Experimental Investigation of Mechanical and Machining Characteristics of Aramid-Natural Fiber Composite

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July 3, 2020

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Abstract

Growth of science and technology over the past few decades demands a new and hybrid material to meet variety of purposes. Composite materials are one among those new emerging engineering material which plays a major role in engineering industry. Here, combination offibers namely Kevlar, neem and kenaf are sandwiched between layers of glass fibersby hand layup method to enhance the stiffness and strength of the laminates which is the conventional way of producing composites. Thus the mechanical properties and behaviors of these samples were identified by Tensile, Impact and Flexural tests. Scanning electron microscopy has been done to observe the morphological changes in the laminate and Also, abrasive water jet machining is done in the laminate by changing the process parameters like traverse speed, pressure and standoff distance. At last ANOVA and Taguchi's method is done to optimize the parameters.

Keywords*:* Fibers, Hand layup method, Mechanical Testing, SEM, Optimization Techniques.

1.0 Introduction

MohdEdeerozey et.al [1] investigated the concentration of NAOH solution on kenaf fibers. It has shown that the fiber with 6% NAOH solution yields the optimized solution for improved fiber properties. Morphological analysis has been done on the fiber in order to check the interfacial adhesion between the fiber and the matrix. Finally the alkalization treatment of the fiber shows the improved results when compared with the untreated kenaf fibers. Sarah et.al [2] studied and examined the filtration characteristics of ground kenaf core. The study has been implemented and tested in various forms with a yeast solution. The result shows that the kenaf fibers removed all the yeast, bacterial and silica particles without flux degradation over the course of filtration. In this regard, kenaf fibers removed around 40% of the particles during the process.Nishinoa et.al [3] experimentally investigated the mechanical properties of kenaf fibers with poly L lactic acid (PLLA) resin. The result shows the improvement of interaction between the kenaf fibers with the resin. It also results with best reinforcement alternating with the bio degradable polymer composites.Yahaya et al [4] experimentally investigated the combined effect of kenaf and Kevlar 129 fiber composites with epoxy resin as the matrix. The results shows that the significant improvement on the tensile strength and better impact resistance properties with non woven kenaf fiber higher than that of the unidirectional and mat samples. Vijayaramnath et al [5, 15] investigated the mechanical properties of a twisted kenaf and neem hybrid composites with vacuum assisted compression molding techniques. The result shows that the significant improvement on mechanical properties. Rajesh et al [6, 13, 14] experimentally proved the hardness and impact property of Kevlar composite. Jeykrishnan et al [7 and 8] have concluded that the Taguchi techniques can be employed for optimizing the variables like applied current, pulse on time and pulse off time in electro-discharge machining in different materials to obtain better responses like MRR, TWR and R_a and also have revealed that the current plays an important role in obtaining the better responses, followed by pulse on time and pulse off time. Meenagupta et al [9] investigated machining characteristics like surface roughness and material removal rate using Taguchi method and optimized the parameters. Prasad et al [10] analyzed finite element methods of jute and banana fiber reinforced hybrid polymer matrix composite and optimized using ANOVA technique. Gupta et al [11] experimentally investigated the effect of minimization of kerf taper angle and kerf width using Taguchi's method in abrasive water jet machining of marble. Patel et al [12] experimentally investigates thermally enhanced abrasive water jet machining of hard to machine metals. Here, combination of fibers namely kevlar, neem and kenaf are sandwiched between layers of glass fibers by hand layup method and behaviors of these samples were identified by tensile, impact and flexural tests finally the parameters were optimized by ANOVA and Taguchi’s method.

2.1 Fabrication of composite

In this work, kenaf, neem and Kevlar are used to fabricate the composite laminate by using hand layup method. Kenaf has high cellulose content in which high tensile strength can be obtained. Kevlar has its own property of high impact resistance. Neem has high saline resistance in which it will be used as natural resource in rural and urban areas. The matrix used to fabricate the composite specimen is epoxy LY 556 of density 1.13-1.16 (g/cm$^{3)}$ and it is mixed with hardener HY 951 of density 0.946 (g/cm$^{3)}$. The weight ratio of mixing epoxy and hardener is 10:1. Table 1 shows the sequence of different categories in which the laminate is prepared.

Category 1	Category 2	Category 3
GFRP	GFRP	GFRP
KEVLAR	KEVLAR	KEVLAR
KENAF	NEEM	KENAF
KENAF	NEEM	NEEM
KEVLAR	KEVLAR	KEVLAR
GFRP	GFRP	GFRP

Table 1: Sequence of Composite Laminate

2.2 Testing of composites

2.2.1 Tensile Test

The tensile test is performed to find the tensile behavior of materials. For each test of composite three samples were tested and average was taken for analysis. Figure1shows the specimen for tensile test.

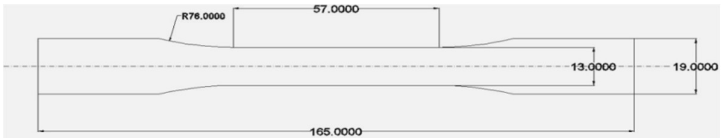

Figure 1: Tensile test specimen [ASTM: D638]

2.2.2 Flexural test

The three point bend test was carried out in accordance with ASTM D790 standard as shown in figure 2to measure the flexural strength of the composites.

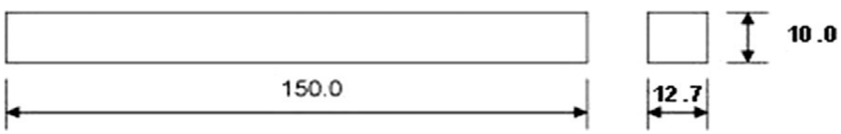

Figure 2: Flexural test specimen [ASTM: D790]

2.2.3 Impact test

A V-notch is provided and the pendulum is free to oscillate so that it tends to break the specimen at a specific point during impact loading condition. The specimen is prepared as per the ASTM D256 standards as shown in figure3.

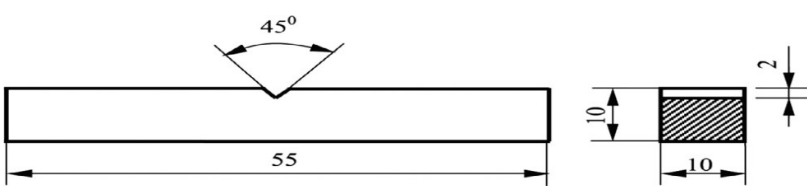

Figure 3: Impact test specimen [ASTM: D256]

2.2.4 Double shear test

The load has been applied until the sample breaks. The graph has been plotted with stress corresponding to strain. The specimen is prepared as per the ASTM D5379 standards as shown in fig.4.

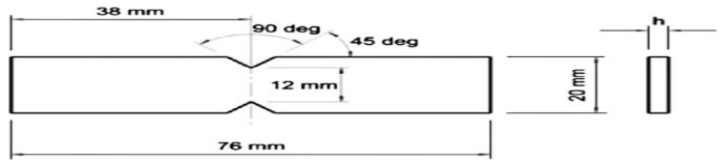

Figure 4: Double shear test specimen [ASTM: D5379]

2.2.5 Inter de-lamination test

This test has been carried out to observe the failure cause by the layers in the composite sample internally. Here the load is applied and the corresponding strain has been observed the graphs between the deflection and the load is drawn.

2.2.6 Hardness Test

Hardness is the resistance of a material to permanent indentation. Hardness is mainly depends on the material property in which the intended portion tends to absorb sudden shock which results testing of hardness of the material.

2.3 Results and Discussion

2.3.1 Result of Tensile Test

Tensile test has been carried out on three categories of composites, and in each 3 samples are tested and the values are noted. The fig. 5shows the graph plotted between the load and the displacement as the result of tensile test. Here, category I withstand higher tensile load when compared to other two categories because of the Kevlar and kenaf fiber present in the composite laminate. The load carrying capacity is high in this category in presence of kenaf which results in higher adhesion and bond between the fiber and the resin.

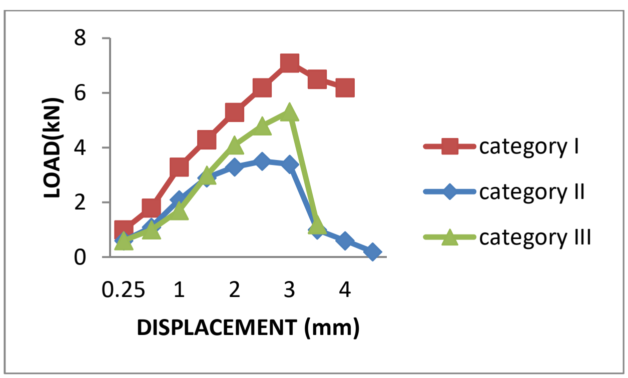

Figure 5: Result of tensile test

2.3.2Result of Flexural Test

Flexural test otherwise known as three point bending test which measures the force required to deflect the beam under boundary conditions. Here, the load is applied at the midpoint of the beam in which we can attain the maximum deflection when the specimen bends and breaks. The ultimate load, flexural strength and the displacement are noted andfig.6shows the graph plotted between the load and the displacement as the result of flexural test.Here the bending strength is higher in category I when compared to category II and III due to the Kevlar fiber present in the outer layer which tends to reduce the bending effect in the composite laminate. The fiber orientation is strong enough to withstand the bending load in mid span of the specimen which influences the flexural properties.

4.3Result of Impact Test

In Impact test the total energy absorbed by the specimen is calculated and the corresponding values are noted. The graph in fig.7 shows a plot between impact strength and energy absorbed, here category I of samplee I recorded higher value due to the presence of higher shock absorbing capacity of kenaf fiber in the middle layer which results in high impact resistance during impact loading condition. The fiber reinforcement and the resin medium offers stiffness and high impact strength.

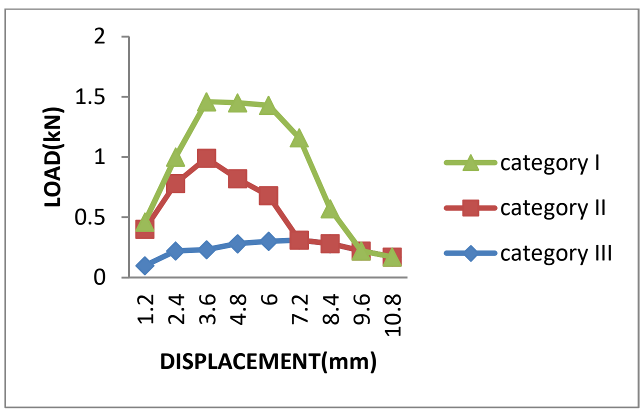

Figure 6: Result of flexural test

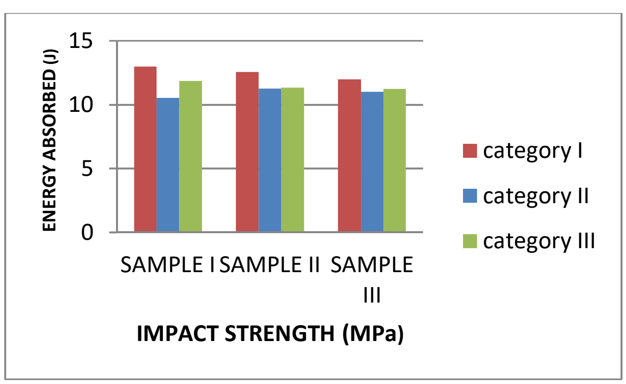

Figure 7: Result of impact test

2.3.4 Result of Double Shear Test

Double shear test influences the high shear properties which pretends equally distributed load on either direction supports shear loading. Fig. 8 shows the result for double shear which results in high in category I due to the presence of fiber orientation which influences shear properties.

2.3.5Result of Inter De-lamination Test

Delamination test has been carried out to find the internal mode of failure caused by repeated cyclic stresses. In fig. 9, category I has maximum diplacement with respect to continous fiber orientation which influences the inter delamination property.

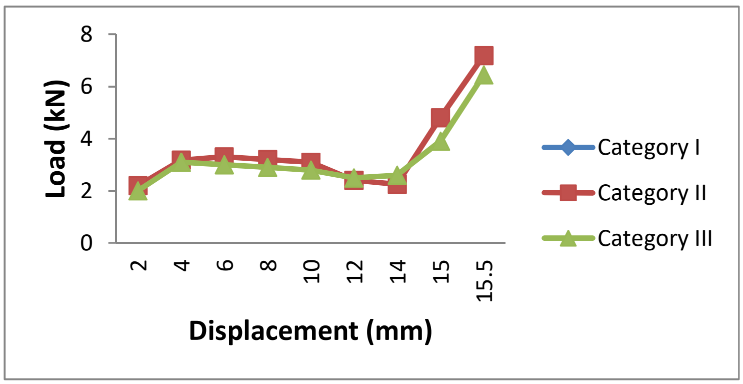

Figure 8: Result of double shear test

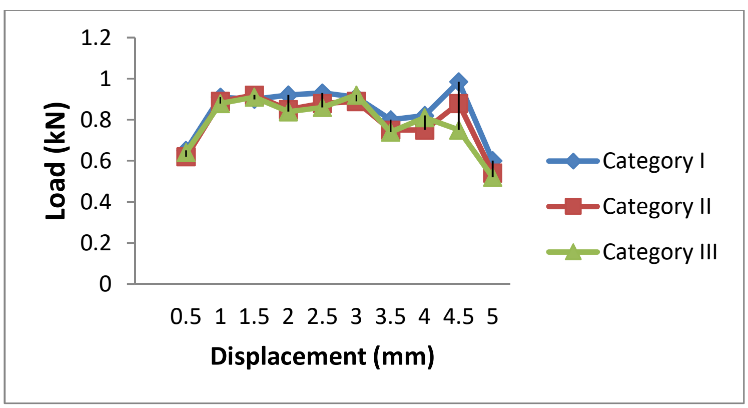

Figure 9: Result of inter Delaminating test

2.3.6 Result of Hardness Test

The fig. 10 shows the specimen result for hardness test.Category I of sample III shows the high hardness valuebecause of the kevlar fiber present in the outer layer of the laminate.

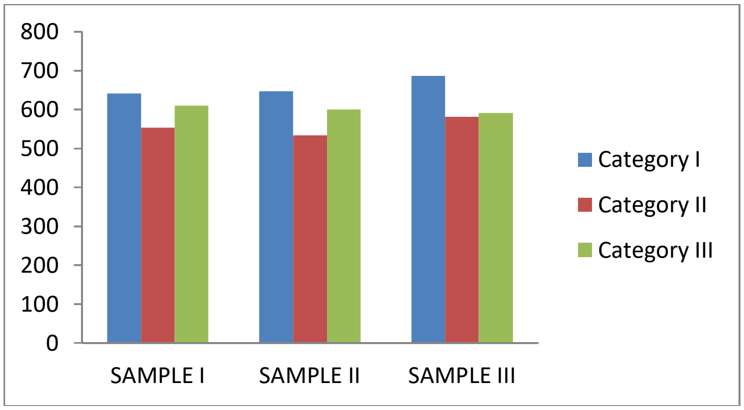

Figure 10: Result of hardness test

2.4 Morphologicalanalysis of composite laminate

The fig 11 shows the fiber layers separation when the tensile test has been carried out. It clearly shows the elongation of fibers in direction which has the maximum pull in either direction axially. As the kenaf fiber has high load carrying capacity, the damage of the fibers are very less shown in fig.12.

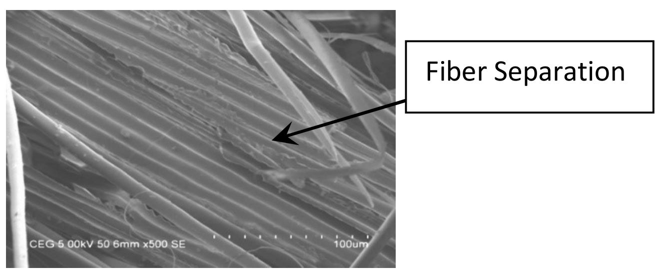

Figure 11: 16100 µm tensile test

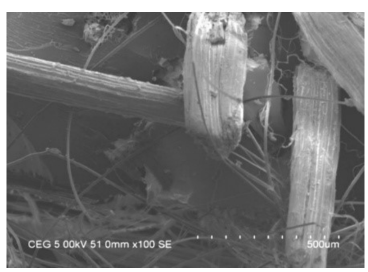

Figure 12: 17 500 µm tensile test

Fig. 13 shows the intended portion during impact test in which the category I shows higher value due to the Kevlar fiber has the tendency to absorb the maximum energy due to impact loading. The micron level has been increased to see the blow holes and cracks due to shock produced during the impact loading condition as shown in the fig. 14.

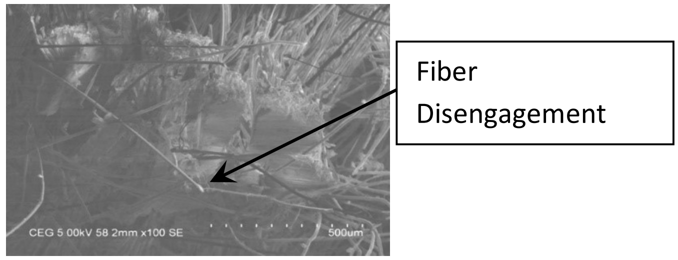

Figure 13: 18500 µm impact test

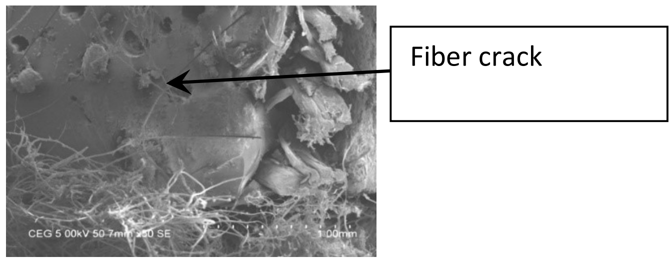

Figure 14: 19100 µm impact test

The fig. 15 shows the scanning electron microscope of flexural test which shows the bending effect of fibers in which the maximum portion is in the middle layer and also the presence of kenaf fibers restricts the bending effect thereby which influences the flexural properties. Fig. 16 shows the enlargement of fibers with high effect of bending during test.

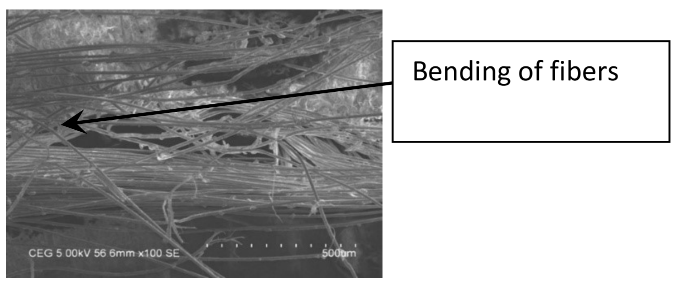

Figure 15: 20500 µm flexural test

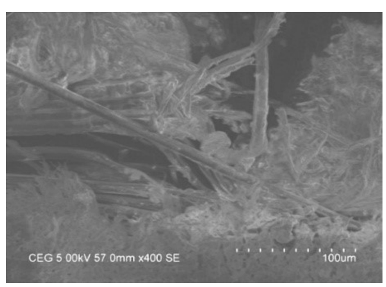

Figure 16: 21100 µm flexural test

The inter Delamination test has been carried out to see the internal changes in the fibers with maximum distortion taking place during breakage of fibers inside the laminate as shown in fig. 17.The distortion occurs at the corner of the laminate due to the crack propagation takes place in the laminate which is having high stress concentration factor as shown in the fig.18.

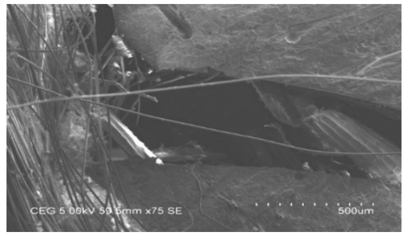

Figure 17: 22500 µm Delamination test

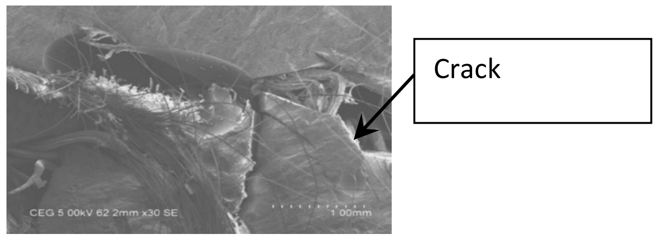

Figure 18: 23100 µm Delamination test

The above fig. 19 repesents the image with varying micro levels, cracks are formed in the composite specimen due to double shear effect acting simulataneously in either direction axially. This results in blow holes formed due to homogeneity in the laminate.The optical microscope images show the distribution fiber particles in the sample as shown in the fig. 20 with varying micro levels to obtain a clear view of the fiber distribution and damages of the composite specimen during double shear test.

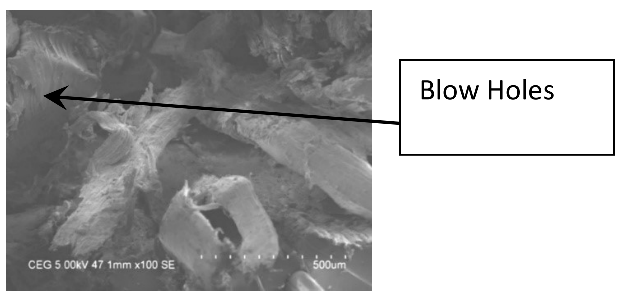

Figure 19: 24500 µm double shear test

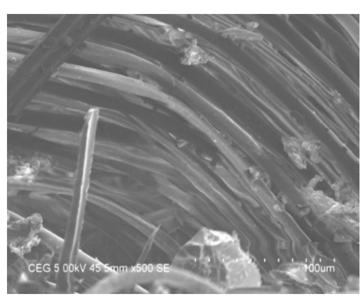

Figure 20: 25100 µm double shear test

2.6 Machining of Composite Material

In this work, the machining of composite is carried out by using abrasive water jet machine (AWJM) by changing its 3 parameters making it to 16 combinations. Here garnet is used as the abrasive material for machining process.

Table.2 Parameters table

S.No	Machining parameters / Input factors	Level			
		1	2	3	4
1	Standoff distance (mm)	2	3	4	5
2	Pressure (psi)	17000	18000	19000	20000
3	Traverse speed (m/s)	620	540	460	380

The above mentioned 16 parameters are been taken for the machining optimization process. The surface roughness is measured by using the surface pyrometer device.From this data the S/N ratio for MRR and surface roughness are been measured with the help of ANOVA table and Taguchi method and have been given in table 3.
Here MRR is found by using the following equation.

$$MRR = \frac{[(Actualweight) - (Finalweight)](g/\min)}{Time(\min)} \qquad \text{Eqn. (1)}$$

Table.3Machining parameters table with S/N ratio

No.	Standoff distance (mm)	Pressure (psi)	Traverse speed (mm/s)	MRR (g/min)	Surface roughness (µm)	S/n ratio for MRR	S/n ratio for R_a
1	2	17000	620	108.04	4.563	40.6717	-13.1850
2	2	18000	540	216.09	4.389	46.6927	-12.8473
3	2	19000	460	324.13	4.264	50.2144	-12.5963
4	2	20000	380	420.17	4.125	52.4685	-12.3085
5	3	17000	540	552.22	4.562	54.8422	-13.1831
6	3	18000	620	648.26	4.369	56.2350	-12.8076
7	3	19000	380	816.33	4.289	58.2373	-12.6471
8	3	20000	460	960.38	4.174	59.6489	-12.4110
9	4	17000	460	1068.43	4.560	60.5749	-13.1793
10	4	18000	380	1036.45	4.365	60.3110	-12.7997
11	4	19000	620	1024.52	4.256	60.2104	-12.5800
12	4	20000	540	998.44	4.098	59.9864	-12.2514
13	5	17000	380	856.23	4.565	58.6518	-13.1888
14	5	18000	460	897.56	4.387	59.0613	-12.8434
15	5	19000	540	952.36	4.238	59.5760	-12.5432
16	5	20000	620	987.45	4.099	59.8903	-12.2536

The S/N ratio graph for MRR has been shown in fig. 16 and has been calculated using “Larger the better” criteria. The graph implies that the MRR value increases with increase in SOD. But, as when SOD reaches 5mm, the abrasive particles itself hinders the movement of the abrasives, resulting in the fall of MRR. The response table for the S/N ratio has been calculated and has been given in table 4 as this implies that in order to get better MRR; standoff distance has major contribution, followed by pressure of the abrasives and the traverse speed of the nozzle.

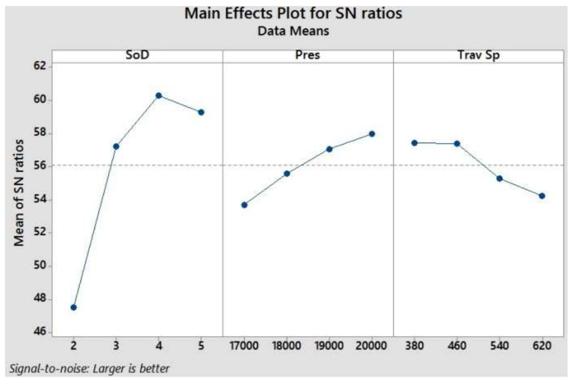

Figure 21: S/N ratio graph for MRR

Table 4 Response for MRR

Level	Standoff distance (mm)	Pressure (psi)	Traverse speed (mm/s)
1	47.51	53.69	57.42
2	57.24	55.57	57.37
3	60.27	57.06	55.27
4	59.29	58.00	54.25
Delta	12.76	4.31	3.17
Rank	1	2	3

The ANOVA table has been given in table 5 as it gives the percentage contribution of each variables, as SOD contributes 89.24% to obtain better MRR, followed by the pressure and traverse speed of the nozzle by 5.81% and 3.38% respectively.

Table 5 ANOVA for MRR

Parameters	Degrees Of freedom	Adj. SS	Adj. MS	F value	% Contribution
Stand off distance (mm)	3	1370042	456681	113.31	89.24
Pressure (psi)	3	89145	29715	7.37	05.81
Traverse speed (mm/s)	3	51904	17301	4.29	03.38
Error	6	24183	4030	--	01.57
Total	8	1535274	--	--	--

The S/N ratio graph for surface roughness (R_a) has been given in fig.17 The graph implies that when SOD and traverse speed of the nozzle increases the R_a also increases, as more abrasives tends to impinge on the same part of the material, thereby the unwanted material gets removed in a gradual process, making the surface smoother. When the pressure increases, R_a increases, as abrasives with high velocity impinges on the material, through which the unwanted material gets cleared away. The response table for R_a has been given in table 6, which indicates that the pressure of the abrasives ahs major impact on getting the better R_a, followed by SOD and the traverse speed of the nozzle.

Table-6 Response for R_a

Level	Standoff distance (mm)	Pressure (psi)	Traverse speed (mm/s)
1	-12.73	-13.18	-12.74
2	-12.76	-12.82	-12.76
3	-12.70	-12.59	-12.71
4	-12.71	-12.31	-12.71
Delta	0.06	0.88	0.05
Rank	2	1	3

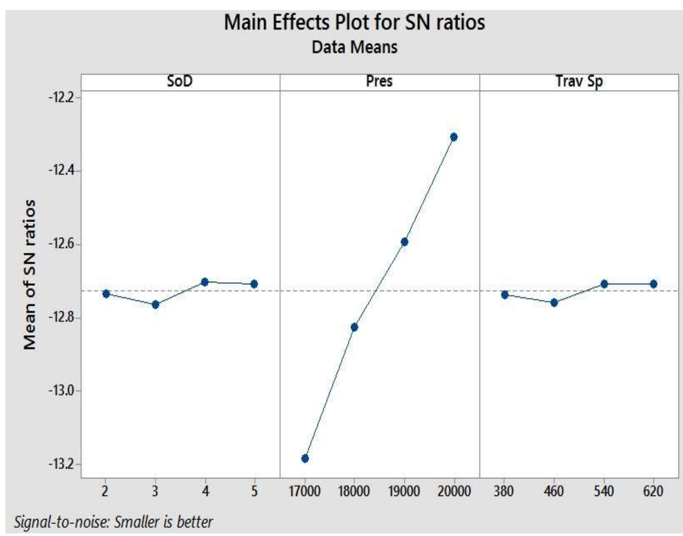

Figure 22: S/N ratio graph for R_a

The ANOVA table represents that the pressure has 91.24% of contribution in order to get the better R_a, followed by SOD and traverse speed of the nozzle with 5.1% and 2.54% respectively, and have been shown in table 7.

Table-7 ANOVA for R_a

Parameters	Degrees of freedom	Adj. SS	Adj. MS	F value	P value
Standoff distance (mm)	3	0.002107	0.000702	2.35	05.10
Pressure (psi)	3	0.413593	0.137864	461.5	91.24
Traverse speed (mm/s)	3	0.001712	0.000571	1.91	02.54
Error	6	0.001792	0.000299	--	01.12
Total	8	0.419204	--	--	--

3.0 Conclusion

In this work, three different fibers namely Kevlar, kenaf and neem are used for fabrication using hand layup method. The fiber influences the sequence of layers which exhibits superior mechanical properties. Various mechanical tests such as tensile strength, flexural strength, impact strength, double shear test, inter Delamination test and hardness test had been carried out to determine the mechanical strength and durability of the laminate. In mechanical characterization, Category I show the higher values in all the tests due to the presence of Kevlar fibers at the outermost layer.

The analysis of experimental results is carried out using Taguchi's analysis. The level of the best process parameters are been determined by using ANOVA .From the above discussions, it has been clear that the optimal MRR value has been obtained at SOD of 4mm, pressure of the abrasives at 17000 psi and traverse speed of the nozzle at 460 mm/s, whereas the optimal value for R_a has been obtained at SOD of 4mm, pressure of the abrasives at 20000 psi and traverse speed of the nozzle at 540 mm/s. Through many predictions, it has been observed that the optimal values of MRR and R_a can be obtained by varying the parameters like SOD (mm), pressure of the abrasives (psi) and the traverse speed of the nozzle (mm/s) by using Taguchi method. Finally it has been concluded that the Kevlar fiber with outer layer combined with kenaf has got better strength and stability which influences superior mechanical properties.

4.0Reference

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