PARAMETRIC APPRAISAL OF EROSION PROCESS IN POLYSTER GLASS FIBER COMPOSTIES

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

Bachelor of Technology in Mechanical Engineering

BY

MANU SRIVASTAVA

ROLL NO: 10503061

Under the guidance of

Prof. Sandhyarani Biswas

DEPARTMENT OF MECHANICAL ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA-769008

CERTIFICATE

This is to certify that the thesis entitled "***Parametric Appraisal of Erosion Process in Polyster Glass Fiber Composties***" submitted by Manu Srivastava *(Roll No.* 10503061*)* 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:

Sandhyarani Biswas
Mechanical Engineering Department
National Institute of Technology
Rourkela-769008

ACKNOWLEDGEMENT

It gives me immense pleasure to express my deep sense of gratitude to my supervisor **Prof. Sandhyarani Biswas** for her invaluable guidance, motivation, constant inspiration and above all her ever co-operating attitude enabled me in bringing up this thesis in present elegant form.

I am extremely thankful to **Prof. R. K. Sahoo**, Head, Department of Mechanical Engineering and the faculty member of Mechanical Engineering Department for providing all kinds of possible help and advice during the course of this work.

It is a great pleasure for me to acknowledge and express my gratitude to my parents for their understanding, unstinted support and endless encouragement during my study.

I am greatly thankful to all the staff members of the department and all my well wishers, class mates and friends for their inspiration and help.

Lastly I sincerely thank to all those who have directly or indirectly helped for the work reported herein.

MANU SRIVASTAVA
Roll No: 10503061
Department of Mechanical Engineering
National Institute of Technology, Rourkela

ABSTRACT

The present work describes the development and characterisation of a new set of hybrid polymer composites consisting of glass fibre reinforcement, polyester resin and red mud particulate fillers. Red mud is an industrial waste generated during the production of alumina by Bayer's process. The newly developed composites are characterized with respect to their physical, mechanical and erosion wear characteristics. Experiments are carried out to study the effect of red mud content, particle velocity, impingement angle and erodent size on the solid particle erosion behaviour of these epoxy based hybrid composites. Then the significant control factors and their interactions predominantly influencing the wear rate are identified by using Taguchi method. The study reveals that the filler content in the composites, erodent temperature, the impingement angle and velocity have substantial influence in determining the rate of material loss from the composite surface due to erosion. Scanning electron microscopy of the eroded surface of the composites is performed for observation of the features such as crack formation, fiber fragmentation and matrix body deformation.

CONTENTS

Chapter 1

INTRODUCTION

1. INTRODUCTION

1.1. Overview of composites

Composites are materials consist of two or more chemically distinct constituents on a macro scale having a distinct interface separating them and having bulk properties significantly different from those of any of the constituents.

A Composite Material consists of two phases:-

1) Matrix phase
2) Reinforcement

Matrix phase

The primary phase having a continuous character is called matrix. Matrix is usually more ductile and less hard. It consists of any of three basic material types polymers, ceramics or metals. The matrix forms the bulk part.

Reinforcement

The secondary phase is embedded in the matrix in a discontinuous form. The dispersed phase is usually harder and stronger than the continuous phase and is called reinforcement. It serves to strengthen the composites and improves the overall mechanical properties of the matrix.

1.2. Structure of Composite

Structure of composite material determines its properties to a significant extent.

Properties

1) Nature of the constituent material (bonding strength)
2) The geometry of the reinforcement (shape, size)
3) The concentration distribution(vol. fraction of reinforcement)
4) The orientation of the reinforcement(random or preferred)

- Good adhesion (bonding) between matrix phase and displaced phase provides transfer of load applied to the material to the displaced phase via the interface. Good adhesion is required for achieving high level of mechanical properties of composites.

- Very small particles less than 0.25 micrometer finely distributed in the matrix impede movement of dislocations and deformation of the material. They have strengthening effect. Large dispersed phase particles have low share load applied to the material resulting in increase of stiffness and decrease of ductility.
- Orientation of Reinforcement:
    - Planar: - In the form of 2-D woven fabric. When the fibers are laid parallel, the composite exhibits axistrope.
    - Random or Three Dimensional:-The composite material tends to posses isotropic properties.
    - One Dimensional: - Maximum strength and stiffness are obtained in the direction of fiber.

1.3. Advantages 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.

1.4. Applications of Composites

Industry	Examples	Comments
Aircraft	Door, elevators	20-35% Weight savings
Aerospace	Space Shuttle, Space stations	Great weight savings
Automotive	Body frames, engine components	High stiffness & damage tolerance
Chemical	Pipes, Tanks, Pressure vessels	Corrosion resistance
Construction	Structural & decorative panels, Fuel tanks etc.	Weight savings, portable.

1.5. Classification of Composites

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

- Metal Matrix Composites (MMC)
- Ceramic Matrix Composites (CMC)
- Polymer Matrix Composites (PMC)

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.

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.

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.

Industrial development over the last decades has generated large amounts of toxic and hazardous inorganic waste like, fly ash, slag, red mud etc. which contain appreciable amounts of hazardous elements such as Pb, Cr, Cu, Zn, Cd and Hg. Most of these wastes are buried in landfills, which is costly and environmentally unsatisfactory. Therefore, it is essential to seek new options to recycle or reuse the inorganic residues. The use of waste materials such as red mud for composite material is a promising development. Production of alumina from bauxite by the Bayer's process is associated with the generation of red mud as the major waste material in alumina industries worldwide. Depending upon the quality of bauxite, the quantity of red mud generated varies from 55-65% of the bauxite processed. The enormous quantity of red mud discharged by these industries poses an environmental and economical problem. The treatment and disposal of this residue is a major operation in any alumina plant. Red mud, as the name suggests, is brick red in colour and slimy having average particle size of about 80 μm. It comprises of the iron, titanium and the silica part of the parent ore along with other minor constituents. It is alkaline, thixotropic and possesses high surface area in the range of 13-16 m^2/g with a true density of 3.30g/cc. Depending on the source, these residues have a wide range of composition: Fe_2O_3 20–60%, Al_2O_3 10–30%, SiO_2 2–20%, Na_2O 2–10%, CaO 2–8%, TiO_2 traces 2–8%. Against this backdrop, the present work has been taken up to develop a series of polyester based composites with glass fiber reinforcement and with industrial waste filler i.e. red mud and to study their response to solid particle erosion.

*****

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.

Solid particle erosion is a general term used to describe mechanical degradation (wear) of any material subjected to a stream of erodent particles impinging on its surface. The effect of solid particle erosion has been recognized by Wahl and Hartenstein [1] for a long time. Damage caused by erosion has been reported in several industries for a wide range of situations. Examples have been cited for transportation of airborne solids through pipes by Bitter [2], boiler tubes exposed to fly ash by Raask [3] and gas turbine blades by Hibbert and Roy [4]. Solid particle erosion is the progressive loss of original material from a solid surface due to mechanical interaction between the surface and impinging particles. Various applications of polymers and their composites in erosive wear situations are reported by Pool et al. [5], Kulkarni et al. [6] and Aglan and Chenock [7] in the literature. But solid particle erosion of polymers and their composites has not been investigated to the same extent as for metals or ceramics. However, a number of researchers Barkoula and Karger-Kocsis [8], Tewari et al. [9] have evaluated the resistance of various types of polymers and their composites to solid particle erosion. It is widely recognized that polymers and their composites have poor erosion resistance. Their erosion rates (Er) are considerably higher than metals. Also, it is well known that the erosion rate of polymer composites is even higher than that of neat polymers as reported by Häger et al. [10]. The solid particle erosion behavior of polymer composites as a function of fiber content has been studied to a limited extent by investigators like Miyazaki and Takeda [11]. Tilly and Sage [12] have investigated the influence of velocity, impact angle, particle size and weight of impacted abrasives on nylon, carbon fiber-reinforced nylon, epoxy resin, polypropylene and glass fiber-reinforced plastic.

Lindsley and Marder[13] found impact velocity (*v*) to be a critical test variable in erosion, and that it can easily over shadow changes in other variables, such as target material, impact angle, etc. Sundararajan and Manish Roy [14] suggested that in addition to velocity, solid particle erosion is governed by the impact angle, particle size, particle shape and hardness. Sinmazcelik and Taskiran [15] concluded in their erosive wear behavior of polyphenylene sulphide (PPS) that peak erosion rates shifts to larger value of impingement angle compared to the ductile materials. Harsha and Jha [16] studied erosive wear at normal incidence and found that bidirectional glass fiber reinforced epoxy composite showed better wear resistance than unidirectional reinforced composites.

A possibility that the incorporation of both particles and fibers in polymer could provide a synergism in terms of improved wear resistance has not been adequately addressed so far. Attempts to understand the modifications in the tribological behavior of the polymers with the addition of fillers or fiber reinforcements have been made by a few researchers [17, 18]. The enhancement in tribological properties of Poly-phenylene-sulfide (PPS) with the addition of inorganic fillers [19] and fibers [20] has been reported. Bahadur et al. [21, 22] reported that the fillers such as CuS, CuF_2, CaS, and CaO reduced the wear rate of polyamide but many other fillers such as CaF_2 increased the wear rate.

Against this background, the present research work has been undertaken, with an objective to explore the potential of red mud as a filler material in polymer composites and to investigate its effect on the erosion wear performance of the resulting composites. Red mud is accumulated at the alumina plant sites at an increasing rate throughout the world (nearly 30 million tons per year) and this work is an attempt to find a possible use of this abundant waste which might gainfully be employed as particulate filler in polymers for developing low cost, light weight, high strength and erosion wear resistant composites. The present work thus aims to develop this new class of particle filled glass fibre composites and to predict their wear behaviour by experimentation. For this, an inexpensive and easy-to-operate experimental strategy based on Taguchi's parameter design has been adopted to study the effect of various control parameters and their interactions.

2.1 Objectives of the Research Work

The objectives of the project are outlined below.

- Fabrication of glass fibre reinforced polyester matrix composite with/without filler content.
- Evaluation of mechanical properties (tensile strength, flexural, hardness, impact strength etc.)
- Erosion wear of composite samples under various operating conditions
- The study of effect of fibre and filler content on erosion rate.

Besides the above all the objective is to develop relatively low cost composites by incorporating cheaper reinforcing phases into a polymeric resin. Also this work is expected to introduce a new class of polymer composite that might find applications in erosive operational situations

******

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. E-glass Fiber
2. Red mud
3. Polyester resin

3.2. Processing of the Composites

Specimen preparation

Cross plied E-glass fibers are reinforced in unsaturated isophthalic polyester resin to prepare the composite (C1). No particulate filler is used in this composite. The composite slabs are made by conventional hand-lay-up technique. Two percent cobalt nephthalate (as accelerator) is mixed thoroughly in isophthalic polyester resin and then 2% methyl-ethyl-ketone-peroxide (MEKP) as hardener is mixed in the resin prior to reinforcement. Red mud collected from NALCO aluminium refinery at Damanjodi, India is sieved to obtain particle size in the range 70-90 μm. Composites of three different compositions (0wt%, 10wt% and 20wt% red mud filling) are made and the fiber loading (weight fraction of polyster 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 [23].

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

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

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

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:

$$V_v = \frac{\rho_{ct} - \rho_{ce}}{\rho_{ct}} \tag{3}$$

Tensile Strength

The tension test is generally performed on flat specimens as shown in Figure 3.1. The most commonly used specimen geometries are the dog-bone specimen and straight-sided specimen with end tabs. A uni-axial load is applied through the ends. The ASTM standard test recommends that the specimens with fibers parallel to the loading direction should be 11.5 mm wide. Length of the test section should be 100 mm. The test-piece used here was of dog-bone type and having dimensions according to the standards. The tension test was performed on all the three samples as per ASTM D3039-76 test standards.

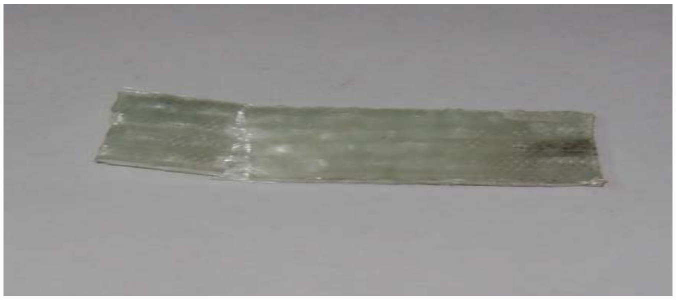

Figure 3.1. Tested Specimen (0% Filler Content)

Flexural Strength

The determination of flexural strength is an important characterization of any structural material. It is the ability of a material to withstand the bending before reaching the breaking point as shown in Figure 3.2a and b. Conventionally a three point bend test is conducted for finding out this material property. In the present investigation also the composites were subjected to this test in a testing machine Instron 1195. The photograph of the machine and the loading arrangement for the specimens are shown in Figure 3.3 and Figure 3.4 respectively. A span of 30 mm was taken and cross head speed was maintained at 10 mm/min. The strength of a material in bending is expressed as the stress on the outermost fibers of a bent test specimen, at the instant of failure. In a conventional test, flexural strength expressed in MPa is equal to:

$$\text{Flexural Strength} = 3PL / 2bd^2$$

Where P= applied central load (N)
L= test span of the sample (m)
b= width of the specimen (m)
d= thickness of specimen under test (m)

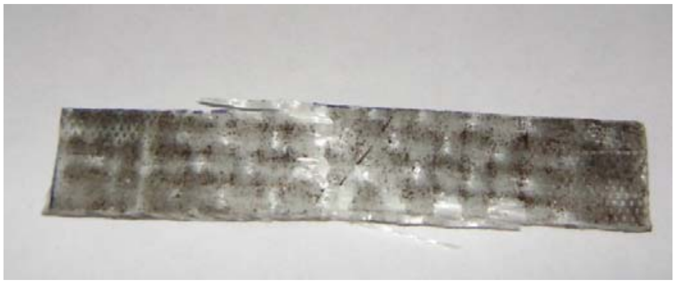

Figure 3.2. Tested Specimen (10% Filler Content)

Figure 3.3. Tested Specimen (20% Filler Content)

Figure 3.3. Experimental set up for three point bend test

Figure 3.4. Loading arrangement for the specimens

Micro-Hardness

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.

$$H_V = 0.1889 \frac{F}{L^2}$$

(4)

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

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).

Impact strength

Low velocity instrumented impact tests are carried out on composite specimens. The tests are done as per ASTM D 256 using an impact tester (Figure 3.5). The pendulum impact testing machine ascertains the notch impact strength of the material by shattering the V-notched specimen with a pendulum hammer, measuring the spent energy, and relating it to the cross section of the specimen. The standard specimen for ASTM D 256 is 64 x 12.7 x 3.2 mm and the depth under the notch is 10.2 mm as indicted in Figure 3.6.

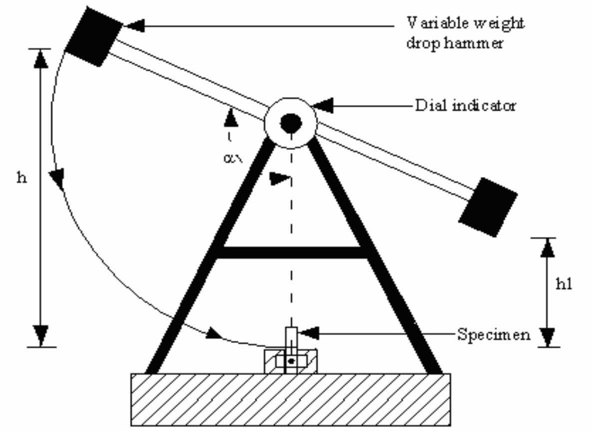

Figure 3.5. Schematic diagram of an impact tester

Figure 3.6. Tested Specimens (0%, 10% and 20% Filler Content)

3.4. Scanning electron microscopy

The surfaces of the raw fish scales and the composite specimens are examined directly by scanning electron microscope JEOL JSM-6480LV. The scales are washed, cleaned thoroughly, air-dried and are coated with 100 Å thick platinum in JEOL sputter ion coater and observed SEM at 20 kV. Similarly the composite samples are mounted on stubs with silver paste. To enhance the conductivity of the samples, a thin film of platinum is vacuum-evaporated onto them before the photomicrographs are taken.

3.5. Test Apparatus

Figure 3.7 shows the schematic diagram of erosion test rig confirming to ASTM G 76. The set up is capable of creating reproducible erosive situations for assessing erosion wear resistance of the prepared composite samples. It consists of an air compressor, an air particle mixing chamber and an accelerating chamber. Dry compressed air is mixed with the particles which are fed at constant rate from a sand flow control knob through the nozzle tube and then accelerated by passing the mixture through a convergent brass nozzle of 3 mm internal diameter. These particles impact the specimen which can be held at various angles with respect to the direction of erodent flow using a swivel and an adjustable sample clip. The velocity of the eroding particles is measured using double disc method. In the present study, dry silica sand (angular) of different particle sizes (450, 600 and 800 μm) is used as erodent. Each sample is cleaned in acetone, dried and weighed to an accuracy of ±0.1 mg using a precision electronic balance. It is then eroded in the test rig for 10 min and weighed again to determine the weight loss. The process is repeated till the erosion rate attains a constant value called steady-state erosion rate. The ratio of this weight loss to the weight of the eroding particles causing the loss is then computed as a dimensionless incremental erosion rate. The erosion rate is defined as the weight loss of the specimen due to erosion divided by the weight of the erodent causing the loss.

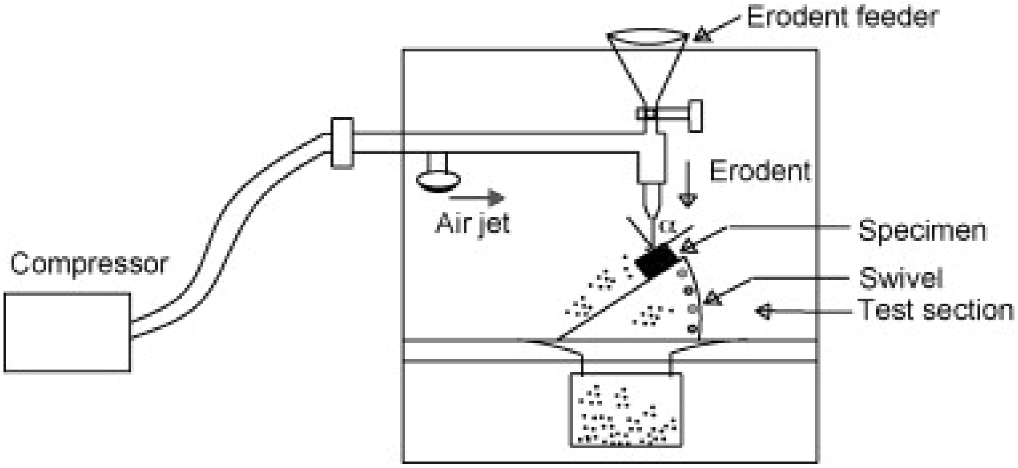

Figure 3.7. A schematic diagram of the erosion test rig

*****

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

- Glass fiber Reinforced polyester resin
- Glass fiber reinforced polyester resin filled with different weight percentage of red mud.

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

Mechanical properties of composites

The characterization of the composites reveals that inclusion of any particulate filler has strong influence on the physical and mechanical properties of composites. The modified values of the properties of the composites under this investigation are presented and compared against the unfilled glass polyester composite in Table 4.1.

Table 4.1. Mechanical properties of the composites

Composites	Hardness (Hv)	Tensile strength (MPa)	Tensile modulus (GPa)	Flexural strength (MPa)	Impact energy (J)
C_1	40	351.02	5.81	371.71	1.25
C_2	45	315.21	5.95	443.23	1.42
C_3	49	292.40	6.23	314.12	1.35

Micro-hardness

The measured hardness values of all the three composites are presented in Figure 4.1. It can be seen that the hardness is increasing with the addition of red mud. It gives higher micro-hardness value as compared to unfilled composite. When the red mud percentage increases, formation of air bubbles and void in composites decreases causing homogeneity in microstructure and affect the mechanical properties.

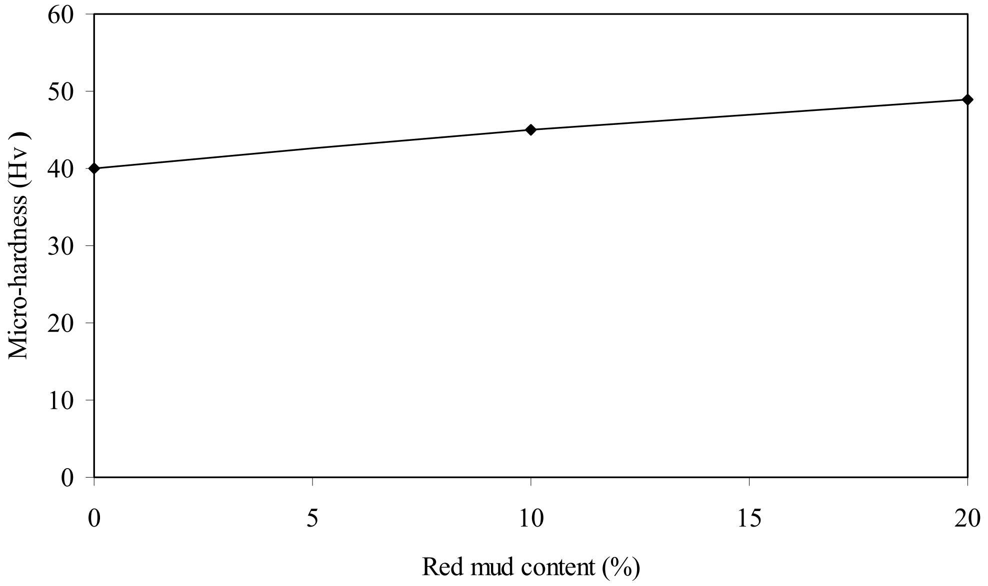

Figure 4.1. Variations of micro-hardness of the red mud filled composites

Tensile Properties

The test results for tensile strengths and moduli are shown in Figures 4.2 and 4.3, respectively. It is seen that in all the samples irrespective of the filler material the tensile strength of the composite decreases with increase in filler content. The unfilled glass polyester composite has a strength of 351.02MPa in tension and it may be seen from Table 4.1 that this value drops to 315.21Mpa and 292.4MPa with the addition of 10wt% and 20 wt% of red mud content respectively. There can be two reasons for this decline in the strength properties of these particulate filled composites compared to the unfilled ones. One possibility is that the chemical reaction at the interface between the filler particles and the matrix may be too weak to transfer the tensile stress; the other is that the corner points of the irregular shaped particulates result in stress concentration in the polyester matrix. These two factors are responsible for reducing the tensile strengths of the composites so significantly.

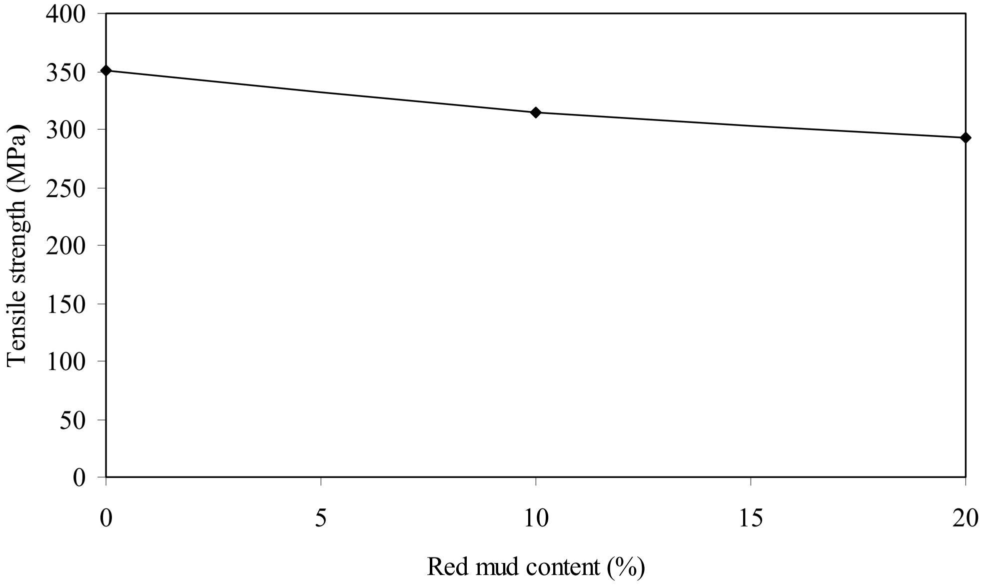

Figure 4.2. Effect of red mud content on tensile strength of glass fiber polyester composites.

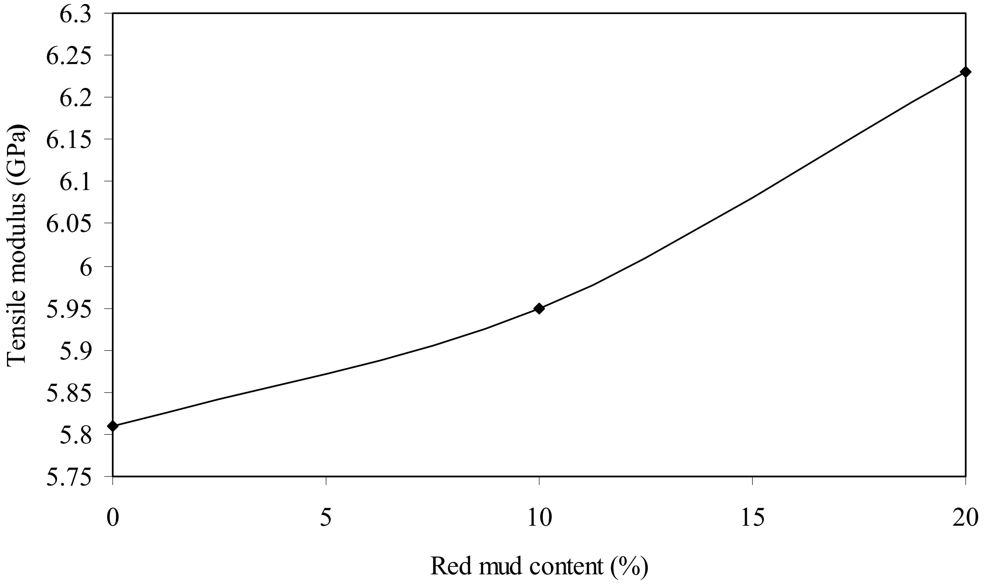

Figure 4.3. Effect of red mud content on tensile modulus of glass fiber polyester composites.

Tensile Modulus

From figure it is clear that with addition of red mud the tensile moduli of the glass polyester composites improve reasonably (Figure 4.3). This improvement is attributed to the relatively lower strain rates of composites C2 and C3 during the tensile test.

Flexural Strength

Figure 4.4 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%) red mud improves the flexural strength of glass polyester composite structure. But further addition (20 wt%) lowers the strength value drastically.

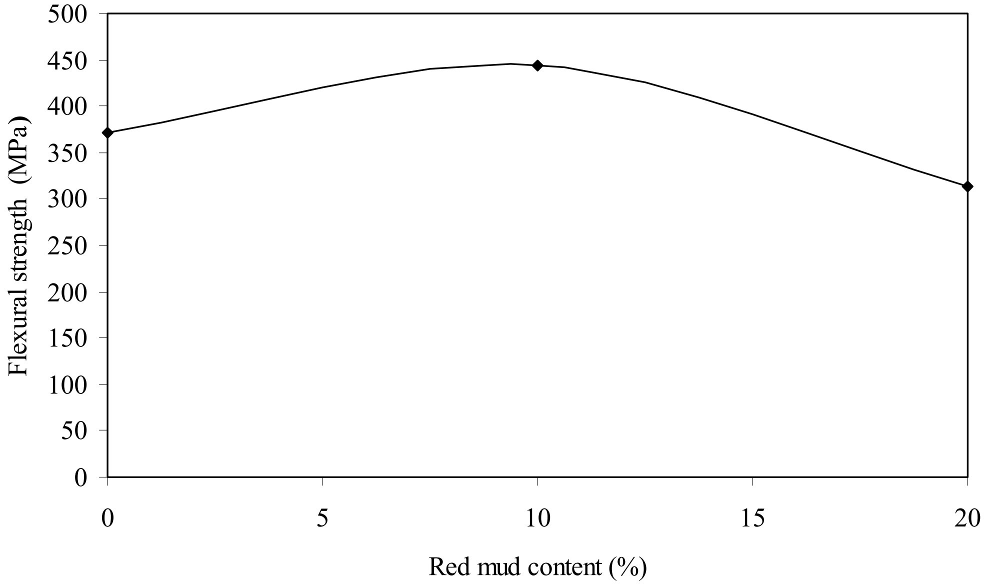

Figure 4.4. Effect of red mud content on flexural strength of glass fiber polyester composites.

Impact Strength

The impact energy values of different composites recorded during the impact tests are given in Table 4.1. It shows that the resistance to impact loading of glass polyester 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 4.5. 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.

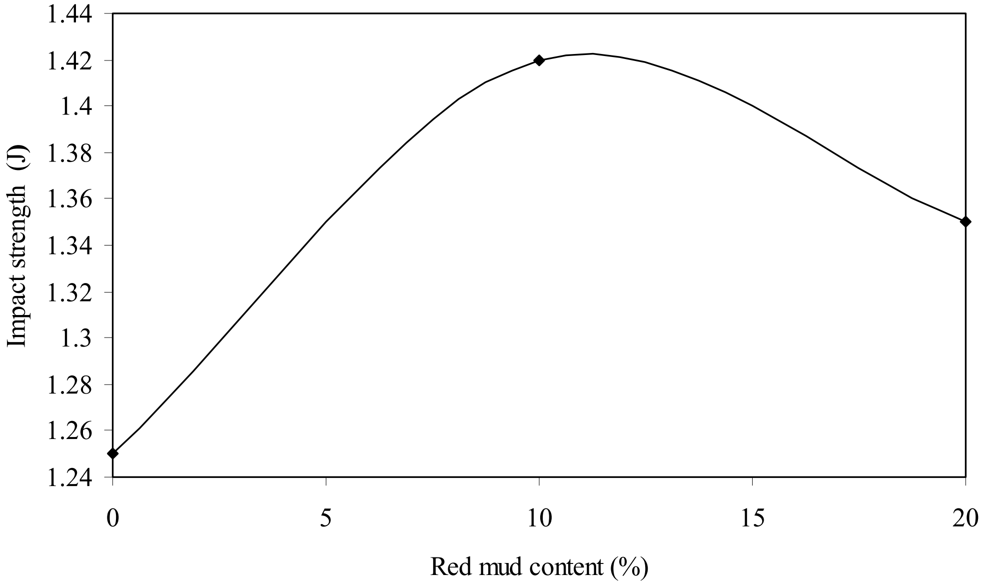

Figure 4.5. Effect of red mud content on impact strength of glass fiber polyester composites.

4.3. Design of experiments via Taguchi method

The Taguchi method involves reducing the variation in a process through robust design of experiments. The overall objective of the method is to produce high quality product at low cost to the manufacturer. The Taguchi method was developed by Dr. Genichi Taguchi of Japan who maintained that variation. Therefore, poor quality in a process affects not only the manufacturer but also society. He developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varied; it allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources. Analysis of variance on the collected data from the Taguchi design of experiments can be used to select new parameter values to optimize the performance characteristic.

The general steps involved in the Taguchi Method are as follows:

1) Define the process objective, or more specifically, a target value for a performance measure of the process. This may be a flow rate, temperature, etc. The target of a process may also be a minimum or maximum; for example, the goal may be to maximize the output flow rate. The deviation in the performance characteristic from the target value is used to define the loss function for the process.
2) Determine the design parameters affecting the process. Parameters are variables within the process that affect the performance measure such as temperatures, pressures, etc. that can be easily controlled. The number of levels that the parameters should be varied at must be specified. For example, a temperature might be varied to a low and high value of 40^{o}C and 80^{o}C. Increasing the number of levels to vary a parameter at increases the number of experiments to be conducted.
3) Create orthogonal arrays for the parameter design indicating the number of and conditions for each experiment. The selection of orthogonal arrays will be discussed in considerably more detail.
4) Conduct the experiments indicated in the completed array to collect data on the effect on the performance measure.
5) Complete data analysis to determine the effect of the different parameters on the performance measure.

The most important stage in the design of experiment lies in the selection of the control factors. Therefore, a large number of factors are included so that non-significant variables can be identified at earliest opportunity**.** Exhaustive literature review on erosion behaviour of polymer composites reveal that parameters viz., impact velocity, red mud content, impingement angle and erodent size etc largely influence the erosion rate of polymer composites. The impact of four such parameters are studied using L_9 (3^4) orthogonal design. The tests are conducted as per experimental design given in Table 4.2.

The fixed and variable parameters chosen for the test are given in Table 4.3. The selected levels of the four control parameters are listed in Table 4.4.

Table 4.2. Orthogonal array for L9 (3^4) Taguchi design

Experiment Number	**Column**			
	1(A)	**2(B)**	**3(C)**	**4(D)**
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 4.3. Parameters of the setting

Control Factors	Symbols	Fixed parameters	
Velocity of impact	Factor A	Erodent	Silica sand
Red mud content	Factor B	Erodent feed rate (g/min)	10.0 ± 1.0
Impingement angle	Factor C	Nozzle diameter (mm)	3
Erodent size	Factor D	Length of nozzle (mm)	80

Table 4.4. Levels for various control factors

Control factor	Level			
	I	II	III	Units
A: Impact velocity	43	54	65	m/sec
B: Red mud content	0	10	20	%
D:Impingement angle	30	60	90	degree
E: Erodent size	300	400	500	µm

In Table 4.2, each column represents a test parameter whereas a row stands for a treatment or test condition which is nothing but combination of parameter levels. In conventional full factorial experiment design, it would require $3^4 = 81$ runs to study five parameters each at three levels whereas, Taguchi's factorial experiment approach reduces it to only 9 runs offering a great advantage in terms of experimental time and cost. The experimental observations are further transformed into signal-to-noise (S/N) ratio. There are several S/N ratios available depending on the type of performance characteristics. The S/N ratio for minimum erosion rate can be expressed as "lower is better" characteristic, which is calculated as logarithmic transformation of loss function as shown below.

Smaller is the better characteristic: $\frac{S}{N} = -10 \log \frac{1}{n}\left(\sum y^2\right)$ (12)

Where 'n' the number of observations and y the observed data. The standard linear graph, as shown in Figure 4.6, is used to assign the factors and interactions to various columns of the orthogonal array [21].

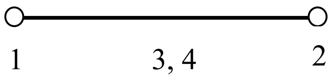

Figure 4.6. Linear Graph for L_9 orthogonal array

The plan of the experiments is as follows: the first column of this orthogonal array is assigned to impact velocity (A), the second column to red mud content (B), the third column to impingement angle (C) and fourth column to erodent size (D) respectively.

*****

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. Taguchi experimental analysis

From Table 5.1, the overall mean for the S/N ratio of the erosion rate is found to be -47.53 db. Figure 5.1 shows graphically the effect of the four control factors on erosion rate. The analysis is 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. Analysis of the result leads to the conclusion that factor combination of A_1, B_1, C_1, and D_2 gives minimum erosion rate. As for as minimization of erosion rate is concerned, factors A, B and C have significant effect whereas factor D has least effect as shown in Table 5.2. It is also observed from figure 5.1 that the significant level of each factor for minimization of erosion rate.

Table 5.1. Experimental design using L_9 orthogonal array

A	B	C	D	Er (mg/kg)	S/N ratio (db)
43	0	30	67	223.45	-46.9836
43	10	60	75	262.55	-48.3842
43	20	90	85	296.96	-49.4540
54	0	60	85	254.65	-48.1189
54	10	90	67	316.77	-50.0149
54	20	30	75	297.76	-49.4773
65	0	90	75	274.78	-48.7797
65	10	30	85	286.67	-49.1476
65	20	60	67	321.87	-50.1536

Table 5.2. Response Table for Signal to Noise Ratios

Level	A	B	C	D
1	-48.27	-47.96	-48.54	-49.05
2	-49.20	-49.18	-48.89	-48.88
3	-49.36	-49.69	-49.42	-48.91
Delta	1.09	1.73	0.88	0.17
Rank	2	1	3	4

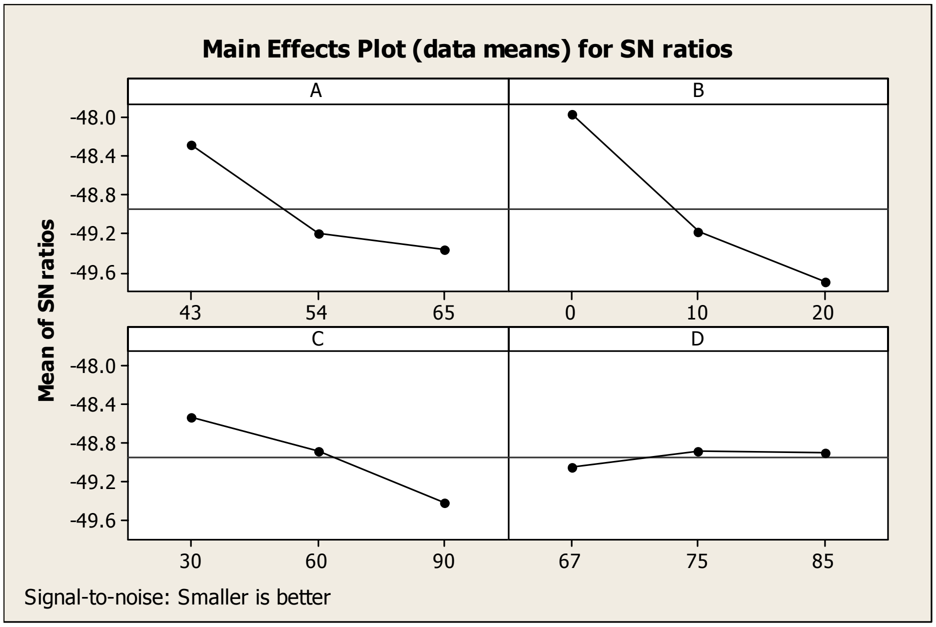

Figure 5.1. Effect of control factors on erosion rate

5.2. Surface morphology of the composites

To characterize the morphology of as-received and eroded surfaces and to identify the mode of material removal, the eroded samples were observed under scanning electron microscope. Figure 5.2 shows the surface of the composite eroded at an impact angle of 60^0. The erodent particle size, stand-off distance and the impact velocity are set at 300µm and 54m/sec respectively. In this micrograph, the crack formation and propagation are clearly visible along with groove formation, which implies the removal of bulk mass of materials from the surface. Figure 5.3 presents the micrograph of the composite surface when eroded with bigger erodent (500µm), and at lower impact velocity (43 m/sec).

Here, a relatively small fraction of the material is seen to be removed from the surface although formation of large amount of grooves is visible. However, crack formation and propagation is not seen. This may be due to either large erodent size which do not help in crack formation or lower impact velocity that has not favored the crack propagation.

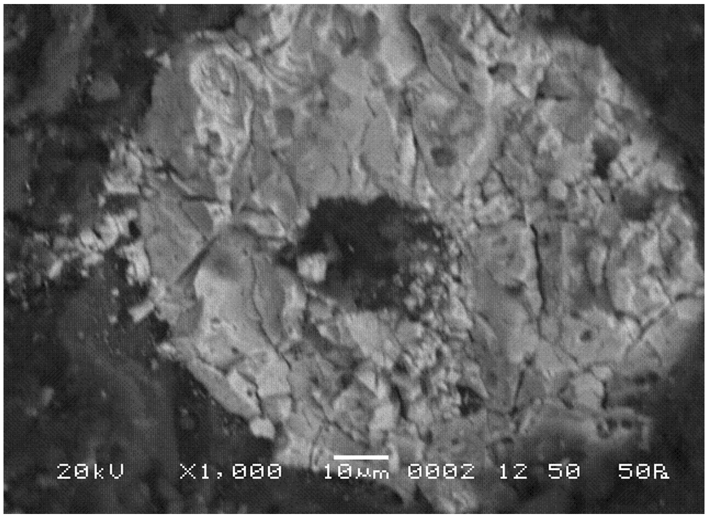

Figure 5.2. Scanning electron micrograph of eroded composite surface (impact velocity 54m/sec, red mud content 20 %, impingement angle 60^0 and erodent size 300µm).

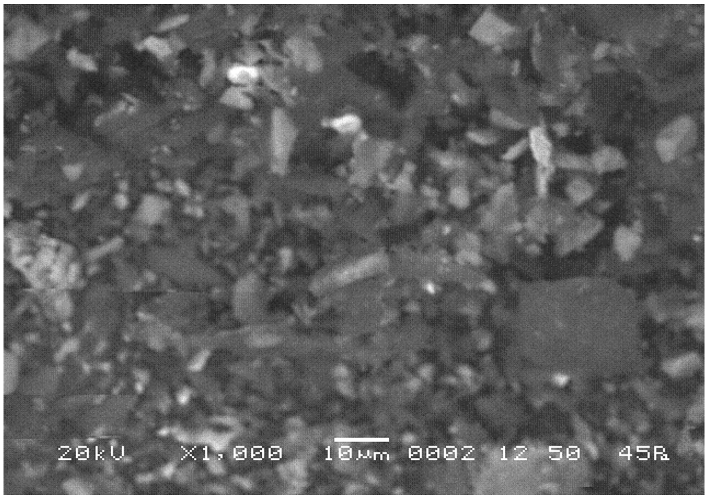

Figure 5.3. Scanning electron micrograph of eroded composite surface (impact velocity 43 m/sec, red mud content 10 %, impingement angle 30^0 and erodent size 500µm).

5.3. ANOVA and the effects of factors

In order to understand a concrete visualization of impact of various factors and their interactions, it is desirable to develop analysis of variance (ANOVA) table to find out the order of significant factors as well as interactions. Table 5.3 shows the results of the ANOVA with the erosion rate. This analysis was undertaken for a level of confidence of significance of 5 %. The last column of the table indicates that the main effects are highly significant (all have very small p-values).

From Table 5.3, one can observe that the erodent size (p=0.686), angle of impingement (p=0.005), velocity of impact (p=0.026) and filler content (p=0.005) have great influence on erosion rate. The filler content and impact velocity and impingement angle show significance of contribution on the erosion rate

Table 5.3. ANOVA table for erosion rate

Source	DF	Seq SS	Adj SS	Seq MS	F	P
A	1	1.7703	1.7703	1.7703	12.02	0.026
B	1	4.5114	4.5114	4.5114	30.64	0.005
C	1	1.1616	1.1616	1.1616	7.89	0.048
D	1	0.0279	0.0279	0.0279	0.19	0.686
Error	4	0.5890	0.5890	0.1473		
Total	8	8.0602				

******

Chapter 6

CONCLUSIONS

6. CONCLUSIONS

This analytical and experimental investigation into the erosion behaviour of red mud filled glass-polyester hybrid composites leads to the following conclusions:

- This work shows that successful fabrication of a glass fiber reinforced polyester composites with and without filler by simple hand lay-up technique.
- An industrial waste like red mud can also be gainfully utilized for the composite making purpose. Incorporation of these fillers modifies the mechanical as well as the tribological properties of the composites.
- A steady decline in the tensile strength is noticed in the filled composites whereas the presence of these particulate matters has caused improvement in impact and flexural strengths of the composites.
- Solid particle erosion characteristics of these composites 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. This approach not only needs engineering judgment but also requires a rigorous mathematical model to obtain optimal process settings.
- The micro-hardness, density and flexural properties of the composites are also greatly influenced by the type and content of fillers.

- Factors like red mud content, impact velocity and impingement angle in order of priority are significant to minimize the erosion rate. Although the effect of erodent size is less compared to other factors, it cannot be ignored because as from literature and past experiment erodent size is also considered one of the major factor.

6.1. Scope for Future Work

Solid particle erosion study of other types of glass fiber except E-glass fiber reinforced with polyester resin composites filled with industrial waste filler has been a much less studied area. There is a very wide scope for future scholars to explore this area of research. In future, this study can be extended to new hybrid composites using other potential fillers and the resulting experimental findings can be similarly analyzed.

******

REFERENCES

REFERENCES

1. Wahl H. and Hartenstein, F.Strahlverschleiss, Frankhsche Verlagshandlung, Stuttgart (1946).
2. G. Bitter, (1963). A study of erosion phenomena. Part II, Wear, 6: 169-190.
3. Raask, E. (1968), Wear, 13: 303-313.
4. Hibbert W.A. and Roy, J. (1965), Aero. Soc., 69: 769-776.
5. Pool, K.V., Dharan, C.K.H. and Finnie, I. (1986). Erosion wear of composite materials, Wear, 107: 1-12.
6. Kulkarni S.M. and Kishore, (2001). Influence of matrix modification on the solid particle erosion of glass/epoxy composites, Polym. Compos., 9: 25-30.
7. Aglan H.A. and Chenock Jr., T.A. (1993). Erosion damage features of polyimide thermoset composites, SAMPE Q. pp. 41-47.
8. Barkoula N.M. and Karger-Kocsis, J. (2002). Effect of fiber content and relative fiber-orientation on the solid particle erosion of GF/PP composite, Wear, 252: 80-87.
9. Tewari, U.S., Harsha, A.P., Hager, A.M. and Friedrich, K. (2002). Solid particle erosion of unidirectional carbon fiber reinforced polyetheretherketone composites, Wear, 252: 992-1000.
10. Friedrich, Häger, K., Dzenis, Y.A. and Paipetis, S.A. (1995). Study of erosion wear of advanced polymer composites. In: K. Street and B.C. Whistler, Editors, Proceedings of the ICCM-10, Canada Wood head Publishing Ltd., Cambridge, 155-162.
11. Miyazaki, N. and Takeda, T. (1993), Solid particle erosion of fiber reinforced plastic, J. Compos. Mater., 27: 21-31.
12. Tilly, G.P. and Sage, W. (1970). The interaction of particle and material behaviour in erosion process, Wear, 16: 447-465.

13. Lindsley, B.A. and Marder, A.R. (1999), The effect of velocity on the solid particle erosion rate of alloys, Wear, 225–229: 510-516.
14. Sundararajan, G.and Manish Roy, (1997). Solid particle erosion behaviour of metallic materials at room and elevated temperatures, Tribol. Int. 30: 339-359.
15. Tamer Sinmazcelik and Isa taskiran, (2006). Erosive wear behaviour of polyphenylenesulphide(PPS) composites,Material and design,28: 2471-2477.
16. Harsha, A.P. and Sanjeev Kumar Jha, (2008). Erosive wear studies of epoxy-based composites at normal incidence, Wear, 265: 1129-1135.
17. Bijwe, J., Logani, C.M., and Tewari, U.S., (1990). Influence of fillers and fiber reinforcement on abrasive wear resistance of some polymeric composites, Wear, 138(1-2):77–92.
18. Wang, J., Gu, M, and Songhao, B, Ge, S, (2003). Investigation of the influence of MoS2 filler on the tribological properties of carbon fiber reinforced nylon 1010 composites, Wear, 255 (1-6):774–779.
19. Sunkara, (2000). The Role of Particulate Inorganic Fillers on the Tribological Behavior of Polyphenylene Sulfide, MS thesis, Iowa State University, Ames.
20. Hanmin, Z, Guoren, He, Guicheng, Y, (1987).Friction and wear of poly (phenylene sulfide) and its carbon fiber composites: I Unlubricated, Wear, 116 (1):59–68.
21. Bahadur, S, Gong, D, and Anderegg, J.W, (1993). Tribochemical studies by XPS analysis of transfer films of nylon 11 and its composites containing copper compounds, Wear, 165 (2):205–212.
22. Bahadur, S, Gong, D, Anderegg, J, (1996). Investigation of the influence of CaS, CaO, and CaF2 fillers on the transfer and wear of nylon by microscopy and XPS analysis, Wear, 197 (1-2): 271–279.
23. Agarwal B D, Broutman L J. Analysis and performance of fiber composites: Second Edition. John Wiley and Sons, Inc.(1990).

******