EROSION WEAR BEHAVIOUR OF BIO-WASTE REINFORCED POLYMER COMPOSITES

A THESIS SUBMITTED IN PARTIAL FULFILMENT
OF THE REQUIREMENT FOR THE DEGREE OF

Bachelor of Technology

In

Metallurgical and Materials Engineering

By

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&
DAVID JOHN (10504030)

Department of Metallurgical and Materials Engineering
National Institute of Technology
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CERTIFICATE

This is to certify that the thesis entitle, "***Erosion wear behavior of Bio-waste reinforced Polymer Composites***" submitted by **GAURAV PRADHAN (10504003) & DAVID JOHN (10504030)** in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Metallurgical and Materials Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the any Degree or Diploma.

Date: 8th May 2009

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ACKNOWLEDGEMENT

I avail this opportunity to extend my hearty indebtedness to my guide **Professor S.C.Mishra**, Metallurgical & Materials Engineering Department, for his valuable guidance, constant encouragement and kind help at different stages for the execution of this dissertation work.

I also express my sincere gratitude to **Professor B.B.Verma**, Head of the Department, Metallurgical & Materials Engineering, for providing valuable departmental facilities.

I am also grateful to **Mr. Samir Pradhan** and **Mr. Rajesh Pattnaik,** Metallurgical & Materials Engineering Department, for their help in carrying out this work.

I am also grateful to **Mr. Nadiya Bihari Nayak** for his help in understanding the various things related to my project.

This project is partially supported by DST, Govt. of India sponsored project (DST/TSG/TC/2005) grant.

Last but not least I thank technical assistants of metallurgical Dept. and my friends to help me directly or indirectly to complete this project successfully.

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ABSTRACT

Composite material has been used in India for last three years. Indigenous production of unsaturated polyester resin has started in 1962 and of glass fibers in 1965, preparing the foundation for growth of composites in India. Polymer composites are gaining popularity in many industrial applications due to their higher specific strength and module.

In recent years the natural or bio-fiber composites have attracted substantial importance as a potential structural material. The attractive features of natural fibers like Jute, Sisal, Coir and banana have been their low cost, light weight, high specific modulus, renewability and biodegradability. Natural composites reinforced with such natural fibers have thus been a subject of intense study for low strength, low cost application in contrast to the synthetic fiber reinforced composite.

In the present work "**Erosion wear behavior of bio-waste reinforced polymer composite**" tests were performed to calculate the erosion rate of the composites with different reinforcements. The composites were fabricated using Epoxy and Polyester resin as polymer, chicken feather and coir dust as reinforcements. Composites without reinforcement and composite with 20% weight fraction reinforcements were made. They were then experimented in the erosion testing machine. The angle of impact was varied keeping other variables constant. Graphs were drawn showing the variation with the mass loss and the erosion rate. The addition of these reinforcements caused a decrease in the density which increases the strength to weight ratio. The erosion test results showed that mass loss and erosion rate increases with the angle of

impact. The erosion rate and mass loss also increase with time but there is a trend of decreasing mass loss and erosion rate at higher time values in reinforced composites. Reinforcement addition decreases the erosion rate. Results showed a lesser erosion rate in coir dust reinforcement than in chicken feather. Also polyester matrix composites showed lesser erosion rate than epoxy matrix composites. Scanning electron microscopy analysis showed that at high angle of impact, high degree of cavitation and formation of cracks is observed in the composites.

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1. INTRODUCTION

1.1 Composites

The material which is composed of two or more different kind of components which are insoluble in each other and maintain their physical phases and they physically and/or chemically separated by a clear-cut interface or interphases called composites. This gives rise to a new material with a combination of properties of both the phases. It consists of a reinforcing material which is embedded in another phase called matrix. Matrix keeps the fibers in desired location and orientation, prevents their abrasion and helps to transfer load between fibers. Matrix is more ductile than fibers. So it is responsible for toughness of composite. Fiber gives stiffness to the composite. High aspect ratio (length/diameter) permits effective load transfer via the matrix. The reinforcement enhances the mechanical properties of the matrix. It is harder, stronger and stiffer than that of the matrix.

The specific properties of composites are listed below.

- Low Density
- High Specific Strength
- High Specific Modulus
- High Thermal Conductivity
- Good Fatigue Modulus
- Control Of Thermal Expansion
- High Abrasion And Wear Resistance

Composites are needed because modern applications require materials with strange combination of properties like low stiffness, high strength, abrasion and impact resistance.

1.2 Uses of composites:

- Advanced composites comprise structural materials that have been developed for high-technology applications, such as airframe structures, for which other materials are not sufficiently stiff. In these materials, extremely stiff and strong continuous or discontinuous fibers, whiskers, or small particles are dispersed in the matrix. A number of matrix materials are available, including carbon, ceramics, glasses, metals, and polymers.

- Components fabricated from advanced organic-matrix composites are used extensively on commercial aircraft as well as for military transports, fighters, and bombers. The propulsion system, which includes engines and fuel, makes up a significant fraction of aircraft weight (frequently 50%) and must provide a good thrust-to-weight ratio and efficient fuel consumption.

- Composites consisting of resin matrices reinforced with discontinuous glass fibers and continuous-glass-fiber mats are widely used in truck and automobile components bearing light loads, such as interior and exterior panels, pistons for diesel engines, drive shafts, rotors, brakes, leaf springs, wheels, and clutch plates.

- Composites are also used for leisure and sporting products such as the frames of rackets, fishing rods, skis, golf club shafts, archery bows and arrows, sailboats, racing cars, and bicycles.

- The excellent electrical insulation, formability, and low cost of glass-fiber-reinforced plastics have led to their widespread use in electrical and electronic applications ranging from motors and generators to antennas and printed circuit boards.

- Advanced composites are used in a variety of other applications, including cutting tools for machining of super alloys and cast iron and laser mirrors for outer-space applications. They have made it possible to mimic the properties of human bone, leading to development of biocompatible prostheses for bone replacements and joint implants. In engineering, composites are used as replacements for fiber-reinforced cements and cables for suspension bridges.

1.3 Classification of composites

Matrix Based

- Polymer Matrix Composites
- Metal Matrix Composites
- Ceramic Matrix Composites

Reinforcement Based

- Fiber Reinforced Composites
- Whisker Reinforced Composites
- Particle Reinforced Composites

Now a day's **polymer composite material** are in massive demand for applications in the field of aerospace vehicles, automobile parts, satellites, sports goods, robots, and thermal insulation structures like cryostats for low temperature technology, hydrogen technology tanks, in superconductivity and also in biomedicine for body compatible implants. These materials exhibit exceptionally good characteristics such as low density, high specific strength, good anticorrosion properties, fatigue resistance and low manufacturing costs.

1.4 Fiber Reinforced Polymer matrix composites:

A fiber reinforced composite consists of fibers embedded in a matrix, with distinct interfaces between the two constituent phases. The fibers are usually of high strength and modulus and serve as the principle load carrying members. The matrix is generally more ductile than the fibers; hence it is the source of composite toughness. We can develop different properties using fibers like high strength, toughness, high-temperature strength, thermal stability. They follow the rule of mixtures. FRPs are typically organized in a laminate structure, such that each lamina (or flat layer) contains an arrangement of unidirectional fibers or woven fiber fabrics embedded within a thin layer of light polymer matrix material. The fibers, typically composed of carbon or glass, provide the strength and stiffness. The matrix, commonly made of polyester, Epoxy or Nylon, binds and protects the fibers from damage, and transfers the stresses between fibers. Among FRP's high strength properties, the most relevant features include excellent durability and corrosion resistance. Furthermore, their high strength-to-weight ratio is of significant benefit; a member composed of FRP can support larger live loads since its dead weight does not contribute significantly to the loads that it must bear. Other features include ease of installation, versatility, anti-seismic behavior, electromagnetic neutrality, excellent fatigue behavior and fire resistance.

Fiber reinforced polymer (FRP) composites are being increasingly considered for use in civil infrastructure. They have tremendous applicability to bridge systems ranging from use in seismic retrofit and strengthening of existing structural components, either in all composite form, or in conjunction with conventional construction materials. FRP composites, today, are used in a variety of applications ranging from replacements for steel reinforcement and tendons in concrete, jackets for retrofit of columns, and externally bonded reinforcement for the rehabilitation of deteriorating structural systems to use in all composite structures such as building frames and even bridge decks.

However, like most structural materials, FRPs have a few drawbacks that would create some hesitancy in civil engineers to use it for all applications: high cost, brittle behavior, susceptibility to deformation under long-term loads, UV degradation, photo-degradation (from exposure to light), temperature and moisture effects, lack of design codes, and most importantly, lack of awareness.

1.5 Constituents of FRP COMPOSITES

The fibers are usually fiberglass, carbon, or aramid fiber.

The polymer may be

Thermosetting -- Epoxy resin, polyester

Thermoplastics – Amorphous – polysalphones

Semi crystalline – PEEK (Poly Ether Ether Ketone)

Crystalline - Nylon

Additives and modifier ingredients expand the usefulness of polymers, enhance their processability or extend product durability.

1.6 Bio Fibers

Bio fibers have recently attracted the attention of scientists and technologists because of the advantages that these fibers provide over conventional reinforcement materials, and the development of bio fiber composites has been a subject of interest for the past few years. These bio fibers have low-cost with low density and high specific properties. These are biodegradable and nonabrasive, unlike other reinforcing fibers. Also, they are readily available and their specific properties are comparable to those of other fibers used for reinforcements. However, certain drawbacks such as incompatibility with the hydrophobic polymer matrix, the tendency to form aggregates during processing, and poor resistance to moisture limit the potential of bio-fibers to be used as reinforcement in polymers [**1–4**].

Another important aspect is the thermal stability of these fibers. These fibers are lingo-cellulosic and consist of mainly lignin, hemi-cellulose, and cellulose. The cell walls of the fibers undergo pyrolysis with increasing processing temperature and contribute to char formation. These charred layers help to insulate the lingo- cellulosic from further thermal degradation. Since most thermoplastics are processed at high temperatures, the thermal stability of the fibers at processing temperatures is important.

Thus the key issues in development of bio reinforced composites are

(i) Thermal stability of the fibers,

(ii) Surface adhesion characteristics of the fibers, and

(iii) Dispersion of the fibers in the case of thermoplastic composites.

1.7 Bio Fiber Reinforced Composites

A bio-composite is a material formed by a matrix (resin) and a reinforcement of bio fibers (usually derived from plants or cellulose). With wide-ranging uses from environment-friendly biodegradable composites to biomedical composites for drug/gene delivery, tissue engineering applications and cosmetic orthodontics, they often mimic the structures of the living materials involved in the process in addition to the strengthening properties of the matrix that was used but still providing biocompatibility. Bio-composites are characterized by the fact that the bolsters (glass or carbon fiber or talc) are replaced by bio fiber (wood fibers, hemp, flax, sisal, jute...)These bio/bio-fiber composites (bio-Composites) are emerging as a viable alternative to glass-fiber reinforced composites especially in automotive and building product applications. The combination of bio-fibers such as kenaf, hemp, flax, jute, henequen, pineapple leaf fiber, and sisal with polymer matrices from both nonrenewable and renewable resources to produce composite materials that are competitive with synthetic composites requires special attention.

Bio fiber–reinforced polypropylene composites have attained commercial attraction in automotive industries. Bio fiber-polypropylene or bio fiber-polyester composites are not sufficiently eco-friendly because of the petroleum-based source and the non-biodegradable nature of the polymer matrix. Using bio fibers with polymers based on renewable resources will allow many environmental issues to be solved. By embedding bio-fibers with renewable resource–based biopolymers such as cellulosic plastics; polylactides; starch plastics; polyhydroxy-alkanoates (bacterial polyesters); and soy-based plastics, the so-called green bio-composites are continuously being developed.

1.8 Mechanical properties of bio fibers:-

As can be seen from Table 1, the tensile strength of glass fibers is substantially higher than that of bio fibers even though the modulus is of the same order. However, when the specific modulus of bio fibers (modulus/specific gravity) is considered, the bio fibers show values that are comparable to or better than those of glass fibers. These higher specific properties are one of the major advantages of using bio fiber composites for applications wherein the desired properties also include weight reduction.

FIBER	SPECIFIC GRAVITY	TENSIL STRENGTH(MPa)	MODULUS(GPa)	SPECIFIC MODULUS
Jute	1.3	393	55	38
Sisal	1.3	510	28	22
Flax	1.5	344	27	50
Sunhemp	1.07	389	35	32
Pineapple	1.56	170	62	40
Glass fiber-E	2.5	3400	72	28

Table 1 Mechanical Properties of Bio Fibers [5]

1.9 Types of Bio Fibers

Bio fibers are grouped into three types: seed hair, bast fibers, and leaf fibers, depending upon the source. Some examples are cotton (seed hairs), ramie, jute, and aflax (bast fibers), and sisal and abaca (leaf fibers). Of these fibers, jute, ramie, flax, and sisal are the most commonly used fibers for polymer composites. On the basis of the source which they are derived from bio fibers can also be grouped as:

- Fibers obtained from plant/vegetable (cellulose: sisal, jute, abaca, bagasse, coir dust)
- Fibers obtained from mineral (minerals: asbestos)
- Fibers derived from animal species (sheep wool, goat hair, cashmere, rabbit hair, angora fiber, horse hair)
- Fibers from bird / aqueous species

Numerous reports are available on the bio fiber composites. The research works on development of bio/bio-fiber reinforced polymer composites have been extensively reviewed also. Many researchers have been conducted to study the mechanical properties, especially interfacial performances of the composites based on bio fibers due to the poor interfacial bonding between the hydrophilic bio fibers such as sisal, jute and palm fibers and the hydrophobic polymer matrices.

Hence keeping the above in view, the present piece research work is undertaken aiming at processing poultry feather and coir dust reinforced polymer composite and to evaluate the physico- mechanical properties at different conditions.

2. LITERATURE SURVEY

Composite materials offer exciting advantages over traditional monolithic materials. Modern advanced composites are a success story from the view point of their widespread applications, ranging from tennis rackets to advanced space vehicles. Aggressive research is being carried out worldwide to explore new composites with improved functional properties. This chapter outlines some of the recent reports published in literature on natural/bio-fiber reinforced composites and on the wear behavior polymer composites

2.1 On natural/bio-fiber reinforced composites

Natural fiber reinforced polymer composites have raised great attention and interest among materials scientists and engineers in recent years due to the considerations of developing an environmental friendly material and partly replacing currently used glass or carbon fibers in fiber reinforced composites [**5**]. They are high specific strength and modulus materials, low priced, recyclable and are easily available. Some experimental techniques, from micro scale to macro scale, such as single fiber pull-out test, single fiber fragmentation test, short beam shear test etc. have been employed to evaluate the interfacial performances of this kind of composites. It is known that natural fibers are non-uniform with irregular cross sections which make their structures quite unique and much different with man-made fibers such as glass fibers, carbon fibers etc. Saheb and Jog [**6**] have presented a very elaborate and extensive review on the reported work on natural fiber reinforced composites with special reference to the type of fibers, matrix polymers, treatment of fibers and fiber-matrix interface. Many researchers have been conducted to study the mechanical properties, especially interfacial performances of the composites based on natural fibers due to the poor interfacial bonding between the hydrophilic natural fibers such as sisal, jute and palm fibers and the hydrophobic polymer matrices. Worldwide laboratories have worked on this topic [**7-10**]**.** But reports on composites using fibers like poultry feathers are rare.

2.2 On poultry feather

Materials derived from chicken (poultry) feathers can also be used advantageously as the reinforcing materials in polymer matrix composites. Such applications can potentially consume the huge quantity of feathers produced annually as a by- product of various poultry units worldwide. Chicken feathers are approximately 91% protein (keratin), 1% lipids, and 8% water [**13**]**.** The amino acid sequence of a chicken feather is very similar to that of other feathers and also has a great deal in common with reptilian keratins from claws [**14**]. The sequence is largely composed of cystine, glycine, proline, and serine, and contains almost no histidine, lysine, or methionine [**15**].

2.3 On Coir dust

Coir dust is the spongy, peat like residue from the processing of coconut husks (mesocarp) for coir fiber. Also known as coco peat, it consists of short fibers (<2cm) around 2% - 13% of the total and cork like particles ranging in size from granules to fine dust. Coir dust strongly absorbs liquids and gases. This property is due in part to the honeycomb like structure of the mesocarp tissue which gives it a high surface area per unit volume. Coir dust is also hydrophilic (attracts water) which means that moisture spreads readily over these surfaces. The extensive film of water that is produced gives moist coir the capacity to absorb air and other gases (odours). Coir dust is a by-product of coir fiber production. Coir fiber is used in a wide variety of ways. Ropes, mats, brushes, furniture, car seat covers, mattresses, packaging, floor coverings, pots and basket liners, erosion control netting, aquarium filters and absorbent pads for cleaning up oil spills are just some of the inventive applications found for this versatile fiber.

2.4 On the erosion wear behavior of polymer composites

The erosion of materials caused by impact of hard particles is one of several forms of material degradation generally classified as wear. Bitter [**16**] defined erosion as “Material damage caused by the attack of particles entrained in a fluid system impacting the surface at high speed” while Hutchings [**17**] wrote “ Erosion is an abrasive wear process in which the repeated impact of small particles entrained in a moving fluid against a surface results in the removal of material from the surface”. Solid particle erosion is a serious problem in gas turbines, rocket nozzles, cyclone separators, valves, pumps and boiler tubes. Polymer composite materials are finding increased application under conditions in which they may be subjected to solid particle erosion. Examples of such applications are pipe lines carrying sand slurries in petroleum refining, helicopter rotor blades [**18, 19**], pump impeller blades, high speed vehicles, air-crafts operating in desert environments, water turbines, and aircraft engine blades [**20**]. Polymers and composites are extensively used in tribo-applications such as bearings, gears etc. where liquid lubricants can not always be used because of various constraints [**18**]. Apart from adhesive wear mode, some polymers and composites have exhibited excellent tribo-potential in other wear situations also such as abrasive, fretting, reciprocating and erosive [**19**]. Comparatively less is reported on erosive wear performance of polymers and composites though some polymers such as rubbers have proved their superiority over metals [**20, 21**]. Finnie [**22, 23**] has done pioneering research in the case of metals. But it is imperative to study erosive wear behavior of polymeric engineering materials as well in various operating conditions. In general, the operating conditions and material properties decide the erosive wear performance of the material. Pool et al. [**24**] though have summarized some general trends about the influence of various factors such as hardness, ductility, brittleness, stress levels, surface finish of materials, erodent and operating conditions on erosive wear behavior of polymers, it is not necessarily true in the case of all polymers and composites. Various researchers have correlated several properties such as hardness, brittleness index, resilience, fracture energy, etc. [**25**] with the erosive wear behavior of polymers and composites. Many researchers have evaluated the resistance of various types of polymers and their composites to solid particle erosion. Materials that have been eroded include nylon, epoxy**,** polypropylene, polyethylene, poly-ether ether-ketone (PEEK) ultra high molecular weight polyethylene (UHMWPE) and various polymer based composites.

There are also several reports in the literature which discuss the erosion behavior of fibrous composites. These papers mainly showed, however, only the erosion behavior and performance to erosive damage. Although various types of fiber are used for reinforcing plastics, no paper has been published in which the effect of types of fiber, e.g. strand mat, woven cloth, unidirectional UD fiber, etc. on sand erosion damage have been discussed systematically. And no convenient method to predict the erosion rate has been reported anywhere.

It is often seen from the published reports that fiber reinforced composite materials compared to neat polymers present a rather poor resistance to solid particle erosion. In spite of this they are attractive for their high specific strength and are frequently used in engineering parts in automobile, aerospace, marine and energetic applications. Due to operational requirements in dusty environment, the erosion characteristics of the polymeric composites are of high relevance. As different mechanism of material removal seems to govern the erosion of polymer matrix composite, it is important to study the behavior of a specific composition in order to identify suitable application areas.

Against this background, the present investigation is undertaken which explores the possible utilization of poultry feathers and coir dust in the form of short fibers in polymer composites. The objective is to study the effect of feather and coir dust reinforcement on the erosive wear behavior of epoxy under multiple impact conditions. An attempt is made to find the process parameters for minimum erosion.

3 EXPERIMENTAL PROCEDURE

3.1 Composite fabrication

Epoxy resins and polyester resins are used as matrix in different type of composites. These materials are noted for their versatility, but their relatively high cost has limited their use. High resistance to chemicals and outstanding adhesion, durability, and toughness has made them valuable as coatings. Because of their high electrical resistance, durability at high and low temperatures, and the ease with which they can be poured or cast without forming bubbles, epoxy resin plastics are especially useful for encapsulating electrical and electronic components. Epoxy resin adhesives can be used on metals, construction materials, and most other synthetic resins. They are strong enough to be used in place of rivets and welds in certain industrial applications.

Epoxy or poly-epoxide is a thermosetting peroxide polymer that polymerizes and cross links when mixed with a catalyzing agent or "hardener". Most common epoxy resins are produced from a reaction between epichlorohydrin and bisphenol-A. Unsaturated isophthalic polyester resin is used as polyester resin, 2%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.

a) with reinforcement of poultry feather

The chicken feathers collected from poultry units are cleaned with a polar solvent, like ethanol, and are dried. The quills are removed and the short fibers (10-15 mm length) are obtained. To prepare the composite slabs, these fibers in pre-determined weight proportion (20%) are reinforced with random orientation into the epoxy resin and polyester resin. A block of size (300mm X 150mm X 6 mm) is thus cast. The casting is 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.

b) with reinforcement of coir dust

The coir dusts collected from coconut husks are dried. The coir dust particles obtained were used to prepare composites. To prepare the composite slabs, these particles in pre-determined weight proportion (20%) are reinforced with random orientation into the epoxy resin and polyester resin. A block of size (300mm X 150mm X 6 mm) is thus cast. The casting is 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.

The detailed compositions along with the designation are presented in Table 2.

EPOXY	100 % Epoxy
POLYESTER	100 % Polyester
EPOXY + CHICKEN FEATHER	Epoxy + 20 wt% chicken feather
EPOXY + COIR DUST	Epoxy + 20 wt% coir dust
POLYESTER + CHICKEN FEATHER	Polyester + 20 wt% chicken feather
POLYESTER + COIR DUST	Polyester + 20 wt% coir dust

Table 2 Fabrication of composites

3.2 Density and void fraction

The theoretical density of composite materials in terms of weight fraction can easily be obtained as for the following equations given by Agarwal and Broutma

$$\rho_{ct} = \frac{1}{\left(\frac{Wf}{\rho f}\right) + \left(\frac{Wm}{\rho m}\right)}$$

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

$$V_{ct} = \frac{\rho ct - \rho ce}{\rho ct} \quad [1]$$

3.3 Flexural strength

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.

$$F.S = \frac{3PL}{2bt^2} \qquad [2]$$

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 Wear

A progressive loss of material from its surface is called wear. It is a material response to the external stimulus and can be mechanical or chemical in nature. Wear is unwanted and the effect of wear on the reliability of industrial components is recognized widely; also, the cost of wear has also been recognized to be high. Systematic efforts in wear research were started in the 1960's in industrial countries. The direct costs of wear failures, i.e., wear part replacements, increased work and time, loss of productivity, as well as indirect losses of energy and the increased environmental burden, are real problems in everyday work and business. In catastrophic failures, there is also the possibility of human losses. Although wear has been extensively studied scientifically, in the 21st century there are still wear problems present in industrial applications. This actually reveals the complexity of the wear phenomenon.

3.5 Solid Particle Erosion Wear

Solid particle erosion (SPE), a typical wear mode, is the loss of material that results from repeated impact of small, solid particles. In some cases SPE is a useful phenomenon, as in sandblasting and high-speed abrasive water jet cutting, but it is a serious problem in many engineering systems, including steam and jet turbines, pipelines and valves carrying particulate matter, and fluidized bed combustion(FBC) systems. Solid particle erosion is to be expected whenever hard particles are entrained in a gas or liquid medium impinging on a solid at any significant velocity. SPE can also occur in a gaseous or liquid medium containing solid particles. In both cases, particles can be accelerated or decelerated, and their directions of motion can be changed by the fluid. Polymer composites are often used as engineering as well as structural components where erosive wear occurs. Due to the operational requirements in dusty environments, the study of solid particle erosion characteristics of the polymeric composites becomes highly relevant. Differences in the erosion behavior of various types of composite materials are caused by the amount, type, orientation and properties of the reinforcement on the one hand and by the type and properties of the matrix and its adhesion to the fibers/fillers on the other. 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. The subject of erosion wear of polymer composites has not received substantial attention in past two decades. Interest in this area is commensurate with the increasing utilization of composites in aerospace, transportation and process industries, in which they can be subjected to multiple solid or liquid particle impact. Examples of these applications are pipe lines carrying sand slurries in petroleum refining, helicopter rotor blades, pump impeller blades, high speed vehicles and aircrafts operating in desert environments, water turbines, aircraft engines, missile components, canopies, radomes, wind screens and outer space applications. Resistance to rain and sand erosion is called among the major issues in the defense application of non-metallic materials. Although a great amount of work has already been devoted to this topic many questions are still open. A comprehensive and systematic investigation of erosion in polymer composites has not been performed yet. There is no clear understanding of the mechanism of erosion and how the properties of the constituents and the interface affect the erosion behavior of these composites. Extensive research is therefore needed to develop various methods and theoretical models for predicting erosion behavior and its dependence on the proportion of the components and the composite-microstructure.

3.6 Erosion Test Apparatus

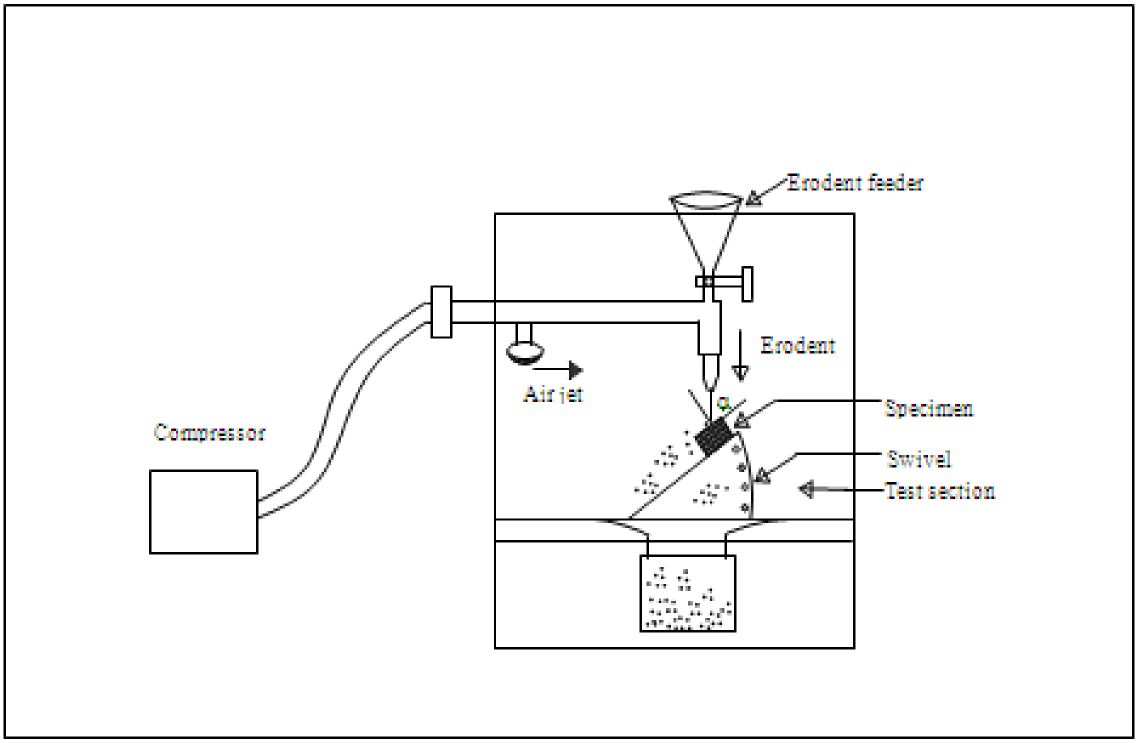
The set up used in this study for the wear test is capable of creating reproducible erosive situations for assessing erosion wear resistance of the prepared composite samples. Erosion is usually simulated in the laboratory by one of two methods. The ‘sand blast’ method, where particles are carried in an air flow and impacted onto a stationary target, and the ‘whirling arm’ method, where the target is spun through a chamber of falling particles. In the present investigation, a self- made erosion apparatus of the “sand blast” type was used. It was designed and then was fabricated in our laboratory. It is capable of creating highly reproducible erosive situation over a wide range of particles sizes, velocities, particles fluxes and incident angles, in order to generate quantitative data on materials and study the mechanism of damaged.

Erosion is an important wear mechanism in industrial applications. Despite the existence of ASTM and DIN standard methods, everyone has their own way of doing erosion tests. ASTM G-76 [74] "Standard Practice for Conducting Erosion Tests by Solid Particle Impingement" in fact acknowledges that one single laboratory test may not be sufficient to evaluate expected service performance. Actual erosion service can involve a range of particle sizes, velocities, attack angles & environments, all of which influence erosion rate. The test performed in this work more or less confirms to the prescribed ASTM G76 standards.

Key parameters to define and control in an erosion test are as follows:

1. Particle velocity. (Not the same as the air velocity, but is often assumed to be)
2. Particle mass flow rate
3. Nozzle wear
4. Particle spread from nozzle
5. Size and shape of particle
6. Angle of impact of the particles

One particular feature of the ASTM G76 method is the fact that the very small jet diameter (1.5-mm) results in the particles "drilling" into the surface. The standard states that the depth of penetration should not exceed 1 mm. This is a deep hole in any surface and in fact the deeper the penetration, the more the physical state of the erosion jet will change (due to interaction of the particles hitting the surface and rebounding).



Description:

The jet erosion rig developed for this work uses a larger nozzle of 3.0 mm bore and 300mm long. This means that operating pressures are very much lower. The nozzle used for the present investigation is made of brass. The advantage of using brass is that internal surface finish can be carefully control and the cost of replacement nozzles when necessary is very low. A larger nozzle diameter results in a wider spread of particles, which is therefore more suited to erosion testing on coatings as well as solid material. There is less of a tendency to "drill" holes in the surface; in addition, there is little influence of rebounding of particles on the impinging jet, resulting in a better controlled erosion process. The larger nozzle size also permits a wider range of particle types to be used in the course of testing, allowing better simulations of real erosion conditions. The mass flow rate was measured by conventional method. Particles are fed from a simple hopper under gravity into the groove.

Key features of the designed setup:

Vertical traverse for the nozzle: provides variable nozzle to target standoff distance, which influences the size of the eroded area.

Different sizes of nozzle may be accommodated: provides ability to change the particle dimensions and the velocity range.

Large test chamber with sample mount (typical sample size 50 mm x 25 mm) that can be angled to the flow direction: by tilting the sample stage, the angle of impact of the particles can be changed and this will influence the erosion process.

The erosion test conditions are shown in Table

Experiment Parameters	
Erodent	Silica Sand
Erodent Size	200 micron
Erodent Shape	Irregular, slightly rounded
Impact Angles	30˚, 45˚, 60˚, 75˚, 90˚.
Stand off distance(cms)	12
Pressure(bar)	5-6
Test Temperature	Room Temperature

Table 3 Parameters used for erosion test

3.7 Scanning electron microscopy

The surfaces of the composite specimens are examined directly by scanning electron microscope JEOL JSM-6480LV after they are eroded to view the fractured and eroded surface. The eroded area is cleaned thoroughly, air-dried and is 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.

4 RESULTS AND DISCUSSION

4.1 Mechanical properties of composite:

In the present investigation the reinforcement of chicken feather and coir dust in short form into epoxy and polyester resin has not shown any encouraging results in terms of mechanical properties. The flexural strength of the composite is measured to be 23.08 MPa when incorporated with 20% wt fraction chicken feather where as that of neat epoxy is about 22.19 MPa. The incorporation of coir dust has caused a little improvement in the flexural strength in epoxy. But there is a decrease in the flexural strength with reinforcement in case of polyesters. However, there enforcement has caused a reduction of about 13% in the composite density which leads to improvement in the strength to weight ratio. The density of the composite is measured to be 0.97 gm/cc (with void fraction of 1.2%) which is less than the density of neat epoxy (1.12 gm/cc)

Sample	Flexural Strength(MPa)
100% Epoxy	22.19
100% Polyester	57.88
Epoxy + 20 wt% Chicken Feather	23.08
Polyester + 20 wt% Chicken Feather	51.54
Epoxy + 20 wt% Coir dust	39.25
Polyester + 20 wt% Coir dust	48.43

Table 4 Flexural strength of different composites

4.2 Wear Studies:

The erosion wear of poultry feather fiber and coir dust are reinforced in epoxy and polyester matrixes are carried out with different sand size by varying speed and distance. It is found that the erosion rate of different composites varies as a function of impingement angle (α). It can be seen that reinforcement of short feather fibers reduces the wear rate of the epoxy resin quite significantly, but poultry feather in particulate form both epoxy and polyester composite do not show any significant result as compared to short fiber poultry feather composite.

In the following graphs:

E – Epoxy

E + CF – Epoxy + 20 wt% chicken feather

E + CD – Epoxy + 20 wt% coir dust

P – Polyester

P + CF – Polyester + 20 wt% chicken feather

P + CD – Polyester + 20 wt% coir dust

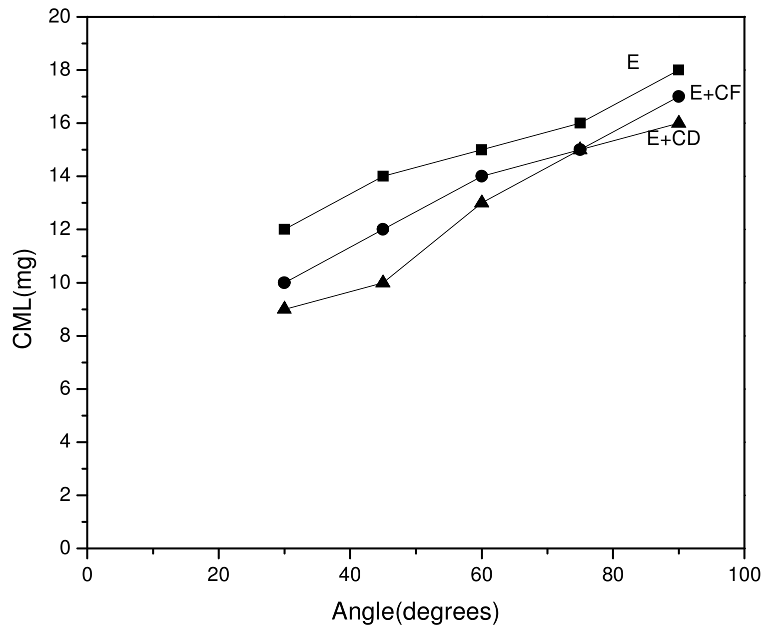


Fig.1 Cumulative mass loss for Epoxy composites at different angles

Fig.1 illustrates the characteristic curve of Cumulative Mass Loss (CML) with respect to Impact angle for Epoxy composites. It is observed that erosion rate increases with increase in impact angle. Maximum mass loss (Max.value-18 mg) is observed in Epoxy at all impact angles. With addition of Chicken Feather and Coir Dust as reinforcement, the mass loss decreases. Mass loss is least for Coir dust reinforced Epoxy composite (Max.value-14 mg). Mass loss observed in case of Chicken feather reinforced Epoxy composite lies in between Epoxy and Coir dust reinforced Epoxy composite (Max.value-16 mg).

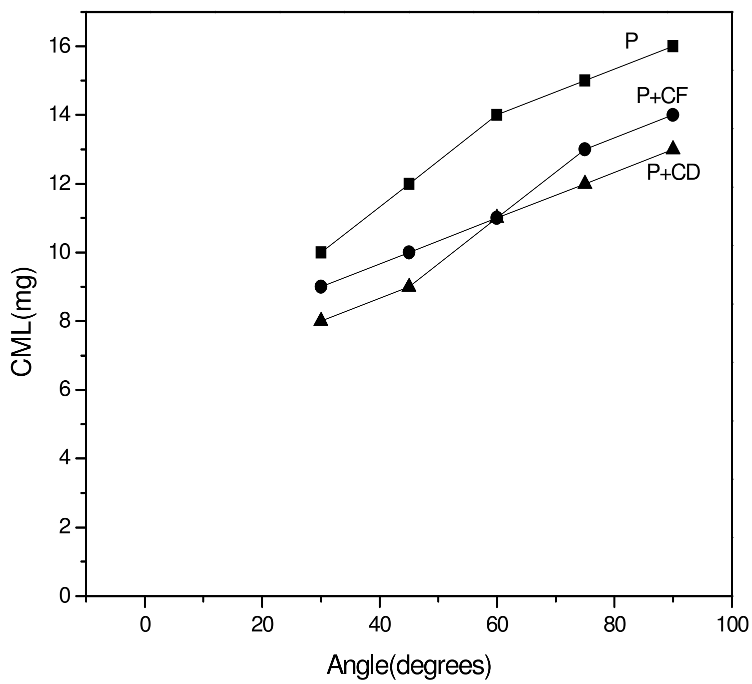


Fig.2 Cumulative mass loss for Polyester composites at different angles

Fig 2 illustrates the characteristic curve of Cumulative Mass Loss (CML) with respect to Impact angle for Polyester composites. It is observed that erosion rate increases with increase in impact angle. Maximum mass loss (Max.value-16 mg) is observed in Polyester at all impact angles. With addition of Chicken Feather and Coir Dust as reinforcement, the mass loss decreases. Mass loss is least for Coir dust reinforced Polyester composite (Max.value-12 mg). Mass loss observed in case of Chicken feather reinforced Polyester composite lies in between Polyester and Coir dust reinforced Polyester composite (Max.value-13 mg).

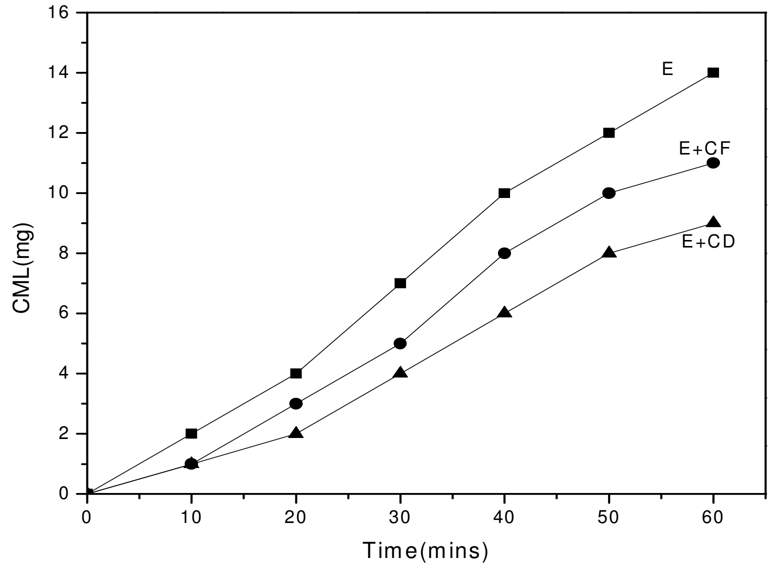


Fig.3 Cumulative mass loss for Epoxy composites with time (at 30˚)

Fig 3 illustrates the characteristic curve of Cumulative Mass Loss (CML) with respect to Time for Epoxy composites at an impact angle of 30˚. Increase in erosion rate is more or less uniform with increasing time. Maximum mass loss (Max. value-14 mg) is observed in Epoxy at all time intervals. With addition of Chicken Feather and Coir Dust as reinforcement, the mass loss decreases. Mass loss is least for Coir dust reinforced Epoxy composite (Max.value-8 mg). Mass loss observed in case of Chicken feather reinforced Epoxy composite lies in between Epoxy and Coir dust reinforced Epoxy composite (Max.value-11 mg). There is a trend of decreasing mass loss at higher time values observed in case of reinforced composites.

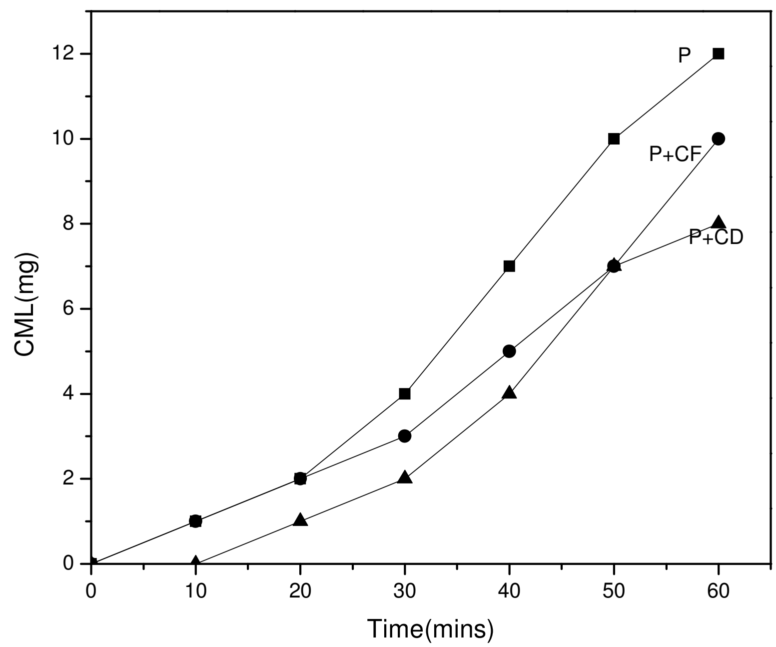


Fig.4 Cumulative mass loss for Polyester composites with time (at 30˚)

Fig 4 illustrates the characteristic curve of Cumulative Mass Loss (CML) with respect to Time for Polyester composites at an impact angle of 30˚. Increase in erosion rate is more or less uniform with increasing time at higher time intervals. Maximum mass loss (Max. value-12 mg) is observed in Polyester at all time intervals. With addition of Chicken Feather and Coir Dust as reinforcement, the mass loss decreases. Mass loss is least for Coir dust reinforced Polyester composite (Max.value-7 mg). Mass loss observed in case of Chicken feather reinforced Polyester composite lies in between Polyester and Coir dust reinforced Polyester composite (Max.value-9 mg). There is a trend of decreasing mass loss at higher time values observed in case of reinforced composites.

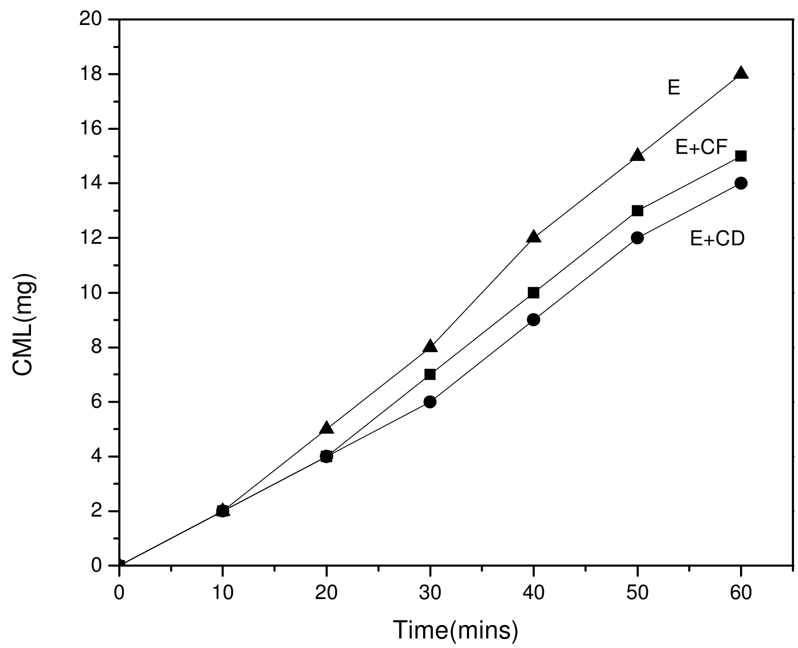


Fig.5 Cumulative mass loss for Epoxy composites with time (at 90˚)

Fig 5 illustrates the characteristic curve of Cumulative Mass Loss (CML) with respect to Time for Epoxy composites at an impact angle of 90˚. Increase in erosion rate is more or less uniform with increasing time. Maximum mass loss (Max. value-18 mg) is observed in Epoxy at all time intervals. With addition of Chicken Feather and Coir Dust as reinforcement, the mass loss decreases. Mass loss is least for Coir dust reinforced Epoxy composite (Max.value-13 mg). Mass loss observed in case of Chicken feather reinforced Epoxy composite lies in between Polyester and Coir dust reinforced Epoxy composite (Max.value-15 mg).

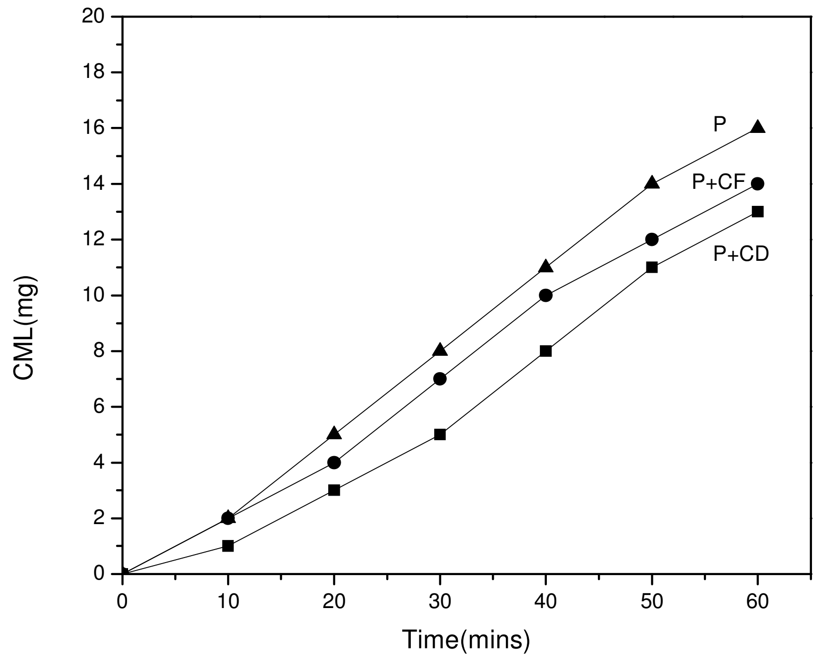


Fig.6 Cumulative mass loss for Polyester composites with time (at 90˚)

Fig 6 illustrates the characteristic curve of Cumulative Mass Loss (CML) with respect to Time for Polyester composites at an impact angle of 90˚. Increase in erosion rate is more or less uniform with increasing time. Maximum mass loss (Max. value-16 mg) is observed in Polyester at all time intervals. With addition of Chicken Feather and Coir Dust as reinforcement, the mass loss decreases. Mass loss is least for Coir dust reinforced Polyester composite (Max.value-12 mg). Mass loss observed in case of Chicken feather reinforced Polyester composite lies in between Polyester and Coir dust reinforced Polyester composite (Max.value-13 mg).

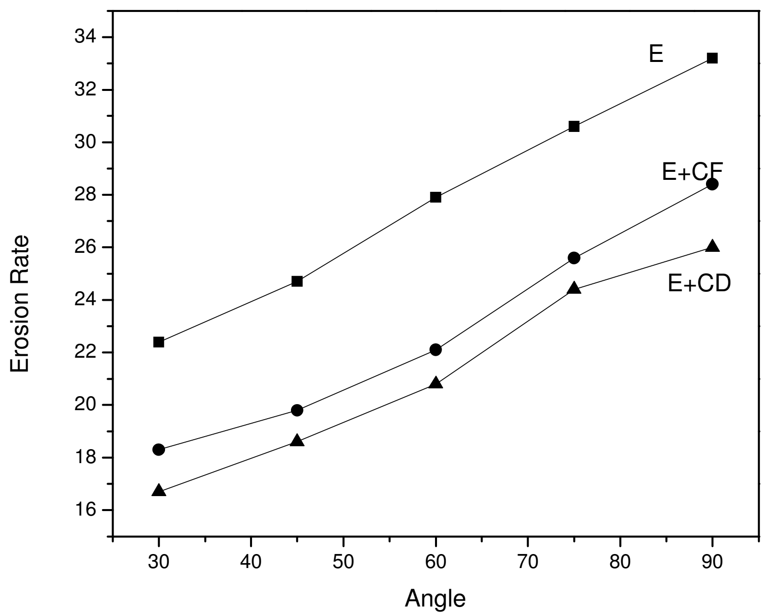


Fig.7 Erosion rates for Epoxy composites at different angles

Fig 7 illustrates the characteristic curve of Erosion rate with respect to Impact angle for Epoxy composites. Increase in erosion rate is more or less uniform with increase in impact angle. Maximum erosion rate (Max.value-33 g/g) is observed in Epoxy at all impact angles. With addition of Chicken Feather and Coir Dust as reinforcement, the erosion rate decreases. Erosion rate is least for Coir dust reinforced Epoxy composite (Max.value-25 g/g). Erosion rate observed in case of Chicken feather reinforced Epoxy composite lies in between Epoxy and Coir dust reinforced Epoxy composite (Max.value-27 g/g). There is a trend of decreasing erosion rate at higher angles observed in case of reinforced composites.

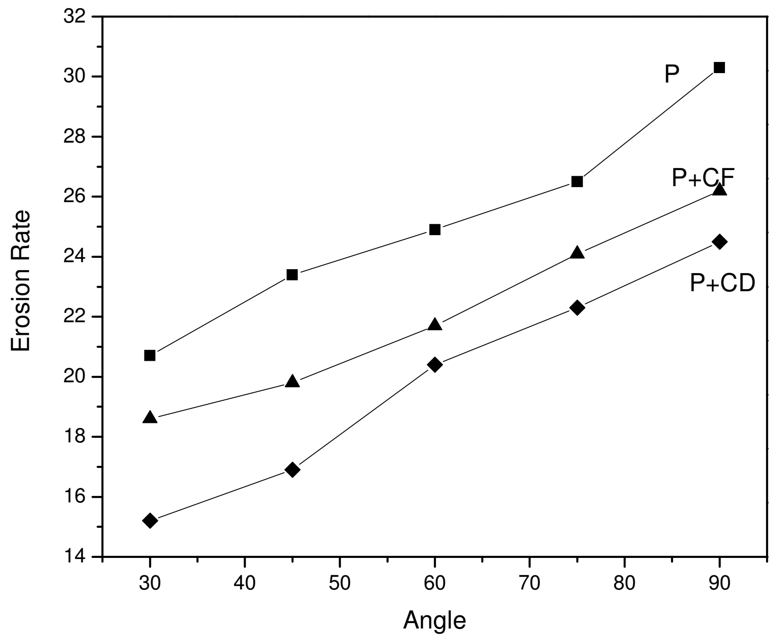


Fig.8 Erosion rates for Polyester composites at different angles

Fig 8 illustrates the characteristic curve of Erosion rate with respect to Impact angle for Polyester composites. Increase in erosion rate is more or less uniform with increase in impact angle. Maximum erosion rate (Max. value-30 g/g) is observed in Polyester at all impact angles. With addition of Chicken Feather and Coir Dust as reinforcement, the erosion rate decreases. Erosion rate is least for Coir dust reinforced Polyester composite (Max.value-24 g/g). Erosion rate observed in case of Chicken feather reinforced Polyester composite lies in between Polyester and Coir dust reinforced Polyester composite (Max.value-26 g/g). There is a trend of decreasing erosion rate at higher angles observed in case of reinforced composites.

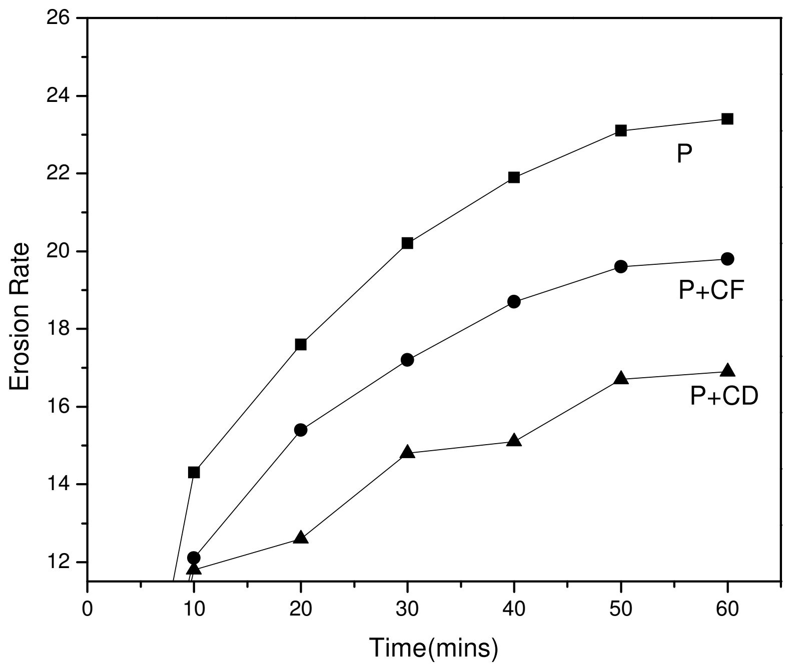


Fig.9 Erosion rates for Polyester composites at different time (at 30˚)

Fig 9 illustrates the characteristic curve of Erosion rate with respect to Time for Polyester composites at impact angle of 30˚. Increase in erosion rate is more or less uniform with increase in time. Maximum erosion rate (Max.value-24 g/g) is observed in Polyester at all time intervals. With addition of Chicken Feather and Coir Dust as reinforcement, the erosion rate decreases. Erosion rate is least for Coir dust reinforced Polyester composite (Max.value-17 g/g). Erosion rate observed in case of Chicken feather reinforced Polyester composite lies in between Polyester and Coir dust reinforced Polyester composite (Max.value-20 g/g). There is a trend of decreasing erosion rate at higher time values, almost attaining a stable state, observed in case of reinforced composites.

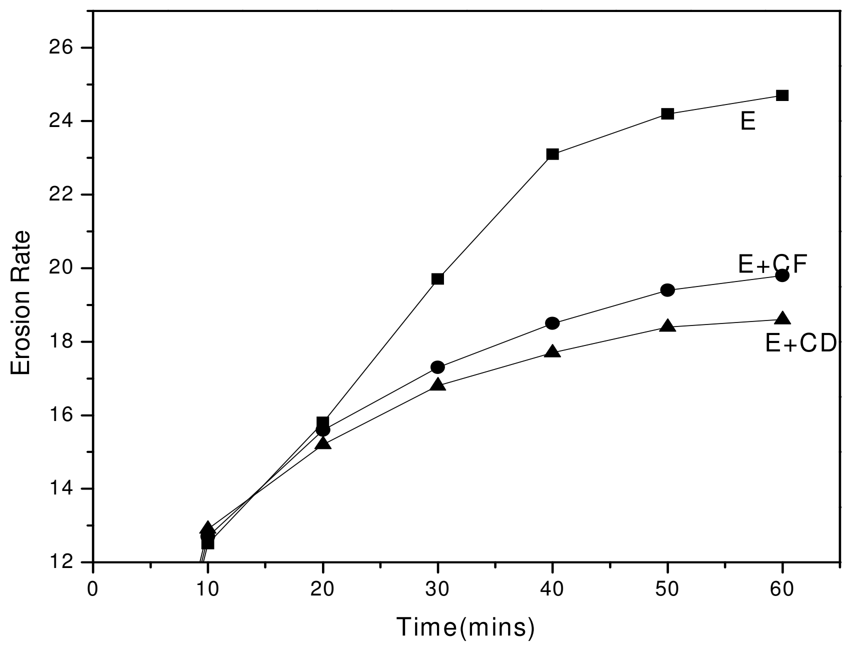


Fig.10 Erosion rates for epoxy composites at different time (at 30˚)

Fig 10 illustrates the characteristic curve of Erosion rate with respect to Time for Epoxy composites at impact angle of 30˚. Increase in erosion rate is more or less uniform with increase in time. Maximum erosion rate (Max.value-25 g/g) is observed in Epoxy at all time intervals. With addition of Chicken Feather and Coir Dust as reinforcement, the erosion rate decreases. Erosion rate is least for Coir dust reinforced Epoxy composite (Max.value-18 g/g). Erosion rate observed in case of Chicken feather reinforced Epoxy composite lies in between Epoxy and Coir dust reinforced Epoxy composite (Max.value-19 g/g). There is a trend of decreasing erosion rate at higher time values, almost attaining a stable state, observed in case of reinforced composites.

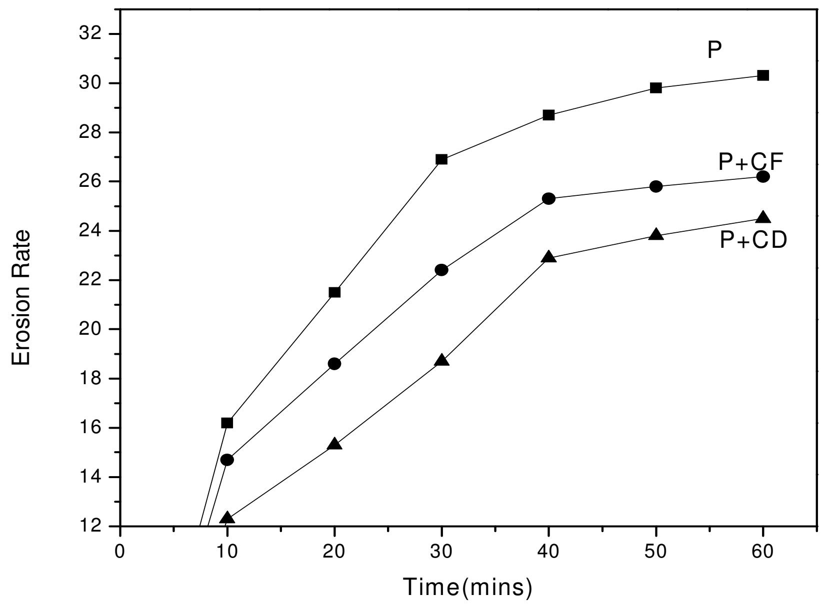


Fig.11 Erosion rates for Polyester composites at different time (90˚)

Fig.11 illustrates the characteristic curve of Erosion rate with respect to Time for Polyester composites at impact angle of 90˚. Increase in erosion rate is more or less uniform with increase in time. Maximum erosion rate (Max.value-30 g/g) is observed in Polyester at all time intervals. With addition of Chicken Feather and Coir Dust as reinforcement, the erosion rate decreases. Erosion rate is least for Coir dust reinforced Polyester composite (Max.value-24 g/g). Erosion rate observed in case of Chicken feather reinforced Polyester composite lies in between Polyester and Coir dust reinforced Polyester composite (Max.value-26 g/g). There is a trend of decreasing erosion rate at higher time values, almost attaining a stable state, observed in case of reinforced composites.

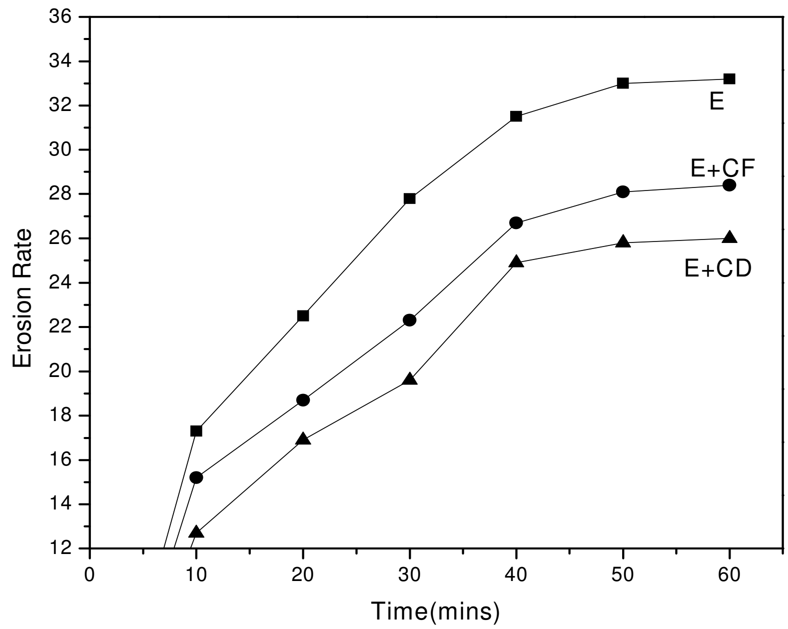


Fig.12 Erosion rates for epoxy composites at different time (90˚)

Fig.12 illustrates the characteristic curve of Erosion rate with respect to Time for Epoxy composites at impact angle of 90˚. Increase in erosion rate is more or less uniform with increase in time. Maximum erosion rate (Max. value-33 g/g) is observed in Epoxy at all time intervals. With addition of Chicken Feather and Coir Dust as reinforcement, the erosion rate decreases. Erosion rate is least for Coir dust reinforced Epoxy composite (Max.value-25 g/g). Erosion rate observed in case of Chicken feather reinforced Epoxy composite lies in between Epoxy and Coir dust reinforced Epoxy composite (Max.value-28 g/g). There is a trend of decreasing erosion rate at higher time values, almost attaining a stable state, observed in case of reinforced composites.

4.3 SEM Analysis

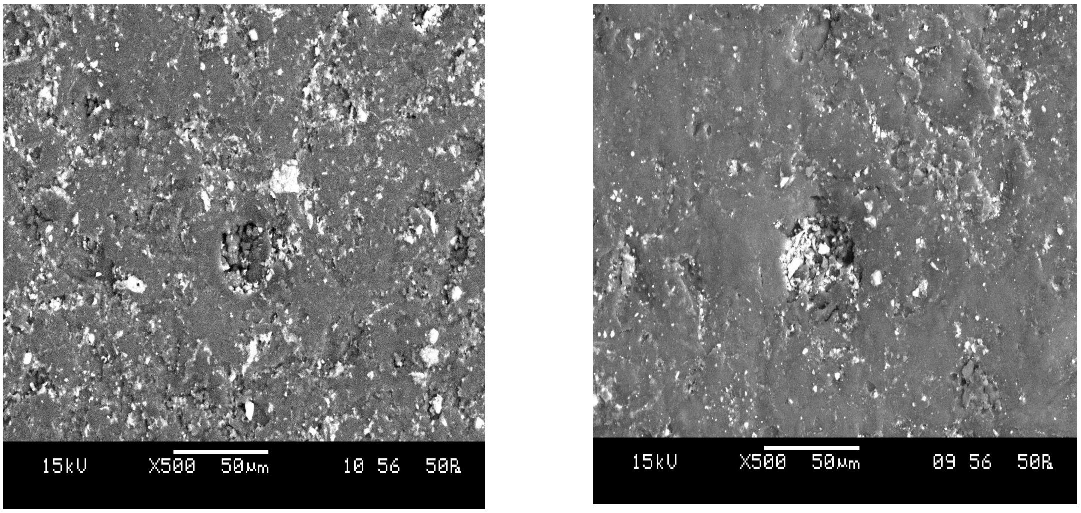


Fig.13 SEM of pure Epoxy at impact angle (i) 30^0 (ii) 90^0

Fig.13 shows the eroded surface of epoxy when impacted at 30^0 and 90^0. For 30^0, impact the figure shows a number of pits whereas when impacted at 90^0, less number of pits is observed.

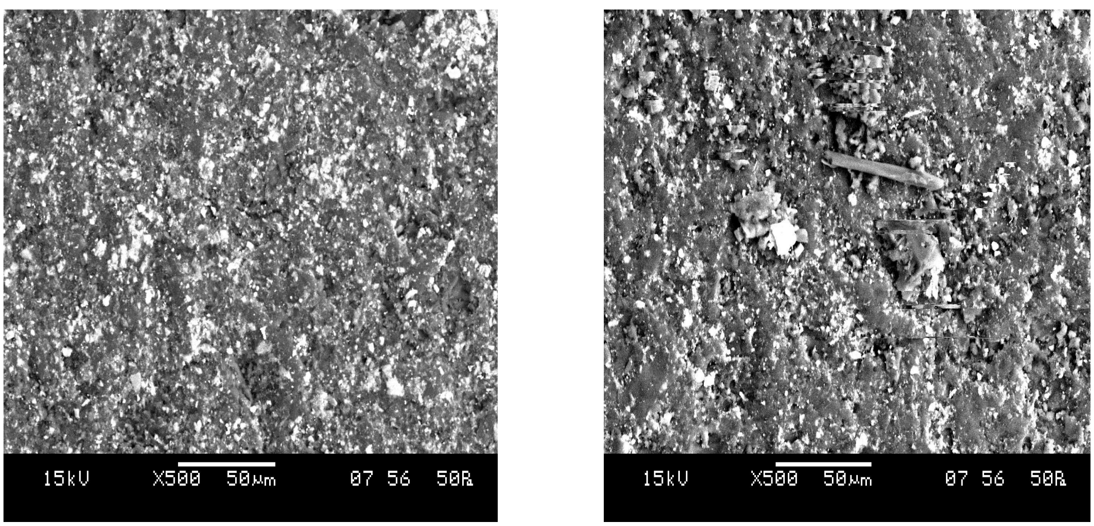


Fig. 14 SEM of Epoxy + 20 wt% Coir dust at impact angle (i) 30^0 (ii) 90^0

Fig.14 shows eroded surfaces of epoxy with coir dust as reinforcement. At 30˚, there is layer removal and fragmented things are found whereas at 90˚, pore structure is observed.

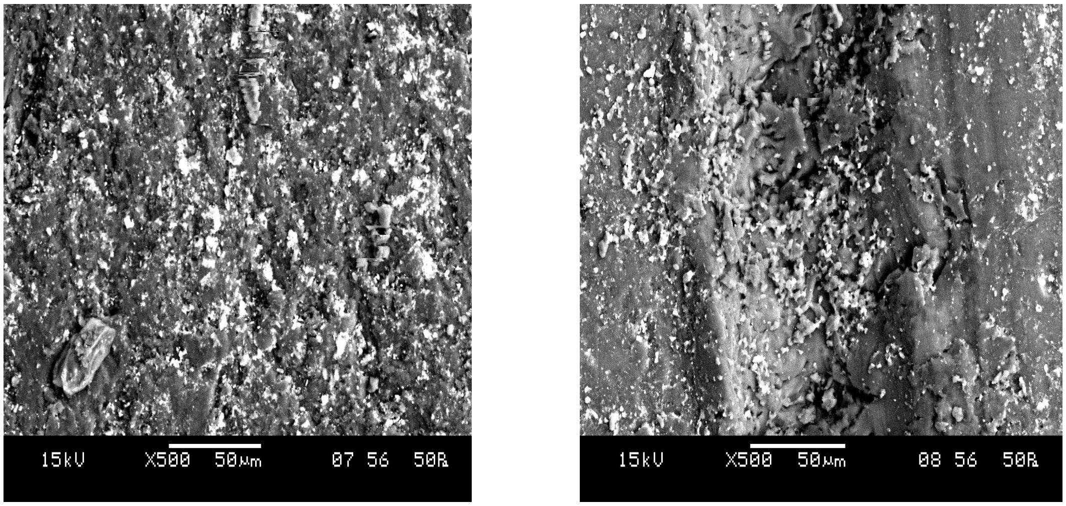


Fig.15. SEM of Epoxy + 20 wt% Chicken feather at impact angle (i) 30^0 (ii) 90^0

Fig.15 shows the eroded surface of epoxy with chicken feather as reinforcement. At 30˚, the material is removed layer wise (like the movement of slurry) and cavitation is almost not present. At 90˚, there are origin of cracks which are spreaded in different direction (multi-directional propagation of cracks) and cavitation is observed.

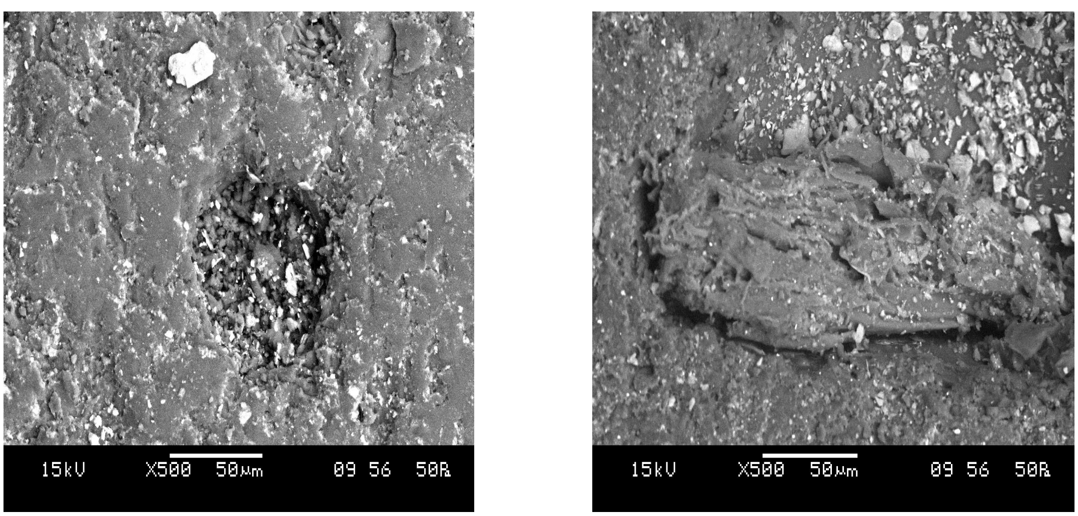


Fig.16. SEM of pure Polyester at impact angle (i) 30^0 (ii) 90^0

Fig.16 shows the eroded surface of polyester. At 30˚, the surface is flat and no cracks are observed. Small pits are observed with less material removal. At 90˚, more amount of material is removed. Fragmented things are found.

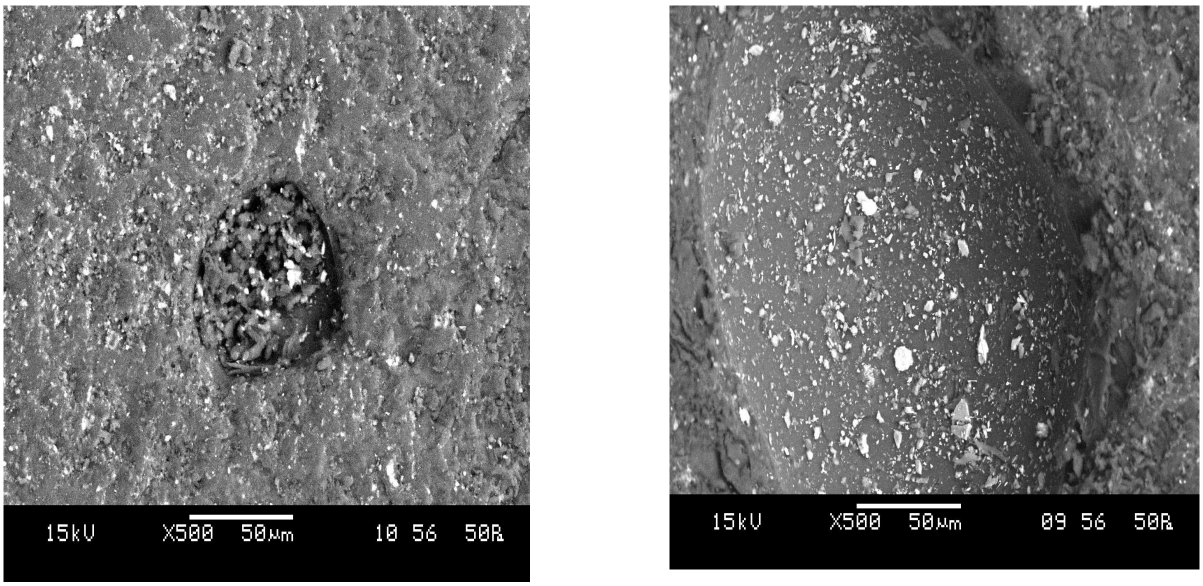


Fig.17. SEM of Polyester + 20 wt% Coir dust at impact angle (i) 30^0 (ii) 90^0

Fig.17 shows the SEM of Polyester + 20 wt % Coir Dust composite after erosion testing of impact angle 30˚ & 90˚ respectively. In Fig.17(i), the matrix surface is observed to be almost flat which signifies that the erosion of the matrix surface has been more or less uniform. Some cavitation is also observed along with removal of some amount of reinforcement (coir dust).

In Fig.17(ii) we see that the cavitation is more and also deeper pits are formed in comparison to the surface of the specimen subjected to erosion at an impact angle of 30˚.

Multi-directional cracks are seen on the edges of the pit due to higher magnitude of the normal component of the impact velocity, which is not seen in the case specimen subjected to erosion at an impact angle of 30˚.

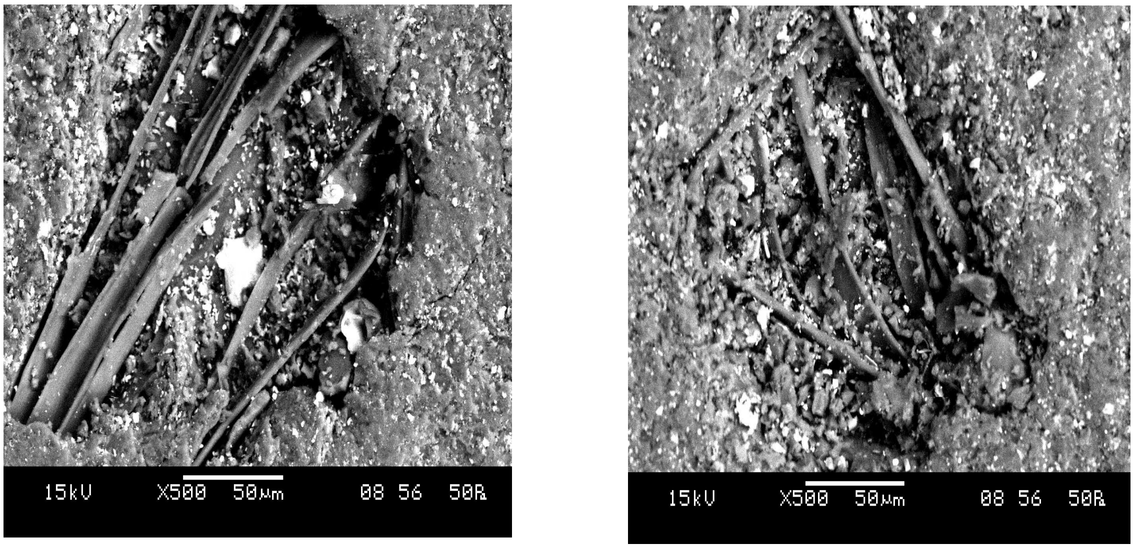


Fig.18. SEM of Polyester + 20 wt% Chicken Feather at impact angle (i) 30^0 (ii) 90^0

Fig 18 shows the SEM of Polyester + 20 wt% Chicken Feather composite after erosion testing of impingement angle 30˚ & 90˚ respectively. In Fig.18(i), removal of matrix material is observed along with exposure of fibers to the surface. Fiber breakage is also observed at some points along with some amount of cavitation. In Fig.18(ii), removal of matrix material is observed with greater degree of severity as compared to Fig.18(i). Fiber breakage is more in this case because of the higher magnitude of the normal component of impact velocity where as in Fig.18(i), the tangential component of impact velocity is more. Some multidirectional crack as also observed in Fig.18(ii).

CONCLUSIONS

1. Chicken feather & Coir dust reinforced PMC can be successfully fabricated.
2. The erosion rate behavior is different for oblique and at normal impact angles.
3. The results indicate that angle of impact is the most important parameter during erosion. The angle of impact greatly affects the erosion wear behavior of poultry feather and coir dust reinforced epoxy and polyester matrix composites. Maximum erosion rate is observed at 90˚ impact angle.
4. Coir dust reinforced PMCs show better resistance to erosion compared to Chicken feather reinforced PMCs and PMCs.
5. Polyester composites showed better resistance to erosion than epoxy composites.
6. At higher impact angles, high degree of cavitation along with formation of cracks is observed in case of all the PMCs.
7. Steady state erosion rate is observed in case of reinforced PMCs at higher time values.
8. There is no pronounced improvement in flexural strength of PMCs after introducing the reinforcement. There is a slight increase in flexural strength of chicken feather reinforced PMCs compared to other coir dust reinforced PMCs and PMCs. However, the density of the composites decreases due to the reinforcements which tend to increase the strength to weight ratio which is an important parameter in industrial and commercial application of composite.

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