Journal of Basic and Applied Engineering Research
p-ISSN: 2350-0077; e-ISSN: 2350-0255; Volume 4, Issue 2; January-March, 2017, pp. 145-156

http://www.krishisanskriti.org/Publication.html

"A Study on Mechanical Characterization and Solid Particle Erosion Response of Glass Fiber Epoxy Based Composite with Filler SiC"

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Abstract—*The present research work is undertaken to study the mechanical characterization and erosion wear performance of glass fibre reinforced epoxy composites with and without particulate filler. Attempts have been made to explore the possible use of Silicon Carbide (SiC) as filler materials in these composites. To make an assessment of their reinforcing potential in terms of wear performance and mechanical properties. The glass epoxy composite without filler has a strength of 90.92 MPa in tension at maximum load 4.64 kN and this value drops to 78.82 MPa with addition of 5wt% filler and increase with addition of 10wt% SiC respectively.the glass epoxy composites without filler has a maximum tensiles modulus and also increase with increasing filler. The glass epoxy composite without filler has a flexural strength of 126.18 MPa at maximum load 2.57 kN,flexural strength increase with increasing particulate filler.flexural modulus also increase with increasing load and particulate filler. the glass-epoxy composites have maximum erosion rate without particulate filler and minimum with addition of 10wt% SiC at constant impingement angle 60°. The glass-epoxy composites have maximum erosion rate without particulate filler and minimum with addition of 10wt% SiC with impingement angle of 45° at constant velocity 70m/sec respectively.*

This study indicates that erosion wear performance of glass fibre epoxy with filler based composites is better than that of the glass fibre reinforced composites without filler..Then, a series of erosion experiments are conducted using an air jet type test rig on these composites under various test conditions. For this purpose, an experiment schedule is prepared following design of experiments approach using Taguchi's orthogonal arrays in order to reduce the number of experiments without sacrificing the information to be extracted.The analytical and experimental investigation suggests that successful fabrication of glass-epoxy composites with reinforcement of ceramic filler (SiC) is possible. Incorporation of filler modifies the tensile, flexural strength, tensile modulus and flexural modulus of the glass fibre epoxy composites.The presence of particulate filler in these composites improves their erosion wear resistance also depends on the particulate filler. Erosion characteristics of these composites have been successfully analyzed using Taguchi experimental design scheme.

Keywords*: Mechanical properties, SiC filler, chopped glass fibre, epoxy resin, Taguchi method, ANOVA, wear,*

1. INTRODUCTION

A composite material is made by combining two or more dissimilar materials. They are combined in such a way that the resulting composite material or composite possesses superior properties which are not obtainable with single constituent materials. the most common synthetic composite material is glass fibre reinforced plastics(GRP) due to high strength and sufficiently stiff and durable. Composites are materials consisting of two or more chemically distinct constituents on a micro- scale having a distinct interface separating them. One or more discontinuous phase are therefore, surrounded in a continuous phase to appearance a composites [1]. When the matrix is a a ceramic, the composite is called ceramic matrix composite (CMC) and when the matrix material is a polymer, the composite is called polymer matrix composite (PMC).

Due to operational requirements in grimy environment, the erosion characteristics of these composites have essential importance. Since erosive wear of engineering components caused by abrasive particles is a major industrial problem, a complete accepting of the effects of all system variables on the wear rate is necessary in order to assume appropriate steps in the design of machine or structural component and in the choice of materials to reduce/control wear. The most common synthetic composite material is glass fibre reinforced plastics (GRP) which is made out of plastics and glass fibre. Fibre reinforcement polymer composites used in aircraft, helicopters, space-craft, satellites, ships, submarines, automobiles and transportation industry, chemical engineering industry ,defence industry, sporting goods and civil infrastructure. There is a potential for common use in medical prosthesis and micro devices. Composites are important materials because of their light weight, high strength, durability, stiffness, excellent fatigue resistance and outstanding corrosion resistance compared to most common metallic alloy such as steel and iron. Advantages of composites include the ability to fabricate, improves

mechanical properties, low thermal expansion coefficients and high dimensional stability.

Composite materials are usually costlier as compared to conventional materials but at rest their use is becoming more and more popular because of their lightness, high specific properties, design and processing flexibility, functional superiority and durability. Mostly, composites used in engineering applications contain fibres made of glass, carbon or aramid.The fibre used in FRP materials can be in the form of small particles, whiskers or continuous filament. The matrix materials employed for fabrication of composite materials are usually polymers commonly called resins. Polymers are thermosetting(e.g.phenol- furfural, urea- formaldehyde, epoxy, polyester) and thermoplastic(e.g. cellulose nitrite,polymides, polyvinyl alcohol , polyisobutylene) resins.composite materials possess a unique combination of properties such as high strength to weight ratio,better toughness, fatigue and stiffness, better corrosion, fire resistance, electrical insulation and anti- friction properties,easy of fabrication or versatility of fabrication methods, better durability and low maintenance cost.Continuous fibre composites are characterised by a two-dimensional (2D) laminated stracture in which the fibres are aligned along the plane(x-and y- directions) of the material. The use of FRP composites continuous to grow at any impressive rate as these materials are used more in their exixting markets and become established in relatively new markets such as biomedical devices and civil structures [2].

Polymer matrix reinforced composites by woven fabrics is probably the most commonly used form of composites in structural application such as air craft, boats, automobiles, etc. The aircraft industry is an motivating application area for new types of quickly manufactured composites because they use prolonged high temperature curing processes for fabrication of composite parts, which is acceptable if high performance materials or high utilization temperatures are required [3].The physical and mechanical characteristics can further be modified by adding a solid filler phase to the matrix composite during the preparation. The improved performance of polymers and their composites in industrial and structural applications by the addition of particulate filler materials has shown a vast secure and so has lately been a subject of considerable interest. Fillers (additives) are added to enhance and modify the quality of composites. The filler play a major role in determining the properties and behaviour of particulate reinforced composite materials .these are invariably used in reasonably large loadings (above 15%). Filler are commonly additional to reduce cost, to recover processing properties and mechanical /electrical/physical properties. The terms additives describes those materials usually added to matrix. The additives are usually added to improve some specific properties e.g surface, thermal, environmental-and they are added in smaller loadings(less than 10%).

There are many examples of these applications are pipe lines carrying sand slurries in Petroleum refining, Helicopter rotor blades [4], Pump impeller blades, high speed vehicles and aircrafts operating in desert environment, water turbines, air craft engines [5]. Studies made on the erosive wear of composites refer more on fibre reinforced polymers (FRP) and less on filler–reinforced – systems. The effect of fibres is considered more as modification of the matrix and less as reinforcement, possible because of the low % of fillers.

Statistical methods have usually been used for analysis, calculation and / or optimization of a quantity of engineering processes. These methods enable the user to define and study the effect of every single condition possible in an experiment where many factors are involved. Solid Particle erosion is a composite wear phenomenon in which a number of control factors jointly determine the performance output (i.e. erosion rate) and there is vast scope in it for implementation of appropriate statistical techniques for process optimization. The present work addresses to this aspect by adopting a efficient statistical approach called Taguchi method to optimize the process parameters leading to minimum erosion of the glass fibre polymer composites under the study.Against this condition, the present work has been undertaken to investigate the erosion characteristics of epoxy based composites. The focus has been on fabrication of a series of composites (glass-fibre-reinforced epoxy composites with and without fillers), evaluation of their mechanical properties, assessment of their relative wear performance and on statistical interpretation of the various test result.

2. MATERIALS AND METHODS

2.1 Matrix Material

The matrix comprised organic, polyester, thermo-stable, vinyl ester, phenolics and epoxy resin. Matrix materials are of dissimilar types of metals, ceramics and polymers. Polymer matrices are basically used because of cost efficiency, ease of fabricating complex parts with less tooling cost and they also have excellent room temperature properties when compared to metal and ceramic matrices.Epoxy groups are made by condensation of epichlorohydrin and biphenyl-A. Epoxy resins are regarded as compounds which include more than one epoxy group, able of being converted to cured (thermoset) form through the help of hardeners/curing agents. Polymer matrices can be either thermoplastic or thermoset. Thermoset matrices are produced due to an irreversible chemical transformation of the resin into a formless cross-linked polymer matrix. Due to infinite molecular structures, thermoset resins provide good electrical and thermal insulation. They have low viscosity, which allow excellent thermal stability and better creep resistance.

The most thermoset resins like epoxy, polyester, vinyl ester and phenolics are commonly used. Among them, the epoxy resins are being widely used for many advanced composites due to their excellent adhesion to variety of fibres, higher mechanical and electrical properties and good performance at

superior temperature. In adding together they have low shrinkage upon curing and good chemical resistance. Due to a number of advantages over other thermoset polymers as mentioned above, epoxy (LY 556) is particular as the matrix material for the present work. Its common name is Biphenyl-A-Diglycidyl-Ether and it's chemically belongs to the epoxide family. The epoxy resin and the equivalent hardener HY-951 are procured from Ciba Geigy India Ltd.

Table 1.1: Density and Young's Modulus of Materials

S. No	Materials	Density	Young's modulus
1	Chopped E – glass fibre	2.5 g/ cm^3	72.5 GPa
2	Epoxy Resign	1.2g/cm^3	3.42 GPa

2.2 Fibre Material

Chopped E-glass fiber (5 to 10 mm long, 200 gm/ m^3 density) manufactured by Ciba Geigy and locally supplied by northern polymers Ltd., New Delhi, India, is used as a Fiber Reinforcement. Commercially existing SiC powder also known as carborundum of particle size 30 to 120 μm (density 3.216 g/cm^3) obtained from Silcarb Recrystalized Pvt. Ltd. Bangalore, India, is used as a particulate filler. The matrix material consist of a epoxy resin. LY 556 and room-temperature curing hardener HY951 supplied by Crystal Chemicals, Delhi, India. The composites fabricated by blending epoxy resin, glass- fiber, and SiC filler in certain weight percentage reinforcement. three different compositions of composites were prepared by varying the SiC filler reinforcement with fixed weight percentage (wt.%) of chopped E- glass fiber reinforcement. SiC filler in five different weight percentage (0wt%,5wt%, 10wt%,) are added with fixed 40 wt.% of chopped glass fiber and remaining epoxy so as to notice the effect of SiC reinforcement on physical, mechanical properties of chopped glass fiber-reinforced epoxy composites.

2.3 Particulate Filler Materials

To make an assessment of their reinforcing potential in terms of wear performance and mechanical properties, the ceramic filler such as SiC are used. SiC has a great potential to be used in various polymeric matrices. It is the simply chemical compound of carbon and silicon. It was firstly created by a high temperature electro-chemical reaction of sand and carbon. Today the particular material has been developed into superior quality technical grade filler with excellent mechanical properties. It is use in abrasives, refractories, and ceramics and in several high-performance structural and wear applications. This can also be prepared an electrical conductor and has applications in resistance heating, flame igniters and electronic components. SiC is collected of tetrahedral of carbon and silicon atoms through strong bonds in the crystal lattice. This produces a extremely hard and strong material. SiC is not attacked by any acids, alkalis or molten salts up to 800°C. It has low density of about 3.2 gm/cc, low thermal expansion, high elastic modulus, high strength, high thermal conductivity, high hardness, excellent thermal shock resistance and better chemical inertness.

Table 1.2: Chemical Composition and physical properties of filler materials

Filler	Composition/ chemical formula	Hardness(H_v)	Density (gm/cm^3)
Silicon Carbide	SiC	2800	3.22

2.4 Composite Fabrication

The fabrication of the composite slabs is done by conventional hand-lay-up technique followed by light compression moulding technique. The low temperature curing epoxy resin and corresponding hardener (HY951) are mixed in a ratio of 10:1 by weight as recommended. Each ply of fiber is of dimension 200 × 200 mm^2. A stainless steel mould having dimensions of 210 × 210 × 40 mm^3 is used. A releasing agent (Silicon spray) is used to make easy subtraction of the composite from the mould after curing. The composites were prepared by blending certain weight percentage of fiber/filler and epoxy resins in certain containers and then poured in a mold of desired dimensions. Labelling was done with the help of rollers, and suitable weights are applied on top of the mold. Similarly, three different compositions of fibres, filler and epoxy resins are poured in separate molds by varying five percentage of SiC filler contained with that of the epoxy resins keeping the chopped of glass fiber weight percentage as constant (40wt%). The composites are then left for solidification at room temperature for 24 hours. After the solidifications process, the composites are then removed from the mold and marking is done as per the test standards. Specimens of proper dimension are cut using a diamond cutter for physical/ mechanical characterization and erosion wear testing.

2.5 Mechanical Characterization

2.5.1 Density

The theoretical density (ρ_{ct}) of composite materials in terms of weight fractions of different constituents can easily be obtained as for the following equation given by Agarwal and Broutman [1].

$$\rho_{ct} = \frac{1}{\left(\frac{W_f}{\rho_f}\right) + \left(\frac{W_m}{\rho_m}\right)} \quad \text{..... (1)}$$

Where, W and ρ present the weight fraction and density respectively. The suffixes f and m stand for the fibre and matrix respectively. Since the composites under this investigation consist of the components namely matrix, fibre and particulate filler, the expression for the density has been modified as

$$\rho_{ct} = \frac{1}{\left(\frac{Wf}{\rho f}\right)+\left(\frac{Wm}{\rho m}\right)+\left(\frac{Wp}{\rho p}\right)} \quad \text{..... (2)}$$

Where, the suffix p stands for particulate fillers. The actual Density (ρ_{ce}) of the composite, However, it can be determined experimentally by simple water immersion method. The volume fraction of voids (V_v) in the composites is calculated using the following equation

$$V_v = \frac{\rho_{ct}-\rho_{ce}}{\rho_{ct}} \quad \text{..... (3)}$$

2.5.2 Tensile Strength

The tensile test is normally performed on flat specimens. The dimension of the specimen is 175x17x3 mm and a uniaxial load is applied through both the ends. The ASTM Standard Test method for tensile properties of fibre resin composites has the description D 3039-76. In present work, this test is performed in the universal testing machine (UTM) INSTRON 1195 at a crosshead speed of 10 mm/min and the results are used to calculate the tensile strength of composite samples. Loading arrangement is shown in Fig. 3.3b.

2.6 Flexural Strength

The flexural strength of a composite is the maximum tensile stress that it can withstand during bending before reaching the breaking point. The three point bend experiment is conducted on all the composite samples in the Universal Testing Machine Instron 1195. The dimension of each specimen is 100x20x3 span length of 50 mm and the cross head speed of 10 mm/min are mentioned. The flexural strength of the composite specimen is determined using the following equation.

$$\text{Flexural Strength} = \frac{3PL}{2bt^2} \quad \text{..... (5)}$$

2.7 Erosion Test Apparatus

Erosion set up for the solid particle erosion wear test used in this study is capable of creating reproducible erosive situations for assessing erosion wear resistance of the prepared composite samples. The pictorial view and the systemic diagram of the erosion test rig are given in Fig. 2.1 respectively. The test rig consists of an air compressor, an air drying unit, a conveyor belt type particle feeder and an air particle mixing and accelerating chamber. In the present study, dry silica sand of size (210μm), are used as the erodent. The dried and compressed air is mixed with the erodent which is fed constantly by a conveyor belt feeder in to a mixing chamber and then is accelerated by passing the mixture through a convergent 99.9 % pure alumina nozzle having Inner diameter 1.5 mm, nozzle length is 50 mm. The erodent particles impact the sample which can be held on different angles (30°, 45°, and 60°) with respect to the direction of erodent flow using a swivel and adjustable sample clip. The velocity of the eroding particles is determined using the standard double disc method [6]. The specimen are cleaned in acetone, dry and weighed before and after the erosion trials using an exactness electronic balance to an accuracy of ±0.1 mg. The weight loss is recorded for the following calculation of erosion rate. The procedure is repeat till the erosion rate attains a stable value called steady state

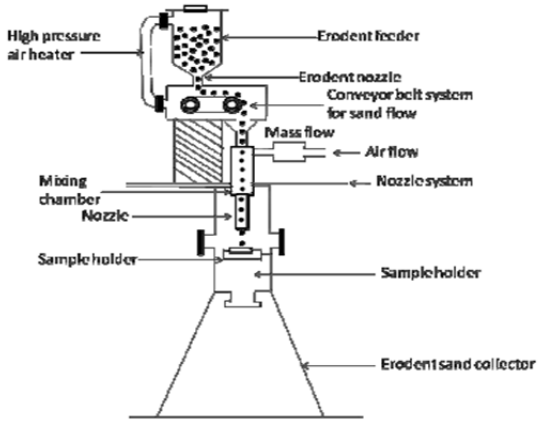

Fig. 2.1: A schematic diagram of the erosion test

erosion state. The erosion rate is defined as the ration of this weight loss to the weight of eroding particles causing the loss.

3. MECHANICAL CHARACTERIZATIONS OF THE COMPOSITES

Glass fibre-epoxy composites

3.1 Density and volume fraction of voids

It may be noted that the composite density values calculated theoretically from weight fractions using Eq.(1) are not equal to the experimentally measured values. This variation is a measure of voids and pores nearby in the composites. It is obviously seen that with the decrease in fiber content from 0wt% to 10 wt%, there is a decrease in the void fraction. These things can lead to the swelling of the composite and reduce density. However, in all the three composites A, B and C, the volume fractions of voids are reasonably small (< 2.5%) and this can be recognized to the absence of particulate fillers in these composites.

$$\Delta V = \frac{[\rho_{ct}-\rho_{ex}]}{\rho_{ct}} \times 100 \quad \text{..... (1)}$$

S. No	Specimen label	Tensile modulus	Tensile strength at yield (offset 0.2 %)	Maximum Load	Tensile strength at Maximum Load
		[MPa]	[MPa]	[kN]	[MPa]
1	Sample A	12837.59	71.96	4.64	90.92
2	Sample B	4059.08	45.06	4.02	78.82
3	Sample C	4623.98	58.36	5.8	113.73

3.2 Tensile Propertie

The test results for tensile strengths and moduli are shown in Figs. 3.1and 3.2 respectively. It has seen that in all the samples the tensile strength of the composite increases with increase in filler content. The unfilled glass epoxy composite (40wt% Fiber loading) has a strength of 90.99 MPa in tension and it may be seen from Table 4.2 that this value drops to 78.82 MPa with addition of 5 wt% of SiC and increase to 113.73 Mpa with addition of 10wt% SiC respectively. There can be two reasons for this turn down in the strength properties of these particulate filled composites compared to the unfilled one. An alternative is that the edge bonding between the filler particles and the matrix may be too weak to transfer the tensile stress; another is that the corner points of the irregular shaped particulates result in stress concentration in the epoxy matrix. These two reasons are responsible for reducing the tensile strengths of the composites so extensively. Previous reports show that usually the fibres in the composite contain the deformation of the matrix polymer, reducing the tensile strain [7,8].The tensile strengths are dissimilar with different filler materials as their compatibility with the matrix and irregularities in shape are different from one another. The tensile modulus of these Silica filled composites B and C, are also found to be less than the modulus of the unfilled one shown in Fig. 3.2. The tensile strength at yield (offset 0.2%) of these Silica filled composites B and C, are also found to be less than the unfilled one shown in Fig. 3.3.

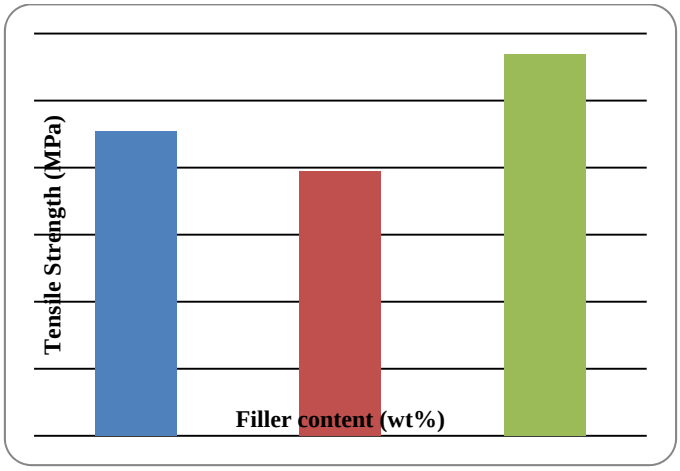

Fig. 3.1 Tensile strength of composites with different wt% of particulate filler

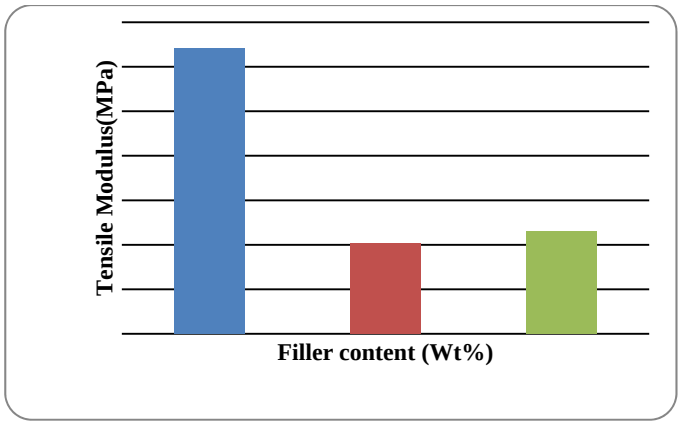

Fig. 3.2: Tensile modulus of composites with different wt% with particulate filler

Table 3.1 Flexural strength of composites with different wt% of particulate fillers

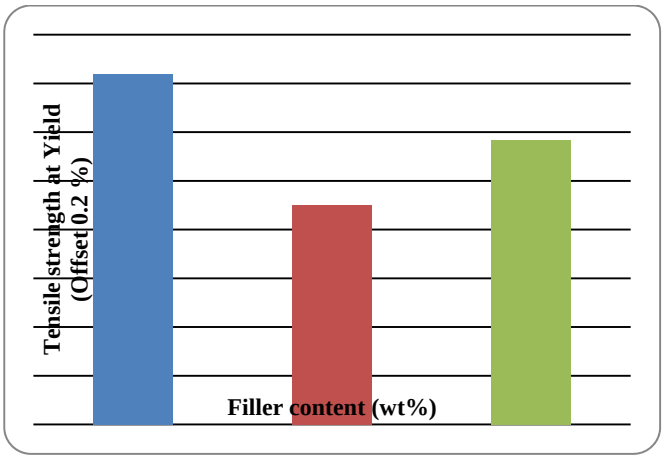

Fig. 3.3 Tensile Strength at yield offset 0.2% (MPa) of composites

3.3 Flexural Strength

The data of sample test given in the below table: Rate – 10 mm/min; Temperature- 18 ^{o}C Room temperature- 23.1 ^{o}C

Table 3.2: Flexural strength of composites with different wt% of particulate fillers

S. No	Specimen label	Maximum Load	Flexural strength	Flexural Modulus
		[N]	[MPa]	[MPa]
1	Sample A	257.4	126.18	4615.47
2	Sample B	224.42	110.01	3609.83
3	Sample C	293.3	143.77	6238.45

The test results for flexural strengths and modulus are shown in Figs. 3.4 and 3.5 respectively. It is seen that in all the samples irrespective of the filler material the flexural strength

of the composite increases with increase in filler content. The unfilled glass epoxy composite (40wt% Fiber loading) has a strength of 126.18 MPa in flexural and it may be seen from Table 4.3 that this value drops to 110.01 MPa with addition of 5 wt% of SiC and increase to 143.73 Mpa with addition of 10wt% SiC shown in Fig. 3.4 respectively. reasons may be the edge bond between the filler particles and the matrix may be too much weak to transfer the tensile stress; another reason may be irregular shaped particulates result in stress concentration in the epoxy matrix.

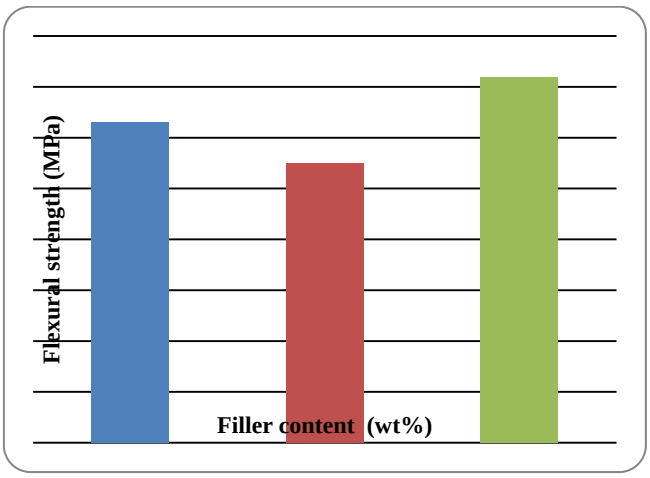

Fig. 3.4: Flexural strength of composites with different wt% of particulate fillers

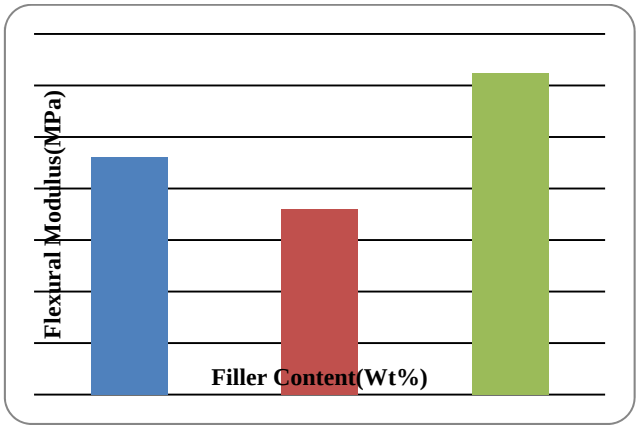

Fig. 3.5: Flexural modulus of composites with different wt% of particulate fillers

The flexural modulus of these SiC filled sample B and sample C are also found to be more than the modulus of unfilled one. Flexural modulus of sample C is found to be more than sample A shown in Fig. 4.3(b) respectively.

4. STUDY ON EROSION WEAR CHARACTERISTICS OF GLASS FIBRE EPOXY COMPOSITES

4.1 Erosion Test Results

Steady state erosion

It can be recognized to the fact that the harder material, larger is the fraction of the crater volume that is removed [10]. In this investigation higher hardness values have been recorded for composites with higher fiber loading and this is one reason why the composites exhibit declining erosion resistance with the increase in fiber content. After experiments It has to be recorded that the maximum erosion occur between 45° to 60° at steady state condition with 10wt% with particulate filler.

According to Hutchings et al. [9], kinetic energy loss is a maximum at normal impact, where erosion rates are highest for brittle materials. In the present study also, the peak erosion rate shifts to a larger value of impingement angle (60^0) and it is clearly due to the brittle nature of glass fibers, the overall mean for the S/N ratio of the erosion rate is found to be -31.99 db. Fig. 4.1 shows graphically the effect of the five control factors on erosion rate. The analysis was made using the popular software specifically used for design of experiment applications known as MINITAB16. 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=impact velocity 70 m/sec), (B = Fibre loading 40 wt% ,(C = impingement angle 60°), (D= stand-off distance 105 mm), (E = discharge 2.5gms/min) gives minimum erosion rate is shown in Fig. 5.2.

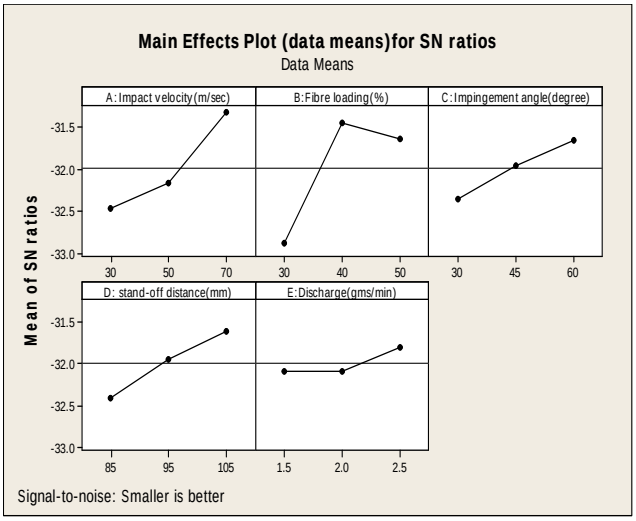

Fig. 4.1 shows that minimum erosion rate at 70m/s impact velocity, impingement angle at 60^0 , stand –off distance at 105mm , discharge at 2.5 gms/min and fibre loading at 40%.

Table 4.1 Analysis of Variance for Erosion rate (gm/kg)

source	DF	Seq SS	Adj SS	Adj MS	F	P
A:Impact velocity(m/sec)	2	0.0002069	0.0002069	0.0001034	1.54	0.244
B:Fibre loading(%)	2	0.0002242	0.0002242	0.0001121	1.67	0.219
C:Impingement angle(degree)	2	0.0000282	0.0000282	0.0000141	0.21	0.488
D: stand-off distance(mm)	2	0.0001007	0.0001007	0.0000503	0.75	0.813
E:Discharge(gms/min)	2	0.0000380	0.0000380	0.0000190	0.28	0.757
Error	16	0.0010740	0.0010740	0.0000671		
Total	26	0.0016720				

4.2 ANOVA and the Effects of factors

In order to identify a existing visualization of impact of various factors and their interactions, it is attractive to construct analysis of variance (ANOVA) table to find out the order of significant factors as well as interactions. Table 4.1 shows the results of the ANOVA with the erosion rate. This test 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.

From Table 4.1 one can observe that A= Impact velocity (p=0.244),B=fibreloading(p=0.219),C=impingement angle(p=0.488),have great influence on erosion rate.D=stand off distance (p=0.813),and discharge (p=0.757), presents less significance of contributation on erosion rate.

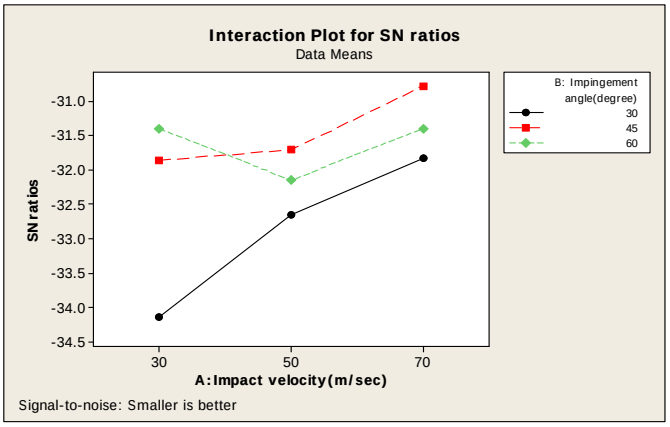

Fig. 4.2: Interaction graph plot between AxB (for unfilled composites)

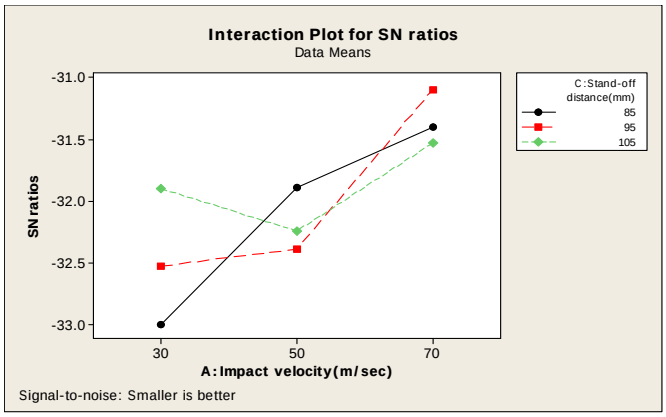

Fig. 4.3: Intraction graph plot between AxC(for unfilled composites)

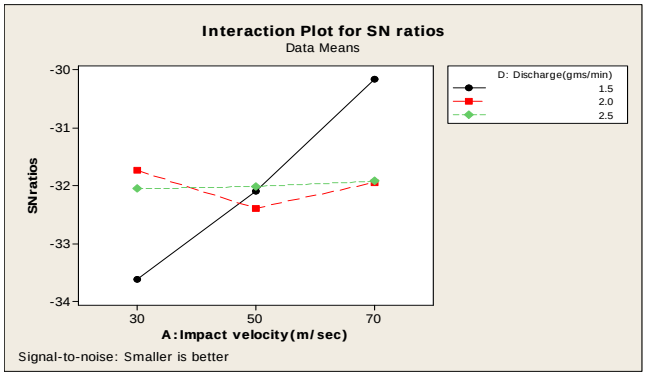

Fig. 4.4: Interaction graph plot between AxD (for unfilled composites)

Fig. 5.1 shows that minimum erosion occur at impact velocity (70 m/s) and Impingement angle at 45^0 . Fig. 5.4 shows that maximum erosion occur at impact velocity (70 m/s) and stand-off distance at 95mm.Fig. 5.5 Interaction graph between discharge and Impact velocity shows that minimum erosion occur at discharge (3.0 gms/min) and the impact of velocity at 70 m/sec.

As far as minimization of erosion rate is concerned, factors A, B,C,D and E have significant effects on all the three different composites, whereas factor C has the least effect. It is observed from Figures 4.2, 4.3,and 4.4 that the interactions between A×B show most significant effect on erosion rate whereas it can be considered from Figures 4.2,4.3,and 4.4 that interaction between A×C is less significant. Thus this analysis suggests that few of the factors have individual effect and similarly, some of the interactions have combined effect on erosion rate. Although, these plots are indicators of the relative significance of various control factors and their interactions, this can be confirmed only after performing the analysis of variance (ANOVA).

5. STUDYON EROSION WEAR CHARACTERISTICS OF PARTICULATE FILLED GLASS- FIBRE EPOXY COMPOSITES

The test results of erosion trials carried out on the glass-epoxy composites (A, B, C,) are presented with the conventional ceramic silicon carbide SiC filler is discussed. The variation of erosion wear rate of the composites with angle of impingement is studied keeping all other parameters at fixed levels. for composites A (60wt% epoxy + 40wt% glass fiber + 0wt% SiC), B (55wt% epoxy + 40wt% glass fiber + 5wt% SiC), C (50wt% epoxy + 40wt% glass fiber + 10wt% SiC).The behaviour of ductile materials like polymers is characterized by maximum erosion rate at impingement angles at 45^0 shown in Fig. 5.1 to show a semi-ductile behaviour with maximum erosion occurring in the angular range 45^0- 60^0 [10].

In the present work also, the erosion results presented in Figures 6.1 show the peak erosion taking place at an impact angle of 60^0 for all the composites. For these two composites with SiC fillers, the maximum erosion has been recorded at an impact angle of 45^0 at 10wt%.. This can further be explained as follows: the erosion of fibers is mainly caused by damage mechanisms as micro-cracking or plastic deformation due to impact of silica sand. This type of scratch is supposed to increase with the increase of kinetic energy loss. According to Hutchings et al. [11], kinetic energy loss is maximum at normal impact (90^0), where erosion rates are maximum for brittle materials. Hence, although the polymer matrix itself is ductile, the composites show semi-ductile or often semi-brittle erosion behaviour. Similar observations for polyphenylenesulphide (PPS) composites have been reported by Tamer et al. [10].

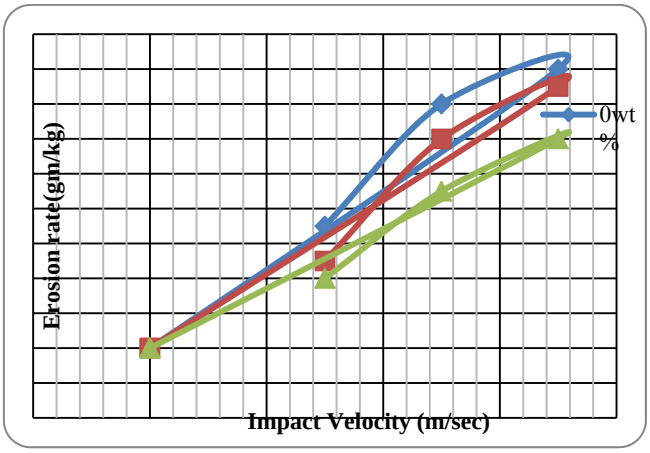

Fig. 5.1: Erosion rate vs impact velocity for different fibre wt%

Fig. 5.1 is a plot showing the erosion rate of the composites with filler contents tested as a function of the constant of the impingement angle ($\theta=60^0$).it is quite evident from Fig. 5.1 that the erosion rate initially increases, attains a peak value at 70m/sec. this trend is exhibited by all the three composites. Fig. 6.1 also demonstrates that erosion rate decreases with the increase in filler contents irrespective of impact velocity. It can be observed that composites have the maximum erosion rate at 70m/sec impact velocity without filler and minimum at 10wt% with particulate filler.

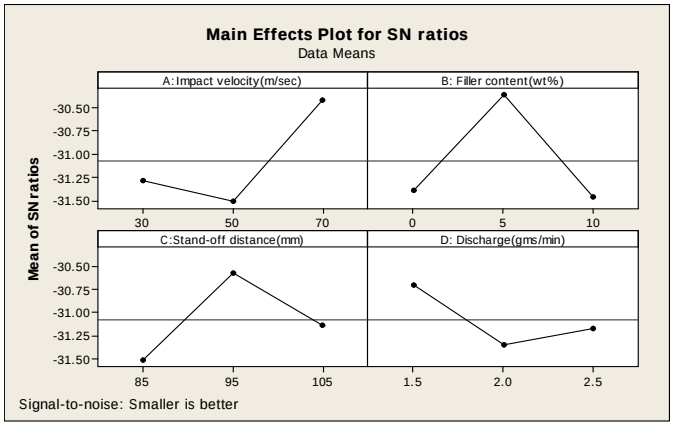

Fig. 5.2: Main Effects Plot for SN ratio for different control factors

5.1 Taguchi Analysis

The analysis was made using the well-liked software particularly used for design of experiment applications known as MINITAB 16. Before any effort is made to use this simple model as a interpreter for the measures of performance, the possible interactions between the control factors must be considered.. Where A,B,C,and D are the input parameters such as A: impact velocity: filler contents, C:stand-off distance, D:discharge.

The effects of control factors on erosion rate of composites with filler are shown in Fig. 5.2 respectively. The analysis of the result gives the grouping of factors producing minimum wear rate of the composites. These combinations are found to be different for different factors with filler(SiC) materials. For SiC the factors combination of A (impact velocity 70 m/sec), B (filler content 5wt %), C (stand-off distance 95mm) and D(discharge 1.5 gms/min) gives minimum erosion rate. As for as minimization rate is concerned, impact velocity has significant effects on the composites, whereas factor discharge has the least effect.

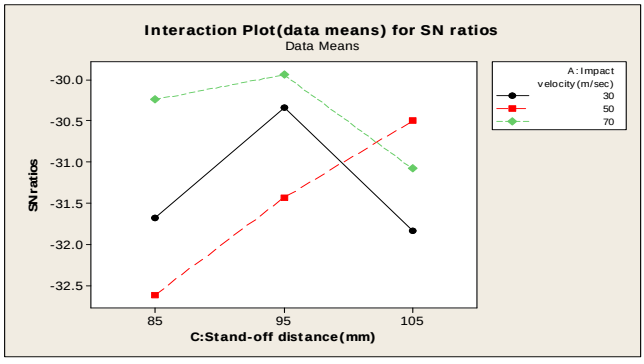

Fig. 5.3: Interaction graph between CxA for erosion rate

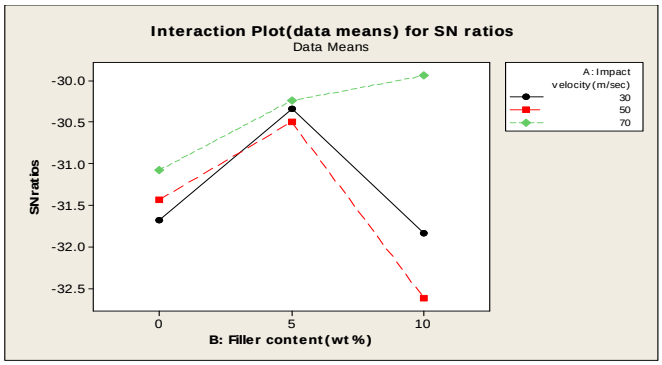

Fig. 5.4: Interaction graph between BxA for erosion rate

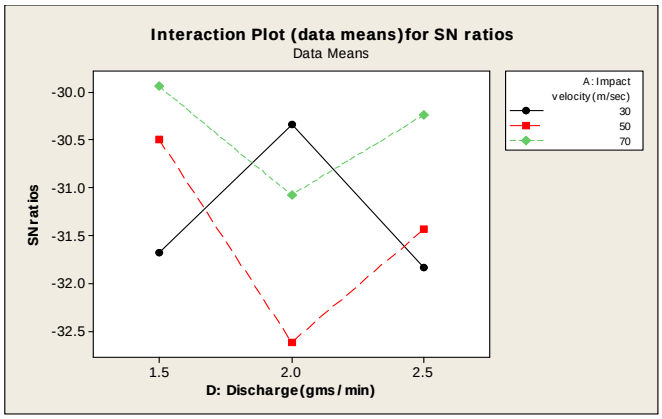

Fig. 5.5: Interaction graph between DxA for erosion rate

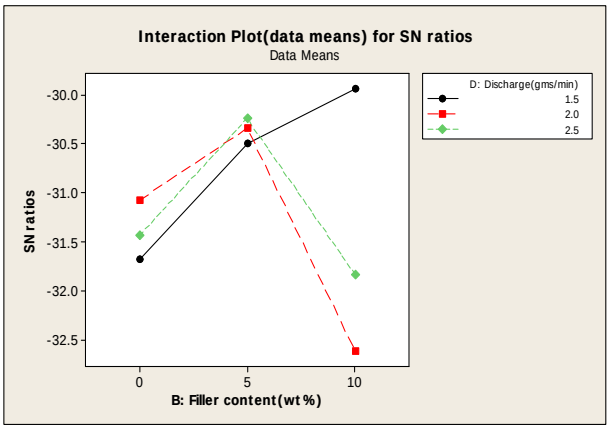

Fig. 5.6: Interaction graph between BxD for erosion rate

Thus this analysis suggests that few of the factors have individual achieve and similarly, some of the interactions have combined effect on erosion rate. Although, these plots are indicators of the relative significance of different control factors and their intractions, this can be confirmed only after performing the analysis of variance (ANOVA).

Table 5.1: Analysis of Variance (ANOVA) for Erosion rate (gm/kg)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A:Impactvelocity(m/sec)	2	0.0003536	0.0003536	0.0001768	2.24	0.135
B: Filler content (wt %)	2	0.0003176	0.0003176	0.0001588	2.01	0.163
C:Stand-off distance(mm)	2	0.0001416	0.0001416	0.0000708	0.90	0.425
D: Discharge(gms/min)	2	0.0001727	0.0001727	0.0000863	1.09	0.356
CxA	2	0.0003143	0.0003152	0.0001547	1.85	0.128
BxA	2	0.0002824	0.0002871	0.0001412	2.24	0.142
DxA	2	0.0001214	0.0001235	0.0000654	0.82	0.389
BxD	2	0.0001537	0.0001457	0.0000725	1.02	0.325
Error	16	0.0014207	0.0014207	0.0000789		
Total	26	0.0024060				

DF: degree of freedom; Seq.SS: sequential sum of squares; Adj.SS:extra sum of squares; Adj.MS: extra mean squares; P: level of significance

S = 0.00888403 R-Sq = 40.95% R-Sq(adj) = 14.71%

5.2 ANOVA and the Effects of Factors

In order to find out statistical significance of many factors like impact velocity (A), SiC content (B), stand-off distance (C), discharge (D), analysis of variance (ANOVA) is performed on experimental data. Table 6.2 show the results of the ANOVA with the erosion rate of glass-epoxy based composites taken in this investigation. The last column of the table shows the percentage involvement of the control factors and their interactions on the performance output i.e. erosion rate.

From Table 5.1 it can be observed for the SiC filled glass-epoxy composites that impact velocity (p=0.135),filler content (p = 0.163), discharge (p=0.356) have more significance factor and stand-off distance(p=0.425)have less significance factor. The interaction of impact velocity and stand-off distance (p=0.128), impact velocity and filler content(p=0.142),stand-off distance and filler content(p=0.325), show more significant contribution on the erosion rate The remaining factors and interactions(DxA) have relatively less significant contribution.

5.3 Erosion rate at constant velocity

The experimental data of erosion test at constant velocity v = 70m/min; frequency = 10Hz; erodent –silica sand, erodent size- 200µm; erodent feed rate- 10 gm/min; test temperature- 30 ^{o}C; Nozzle diameter – 1.5mm; length of nozzle-50mm; time -10min; discharge – 30gms/min.

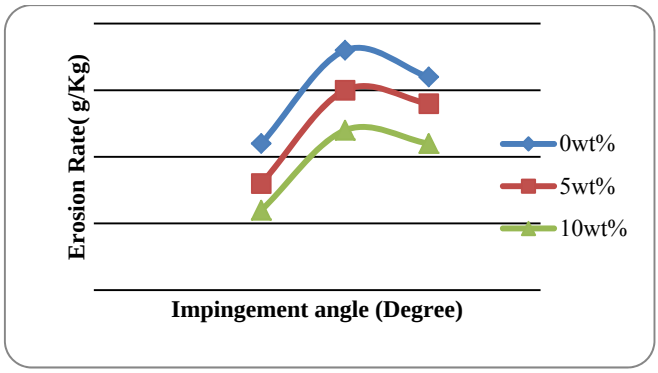

Fig. 5.7: Erosion rates at constant velocity and varied angle

Fig. 6.4 is a plot showing the erosion rate of the composites with filler contents tested as a function of the constant of the impact velocity (v=70m/sec).it is quite evident from Fig. 5.7 that the erosion rate initially increases, attains a peak value at 45^0. This trend is exhibited by all the three composites. Fig. 5.7 also demonstrates that erosion rate decrease with the increase in filler contents irrespective of impingement angle. It can be observed that the composite has the maximum erosion rate at 45^0 impingement angle without particulate filler and minimum at10wt% with particulate filler.

. Fig. 5.8 show graphically the effect of the four control factors on erosion rate. The analysis has been completed using the popular software especially used for design of experiment applications known as MINITAB 16, the possible interactions between the control factors must be considered. Thus factorial design incorporates a simple means of testing for the presence of the interaction effects. The interaction graphs are shown in Fig. 5.9 to 5.11. The analysis of the result gives the combination of factors producing minimum rate of the composites. These combinations are found to be different for different factors with filler (SiC) materials. For SiC the factors combination of A (impingement angle 60^0), B (filler content 10wt %), C (stand-off distance 85mm) and D (discharge 1.5 gms/min) gives minimum erosion rate. As for as minimization rate is concerned, impingement angle has significant effects on the composites, whereas factor stand-off distance has the least effect. It is observed from Figures 5.9 that the interaction between BxA show most significant effects on erosion rate whereas it can be measured from figures 5.10and 5.11 is less significant respectively. Thus this analysis suggests that only some of the factors have individual achieve and similarly, some of the interactions have combined effect on erosion rate. Although, these plots are indicators of the comparative significance of different control factors and their interactions, this can be confirmed only after performing the analysis of variance (ANOVA).

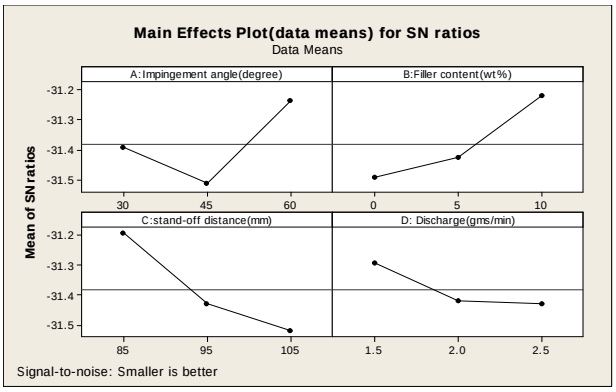

Fig. 5.8 Effect of control factors on erosion rate (for SiC filled composite)

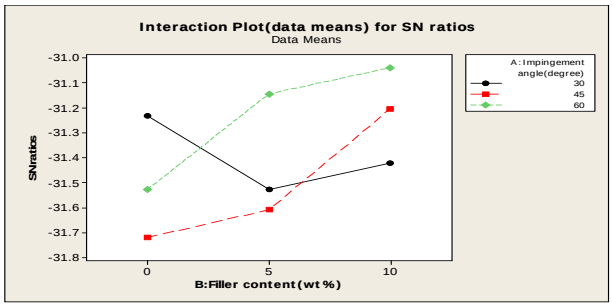

Fig. 5.9 Interaction graph between BxA for erosion rate

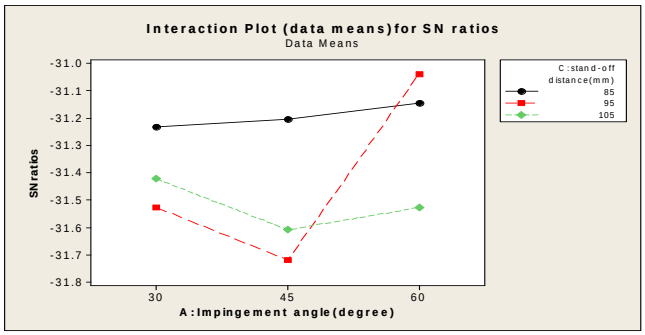

Fig. 5.10 Interaction graph between AxC for erosion rate

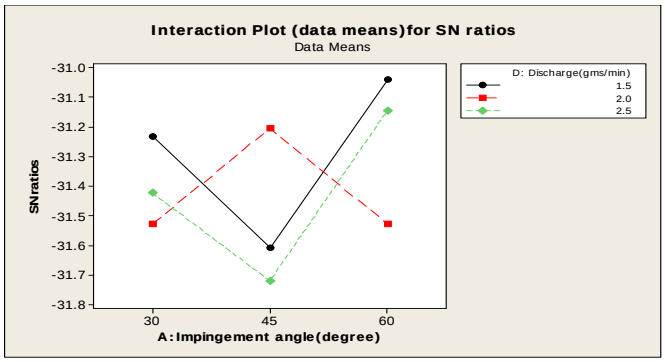

Fig. 5.11 Interaction graph between AxD for erosion rate

6.3 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 6.4 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).

Table 5.2: Analysis of Variance (ANOVA) for Erosion rate (gm/kg)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A:Impingement angle(degree)	2	0.0000269	0.0000269	0.0000134	1.11	0.351
B: Filler content(wt%)	2	0.0000162	0.0000162	0.0000081	0.67	0.524
C:Stand-off distance(mm)	2	0.0000176	0.0000176	0.0000088	0.72	0.498
D: Discharge(gms/min)	2	0.0000060	0.0000060	0.0000030	0.25	0.783
BxA	2	0.0000148	0.0000134	0.0000075	0.62	0.482
AxC	2	0.0000125	0.0000148	0.0000084	0.68	0.592
AxD	2	0.0000058	0.0000054	0.0000028	0.22	0.682
Error	18	0.0002180	0.0002180	0.0000121		
Total	26	0.0002847				

** DF: Degree of freedom, Adj.SS: extra Sum of Squares, Adj. MS: extra mean square, F-Value: F-test, P: percent contribution

S = 0.00348010 R-Sq = 23.42% R-Sq(adj) = 11.81%

The last column of every table indicates p-value for the individual control factors and their possible interactions. It is known that smaller is the p-value, greater is the significance of the factor/interaction corresponding to it [11].

The ANOVA results for SiC filled glass fiber epoxy composites (Table 5.2), show that, the impingement angle (p=0.351), filler content (p= 0.524), stand-off distance (p=0.498) have great influence on erosion rate and discharge (p=0.783) have less significant control factors affecting the erosion rate. It means, the impingement angle is the most significant factor and the discharge with a p-value of 0.783 has negligible influence on the performance output. Between the two possible interactions, the interaction of filler BxA (p=0.482) has greater contribution on the erosion rate compared to the interaction of AxC (p=0.592)and AxD(0.682).

6. SUMMARY AND CONCLUSIONS

Inclusion of fibre in precise epoxy improved the load bearing capacity (tensile strength) and the ability to survive bending (flexural strength) of the composites. This decline in strength may be attributed to two reasons: one possibility is that the due to the absence of pores at the interface between the filler particles and the matrix, the interfacial adhesion may be too strong to transfer the tensile stress; the other is that there is maximum regular shaped particulates in the corner points of the composites so that no stress concentration create in the matrix body. The increase in tensile strength with the integration of fillers can be explained as follows: under the action of a tensile force, the filler-matrix interface is strong in bonding depending on interfacial bond strength and this may lead to strength in the composite. The tensile strength of the composite increases with increase in filler content. The unfilled glass epoxy composite (40wt% Fiber loading) has a strength of 90.92 MPa in tension and this value drops to 78.82 MPa with addition of 5 wt% of SiC and increase to 113.73 MPa with addition of 10wt% SiC respectively.

7. CONCLUSION

Erosion properties of these composites can be fruitfully analyzed using Taguchi experimental design format. Taguchi method provides a simple, planned and efficient methodology for the analysis of the control factors. Considerable factors affecting the erosion rate of composites are identified through successful implementation of ANOVA. It is found that impact velocity and impingement angle are the two most significant factors for all glass-epoxy composites for which discharge and erodent size are the parameters most significantly influencing the erosion rate. The peak erosion rate is found to be occurring at 45°- 60° impingement.

1. Successful fabrication of glass-epoxy composites with reinforcement of ceramic filler such as SiC is possible.
2. Incorporation of the filler modifies the tensile, flexural, strengths of the glass epoxy composites. Therefore, while fabricating a composite of specific requirements, there is a need for the option of proper filler material and for optimizing its content in the composite preparation.
3. The unfilled glass epoxy composite has a strength of 90.92 MPa in tension at maximum load 4.64 and this value drops to 78.82 MPa with addition of(40wt%glass fibre+55wt%epoxy+ 5 wt% SiC) and this value increase 113.73MPa with addition of(40wt% glass fibre+50wt% epoxy + 10wt% SiC) respectively.The Maximum tensile strength of the composites at (40wt% glass fibre+50wt% epoxy + 10wt% SiC) respectively.

4. It is observed that the tensile modulus of glass-epoxy composites improve significantly with addition of (40wt% glassfibre+60wt% epoxy+0wt% SiC) respectively. It is further noted that without particulate fillers (0wt%SiC) tensile modulus is maximum and at (40wt% glass fibre+55wt%epoxy+5wt%SiC) particulate filler the tensile modulus is lower than(40wt%glass fibre+50wt%epoxy+10wt%SiC) particulate .
5. It is seen that in all the samples irrespective of the filler material the flexural strength of the composite increases with increase in filler content. The unfilled glass epoxy composite (40wt% Fiber loading) has a strength of 126.18 MPa in flexural and this value drops to 110.01 MPa with addition of 5 wt% of SiC and increase to 143.73 MPa with addition of 10wt% SiC. The flexural modulus of these SiC filled sample B and sample C are also found to be more than the modulus of unfilled one. Flexural modulus of sample C is found to be more than sample A respectively.
6. It is observed that the erosion rate of glass-epoxy composite maximum with addition of (40wt% glassfibre+40wt% epoxy+10wt% SiC) with velocity 70 m/sec at constant impingement angle of 60°.
7. Major control factors affecting the erosion rate have been identified through successful implementation of Analysis of Variance (ANOVA). impingement angle, impact velocity, Filler content, and discharge in declining series are found to be important for minimizing the erosion rate of all the particulate filled composites except the ones with SiC filling. In the SiC filled composite impingement angle emerged as the most significant control factor followed by filler content, impact velocity, discharge, and stand-off distance.

Scope for Future Work

The present research work leaves a wide scope for future investigators to explore many other aspects of such composites. Some recommendations for future research include:

- Study on the response of these composites to other wear modes such as sliding and abrasion.
- Likely use of other ceramic/metallic fillers, polymeric resins and natural fibers in the development of new composites.
- Cost analysis of these composites to assess their economic viability in industrial applications.

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