SLIDING WEAR BEHAVIOR OF GLASS FIBRE REINFORCED TiO_2 FILLED EPOXY RESIN COMPOSITE

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology in Mechanical Engineering

BY

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Under the guidance of

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CERTIFICATE

This is to certify that the thesis entitled "***Sliding Wear Behavior of Glass Fibre Reinforced Tio$_2$ Filled Epoxy Resin Composite***" submitted by ***Tarun Aggarwal*** *(Roll No.* 10503057*)* in partial fulfillment of the requirements for the award of ***Bachelor of Technology*** in the department of Mechanical Engineering, National Institute of Technology, Rourkela is an authentic work carried out under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to elsewhere for the award of any degree.

Place: Rourkela
Date:

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ABSTRACT

Glass fiber reinforced polymer composites find widespread applications these days in hostile environment due to their several advantages like high wear resistance, strength-to-weight ratio and low cost. The performance of the composites can further be improved by adding particulate fillers to them. To this end, this work successfully uses TiO_2 as a filler material in polymer. The present work includes the processing, characterization and study of the sliding wear behaviour of a series of such TiO_2 filled short glass-epoxy composites. It further outlines a methodology based on Taguchi's experimental design approach to make a parametric analysis of sliding wear behaviour. The systematic experimentation leads to determination of significant process parameters and material variables that predominantly influence the wear rate.

CONTENTS

Chapter 1

INTRODUCTION

1. INTRODUCTION

1.1. Overview of composites

Composite materials (or composites for short) are engineering materials made from two or more constituent materials that remain separate and distinct on a macroscopic level while forming a single component. There are two categories of constituent materials: matrix and reinforcement. At least one portion of each type is required. The matrix material surrounds and supports the reinforcement materials by maintaining their relative positions. The reinforcements impart their special mechanical and physical properties to enhance the matrix properties. The primary functions of the matrix are to transfer stresses between the reinforcing fibers/particles and to protect them from mechanical and/or environmental damage whereas the presence of fibers/particles in a composite improves its mechanical properties such as strength, stiffness etc. A composite is therefore a synergistic combination of two or more micro-constituents that differ in physical form and chemical composition and which are insoluble in each other. The objective is to take advantage of the superior properties of both materials without compromising on the weakness of either. The synergism produces material properties unavailable from the individual constituent materials. Due to the wide variety of matrix and reinforcement materials available, the design potentials are incredible.

Composite materials have successfully substituted the traditional materials in several light weight and high strength applications. The reasons why composites are selected for such applications are mainly their high strength-to-weight ratio, high tensile strength at elevated temperatures, high creep resistance and high toughness. Typically, in a composite, the reinforcing materials are strong with low densities while the matrix is usually a ductile or tough material. If the composite is designed and fabricated correctly it combines the strength of the reinforcement with the toughness of the matrix to achieve a combination of desirable properties not available in any single conventional material. The strength of the composites depends primarily on the amount, arrangement and type of fiber and /or particle reinforcement in the resin.

1.2. Merits of Composites

Advantages of composites over their conventional counterparts are the ability to meet diverse design requirements with significant weight savings as well as strength-to-weight ratio. Some advantages of composite materials over conventional ones are as follows:

- Tensile strength of composites is four to six times greater than that of steel or aluminium (depending on the reinforcements).
- Improved torsional stiffness and impact properties.
- Higher fatigue endurance limit (up to 60% of ultimate tensile strength).
- 30% - 40% lighter for example any particular aluminium structures designed to the same functional requirements.
- Lower embedded energy compared to other structural metallic materials like steel, aluminium etc.
- Composites are less noisy while in operation and provide lower vibration transmission than metals.
- Composites are more versatile than metals and can be tailored to meet performance needs and complex design requirements.
- Long life offer excellent fatigue, impact, environmental resistance and reduce maintenance.
- Composites enjoy reduced life cycle cost compared to metals.
- Composites exhibit excellent corrosion resistance and fire retardancy.
- Improved appearance with smooth surfaces and readily incorporable integral decorative melamine are other characteristics of composites.
- Composite parts can eliminate joints / fasteners, providing part simplification and integrated design compared to conventional metallic parts.

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)

a) Metal Matrix Composites

Metal Matrix Composites have many advantages over monolithic metals like higher specific modulus, higher specific strength, better properties at elevated temperatures, and lower coefficient of thermal expansion. Because of these attributes metal matrix composites are under consideration for wide range of applications viz. combustion chamber nozzle (in rocket, space shuttle), housings, tubing, cables, heat exchangers, structural members etc.

b) Ceramic matrix Composites

One of the main objectives in producing ceramic matrix composites is to increase the toughness. Naturally it is hoped and indeed often found that there is a concomitant improvement in strength and stiffness of ceramic matrix composites.

c) Polymer Matrix Composites

Most commonly used matrix materials are polymeric. The reason for this are two fold. In general the mechanical properties of polymers are inadequate for many structural purposes. In particular their strength and stiffness are low compared to metals and ceramics. These difficulties are overcome by reinforcing other materials with polymers. Secondly the processing of polymer matrix composites need not involve high pressure and doesn’t require high temperature. Also equipments required for manufacturing polymer matrix composites are simpler. For this reason polymer matrix composites developed rapidly and soon became popular for structural applications.

Composites are used because overall properties of the composites are superior to those of the individual components for example polymer/ceramic.

Composites have a greater modulus than the polymer component but aren't as brittle as ceramics.

Two types of polymer composites are:

- Fiber reinforced polymer (FRP)
- Particle reinforced polymer (PRP)

Fiber Reinforced Polymer

Common fiber reinforced composites are composed of fibers and a matrix. Fibers are the reinforcement and the main source of strength while matrix glues all the fibers together in shape and transfers stresses between the reinforcing fibers. The fibers carry the loads along their longitudinal directions. Sometimes, filler might be added to smooth the manufacturing process, impact special properties to the composites, and / or reduce the product cost.

Common fiber reinforcing agents include asbestos, carbon / graphite fibers, beryllium, beryllium carbide, beryllium oxide, molybdenum, aluminium oxide, glass fibers, polyamide, natural fibers etc. Similarly common matrix materials include epoxy, phenolic, polyester, polyurethane, polyetherethrketone (PEEK), vinyl ester etc. Among these resin materials, PEEK is most widely used. Epoxy, which has higher adhesion and less shrinkage than PEEK, comes in second for its high cost.

Particle Reinforced Polymer

Particles used for reinforcing include ceramics and glasses such as small mineral particles, metal particles such as aluminium and amorphous materials, including polymers and carbon black. Particles are used to increase the modules of the matrix and to decrease the ductility of the matrix. Particles are also used to reduce the cost of the composites. Reinforcements and matrices can be common, inexpensive materials and are easily processed. Some of the useful properties of ceramics and glasses include high melting temp., low density, high strength, stiffness, wear resistance, and corrosion resistance. Many ceramics are good electrical and thermal insulators. Some ceramics have special properties; some ceramics are magnetic materials; some are piezoelectric materials; and a few special ceramics are even superconductors at very low temperatures. Ceramics and glasses have one major drawback: they are brittle. An example of particle reinforced composites is an automobile tire, which has carbon black particles in a matrix of poly-isobutylene elastomeric polymer.

Polymer composite materials have generated wide interest in various engineering fields, particularly in aerospace applications. Research is underway worldwide to develop newer composites with varied combinations of fibers and fillers so as to make them useable under different operational conditions. Against this backdrop, the present work has been taken up to develop a series of PEEK based composites with glass fiber reinforcement and with ceramic fillers and to study their response to solid particle erosion.

1.3. Scope of the project

1. The basic aim of the present work is to develop and characterize a new class of composites with a polymer called epoxy-filler as the matrix and glass fiber as the reinforcing material.
2. Their physical and mechanical characterization is done. Attempt is made to use TiO_2 as filler in these fiber reinforced polymer matrix composites.
3. Wear behaviour of this new class of composites is investigated in this project work. Dry sliding wear is performed on the composites.
4. This work is expected to introduce a new class of functional polymer composites suitable for tribological applications.

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Chapter 2

LITERATURE SURVEY

2. LITERATURE SURVEY

This chapter outlines some of the recent reports published in literature on composites with special emphasis on erosion wear behavior of glass fiber reinforced polymer composites.

Polymers have generated wide interest in various engineering fields including tribological applications, in view of their good strength and low density as compared to monolithic metal alloys. Being lightweight they are the most suitable materials for weight sensitive uses, but their high cost sometimes becomes the limiting factor for commercial applications. Use of low cost, easily available fillers is therefore useful to bring down the cost of component. Study of the effect of such filler addition is necessary to ensure that the mechanical properties of the composites are not affected adversely by such addition. Available references suggest a large number of materials to be used as fillers in polymers [1]. The purpose of use of fillers can therefore be divided into two basic categories; first, to improve the mechanical, thermal or tribological properties and second, to reduce the cost of the component. There have been various reports on use of materials such as minerals and inorganic oxides, such as alumina and silica mixed into widely employed thermoplastic polymers like polypropylene [2,3] and polyethylene [4,5]. But very few attempts have indeed been made to utilize cheap materials like industrial wastes in preparing particle-reinforced polymer composites.

A key feature of particulate reinforced polymer composites that makes them so promising as engineering materials is the opportunity to tailor the materials properties through the control of filler content and matrix combinations and the selection of processing techniques. A judicious selection of matrix and the reinforcing solid particulate phase can lead to a composite with a combination of strength and modulus comparable to or even better than those of conventional metallic materials [6]. Hard particulate fillers consisting of ceramic or metal particles and fiber fillers made of glass are being used these days to dramatically improve the wear resistance of composites, even up to three orders of magnitude [7]. The improved performance of polymers and their composites in industrial and structural applications by the addition of particulate fillers has shown a great promise and so has lately been a subject of considerable interest. Various kinds of polymers and polymer matrix composites reinforced with metal particles have a wide range of industrial applications such as heaters, electrodes [8], composites with thermal durability at high temperature [9] etc. These engineering composites are desired due to their low density, high corrosion resistance, ease of fabrication, and low cost [10, 11]. Similarly, ceramic filled polymer composites have been the subject of extensive research in last two decades.

A number of experiments have been performed using different ceramics such as Al_2O_3, TiC, and SiC by varying the particle size and particle volume fraction [12]. Polymer/TiO_2 composites have been successfully synthesized in different polymer matrixes such as silicone elastomer [13], polycarbonate [14], polyamide 6 [15], epoxy [16], unsaturated polyester [17], polyacrylate [18], poly(methyl methacrylate) [19], polyimide [20], polystyrene [21] and dental composites [22]. Titanium dioxide pigment is a fine white powder is one of the most important filler used for making composites for many engineering applications. Against this background, the present research work has been undertaken, with an objective to explore the potential of TiO_2 as a filler material in polymer composites and to investigate its effect on the dry sliding wear performance of the composites and also study the mechanical characterization of different filler contents of the composites.

To study the correlation between the wear properties and the characteristic parameters, e.g. the composition of the composite and the operating conditions, is of prime importance for designing proper composites in order to satisfy various functional requirements. But visualization of impact of any individual control factor in an interacting environment really becomes difficult. To this end, an attempt has been made in this study, to analyze the impact of more than one parameter on sliding wear of the polyester composite. It is important as in actual practice, the resultant wear rate is the combined effect of more than one interacting variables. An inexpensive and easy-to-operate experimental strategy based on Taguchi's parameter design has been adopted to study effect of various parameters and their interactions. This experimental procedure has been successfully applied for parametric appraisal in wire electrical discharge machining (WEDM) process, drilling of metal matrix composites, and erosion behavior of polymer matrix composites [23, 24, 25].

2.1 Objectives of the Present Work

The objectives of the project are outlined below.

- Fabrication of glass fibre reinforced epoxy based hybrid composite with/without filler content.
- Evaluation of mechanical properties (tensile strength, flexural, hardness, impact strength etc.)
- Dry sliding wear of composite samples under various operating conditions
- The study of effect of fibre and filler content on sliding wear analysis.

Besides the above all the objective is to develop new class of composites by incorporating TiO_2 reinforcing phases into a polymeric resin. Also this work is expected to introduce a new class of polymer composite that might find tribological applications.

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Chapter 3

MATERIALS AND METHODS

3. MATERIALS AND METHODS

3.1. Introduction

This chapter describes the details of processing of the composites and the experimental procedures followed for their characterization and tribological evaluation. The raw materials used in this work are

1. Short E-glass Fiber
2. TiO_2
3. Epoxy resin

3.2. Processing of the Composites

Short E-glass fibers (360 roving taken from Saint Gobian) are reinforced with Epoxy LY 556 resin, chemically belonging to the 'epoxide' family is used as the matrix material. Its common name is Bisphenol A Diglycidyl Ether. The low temperature curing epoxy resin (Araldite LY 556) 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. E-glass fiber and epoxy resin has modulus of 72.5 GPa and 3.42GPa respectively and possess density of 2590 kg/m^3 and 1100kg/m^3 respectively. Composites of three different compositions such as 0wt% filler, 10wt% and 20wt% TiO_2 are made and the fiber loading (weight fraction of glass fiber in the composite) is kept at 50% for all the samples. The castings are put under load for about 24 hours for proper curing at room temperature. Specimens of suitable dimension are cut using a diamond cutter for physical characterization and erosion test.

3.3. Characterization of the Composites

Density

The theoretical density of composite materials in terms of weight fraction can easily be obtained as for the following equations given by Agarwal and Broutman [26].

$$\rho_{ct} = \frac{1}{(W_f/\rho_f) + (W_m/\rho_m)} \qquad (1)$$

Where, W and ρ represent the weight fraction and density respectively. The suffix f, m and ct stand for the fiber, matrix and the composite materials respectively.

The composites under this investigation consists of three components namely matrix, fiber and particulate filler. Hence the modified form of the expression for the density of the composite can be written as

$$\rho_{ct} = \frac{1}{(W_f/\rho_f) + (W_m/\rho_m) + (W_p/\rho_p)} \qquad (2)$$

Where, the suffix '*p*' indicates the particulate filler materials.

The actual density (ρ_{ce}) of the composite, however, can be determined experimentally by simple water immersion technique. The volume fraction of voids (V_v) in the composites is calculated using the following equation:

$$V_v = \frac{\rho_{ct} - \rho_{ce}}{\rho_{ct}} \qquad (3)$$

Micro-hardness measurement

Micro-hardness measurement is done using a Leitz micro-hardness tester. A diamond indenter, in the form of a right pyramid with a square base and an angle 136^0 between opposite faces, is forced into the material under a load F. The two diagonals X and Y of the indentation left on the surface of the material after removal of the load are measured and their arithmetic mean L is calculated. In the present study, the load considered F = 24.54N and Vickers hardness number is calculated using the following equation.

$$H_V = 0.1889 \frac{F}{L^2} \qquad (4)$$

and $L = \frac{X + Y}{2}$

Where F is the applied load (N), L is the diagonal of square impression (mm), X is the horizontal length (mm) and Y is the vertical length (mm).

Tensile and flexural strength

The tensile test is generally performed on flat specimens. The commonly used specimens for tensile test are the dog-bone type and the straight side type with end tabs. During the test a uni-axial load is applied through both the ends of the specimen. The ASTM standard test method for tensile properties of fiber resin composites has the designation D 3039-76. The length of the test section should be 200 mm. The tensile test is performed in the universal testing machine (UTM) Instron 1195 and results are analyzed to calculate the tensile strength of composite samples. The short beam shear (SBS) tests are performed on the composite samples at room temperature to evaluate the value of flexural strength (FS). It is a 3-point bend test, which generally promotes failure by inter-laminar shear. The SBS test is conducted as per ASTM standard (D2344-84) using the same UTM. Span length of 40 mm and the cross head speed of 1 mm/min are maintained. The flexural strength (*F.S.*) of any composite specimen is determined using the following equation.

$$F.S = \frac{3PL}{2bt^2} \tag{5}$$

Where, *L* is the span length of the sample. P is the load applied; b and t are the width and thickness of the specimen respectively.

3.4. Sliding Wear Test

To evaluate the performance of these composites under dry sliding condition, wear tests are carried out in a pin-on-disc type friction and wear monitoring test rig (supplied by DUCOM) as per ASTM G 99. The experimental set up is shown in Figure 1. The counter body is a disc made of hardened ground steel (EN-32, hardness 72 HRC, surface roughness 0.6 μ Ra). The specimen is held stationary and the disc is rotated while a normal force is applied through a lever mechanism. A series of test are conducted with three sliding velocities of 210, 261 and 314 cm/sec under three different normal loading of 10N, 20N and 30N. The material loss from the composite surface is measured using a precision electronic balance with accuracy $\pm$ 0.1 mg and the specific wear rate (mm^3/N-m) is then expressed on 'volume loss' basis as

$$W_S = \Delta m/\rho t\ V_S.F_N \tag{6}$$

where

Δm is the mass loss in the test duration (gm)

ρ is the density of the composite (gm/mm^3)

t is the test duration (sec).

V_s is the sliding velocity (m/sec)

F_N is the average 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.

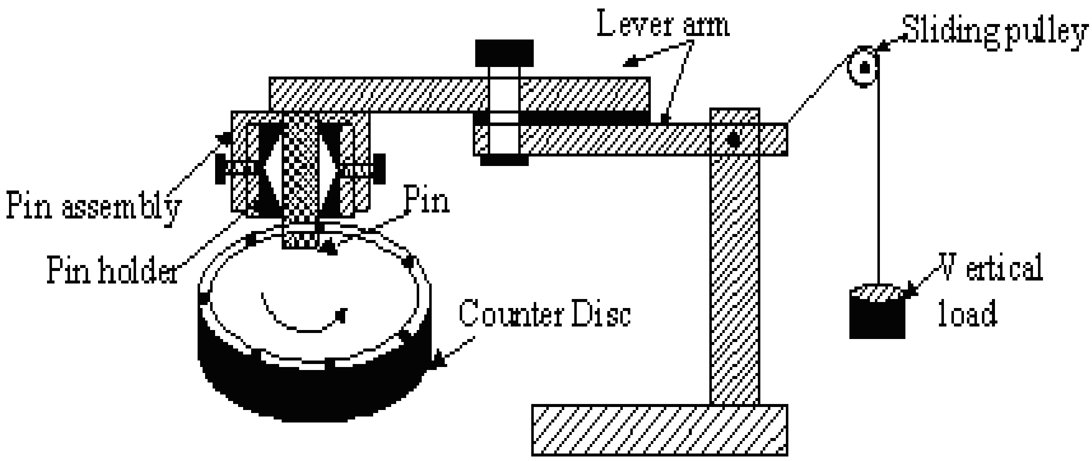

Figure 1. Schematic diagram of a Pin-on-Disc set-up

3.5. Experimental design

Design of experiment is a powerful analysis tool for modeling and analyzing the influence of control factors on performance output. The most important stage in the design of experiment lies in the selection of the control factors. Therefore, a number of factors are included so that non-significant variables can be identified at earliest opportunity**.** The wear tests are carried out under operating conditions given in Table 1. The tests are conducted at room temperature as per experimental design given in Table 2. Three parameters viz., sliding velocity, normal load, filler content and sliding distance each at three levels, are considered in this study in accordance with L_{27} (3^{13}) orthogonal array design. In Table 2, each column represents a test parameter and a row gives a test condition which is nothing but a combination of parameter levels.

The experimental observations are transformed into signal-to-noise (S/N) ratios. There are several S/N ratios available depending on the type of characteristics. The S/N ratio for minimum wear rate coming under smaller is better characteristic, which can be calculated as logarithmic transformation of the loss function as shown below.

Smaller is the better characteristic: $\frac{S}{N} = -10 \log \frac{1}{n} \left(\sum y^2 \right)$ (7)

where n is the number of observations, and y is the observed data. “Lower is better” (LB) characteristic, with the above S/N ratio transformation, is suitable for minimization of wear rate. The standard linear graph, as shown in Fig. 2, is used to assign the factors and interactions to various columns of the orthogonal array [27].

Table 1. Control factors and levels used in the experiment

Control factor	Level			
	I	II	III	Units
A: Sliding velocity	210	261	314	cm/sec
B: Normal load	10	20	30	N
C: Filler content	0	10	20	%
D: Sliding distance	2	4	6	km

The plan of the experiments is as follows: the first column is assigned to sliding velocity (A), the second column to normal load (B), the third column to filler content (C) and forth column to sliding distance (D) and the third and fourth column are assigned to $(A\times B)_1$ and $(A\times B)_2$, respectively to estimate interaction between sliding velocity (A) and normal load (B), the sixth and seventh column are assigned to $(B\times C)_1$ and $(B\times C)_2$ respectively, to estimate interaction between the normal load (B) and filler content (C), the eighth and eleventh column are assigned to $(A\times C)_1$ and $(A\times C)_2$ respectively, to estimate interaction between the sliding velocity (A) and filler content (C). The remaining columns are assigned to error columns respectively.

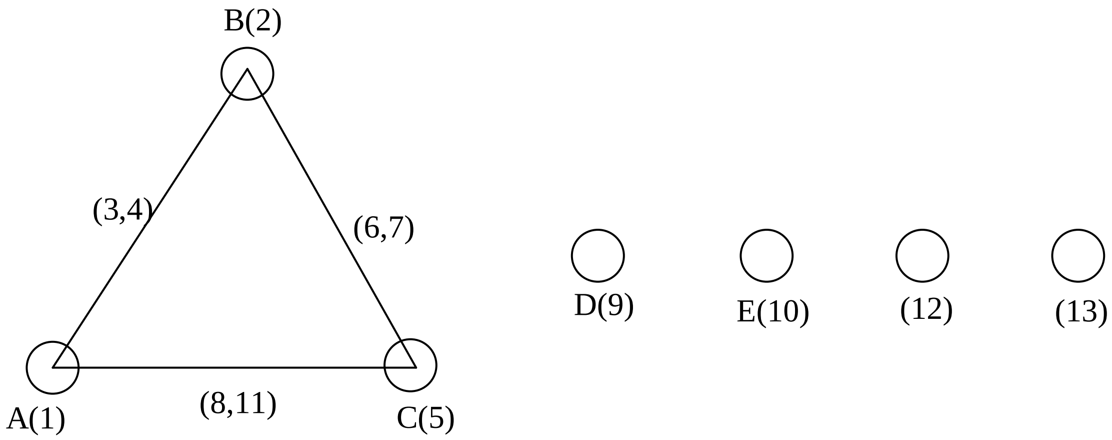

Figure 2. Linear graphs for L_{27} array

Table 2. Orthogonal array for L_{27} (3^{13}) Taguchi's Experimental Design

$L_{27}(3^{13})$	1 A	2 B	3 $(AxB)_1$	4 $(AxB)_2$	5 C	6 $(BxC)_1$	7 $(BxC)_2$	8 $(AxC)_1$	9 D	10	11 $(AxC)_2$	12	13
1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	2	2	2	2	2	2	2	2	2
3	1	1	1	1	3	3	3	3	3	3	3	3	3
4	1	2	2	2	1	1	1	2	2	2	3	3	3
5	1	2	2	2	2	2	2	3	3	3	1	1	1
6	1	2	2	2	3	3	3	1	1	1	2	2	2
7	1	3	3	3	1	1	1	3	3	3	2	2	2
8	1	3	3	3	2	2	2	1	1	1	3	3	3
9	1	3	3	3	3	3	3	2	2	2	1	1	1
10	2	1	2	3	1	2	3	1	2	3	1	2	3
11	2	1	2	3	2	3	1	2	3	1	2	3	1
12	2	1	2	3	3	1	2	3	1	2	3	1	2
13	2	2	3	1	1	2	3	2	3	1	3	1	2
14	2	2	3	1	2	3	1	3	1	2	1	2	3
15	2	2	3	1	3	1	2	1	2	3	2	3	1
16	2	3	1	2	1	2	3	3	1	2	2	3	1
17	2	3	1	2	2	3	1	1	2	3	3	1	2
18	2	3	1	2	3	1	2	2	3	1	1	2	3
19	3	1	3	2	1	3	2	1	3	2	1	3	2
20	3	1	3	2	2	1	3	2	1	3	2	1	3
21	3	1	3	2	3	2	1	3	2	1	3	2	1
22	3	2	1	3	1	3	2	2	1	3	3	2	1
23	3	2	1	3	2	1	3	3	2	1	1	3	2
24	3	2	1	3	3	2	1	1	3	2	2	1	3
25	3	3	2	1	1	3	2	3	2	1	2	1	3
26	3	3	2	1	2	1	3	1	3	2	3	2	1
27	3	3	2	1	3	2	1	2	1	3	1	3	2

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Chapter 4

COMPOSITE CHARACTERIZATION: RESULTS & DISCUSSION

4.COMPOSITE CHARACTERIZATION: RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the physical and mechanical characterization of the class of polymer matrix composites developed for the present investigation. They are

- Short glass fiber Reinforced epoxy resin composites.
- Short glass fiber reinforced epoxy resin filled with different weight percentage of TiO_2.

Details of processing of these composites and the tests conducted on them have been described in the previous chapter. The results of various characterization tests are reported here. They include evaluation of tensile strength, flexural strength, measurement of density and micro-hardness has been studied and discussed.

4.2 Composite Characterization

Physical and mechanical properties

The theoretical and measured densities of all composite samples along with the corresponding volume fraction of voids are presented in Table 3. It may be noted that the composite density values calculated theoretically from weight fractions using Eq. (2) are not in agreement with the experimentally determined values. The difference is a measure of voids and pores present in the composites.

Table 3. Theoretical and measured densities along with void fractions in composites

Sample No.	Filler content (wt%)	Theoretical Density (gm/cc)	Measured Density (gm/cc)	Void Fraction (%)
1	0	1.1	1.103	0.27
2	10	1.124	1.112	1.06
3	20	1.149	1.138	0.95

It is clear from Table 3 that the percentage of voids in hardened neat epoxy is negligibly small i.e. 0.27 % and this may be due to the absence of any filler. With the addition of filler content more voids are found in the composites and with 10 to 20 wt% of filler, the volume fraction of voids is also found to be at about 1 %. Density of a composite depends on the relative proportion of matrix and reinforcing materials and this is one of the most important factors determining the properties of the composites. The void content is the cause for the difference between the values of true density and the theoretically calculated one. The voids significantly affect some of the mechanical properties and even the performance of composites in the place of use. The knowledge of void content is desirable for estimation of the quality of the composites. It is understandable that a good composite should have fewer voids. However, presence of void is unavoidable in composite making particularly through hand-lay-up route. The composites under the present investigation possess very less voids and can thus be termed as good composites.

In this study, the reinforcement of TiO_2 particulate in glass fiber reinforced epoxy resin has not shown encouraging results in terms of mechanical properties. The tensile strengths of the composites with 10 wt% and 20 wt% are recorded as 263.65 MPa and 257.76 MPa respectively where as that of neat epoxy with short glass fiber is about 370 MPa. There can be two reasons for this decline in the strength properties of these filled composites compared to the unfilled one as shown in Figure 3. One possibility is that the chemical reaction at the interface between the filler and the matrix may be too weak to transfer the tensile stress; the other is that the corner points of the irregular shape of the particulate result in stress concentration in the epoxy matrix. These two factors are responsible for reducing the tensile strengths of the composites so significantly.

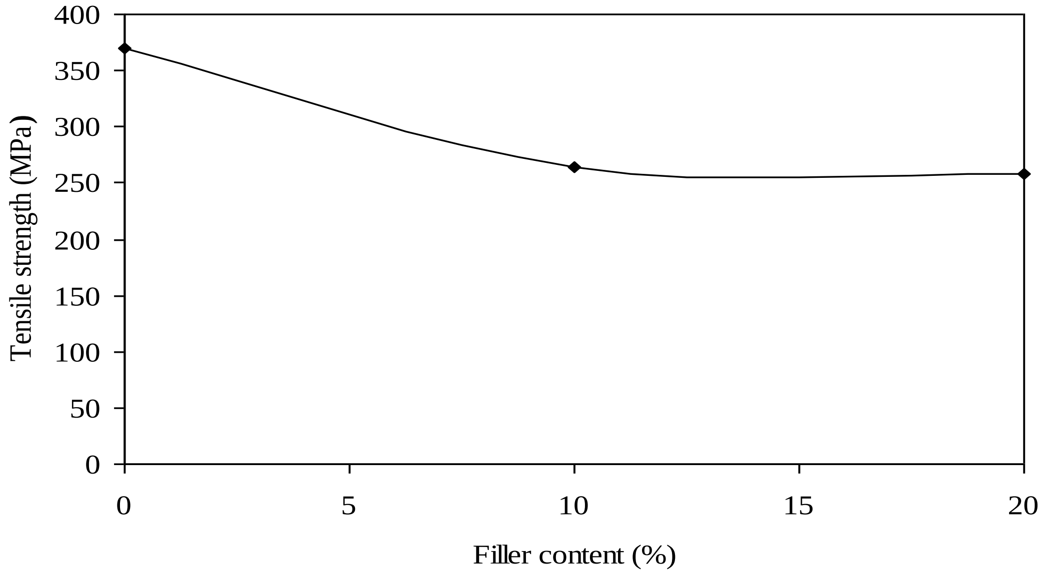

Figure 3. Variations of tensile strength of the composites

Figure 4 shows the comparison of flexural strengths of the composites obtained experimentally from the bend tests. It is interesting to note that addition of small amount (10 wt%) TiO_2 improves the flexural strength of glass epoxy composite structure. But further addition (20 wt%) lowers the strength value drastically.

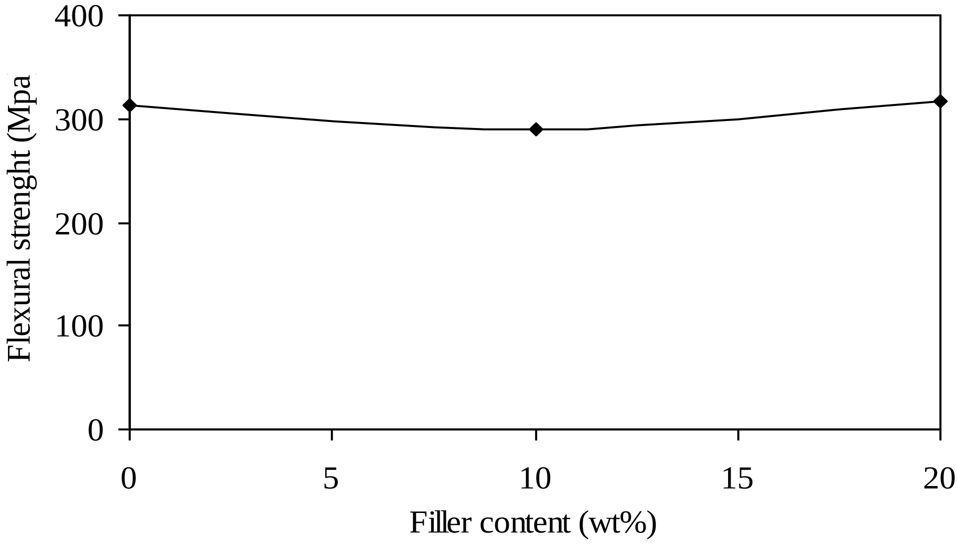

Figure 4. Variations of flexural strength of the composites

The hardness values of the composites with filler content of 10 wt% and 20 wt% are recorded as 47 Hv and 49.5 Hv respectively. For hardened of unfilled composite, is found to be 41.75 Hv. It is thus seen that the hardness is improved, though marginally, by the incorporation of TiO_2 as shown in Figure 5. The reduction in tensile strength and the improvement in hardness with the incorporation of filler can be explained as follows: under the action of a tensile force the filler matrix interface is vulnerable to debonding, depending on interfacial bond strength and this may lead to a break in the composite. But in case of hardness test, a compression or pressing stress is in action. So the matrix phase and the solid filler phase would be pressed together and touch each other more tightly. Thus the interface can transfer pressure more effectively although the interfacial bond may be poor. This results in enhancement of hardness.

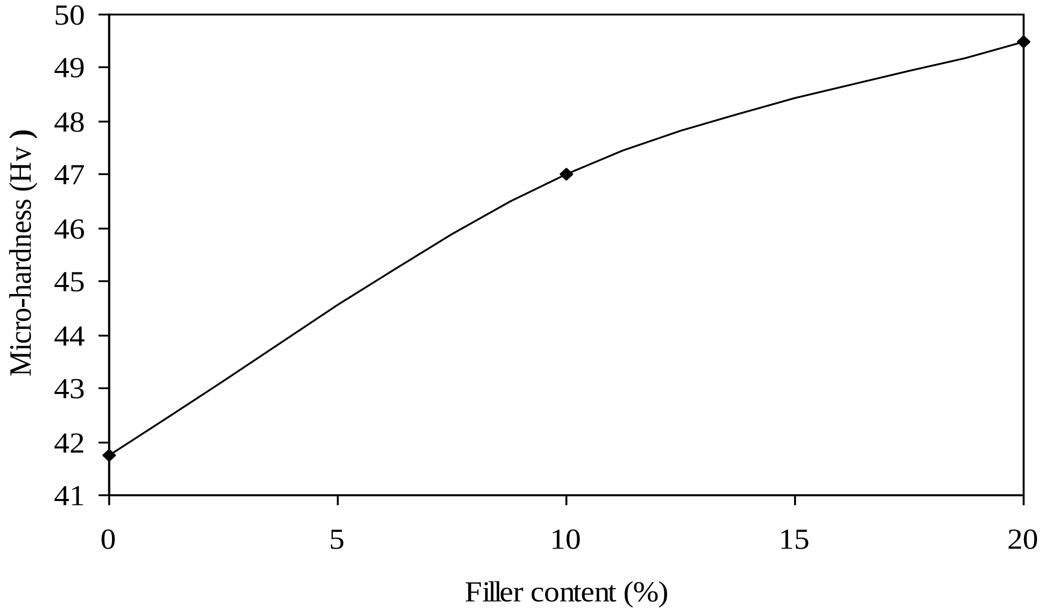

Figure 5. Effect of filler content on micro-hardness of different composites

It shows that the resistance to impact loading of glass epoxy composites improves with addition of particulate filler up to 10wt% but further increase in filler content up to 20w% it is decreasing as shown in Figure 6. High strain rates or impact loads may be expected in many engineering applications of composite materials. The suitability of a composite for such applications should therefore be determined not only by usual design parameters, but by its impact or energy absorbing properties.

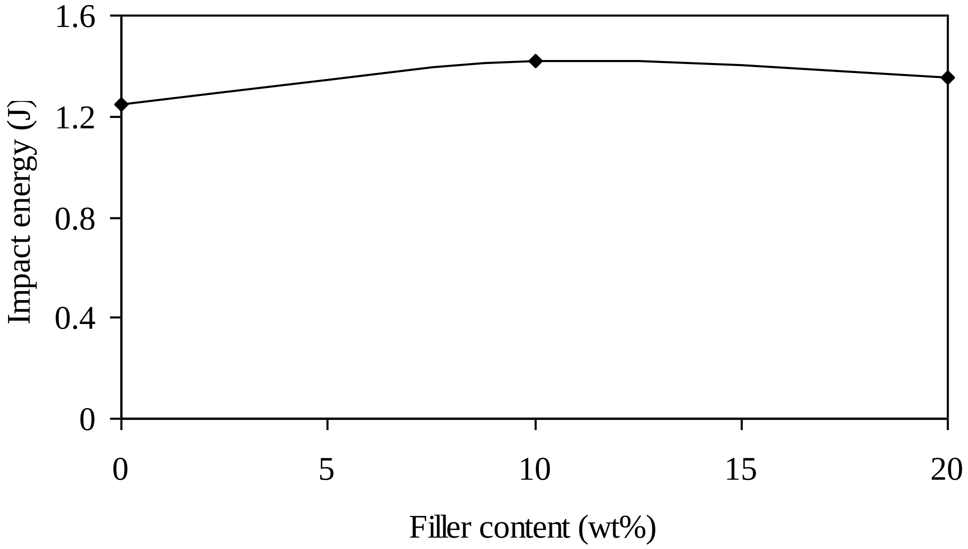

Figure 6. Effect of filler content on impact energy of different composites

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Chapter 5

RESULTS & ANALYSIS

5. RESULTS AND ANALYSIS

The experimental results are analyzed using Taguchi method and the significant parameters affecting material erosion have been identified. The results of the Taguchi analysis are also presented here.

5.1. Wear characteristics analysis

From Table 4, the overall mean for the S/N ratio of the wear rate is found to be 7.16 db. Figure 7 shows graphically the effect of the three control factors on specific wear rate. The analyses are made using the popular software specifically used for design of experiment applications known as MINITAB 14. Before any attempt is made to use this simple model as a predictor for the measures of performance, the possible interactions between the control factors must be considered. Thus factorial design incorporates a simple means of testing for the presence of the interaction effects. The S/N ratio response are given in Table 5, from which it can be concluded that among all the factors, sliding velocity is most significant factor followed by fiber content and normal load while the sliding distance has the least or almost no significance on wear rate of the reinforced composite. Analysis of the results leads to the conclusion that factor combination of A_1, B_2, C_3 and D_2 gives minimum specific wear rate. The interaction graphs are shown in Figures 8-10. As for as minimization of wear rate is concerned, factors A, B and C have significant effect whereas factor D has least effect. It is observed from Fig. 6 that the interaction between $A \times B$ shows greater significant effect on wear rate. Similarly, interaction between $B \times C$ also having second highest significant effect on the output performance as shown in Fig. 9.

Table 4. Test conditions with output results using L_{27} orthogonal array

Sl No.	Sliding velocity A (cm/sec)	Normal load B (N)	Fiber content C (%)	Sliding distance D (km)	Wear rate W_s (mm^3/N-km)	S/N ratio (db)
1	210	10	0	2	1.0685	-0.57550
2	210	10	10	4	0.2224	13.0573
3	210	10	20	6	1.1701	-1.36450
4	210	20	0	4	0.1324	17.5620
5	210	20	10	6	0.3339	9.52770
6	210	20	20	2	0.1128	18.9538
7	210	30	0	6	0.4361	7.20830
8	210	30	10	2	0.1436	16.8569
9	210	30	20	4	0.0694	23.1728
10	261	10	0	4	0.1643	15.6872
11	261	10	10	6	0.4234	7.46500
12	261	10	20	2	0.1311	17.6479
13	261	20	0	6	0.3729	8.56820
14	261	20	10	2	0.2435	12.2700
15	261	20	20	4	0.231	12.7278
16	261	30	0	2	1.0231	-0.19840
17	261	30	10	4	1.0034	-0.02950
18	261	30	20	6	0.5487	5.21330
19	314	10	0	6	1.1201	-0.98510
20	314	10	10	2	0.6382	3.90090
21	314	10	20	4	0.4312	7.30640
22	314	20	0	2	1.2137	-1.68220
23	314	20	10	4	0.8794	1.11630
24	314	20	20	6	0.4378	7.17450
25	314	30	0	4	1.3248	-2.44300
26	314	30	10	6	1.0675	-0.56740
27	314	30	20	2	0.8754	1.15590

Table 5. Response table for signal to noise ratios

Level	A	B	C	D
1	10.999	6.904	4.794	7.592
2	8.817	9.580	7.066	9.194
3	1.664	4.995	9.620	4.693
Delta	9.335	4.585	4.826	4.501
Rank	1	3	2	4

But the factors A and C individually have greater contribution on output performance, and their combination of interaction with factor A and C is shown in Fig. 8 have least effect on wear rate and from this analysis the factor D has least effect on the specific wear rate and A×C interaction also have least effect on the output performance. Hence, factor D and interaction A×C can be neglected for further study. In order to justified/conform the insignificant factor and insignificant interaction a further statistical analysis is necessary i.e analysis of variance.

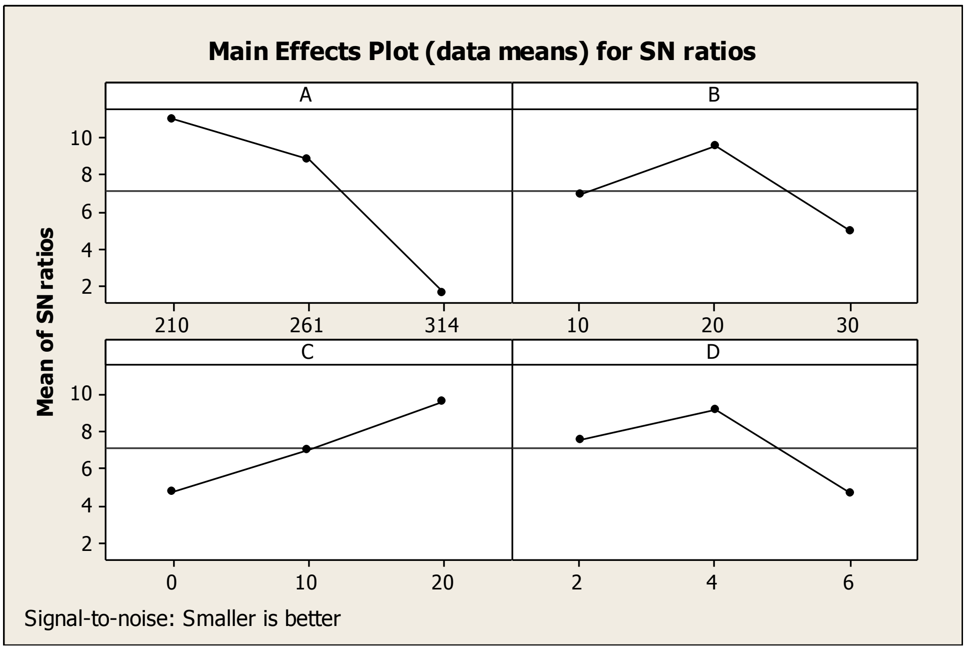

Figure 7. Effect of control factors on wear rate

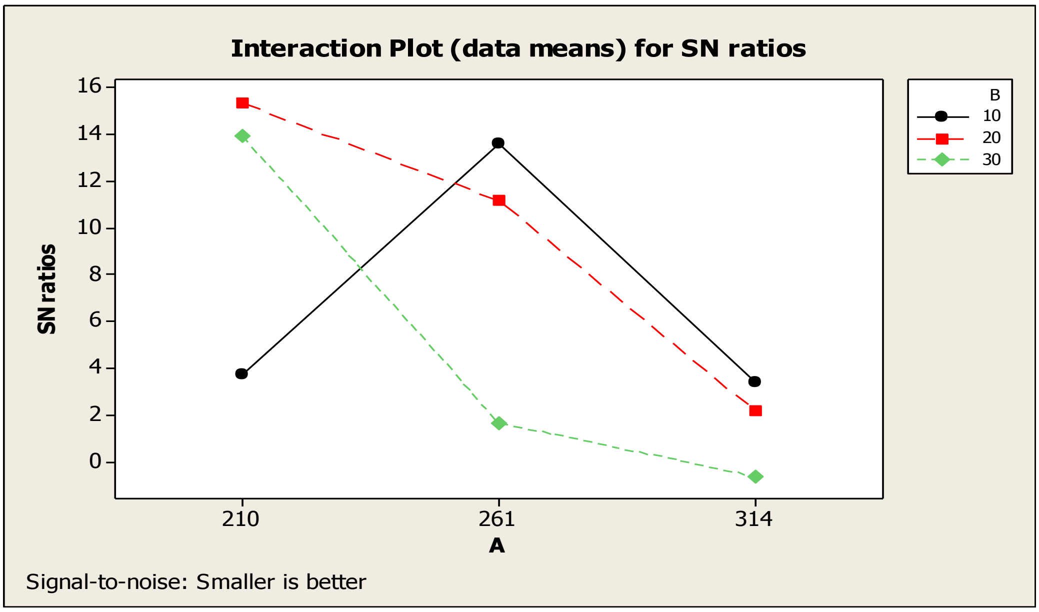

Figure 8. Interaction graph between A×B for wear rate

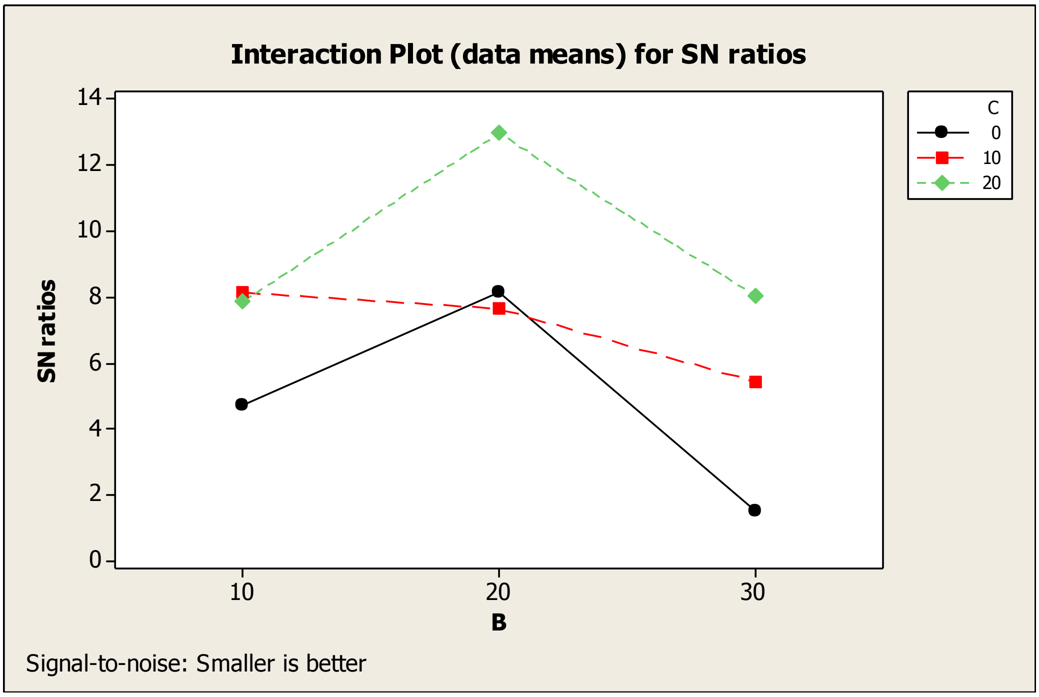

Figure 9. Interaction graph between B×C for wear rate

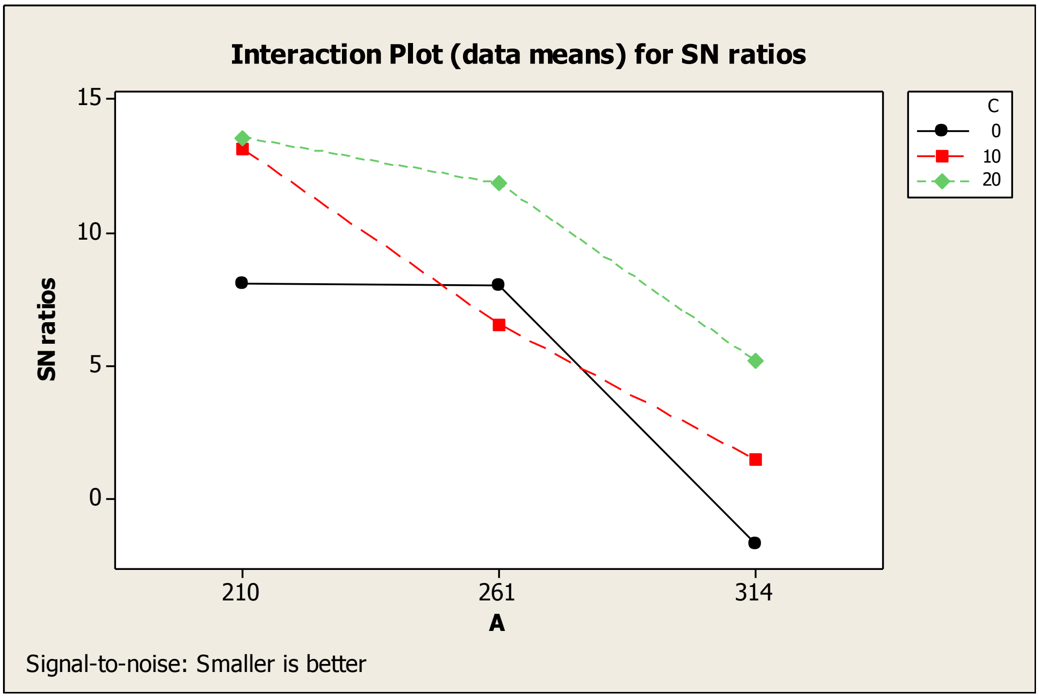

Figure 10. Interaction graph between A×C for wear rate

5.2. ANOVA and the effects of factors

In order to understand a concrete visualization of impact of various factors effect on the output performance, it is desirable to develop analysis of variance (ANOVA) table to find out the order of significant factors. Table 6 shows the results of the ANOVA with the specific wear rate. This analysis is undertaken for a level of confidence of significance of 5 %. The last column of the table indicates the order of significance among factors and interactions.

From Table 6, one can observe that the sliding velocity (p = 0.011), fiber content (p= 0.082) and normal load (p=0.111) have great influence on specific wear rate and the factor like sliding distance has least effect on specific wear rate. Therefore, the like fiber content can be neglected for further study. However, the interaction between sliding velocity $\times$ normal load (p=0. 0.032) and normal load $\times$ fiber content (p=0. 0.233) show significance of contribution on the wear rate and the remaining interaction i.e sliding velocity $\times$fiber content (p=0.648) presents less significance of contribution on wear rate.

Table 6. ANOVA table for specific wear rate

Source	DF	Seq SS	Adj SS	MS	F	P	Rank
A	2	1.21923	1.21923	0.60961	10.56	0.011	1
B	2	0.37497	0.37497	0.18749	3.25	0.111	3
C	2	0.45095	0.45095	0.22547	3.91	0.082	2
D	2	0.11179	0.11179	0.05589	0.97	0.432	4
A*B	4	1.28032	1.28032	0.32008	5.55	0.032	1
A*C	4	0.14987	0.14987	0.03747	0.65	0.648	3
B*C	4	0.43464	0.43464	0.10866	1.88	0.233	2
Error	6	0.34624	0.34624	0.05771			
Total	26	4.36800					

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Chapter 6

CONCLUSIONS

6. CONCLUSIONS

- This analytical and experimental investigation into the erosion behaviour of TiO_2 filled glass-epoxy hybrid composites leads to the following conclusions:
- This work shows that successful fabrication of a glass fiber reinforced epoxy composites with and without filler by simple hand lay-up technique.
- These composites using TiO_2 have adequate potential for tribological applications. With the reinforcement of filler, they exhibit significantly improved sliding wear resistance.
- Dry sliding wear response of these composites under different loads and sliding velocities can be successfully analyzed using Taguchi experimental design scheme. Taguchi method provides a simple, systematic and efficient methodology for the optimization of the control factors. While sliding velocity emerges as the most significant factor affecting wear rate of these composites, other factors like filler content and normal load and their interactions have been found to play significant role in determining wear magnitude.

6.1. Scope for Future Work

- This study leaves wide scope for future investigations. It can be extended to newer composites using other reinforcing phases and the resulting experimental findings can be similarly analyzed.
- Tribological evaluation of TiO_2 filled short glass fiber reinforced epoxy resin composite has been a much less studied area. There is a very wide scope for future scholars to explore this area of research. Many other aspects of this problem like effect of fiber orientation, loading pattern, weight fraction of ceramic fillers on wear response of such composites require further investigation.

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