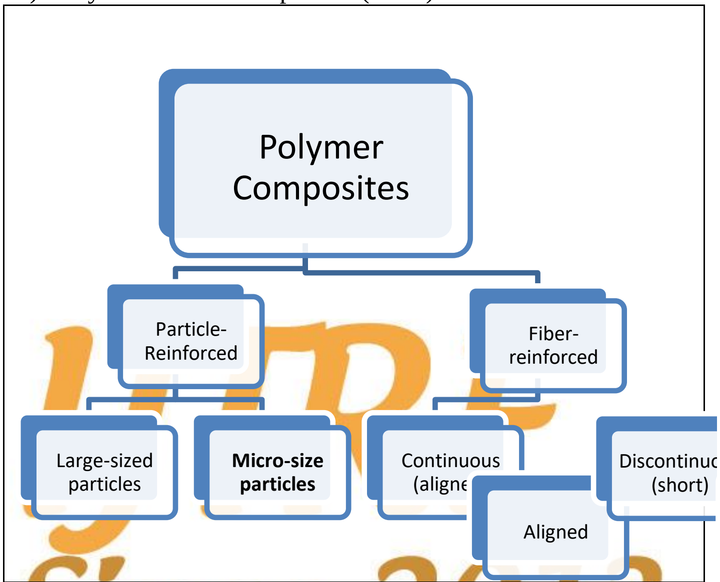

Fig 1.1 Classification of composites based on reinforcement type

Introduction to the Research Topic

The present piece of research is basically an experimental investigation focused on the mechanical and tribological characteristics of two different class of short fiber reinforced polymer composites. It also includes fabrication of the composites and their physical and morphological characterization.

Polymers and their composites form a very important class of tribo- engineering materials and are invariably used in mechanical components, where wear performance in non-lubricated condition is a key parameter for the material selection. Nowadays much attention is devoted towards the study of dry sliding wear and solid particle erosion wear behaviour of polymer composites due to the high potential use of these materials in many mechanical and structural applications. Hence, wear resistance of polymer composites has become an important material property, particularly in selection of alternative materials and therefore the study of wear characteristics of the polymeric composites has become highly relevant. A full understanding of the effects of all system variables on the wear rate is necessary in order to undertake appropriate steps in the design of machine or structural component and in the choice of materials to reduce/control wear.

LITERATURE REVIEW

In the current section, summary of the literature surveyed during the course of the research has been presented. This survey is expected to provide the background information and thus to select the objectives of the present investigation. A treatise on glass fiber and banana fiber reinforced polymer composites has been given illustrating the research findings. The physical behavior, mechanical behavior and wear characteristics of different composites as reported in existing literature have been cited. A note on the present status of utilization of both the fiber is included. This chapter also summarizes the use of glass as well as banana fiber as filler and current research trends.

In short, this treatise embraces various aspects of polymer composites with a special reference to their physical, mechanical and tribological characterization. This chapter includes reviews of available research reports:

- On study of synthetic fiber based polymer composites
- On structure and property of glass fiber
- On study of glass fiber reinforced polymer composites
- On study of natural fiber based polymer composites
- On structure and property of banana fiber
- On banana fiber reinforced in thermoplastic polymer
- On banana fiber reinforced in thermoset polymer

At the end of the chapter, the knowledge gaps in the earlier investigations are presented. On that basis, the objectives of the present research work are also outlined.

On study of synthetic fiber based polymer composites

A great deal of work has been done by many researchers on synthetic fiber based polymer composites. Jawaid and Khalil [5] presented review that deals with the recent development of cellulosic/cellulosic and cellulosic/synthetic fibers based reinforced hybrid composites. They intended to present an outline of main results presented on hybrid composites focusing the attention in terms of processing, mechanical, physical, electrical, thermal and dynamic mechanical properties. Marom et al. [6] focused on the elastic properties of synthetic fiber-reinforced polymer composite materials that pertain to biomedical applications and demonstrates the range of stiffness obtainable through selection of constituents and by choice of angle of reinforcement.

Objectives of the present work

The knowledge gap in the existing literature summarized above has helped to set the objectives of this research work which are outlined as follows:

1. Fabrication of a new class of epoxy based composites reinforced with short glass fiber in different weight fraction using hand lay-up technique as first set of composites.
2. For second set, another epoxy based composites are fabricated with short banana fiber as a reinforcing material.
3. Evaluation of various physical and mechanical characterizations of both sets epoxy composites.
4. Evaluations of erosion wear characterization of all the fabricated composites.
5. Statistical analysis based on Taguchi experimental design for parametric appraisal of erosion wear process for the composites under study.
6. Finally the comparisons of both set of composite are done.

MATERIALS AND METHODS

This chapter describes the materials and methods used for processing and characterizing the composites under investigation. It presents the details of the tests related to the physical, mechanical and tribological characterization of the prepared short fiber reinforced polymer composite specimens.

Matrix Material

Matrix materials are of different types like metals, ceramics and polymers. Polymer matrices are most commonly used because of cost efficiency, ease of fabricating complex parts with less tooling cost and they also have excellent room temperature properties when compared to metals and ceramic matrices. Polymer matrices can be either thermoplastic or thermoset. Thermoset matrices are formed due to an irreversible chemical transformation of the resin into an amorphous cross-linked polymer matrix. Due to huge molecular structures, thermoset resins provide good electrical and thermal insulation. They have low viscosity, which allow proper fiber wet out, excellent thermal stability and better creep resistance followed through Barbero [70].

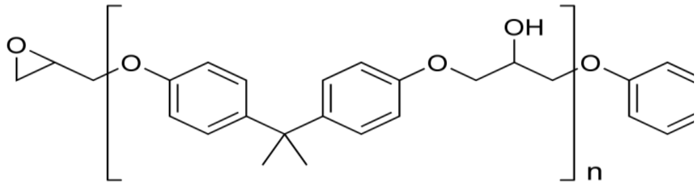

Fig. 3.1: Unmodified epoxy resin chain ('n' denotes number of polymerized unit)

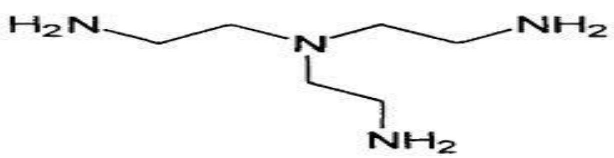

Fig. 3.2: Tri-ethylene-tetramine (hardener used for epoxy matrix)

Fig. 3.3 Epoxy resin and hardener

The most commonly used thermoset resins are epoxy, polyester, vinyl ester and phenolics. Among them, the epoxy resins are being widely used for many advanced composites due to their excellent adhesion to a wide variety of fibers, superior mechanical and electrical properties and good performance at elevated temperatures. In addition to that they have low shrinkage upon curing and good chemical resistance. Due to several advantages over other thermoset polymers as mentioned above, epoxy (LY 556) is chosen as the matrix material for the present research work. It chemically belongs to the 'epoxide' family. Its common name is Bisphenol-A-Diglycidyl-Ether (commonly abbreviated to DGEBA or BADGE) and its molecular chain structure is shown in Figure 3.1. It provides a solvent free room temperature curing system when it is combined with the hardener tri-ethylene-tetramine (TETA) which is an aliphatic primary amine with commercial designation HY 951 (Figure 3.2). The LY 556 epoxy resin (Figure 3.3) and the corresponding hardener HY-951 are procured from Ciba Geigy India Ltd. Table 3.1 provides some of the important properties of epoxy.

Table 3.1 Some important properties of epoxy

Characteristic Property	Inferences
Density	1.1 gm/cc
Compressive strength	90 MPa
Tensile strength	58 MPa
Micro-hardness	0.085 GPa
Thermal conductivity	0.363 W/m-K
Coefficient of Thermal expansion	62.83 ppm /°C

PHYSICAL AND MECHANICAL PROPERTIES OF THE COMPOSITES

Density and Void Fraction

The theoretical and measured densities along with the corresponding volume fraction of voids in the epoxy-glass fiber and epoxy- banana fiber composites are presented in Tables 4.1 and 4.2 respectively. It may be noted that the composite density values calculated theoretically from weight fractions using Eqn. 3.1 are not equal to the experimentally measured values. This difference is a measure of voids and pores present in the composites. It was found that with the increase in glass fiber content in epoxy resin from 0 to 30 wt %, there was a substantial rise in density of the composite by about 12.3 % although there was a simultaneous increase in the void fraction or porosity to 6.58 % (Table 4.1). Similarly, a little rise in composite density by about 3.45 % was observed as the banana fiber content in epoxy increased from 0 to 30 wt %. For the epoxy-banana fiber composite with fiber content of 30 wt%, the volume fraction of voids was estimated to be as 2.31% (Table 4.2).

Table 4.1 Measured and theoretical densities of the composites (Epoxy filled with short glass fiber)

Composites	Measured density (gm/cc)	Theoretical density (gm/cc)	Void fraction (%)
Neat Epoxy (hardened)	1.1	-	-
Epoxy + short glass fiber (5 wt %)	1.119	1.131	1.06
Epoxy + short glass fiber (10 wt %)	1.146	1.165	1.63
Epoxy + short glass fiber (15 wt %)	1.172	1.201	2.41
Epoxy + short glass fiber (20 wt %)	1.195	1.238	3.47
Epoxy + short glass fiber (25 wt %)	1.214	1.279	5.08
Epoxy + short glass fiber (30 wt %)	1.235	1.322	6.58

Table 4.2 Measured and Theoretical densities of the composites (Epoxy filled with short banana fiber)

Composites	Measured density (gm/cc)	Theoretical density (gm/cc)	Void fraction (%)
Neat Epoxy (hardened)	1.1	-	-
Epoxy + short banana fiber (5 wt %)	1.107	1.110	0.27
Epoxy + short banana fiber (10 wt %)	1.114	1.121	0.62
Epoxy + short banana fiber (15 wt %)	1.120	1.131	0.97
Epoxy + short banana fiber (20 wt %)	1.127	1.142	1.31
Epoxy + short banana fiber (25 wt %)	1.133	1.153	1.73
Epoxy + short banana fiber (30 wt %)	1.138	1.165	2.31

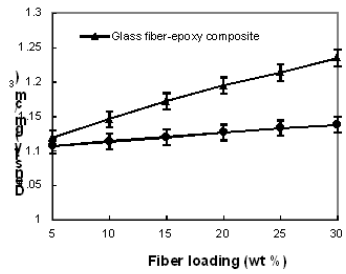

Fig. 4.1 Comparison of experimental densities of both sets of composites

4.1. Micro-hardness

Hardness is considered as one of the most important factors that govern the wear resistance of any material. In the present work, micro-hardness values of the glass fiber-epoxy composites with different weight fraction of filler have been obtained and are compared with those of a similar set of banana fiber-epoxy composites. The test results (Figure 4.2) show that with the presence of short fibers, micro-hardness of the glass fiber-epoxy composites is improved and this improvement is a function of the filler content.

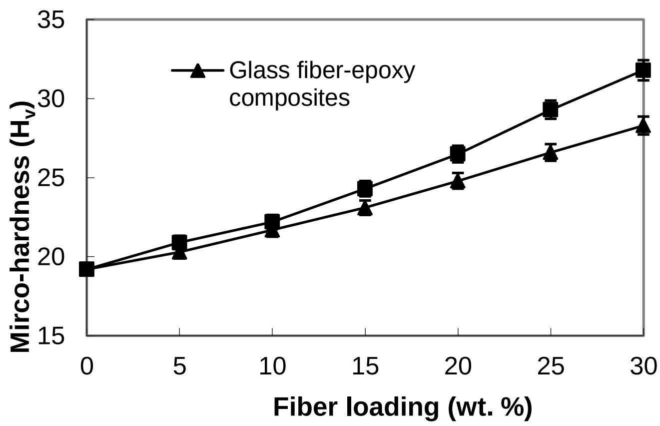

Fig. 4.2 Effect of fiber loading on micro-hardness of epoxy composites

4.2. Tensile properties

It is well known that the strength properties of composites are mainly determined by the fiber content and the fiber strength. So variation in composite strength with different fiber loading is obvious. The variation of tensile strength and tensile modulus of glass fiber-epoxy and banana fiber-epoxy composites with two different fibers are shown in Figure 4.3 and 4.4 respectively.

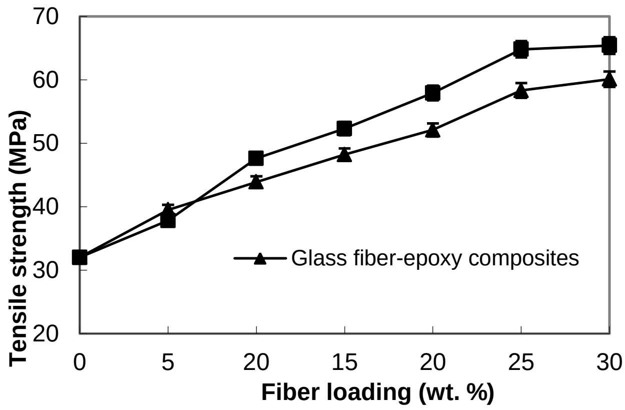

Fig. 4.3 Effect of fiber loading on tensile strength of epoxy composites

Flexural strength

Composite materials used in structures are prone to fail in bending and therefore the development of new composites with improved flexural characteristics is essential. In the present work, the variation of flexural strength of both the glass fiber-epoxy and banana fiber-epoxy composites with different fiber loading is shown in Figure 4.5.

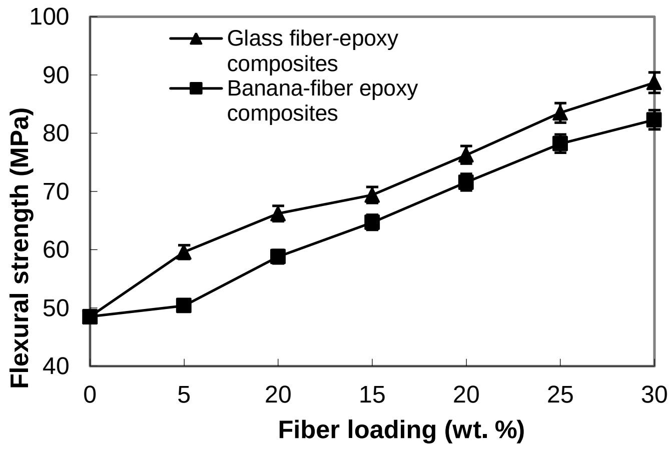

Fig. 4.5 Effect of fiber loading on flexural strength of epoxy composites

4.4. Impact strength

The impact strength of a material is its capacity to absorb and dissipate energies under impact or shock loading. Figure 4.6 presents the measured impact energy values of the various short fibers reinforced composites under this investigation. It is seen from this figure that the impact energies of both sets of composites increase gradually with the fiber content increasing from 0 wt% to 30 wt% .

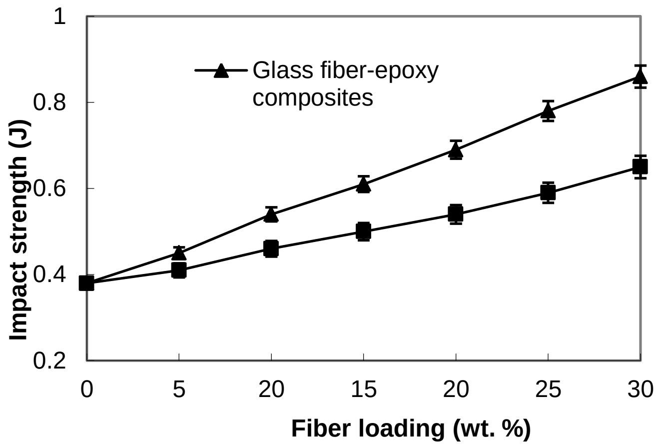

Fig. 4.6 Effect of fiber loading on Impact strength of epoxy composites

TRIBOLOGICAL CHARACTERIZATION OF THE COMPOSITES

Erosion wear analysis of short glass fiber reinforced epoxy composites

This part presents the analysis of erosion response of short glass fiber epoxy composites. The experiments have been carried out using Taguchi experimental design (L27 orthogonal array) given in Table 3.9 and the subsequent analysis of the test results is made using the popular software specifically used for design of experiment applications known as MINITAB 14.

Taguchi experimental analysis

The results of erosion experiments carried out according to the predetermined design on glass fiber-epoxy composites are presented in Table 5.1. This table provides the experimental erosion rate along with the signal-to-noise ratio for each individual test run. Each value of the erosion rate is the average of three replications.

Table 5.1: Erosion wear test result with corresponding S/N ratios using Taguchi method under different test conditions as per L27 orthogonal array for glass fiber epoxy composites

Test run	A (m/s)	B (%)	C (°C)	D (Degree)	E (mm)	F (μm)	E_r (glass fiber-epoxy) (mg/kg)	S/N ratio (db)
1	30	0	40	30	60	300	306.522	-49.7292
2	30	0	50	60	70	450	513.043	-54.2031
3	30	0	60	90	80	600	604.512	-55.6281
4	30	15	40	60	70	600	384.783	-51.7043
5	30	15	50	90	80	300	564.186	-55.0284
6	30	15	60	30	60	450	400.012	-52.0415
7	30	30	40	90	80	450	333.945	-50.4735
8	30	30	50	30	60	600	182.608	-45.2304
9	30	30	60	60	70	300	263.043	-48.4005
10	40	0	40	60	80	450	339.135	-50.6075
11	40	0	50	90	60	600	530.434	-54.4926
12	40	0	60	30	70	300	573.225	-55.1665
13	40	15	40	90	60	300	208.695	-46.3902
14	40	15	50	30	70	450	236.013	-47.4587
15	40	15	60	60	80	600	286.956	-49.1563
16	40	30	40	30	70	600	210.288	-46.4563
17	40	30	50	60	80	300	411.957	-52.2970
18	40	30	60	90	60	450	339.135	-50.6075
19	50	0	40	90	70	600	245.652	-47.8064
20	50	0	50	30	80	300	539.131	-54.6339
21	50	0	60	60	60	450	665.568	-56.4638
22	50	15	40	30	80	450	260.869	-48.3284
23	50	15	50	60	60	600	297.289	-49.4636
24	50	15	60	90	70	300	252.174	-48.0340
25	50	30	40	60	60	300	477.228	-53.5745
26	50	30	50	90	70	450	321.738	-50.1500
27	50	30	60	30	80	600	443.478	-52.9374

The overall mean of the S/N ratios is found to be -50.9801 db for glass fiber based composites. Figures 5.1 illustrate the effect of control factors on erosion rate of glass fiber epoxy composites. Analysis of the results leads to the conclusion that factor combination of A2 (Impact velocity:40m/sec), B2 (Filler content: 15wt%), C1(Erodent temperature: 40°C), D1 (Impingement angle: 30°), E2 (Stand-off distance: 70mm) and F3 (Erodent size: 600μm) gives minimum erosion rate for glass fiber epoxy composites.

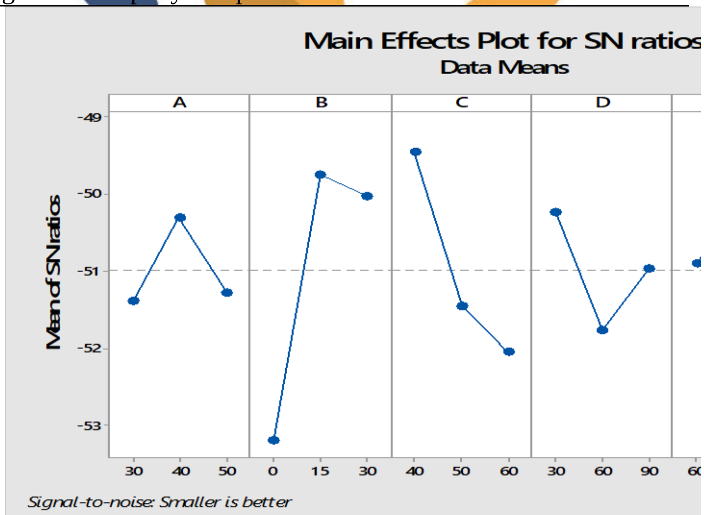

Fig. 5.1 Effect of control factors on erosion wear rate of glass fiber-epoxy composites

Table 5.2: Signal to noise ratio response table for erosion wear rate of glass fiber –epoxy composites

Stage	A	B	C	D	E	F
1	-51.38	-53.19	-49.45	-50.22	-50.89	-51.47
2	-50.29	-49.73	-51.44	-51.76	-49.93	-51.15
3	-51.27	-50.01	-52.05	-50.96	-52.12	-50.32
Delta	1.09	3.46	2.60	1.54	2.19	1.15
Rank	6	1	2	4	3	5

5.1. Erosion wear analysis of short banana fiber reinforced epoxy composites

This part presents the analysis of erosion response of short banana fiber-epoxy composites. The experiments have been carried out using similar Taguchi experimental design that has been used for glass fiber-epoxy composites.

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