



# Tribological Characterization of Natural Fiber Composites

Abhishek Kumar Choubey<sup>1</sup>, Prof. Suraj Mukti<sup>2</sup>  
Executive<sup>1</sup>, Assistant Professor<sup>2</sup>  
Bhilai Engineering Corporation Ltd. Bhilai, CG, India<sup>1</sup>  
NIT Raipur, CG, India<sup>2</sup>

## Abstract:

Solid particle erosion of polymer composites is a complex surface damage process, strongly affected by material properties and operational conditions. The present research work is undertaken to study the development, characterization and erosion wear performance of natural fibers i.e. banana fiber when reinforced in polymers. In the above cases matrix material will remain epoxy. Attempts have been made to explore the possible use of a natural fiber as filler material in composites. To make an assessment of their (banana fiber) reinforcing potential in terms of wear performance and mechanical properties, various physical, mechanical and wear performance of the composites are studied in details. The reported data are purely extracted from experimental measurement under controlled laboratory conditions. From the performed experiments it can be seen that a banana fiber as far as wear performance is concerned, as the study indicates that erosion wear performance of banana fiber based composites. Banana fiber is also having a very low specific gravity, so their composites show very low density. From other mechanical characterization it can be said that, in strength point of view, banana fiber-epoxy composites are also used as in potential application.

**Key words:** Banana fiber, epoxy resin and composite material.

## I. INTRODUCTION

### Composite Materials

Composites are combinations of two materials in which one of the materials, called the reinforcing phase, is in the form of fiber sheets or particles and are embedded in the other material called the matrix phase. Composite materials have successfully substituted the traditional materials in several light weight and high strength applications.

### Types of Composite Materials

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

- a) Metal Matrix Composites (MMC)
- b) Ceramic Matrix Composites (CMC)

## II. LITERATURE REVIEW

A treatise on glass fiber and banana fiber reinforced polymer composites has been given illustrating the research findings. The physical behavior, mechanical behavior and wear characteristics of different composites as reported in existing literature have been cited. A great deal of work has been done by many researchers on synthetic fiber based polymer composites. Jawaid and Khalil [5] presented review that deals with the recent development of cellulosic/cellulosic and cellulosic/synthetic fibers based reinforced hybrid composites. Marom et al.

[6] focused on the elastic properties of synthetic fiber-reinforced polymer composite materials that pertain to biomedical applications and demonstrates the range of stiffness obtainable through selection of constituents and by choice of

angle of reinforcement. Jansons et al. [7] studied on the effect of water absorption, elevated temperatures and fatigue on the mechanical properties of carbon-fiber-reinforced epoxy composites. Kutty and Nando [8] studied the effect of processing parameters on the mechanical properties of short Kevlar aramid fiber-thermoplastic polyurethane composite and observed that processing parameters like nip gap, friction ratio and mill roll temperature have extreme influence on the fiber orientation and hence on the mechanical properties of short Kevlar aramid fiber-thermoplastic polyurethane composite. Cho et al. [9] studied the mechanical behavior of carbon fiber/epoxy composites and found that the composites reinforced with nanoparticles improved mechanical properties such as enhanced compressive strength and enplane shear properties. Chauhan et al. [10] studied on the effect of fiber loading on mechanical properties, friction and wear behavior of vinyl ester composites under dry and water lubricated conditions and reported that the density of composite specimens is affected marginally by increasing the fiber content.

## III. MATERIALS AND METHODS

Matrix materials are of different types like metals, ceramics and polymers. Polymer matrices are most commonly used because of cost efficiency, ease of fabricating complex parts with less tooling cost and they also have excellent room temperature properties when compared to metals and ceramic matrices. The most commonly used thermoset resins are epoxy, polyester, vinyl ester and phenolics.

### Filler Material - (Short Banana Fiber)

In India, natural fibres such as jute, coir, sisal, pineapple, ramie, bamboo, banana etc., are available in plenty. Sisal and banana fibres are cellulose-rich (> 65%) and have comparable

tensile strength, modulus and failure strain with other cellulose-rich fibres like jute and flax.

**Table.1. Cultivation details of Banana (Source: FAOSTAT)**

	Area (ha)	Production (Ton)	Average Production (t/ha)
World	4544702	69280	15.2
India	529700	16225	30.63

**Table.2. Typical properties of banana fibers**

Material	Density (g/cm <sup>3</sup> )	Tensile Strength (MPa)	Young's Modulus (GPa)	% Elongation at break
Banana fiber	1.35	400-600	16-20	5.9

### III. EXPERIMENTAL DETAILS

#### Composite Fabrication

Epoxy Composites filled with short banana fiber Low temperature curing epoxy resin (LY 556) and corresponding hardener (HY951) are mixed in a ratio of 10:1 by weight as recommended. In a similar manner, epoxy composites of 7 more different compositions (Table 3) were made with short banana fiber. For each composition, the composites were cast in plastic moulds so as to get the similar rectangular specimens (length 150 mm, width 20 mm, thickness 4 mm). banana fiber reinforced epoxy composite samples prepared through hand-layup technique.

**Table.3. Epoxy composites filled with short banana fiber**

Composition
Epoxy + 0 wt % Short banana fiber
Epoxy + 5 wt % Short banana fiber
Epoxy + 10 wt % Short banana fiber
Epoxy + 15 wt % Short banana fiber
Epoxy + 20 wt % Short banana fiber
Epoxy + 25 wt % Short banana fiber
Epoxy + 30 wt % Short banana fiber

### IV. PHYSICAL CHARACTERIZATION

#### Density and volume fraction of voids

Density of a composite depends on the relative proportion of matrix and reinforcing materials and it is one of the most important factors for determining the properties of the composites. The theoretical density ( $\rho_{ct}$ ) of composite materials in terms of weight fractions of different constituents can easily be obtained using the following equation

$$\rho_{ct} = 1 / \left\{ \left( \frac{w_f}{\rho_f} \right) + \left( \frac{w_m}{\rho_m} \right) \right\} \quad (a)$$

where,  $w$  and  $\rho$  represent the weight fraction and density respectively. The suffixes  $f$  and  $m$  stand for the filler and matrix respectively in a composite with single filler.

The actual density ( $\rho_{ce}$ ) of the composite can be determined experimentally by the Archimedes principle or water displacement technique (ASTM D 792-91). The volume fraction of voids ( $v_v$ ) in the composites is calculated by using the following equation:  $v_v = (\rho_{ct} - \rho_{ce}) / \rho_{ct}$  (b)

### V. MECHANICAL CHARACTERIZATION

#### Micro-hardness

Micro-hardness measurement was done using a Leitz micro-hardness tester A diamond indenter, in the form of a right pyramid with a square base and an angle 136° between opposite faces, was forced into the material under a load  $F$ . The two diagonals  $X$  and  $Y$  of the indentation left on the surface of the material after removal of the load were measured and their arithmetic mean was calculated. In the present study, the load considered  $F = 0.2454$  N and Vickers hardness number is calculated using the following equation.

$$H_v = 0.1889 \frac{F}{L^2} \quad \text{Where } L = \frac{X + Y}{2} \quad (c)$$

#### Compressive strength

The cured composite samples of required dimension (length 10 mm, diameter 10 mm), were used for the uni-axial compression test as per ASTM D 695 standard.

#### Tensile strength

The cured dog bone shaped composite samples (prepared from the rectangular slabs) of required dimension (length 150mm, end width 20mm and mid width 12 mm) were used for the tensile test as per ASTM E 1309 standard.

#### Flexural Strength

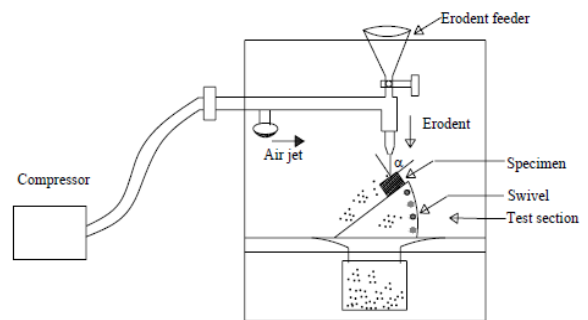
The determination of flexural strength is an important characterization of any structural material. **Impact strength**

Low velocity instrumented impact tests are carried out on composite specimens. The tests are done as per ASTM D 256 using an impact tester.

#### Tribological characterization

##### Solid particle erosion test apparatus

Solid particle erosion (SPE) is usually simulated in 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.



**Figure.1. Schematic diagram of the erosion test rig**

In the present investigation, an erosion apparatus (self-made) of the 'sand blast' type is used.

#### Taguchi experimental design

In any experimental research, since test procedures are generally expensive and time consuming, the need to satisfy the design objectives with the least number of tests is clearly an important requirement. In this context, Taguchi method provides the designer with a systematic and efficient approach for experimentation to determine near optimum settings of design parameters for performance and cost.

**Table.4. Parameter settings for erosion test**

Command factors	Abbreviation	Constant Parameters	
Impact velocity	Factor A	Erodent	Silica sand
Filler content	Factor B	Erodent feed rate (g/min)	10.0 □ □ □ □ □
Erodent temperature	Factor C	Nozzle Diameter (mm)	3 mm
Impingement angle	Factor D	Length of nozzle	80 mm
Stand-off distance	Factor E		
Erodent size	Factor F		

**Table .5. Control factors and their selected levels**

Command factors	Level			
	I	II	III	Units
Factor A : Impact velocity	30	40	50	m/sec
Factor B : Filler content	0	15	30	wt. %
Factor C : Erodent temperature	40	50	60	°C
Factor D : Impingement angle	30	60	90	degree
Factor E : Stand-off distance	60	70	80	mm
Factor F : Erodent size	300	450	600	µm

The selected parameters viz., impact velocity, filler content, erodent temperature, stand-off distance, impingement angle and erodent size, each at three levels, are considered in this study. These six parameters each at three levels would require  $3^6 = 729$  runs in a full factorial experiment whereas Taguchi’s experimental approach reduces it to 27 runs only offering a great advantage. The plan of the experiments as shown in Table 3.5 is as follows: the first, second, fifth, ninth, tenth and twelfth columns are assigned to impact velocity (A), filler content (B), erodent temperature (C), impingement angle (D),

stand-off distance (E) and erodent size (F) respectively. The third and fourth column are assigned to  $(A \times B)_1$  and  $(A \times B)_2$  respectively to estimate interaction between impact velocity (A) and filler content (B), the sixth and seventh column are assigned to  $(B \times C)_1$  and  $(B \times C)_2$  respectively to estimate interaction between filler content (B) and erodent temperature (C), the eighth and eleventh column are assigned to  $(A \times C)_1$  and  $(A \times C)_2$  respectively to estimate interaction between the impact velocity (A) and erodent temperature (C) and the remaining columns are used to estimate experimental errors.

**Table.6. Orthogonal array for L27 ( $3^{13}$ ) Taguchi Design**

Test run	1 A	2 B	3 (A×B) <sub>1</sub>	4 (A×B) <sub>2</sub>	5 C	6 (B×C) <sub>1</sub>	7 (B×C) <sub>2</sub>	8 (A×C) <sub>1</sub>	9 D	10 E	11 (A×C) <sub>2</sub>	12	13
1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	2	2	2	2	2	2	2	2	2
3	1	1	1	1	3	3	3	3	3	3	3	3	3
4	1	2	2	2	1	1	1	2	2	2	3	3	3
5	1	2	2	2	2	2	2	3	3	3	1	1	1
6	1	2	2	2	3	3	3	1	1	1	2	2	2
7	1	3	3	3	1	1	1	3	3	3	2	2	2
8	1	3	3	3	2	2	2	1	1	1	3	3	3
9	1	3	3	3	3	3	3	2	2	2	1	1	1
10	2	1	2	3	1	2	3	1	2	3	1	2	3
11	2	1	2	3	2	3	1	2	3	1	2	3	1
12	2	1	2	3	3	1	2	3	1	2	3	1	2
13	2	2	3	1	1	2	3	2	3	1	3	1	2
14	2	2	3	1	2	3	1	3	1	2	1	2	3
15	2	2	3	1	3	1	2	1	2	3	2	3	1
16	2	3	1	2	1	2	3	3	1	2	2	3	1
17	2	3	1	2	2	3	1	1	2	3	3	1	2
18	2	3	1	2	3	1	2	2	3	1	1	2	3
19	3	1	3	2	1	3	2	1	3	2	1	3	2
20	3	1	3	2	2	1	3	2	1	3	2	1	3
21	3	1	3	2	3	2	1	3	2	1	3	2	1
22	3	2	1	3	1	3	2	2	1	3	3	2	1
23	3	2	1	3	2	1	3	3	2	1	1	3	2
24	3	2	1	3	3	2	1	1	3	2	2	1	3
25	3	3	2	1	1	3	2	3	2	1	2	1	3
26	3	3	2	1	2	1	3	1	3	2	3	2	1
27	3	3	2	1	3	2	1	2	1	3	1	3	2

The experimental observations are further transformed into signal-to-noise (S/N) ratios. There are several S/N ratios available depending on the type of characteristics as given by following equations:

**‘Smaller- the- better’ characteristic:**

$$\frac{S}{N} = -10 \log \frac{1}{n} \left( \sum y^2 \right) \quad (d)$$

**‘Nominal- the- better’ characteristics:**

$$\frac{S}{N} = -10 \log \frac{1}{n} \left( \sum \frac{\bar{Y}}{S_y^2} \right) \quad (e)$$

**‘Larger- the- better’ characteristics:**

$$\frac{S}{N} = -10 \log \frac{1}{n} \left( \sum \frac{1}{y^2} \right) \quad (f)$$

where, ‘n’ is the number of observations and ‘y’ is the observed data. The S/N ratio for minimum wear rate comes under ‘smaller is better’ characteristic, which can be calculated as logarithmic transformation of the loss function by using Equation (d).

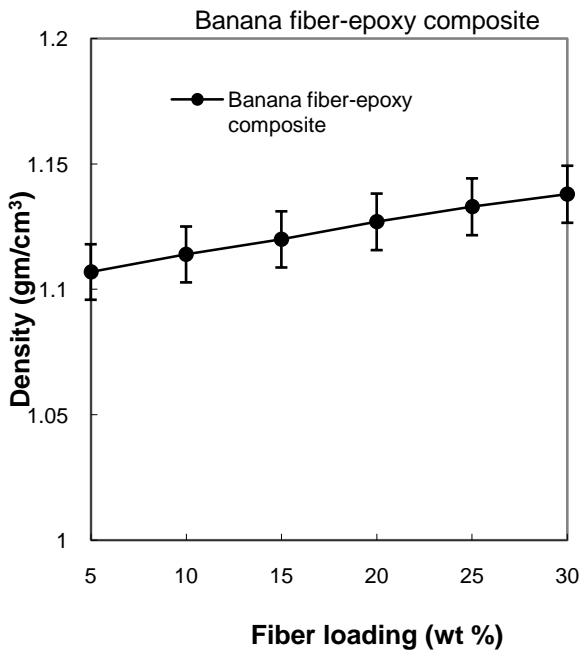
**PHYSICAL AND MECHANICAL PROPERTIES OF THE COMPOSITES**

**Density and Void Fraction**

The theoretical and measured densities along with the corresponding volume fraction of voids in the epoxy- banana fiber composites are presented in Table 7 respectively.

**Table.7. Measured and Theoretical densities of the composites (Epoxy filled with short banana fiber)**

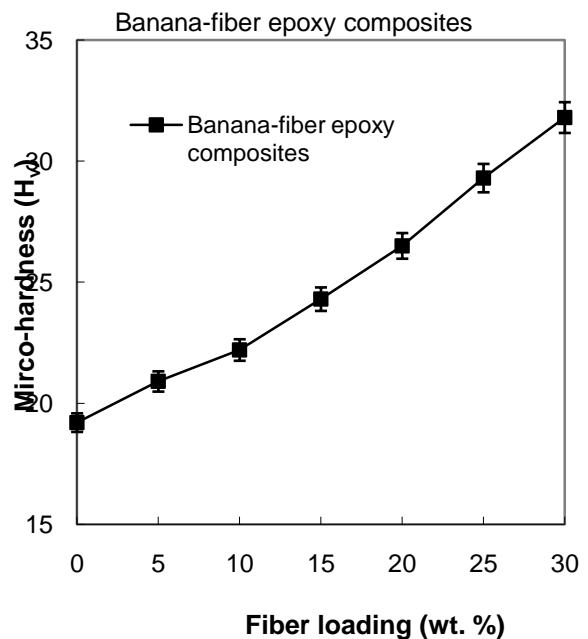
Composites	Measured density (gm/cc)	Theoretical density (gm/cc)	Void fraction (%)
Neat Epoxy ( hardened)	1.1	-	-
Epoxy + short banana fiber ( 5 wt % )	1.107	1.110	0.27
Epoxy + short banana fiber ( 10 wt % )	1.114	1.121	0.62
Epoxy + short banana fiber ( 15 wt % )	1.120	1.131	0.97
Epoxy + short banana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



**Figure.2. Experimental densities of banana fiber epoxy of composites**

**Micro-hardness:**

Hardness is considered as one of the most important factors that govern the wear resistance of any material.



**Figure.3. Effect of fiber loading on micro-hardness of banana fiber epoxy of composites**

**Tensile properties**

It is well known that the strength properties of composites are mainly determined by the fiber content and the fiber strength.

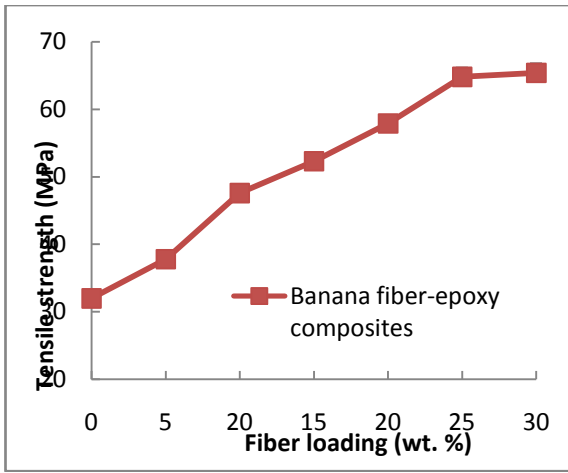


Figure.4. Effect of fiber loading on tensile strength of banana fiber epoxy composites

**Flexural strength:** Composite materials used in structures are prone to fail in bending and therefore the development of new composites with improved flexural characteristics is essential.

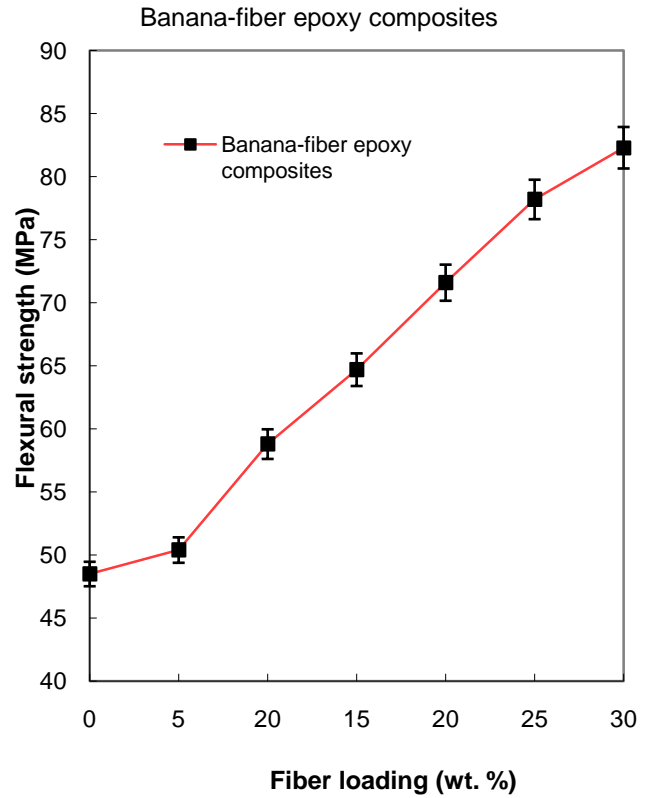


Figure.6. Effect of fiber loading on flexural strength of banana fiber epoxy composites

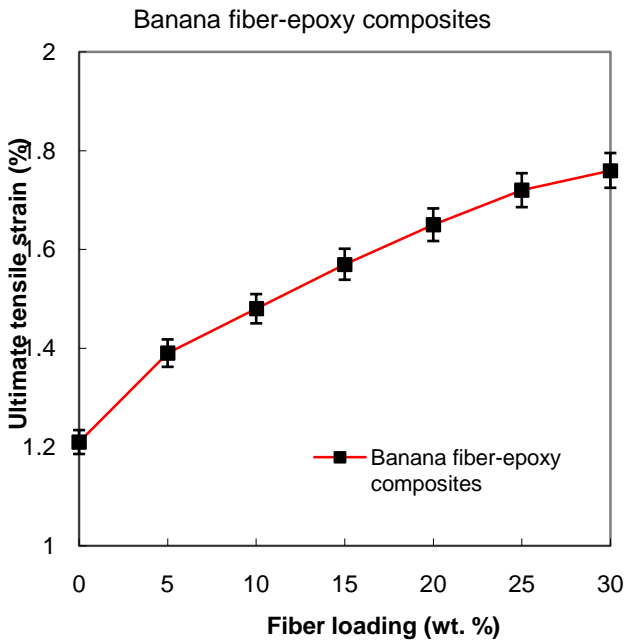


Figure.5. Effect of fiber loading on ultimate tensile strain of banana fiber epoxy composites

**Impact strength**

The impact strength of a material is its capacity to absorb and dissipate energies under impact or shock loading.

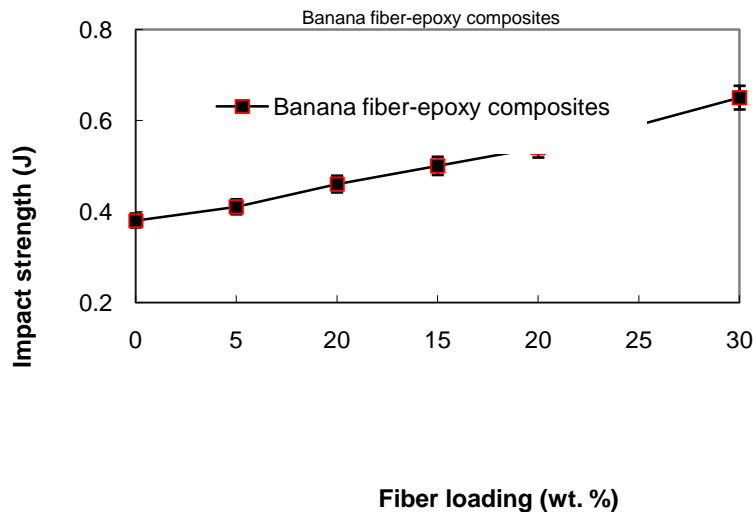


Figure.7. Effect of fiber loading on Impact strength of banana fiber epoxy composites

**TRIBOLOGICAL CHARACTERIZATION OF THE COMPOSITES:** These effects of different short fiber reinforcement on the erosion wear characteristics of glass fiber-epoxy composites and present a comparison with those of

a similar set of banana fiber-epoxy composites under identical test conditions.

**Erosion wear analysis of short banana fiber reinforced epoxy composites:** This part presents the analysis of erosion

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

### Taguchi experimental analysis

The results of erosion experiments carried out according to the predetermined design on banana fiber-epoxy composites are presented in Table 5.3.

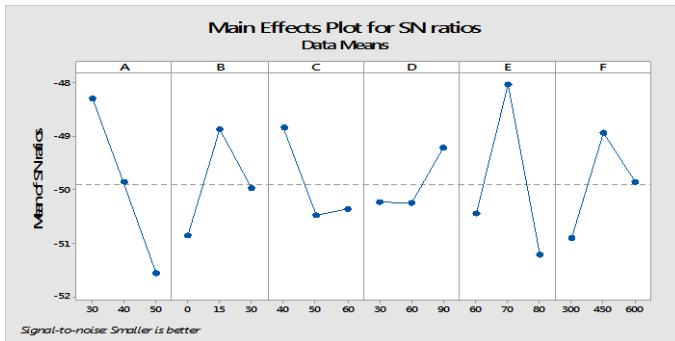
**Table.8. Erosion wear test result with corresponding S/N ratios using Taguchi method as per L27 orthogonal array for banana fiber epoxy composites**

Test run	A (m/s)	B (%)	C (°C)	D (Degree)	E (mm)	F (µm)	E <sub>r</sub> (banana fiber-epoxy) (mg/kg)	S/N ratio (db)
1	30	0	40	30	60	300	225.128	-47.0486
2	30	0	50	60	70	450	199.995	-46.0204
3	30	0	60	90	80	600	375.245	-51.4863
4	30	15	40	60	70	600	225.130	-47.0487
5	30	15	50	90	80	300	301.500	-49.5857
6	30	15	60	30	60	450	205.830	-46.2702
7	30	30	40	90	80	450	202.851	-46.1435
8	30	30	50	30	60	600	526.352	-54.4255
9	30	30	60	60	70	300	211.865	-46.5212
10	40	0	40	60	80	450	416.665	-52.3957
11	40	0	50	90	60	600	337.500	-50.5655
12	40	0	60	30	70	300	436.528	-52.8002
13	40	15	40	90	60	300	247.508	-47.8718
14	40	15	50	30	70	450	228.330	-47.1713
15	40	15	60	60	80	600	273.520	-48.7398
16	40	30	40	30	70	600	187.512	-45.4606
17	40	30	50	60	80	300	480.000	-53.6248
18	40	30	60	90	60	450	316.666	-50.0120
19	50	0	40	90	70	600	262.501	-48.3826
20	50	0	50	30	80	300	585.287	-55.3474
21	50	0	60	60	60	450	483.330	-53.6849
22	50	15	40	30	80	450	366.660	-51.2853
23	50	15	50	60	60	600	325.500	-50.2510
24	50	15	60	90	70	300	375.213	-51.4856
25	50	30	40	60	60	300	495.225	-53.8961
26	50	30	50	90	70	450	233.325	-47.3592
27	50	30	60	30	80	600	412.500	-52.3085

### Taguchi experimental analysis

The results of erosion experiments carried out according to the predetermined design on banana fiber-epoxy composites are presented in Table 14. This table provides the experimental erosion rate along with the signal-to-noise ratio for each individual test run. Each value of the erosion rate is the average of three replications. The overall mean of the S/N ratios is found to be -51.8247 db for banana fiber based composites. Figures 5.2 illustrate the effect of control factors

on erosion rate of glass fiber epoxy composites. Analysis of the results leads to the conclusion that factor combination of A1 (Impact velocity: 30 m/sec), B2 (Filler content: 15 wt%), C1 (Erodent temperature: 40°C), D3 (Impingement angle: 90°), E2 (Stand-off distance: 70mm) and F2 (Erodent size: 450µm) gives minimum erosion rate for banana fiber-epoxy composites



**Figure.8. Effect of control factors on erosion wear rate of banana fiber-epoxy composites**

The S/N ratio response is given in the Table 15., from which it can be concluded that among all the factors, impact velocity of erodent is the most significant factor followed by stand-off distance, fiber loading, erodent size while erodent temperature, impingement angle has the least or negligible significance on wear rate of banana fiber-epoxy composites.

**Table. 9. Signal to noise ratio response table for erosion wear rate of banana fiber –epoxy composites**

Stage	A	B	C	D	E	F
1	48.28	50.86	48.84	50.24	50.45	50.91
2	49.85	48.86	50.48	50.24	48.03	48.93
3	51.56	49.97	50.37	49.21	51.21	49.85
Delta	3.27	2.00	1.65	1.03	3.19	1.98
Rank	1	3	5	6	2	4

## VI. CONCLUSIONS

**This investigation has led to the following conclusions:**

- 1) Successful fabrication of epoxy matrix composites reinforced with natural fiber is possible by simple hand-lay-up technique.
- 2) The density of the fabricated composites increases with increase in weight fraction and also increase in void content is reported with loading.
- 3) These composites possess very low amount of porosity even it is prepared by conventional hand lay-up technique, it also shows improved micro-hardness, tensile, compressive, flexural and impact strengths than those of the neat epoxy.
- 4) Results also show that it is possible to use banana fiber as many potential application.

## VII. REFERENCES

- [1].M. Jawaid, H.P.S. Abdul Khalil. “Cellulosic/Synthetic Fiber Reinforced Polymer Hybrid Composites: A Review”, Carbohydrate Polymers, Vol. 86, pp. 1–18, 2011.
- [2].Gad Marom, Albert Reuveni and Daniel Cohn, “Stiffness Variability and Stress-Dependent Elastic Response of Synthetic Fiber-Reinforced Composites for Biomedical Applications”, Biomaterials, Vol. 14, No. 2, 1993.
- [3].Jansons, J.O., Glejbol, K., Rytter, J., Aniskevich, A.N., Arnautov, A.K. & Kulakov, V.L. “Effect Of Water Absorption, Elevated Temperatures And Fatigue on the Mechanical

Properties of Carbon-Fiber-Reinforced Epoxy Composites for Flexible Risers”, Mechanics of Composite Materials, Vol. 38(4), pp.299-310, 2002.

[4].Kutty, S. K. & Nando, G. B. “Effect of Processing Parameters on the Mechanical Properties of Short Kevlar Aramid Fiber-Thermoplastic Polyurethane Composite Plastics”, Rubber and Composites Processing and Applications, Vol.19 (2), pp.105-110, 1993.

[5].Cho, J., Chen, J. Y. & Daniel, I. M. “Mechanical Enhancement of Carbon Fiber/Epoxy Composites by Graphite Nanoplatelet Reinforcement”, Scripta materialia, Vol.56 (8), pp. 685- 688, 2007.

[6].Chauhan, S. R., Gaur, B. & Dass, K. “Effect of Fiber Loading on Mechanical Properties, Friction and Wear Behaviour of Vinylester Composites Under Dry and Water Lubricated Conditions”, International Journal of Material Science, Vol. 1(1), pp. 1-8, 2011.