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Mechanical Behavior of Short & Long Bamboo Fiber Based Polyester: A Case Study

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Abstract

The traditionally used metal alloys lack in properties like high strength to weight ratio, high stiffness, high corrosion resistance, high fatigue strength etc. where specific applications have to be taken care of. Fiber based polymeric composite material possesses these properties. Despite these properties the use of synthetic fiber based composites is limited because of their high initial cost and adverse environmental effects. But still, the interest in natural fiber reinforced polymer composites is growing rapidly in terms of industrial application and fundamental research, due to their availability, low price, biodegradability and satisfactory level of mechanical properties which make them alternative over glass, carbon and some other synthetic fiber based composites. In this paper, an attempt has been made to explore the effect of fiber loading and fiber length on the mechanical properties of bamboo fiber reinforced polyester composites. Specimens are prepared by conventional hand lay-up technique with different fiber loading (9%, 18%, 27%, 36%, and 54%). Bamboo fibers of length 0.5 and 3.5 cm are used for reinforcement in polyester resin. Bamboo fiber composites are highly used in dusty environment therefore erosion behavior is of great importance. In the present work mechanical & erosion behavior of both short and long bamboo fiber reinforced polyester composites is performed. Erosion test is performed on air jet machine. Taguchi experiment design technique is used to optimize different parameters that affect the wear rate of the composites. The parameters used are impact velocity, impingement angle, fiber loading, and Stand-off distance. In the end various conclusion have been drawn regarding the effects of variable loading of composites.

Keywords: *- Taguchi Approach, Natural Fiber Reinforced Composites Mechanical Behaviour, Erosion Behaviour.*

Introduction

Composites are formed by combining two or more different material to make better use of their merits and by minimizing their scarcity (Geethamma et. al. 2005). These can be prepared as per their application by amalgamating tougher and lighter materials. The fact behind superior performance of the composite materials lies in their high specific strength and stiffness (Potham et. al. 2003). The production of composite material is done in two phases. One is the reinforcement phase and the other is the matrix phase. On the basis of matrix material, composites are of three types:

1. Metal matrix composite
2 .Polymer matrix composite
3 .Ceramics matrix composite

Material used

The material uses in this work are:-

1. Bamboo fiber (.5 cm and 3.5 cm by length).
2. Polyester resin.

Matrix material

In this work the matrix used is a polymeric matrix. For this, unsaturated polyester resin is used as a matrix material, which is a thermoset material. In liquid form all the resin contains monomers which convert into polymer when the polymerization process of the material takes place. Polymerization is basically the chemical reactions which help the resin to solidify. This process is completed with some heat and pressure by adding some hardening agent at room temperature. Hand layup technique is use for preparing the specimen.

Fiber material

In composite material the reinforcing phase is fiber. In present work, the bamboo fiber of length 0.5cm and 3.5cm is taken as reinforcement in polyester matrix to fabricate composite material. Bamboo is a natural resource which is present in large amount all over the world. These plants are fast growing grass which have woody stem. In present study, bamboo fiber is collected from the local source. It is easily available in India. In this work we cut the bamboo fiber of approximate length (figure 1) and then dried it in sunlight for 48 hours.

Fig 1: Long and short fibers

Composite fabrication

In this study, short and long bamboo fibers are taken from the local source which is used as reinforcement. The polyester resin, the accelerator and catalyst cobalt napthenate are supplied by Sakhshi dye and chemicals Tilak Nagar, New Delhi. Among the different fabrication technique, hand layup technique was used for the fabrication of the composites. A wooden mold (figure 2) having dimension of 150*30*7mm was use for the fabrication of composites.

Fig 2: Mold for composite fabrication

The bamboo fibers were filled in the mould. The catalyst and accelerator cobalt napthenate was mixed with polyester resin by a simple mechanical string then the hardener was mixed with polyester resin in the ratio 10:1. After this, solution was poured in the mould conforming to requirements of various testing condition. The composite samples of six different composition psb-1 to psb-6, in which the fiber length is .5 cm, were prepared. Other composite samples plb-1 to plb-6 was also prepared in which the fiber length was taken as 3.5 cm. In order to remove the composite from the mould after curing a releasing agent was also used. Proper attention was given to the formation of air bubbles and if generated or entrapped, these were carefully removed by using a sliding roller. Then container was closed by a glass sheet for curing at a temperature of 38 degree Celsius for 12 hours at constant pressure of 15 kg/cm^2. After curing took place, the specimen was removed from the mold. Now the specimen (figure 3) were ready for mechanical tests.

Fig 3: Fabricated composites

The composition of the composites prepared for this study is shown with their designation in table 1.

Table: 1 Designation of Composites

Test performed:

Composites	Composition
Psb-1	Polyester + bamboo short fiber (.5cm) (9% by volume)
Psb-2	Polyester + bamboo short fiber (.5cm) (18% by volume)
Psb-3	Polyester + bamboo short fiber (.5cm) (27% by volume)
Psb-4	Polyester + bamboo short fiber (.5cm)(36% by volume)
Psb-5	Polyester + bamboo short fiber (.5cm) (45% by volume)
Psb-6	Polyester + bamboo short fiber (.5cm) (54% by volume)
Plb-1	Polyester + bamboo long fiber (3.5cm) (9% by volume)
Plb-2	Polyester + bamboo long fiber (3.5cm) (18% by volume)
Plb-3	Polyester + bamboo long fiber (3.5cm) (27% by volume)
Plb-4	Polyester + bamboo long fiber (3.5cm) (36% by volume)
Plb-5	Polyester + bamboo long fiber (3.5cm) (45% by volume)
Plb-6	Polyester + bamboo long fiber (3.5cm) (54% by volume)

The following tests were performed on the specimen as per ASTM standard.

1. Flexural Test.
2. Impact Test.

Flexural test: - This test was carried on a universal testing machine (figure 4). The flexural strength of the prepared composite specimen was found out in this test. The speed of the machine for the test was maintained constant at 2.38mm/min. As per ASTM 790-03, the dimension of the specimen for flexural strength was 150*30*7 mm.

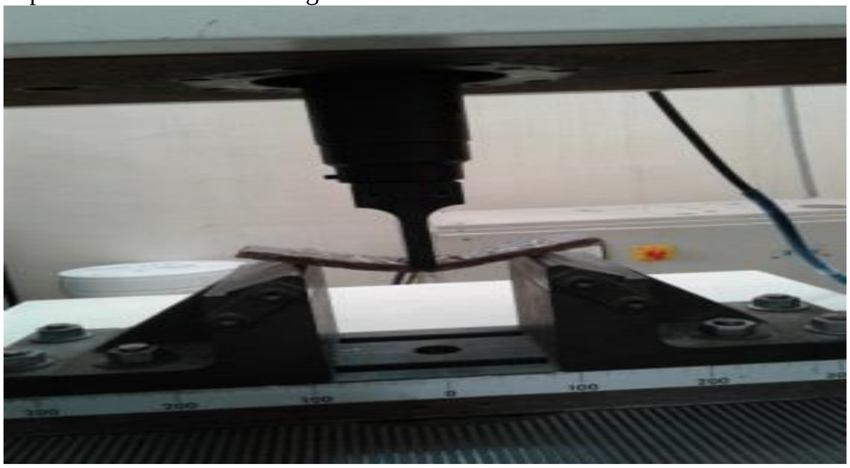

Fig 4: Composite Testing

Secondly, the tests were carried out on the specimen by using an impact testing machine (figure 5). The specimen is made according to ASTM d256. The machine use for impact test was Tinius Olsen. On the composite specimen, Izod impact test was performed. The dimension of the specimen for impact test is 67*15*7 mm.

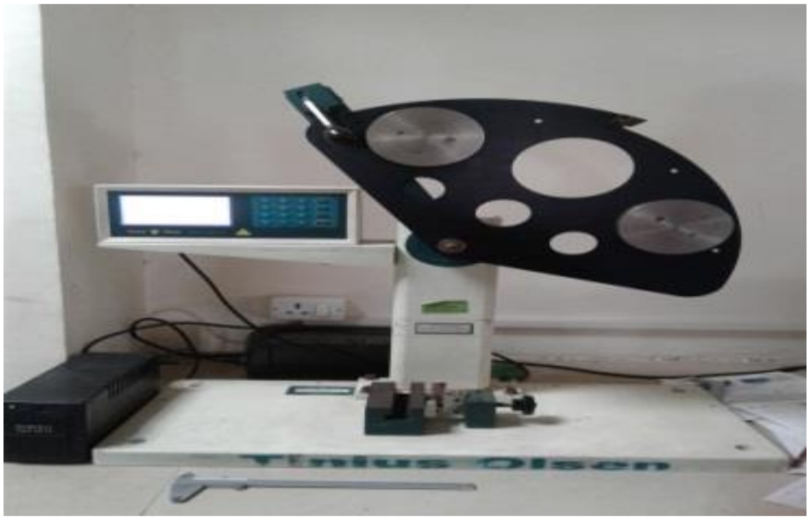

Figure 5: Impact testing machine

Erosion testing of composite specimen:
The erosion test rig basically consist of an air compressor, air filter, air drying unit, hopper, mixing chamber, vibrator which is basically connected to mixing chamber (John and Anandjiwala 2008). Compressor sucks the air from outside, filter it and dry, then this dry air is entered into vibrating chamber where it is mixed with the silica particle and is allowed to pass through the brass nozzle. Nozzle has an internal diameter of 3 mm. The particle size is 500 µm. The Erosion test is done as per ASTM g76.

Taguchi experimental design:
For robust design Taguchi experimental design is an important tool. It is a very simple and organized approach through which the design parameters can be optimized (Mittal & Kaushik 2017; Kaushik et. al. 2016). This approach reduces the overall testing time and experimental cost. Approach consists of two important tools. These tools are:-
1- **Signal to noise ratio**: - It extent quality which accentuate on variation.
2**- Orthogonal Array**: - It holds all the design parameters at the same time.

Table 2: Control factors at each level

	Control factor	Level			Units
		1	2	3	
A	**Impact Velocity**	30	40	50	m/sec
B	**Stand Off Distance**	110	160	220	Mm
C	**Fiber loading**	27	36	45	% by volume
D	**Impingent Angle**	45	60	75	Degree

The selection of the design parameters is a very important stage in the design of experiment (Mansur and Aziz 1983). It conform that parameters like filler content, impact velocity, Stand Off distance, Impingent angle, erodent temperature etc. affects the erosion rate of composite. In Taguchi approach the array chosen was L_9 (3^4). In the present study out of all parameters only four parameters are taken. All four parameters are considered at each three levels. The fixed parameters and the control factors for the erosion test are shown in table 2. Control factors for different levels are as shown in table 3. The operating test conditions are shown in table 4.

Table 3: Fixed parameter and control factors for erosion test

Control factor	Symbols	Fixed parameters	
Impact Velocity	Factor A	Erodent	Silica sand
Stand Off Distance	Factor B	Nozzle Diameter	3 mm
Fibber Loading	Factor C	Erodent Size	500 µm
Impingement Angle	Factor D	Length Of Nozzle	80 mm

Table 4: Orthogonal Array for L_9 Taguchi Design

S. No	Impact velocity (m/sec)	Stand Off Distance(mm)	Fibber Loading (% by volume)	Impingement Angle(Degree)
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Results and Discussion

The mechanical properties of short and long bamboo fiber reinforced polyester composite material with various fiber loading under the study as shown in table 5.

Table 5: Values of Flexural and Impact strength

S. No	Sample	Flexural Strength N/mm^2	Impact strength in J/mm^2
1	Psb-1	15.03	46.4
2	Psb-2	17.08	55.43
3	Psb-3	20.83	58.37
4	Psb-4	16.04	70.4
5	Psb-5	14.81	98.28
6	Psb-6	11.90	95.68
7	Plb-1	11.11	86.98
8	Plb-2	13.41	88.70
9	Plb-3	18.05	116.18
10	Plb-4	15.67	137.5
11	Plb-5	10.81	160.71
12	Plb-6	9.07	157.23

Average F.S for short bamboo fiber composites = 15.03+17.08+20.83+16.04+14.81+11.90 =15.95 N/mm²
Average F.S for long bamboo fiber composites = 11.11+13.41+18.05+15.67+10.81+9.07/6 =13.02 N/mm²
Average I.S for short bamboo fiber composites = 46.4+55.43+58.37+70.4+98.28+95.68/6 =70.76 J/m
Average I.S for Long bamboo composites = 86.98+88.70+116.18+137.5+160.71+157.23/6 =124.55 J/m

Effect of fiber loading on flexural strength of short bamboo composites

The effect of fiber loading on short fiber composites is as shown in figure 6. From figure it has been seen that with increase in fiber loading the flexural strength is also increases up to 27% that is from 15.03 to 20.83 and then start decrease up to 54% that is from 20.83 to 11.90.

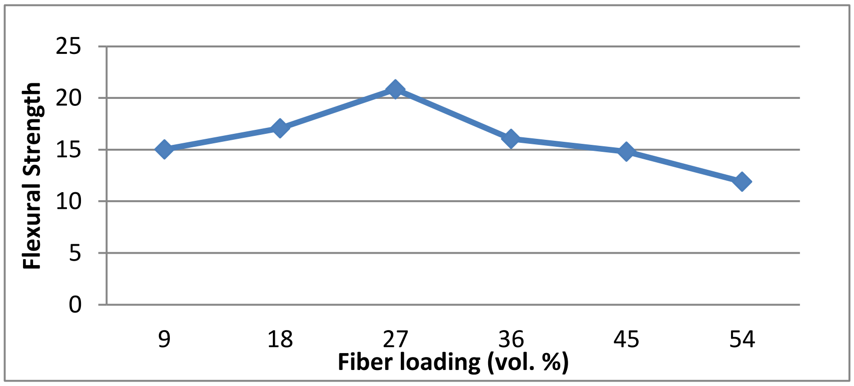

Fig 6: Effect of fiber loading on flexural strength (Short bamboo composites)

Effect of fiber loading on flexural strength of long bamboo composites

The effect of fiber loading on long bamboo fiber composites is as shown in figure 7. From figure it seems that with increase in fiber loading the flexural strength is also increase up to 27% that is from 11.11 to 18.05 and after 27% fiber loading the flexural strength starts decreases up to 54% that is from 18.05 to 9.07

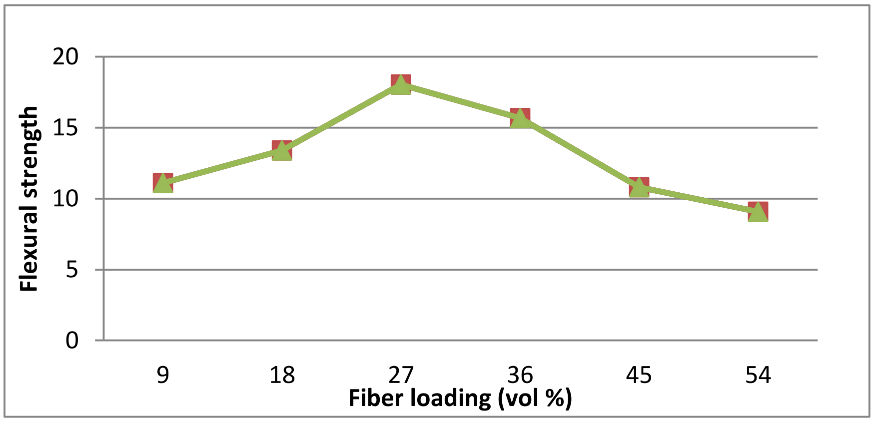

Fig 7: Effect of fiber loading on flexural strength (Long bamboo composites)

Effect of fiber size on flexural strength

The effect of fiber size is as shown in figure 8. By taking the mean of all the values of flexural strength of short and long fiber reinforced composites it is clear that the flexural strength of short bamboo fiber reinforced composites is larger than long fiber reinforced composites.

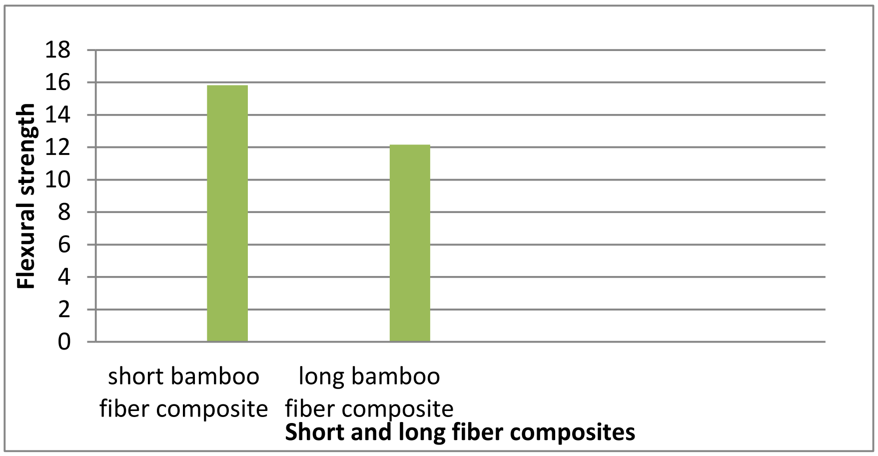

Fig 8: Effect of fiber size on flexural strength

Effect of fiber loading on impact strength of short bamboo reinforced composites

The effect of fiber loading on short bamboo fiber reinforced composites is as shown in figure 9. From figure it has been clear that with increase in fiber loading the impact strength is also increases up to 45 %that is from 46.4 to 98.28 J and then after 45% it starts decreasing

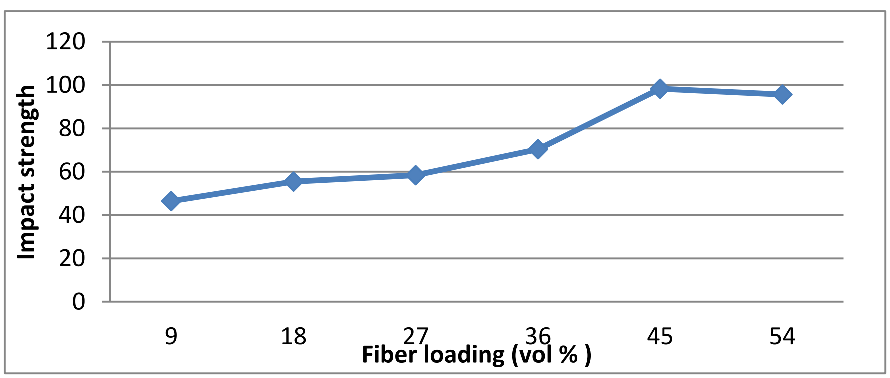

Fig 9: Effect of fiber loading on Impact strength (Short bamboo composites)

Effect of fiber loading on impact strength of long bamboo reinforced composites

The effect of fiber loading on long bamboo fiber composites is as shown in figure 10. From figure it seems that the impact strength is increases with increases in fiber loading up to 45% that is from 86.98 to 160.71 J and after 45 % fiber loading impact strength start decreases with increasing fiber loading.

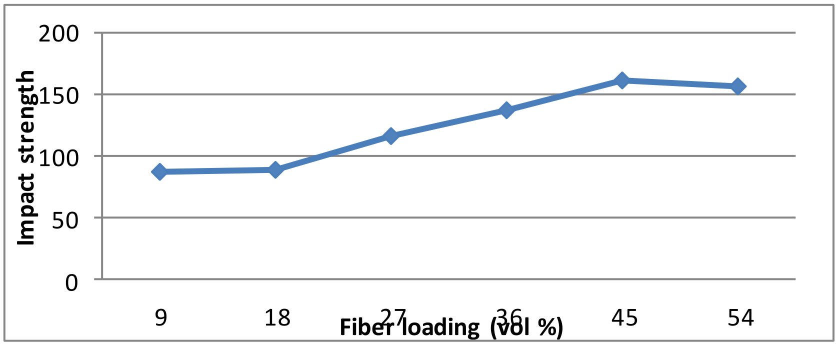

Fig 10: Effect of fiber loading on Impact strength (Long bamboo composites)

Effect of fiber size on Impact strength

The effect of fiber size is as shown in figure 11. By taking the mean of all the values of impact strength of short fiber composites and long fiber composites it is clear that the impact strength of long bamboo fiber reinforced composites is larger than short fiber composite.

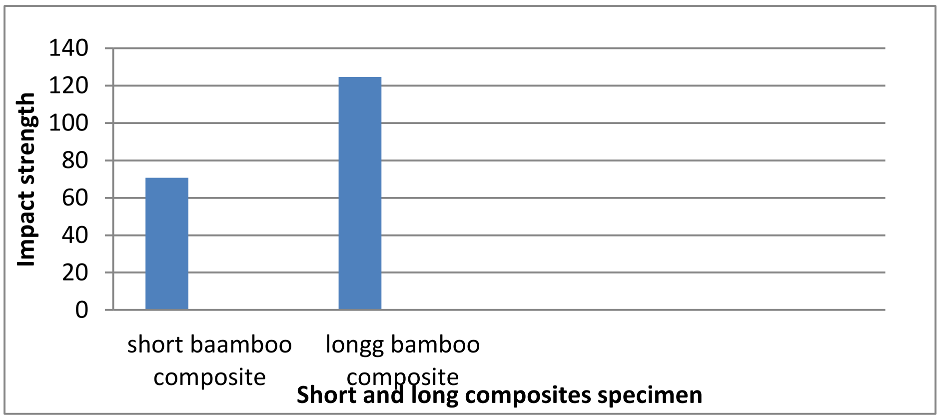

Fig 11: Effect of fiber size on impact strength

Taguchi experimental results: (short bamboo polyester composites):

The analysis of Taguchi experiment was performed by using MINITAB 17 software. The possible combination of all the control factors was considered. The erosion rate was transformed into S/N ratio. For minimum erosion rate the S/N ratio comes under 'smaller the better' characteristics, which can be calculated as

$$S/N = -10 \log 1/n \{\Sigma p^2\}$$

Where n is number of observation, p is the observed data. The S/N Ratio for erosion rate is as shown in table 6.

Table 6. Various values of S/N ratio of erosion rate of short bamboo composite.

S. No	A	B	C	D	ER	SN Ratio
1	30	110	27	45	244.87	-47.7787
2	30	160	36	60	283.48	-49.0504
3	30	220	45	75	309.31	-49.8079
4	40	110	36	75	318.55	-50.0636
5	40	160	45	45	292.95	-49.3359
6	40	220	27	60	269.88	-48.6234
7	50	110	45	60	303.66	-49.6478
8	50	160	27	75	329.59	-50.3795
9	50	220	36	45	291.73	-49.2996

For erosion rate the mean of the S/N ratio is -49.3318 db.

The response table for signal to noise ratio is shown in table 7. From table it is clear that the most significant factor among all the factors was the impingement angle which was followed by impact velocity and then fiber loading while the factor stand-off distance is the least significant factor in erosion of short bamboo reinforced polyester composite. The corresponding main effect plot for the four variables is shown in figure 12.

Table 7: Response of S/N ratios for short bamboo composite.

Level	A	B	C	D
1	-48.88	-49.16	-48.92	-48.80
2	-49.34	-49.58	-49.47	-49.11
3	-49.77	-49.24	-49.60	-50.08
Delta	0.89	0.42	0.68	1.27
Rank	2	4	3	1

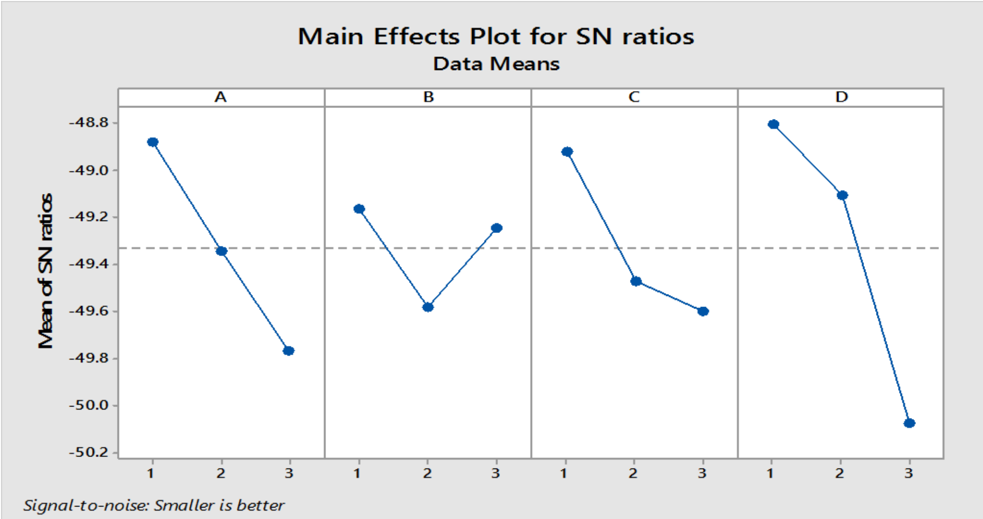

Fig 12: Effect of different factor on each level for short bamboo composite

Taguchi analysis: - (Long Bamboo composite)

The possible combination of all the control factors is similar to the short bamboo. Table 8 shows the erosion rate of short bamboo fiber reinforced polyester composite for 9 different combination of the factor affecting the erosion rate; similarly the S/N ratio comes under 'smaller the better' characteristics.

Table 8: Various values of S/N ratio of erosion rate of long bamboo composite

SR. No	A	B	C	D	ER	SN RATIO
1	30	110	27	45	193.87	-46.5624
2	30	160	36	60	209.48	-47.9407
3	30	220	45	75	183.31	-48.5727
4	40	110	36	75	218.55	-48.7407
5	40	160	45	45	265.95	-47.8873
6	40	220	27	60	214.88	-47.4169
7	50	110	45	60	293.66	-48.7762
8	50	160	27	75	252.59	-49.4431
9	50	220	36	45	223.73	-48.2502

For erosion rate the mean of the S/N ratio is -48.1766 db.

The response table for signal to noise ratio is shown in table 9. From table it is clear that the most significant factor among all the factors was the impingement angle which was followed by impact velocity and then fiber loading while the factor stand-off distance is the least significant factor in erosion of long bamboo reinforced polyester composite. The corresponding main effect plot for the four variables is shown in figure 13.

Table 9: Response for S/N ratios for long bamboo composite.

Level	A	B	C	D
1	-47.69	-48.03	-47.81	-47.57
2	-48.01	-48.42	-48.31	-48.04
3	-48.82	-48.08	-48.41	-48.92
Delta	1.13	0.40	0.60	1.35
Rank	2	4	3	1

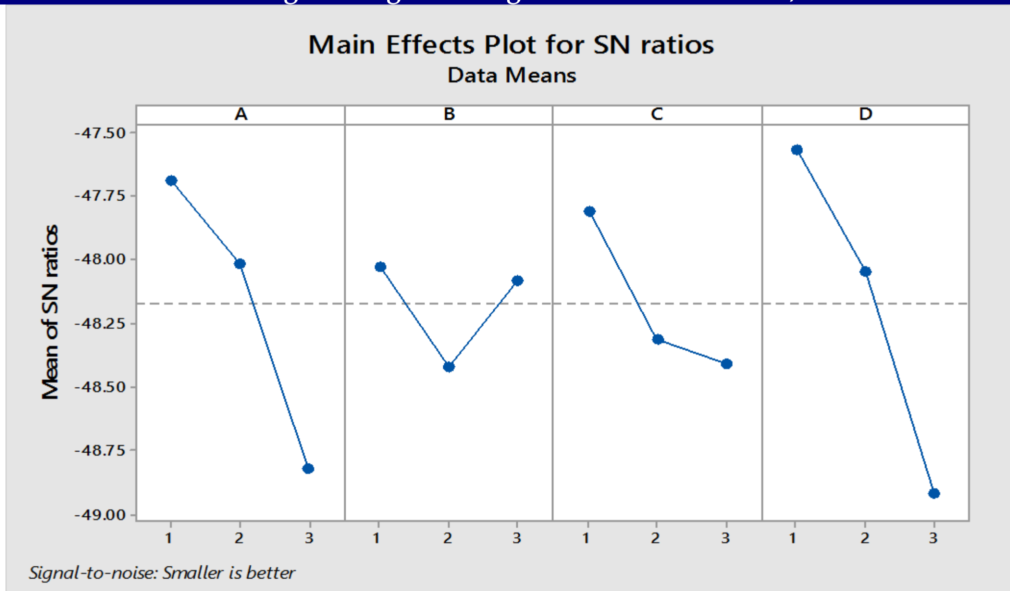

Fig 13: Effect of different factor on each level for long bamboo composite

Conclusion

Following conclusions could be made from current study:-

1. Mechanical properties such as impact strength and flexural strength are largely affected by the fiber loading and fiber length.
2. Flexural strength of both short and long bamboo fiber reinforced polyester composites increases with increase in fiber loading up to 27% then start decreasing.
3. Impact strength of both short and long bamboo fiber reinforced polyester composite increases with increase in fiber loading up to 45 % and then starts decreases with increase in fiber loading.
4. The flexural strength of short fiber reinforced polyester is greater than that of long fiber reinforced composites.
5. The impact strength of long Bamboo fiber reinforced polyester is greater than that of short fiber reinforced composite.
6. It is clear that the most significant factor among all the factors is the impingement angle which is followed by impact velocity and then fiber loading while the factor stand-off distance is the least significant factor in erosion of long and short bamboo reinforced polyester composite.

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