

FABRICATION AND EVALUATION OF MECHANICAL PROPERTIES OF PINE APPLE LEAF FIBER/CARBON POWDER HYBRID COMPOSITES USING TAGUCHI METHOD

¹K.Ravi Babu, ²Dr.S.Madhusudan, ³V.Santha Kumar, ⁴Dr.R.Bhargavi

¹M.Tech Scholar URCET, ²Professor and HOD Mechanical Engineering URCET, ³Asst.Professor URCET, ⁴Associate professor URCET

¹Mechanical Engineering(Machine Design),

¹Usha Rama College of Engineering and Technology, Telaprolu, India

Abstract : The composite manufacturing has been a wide area of research and it is the preferred choice due to its superior properties like low density, stiffness, light weight and possesses better mechanical properties. This has found its wide applications in aerospace, automotive, marine and sporting industries. There has been continuous lookout for synthesizing composites without compromising on the mechanical. In the present study polymer composite reinforced with pine apple leaf fiber and carbon powder are fabricated and tested to determine the mechanical. Experiments were conducted using Taguchi L9 orthogonal array considering the two design parameters viz. weight fraction of the pine apple leaf fiber and carbon powder as filler. The Experimental results were analyzed using Taguchi optimization method. Signal-to- noise (S/N) ratio, Regression analysis and Analysis of variance (ANOVA) were carried out to obtain the significant values of tensile strength, flexural strength and impact strength.

Index Terms - pine apple leaf fiber, carbon powder, polyester resin and Taguchi.

I. INTRODUCTION

The superior mechanical properties of pineapple fibre are related to its high polyose content and relatively low microfibrillar angle. PALF has been used traditionally as threads, works have just started on studying them as industrial material substances. Pineapple leaves are composted or burned by the farmers due to lack of knowledge, consequently losing capacity delivery of best fibres. Among several herbal fibres, pineapple leaf fibres (PALFs) shows outstanding mechanical properties. They're extracted from the leaves of the plant Ananus cosomus happiness belonging to Bromeliaceae family by retting process. The elements of pineapple fibre are polyose (70-82%), polymer (5-12%) and ash (1.1%). [1].

In the present study, pine apple leaf fiber polyester resin composites fabricated and tested for their mechanical properties. Experiments conducted using Taguchi orthogonal array L₉ considering the two deign parameters viz. weight fraction of the fiber and weight fraction of carbon powder. The experimental results were analyzed using Taguchi optimization method. Analysis of variance (ANOVA) carried out to obtain the significant values of tensile strength, flexural strength, and impact strength at 95 % confidence level. Multiple regression analysis technique is applied to obtain the mathematical model for tensile, flexural and impact strengths. Optimizations of tensile, flexural and impact test parameters done with the help of Taguchi analysis.[2]

The increase in cost and adverse effects on environment by synthetic fibre have compelled the scientists and engineers to fabricate new assets i.e. natural composites that, besides having their required physical properties, cheaper and environmentally friendly. During this context, the use of inclusion of natural fibre over the artificial fibre in polymer matrix has received momentum at a few levels during the last decade [3].

Perishable fibre materials will decompose into extraordinarily little fractions via organic interest and adjustments to the chemical form of the material. Biodegradable fibres derived from natural vegetation are copiously accessible and are once thought as waste. It is represented as a coordinated device of making products for delivery, distribution, storage, marketing, advertising and use. Natural fibre materials have many advantages like low cost, denseness, renewable nature, biodegradability, relative non-abrasiveness [4-7].

The massive and large big selection convenience of natural fibre will reduce the pressure on forest and agriculture. The versatile nature of it makes it suitable for motors, railway coach, building construction, partition wall cupboards, or article of furniture for machinery uses and packaging. Natural fibres are crucial agricultural biomass contributing to Malaysian economy. Natural fibres reinforced into bio plastics are an honest example of inexperienced composites that is virtually degradable by bacterium and enzyme. The usage of several raw substances can facilitate to live an ecological balance in nature. Such composite substances display off realistic power via weight importance relation, immoderate tensile and flexural strength, excessive creep resistance, and excessive compactness. [8].

The Global Carbon market is forecasted to rise four percent per annum through 2008 to nine million metric tons, virtually matching projected gains in world rubber consumption over identical amount. The commercial enterprise nicely well worth of

carbon is seen in several industries like vehicle, herbal, packaging, aerospace, prescribed drugs, biomedical, electricity, sports product, waste water treatment and serious metal removal for decades[9-10]. Now a day's unsaturated polyester (UP) organic compound is employed in applications like automotive, building and electronic devices owing to the low price, characterization of high performance and operational at a quick rates. However, as a result the polymer matrix should face up to high mechanical and tribological masses, it's sometimes bolstered with nano fillers. Distinctive Chemical alteration methods are used to improve the fibre, filler and matrix adhesion, Due to the advance of adhesion between matrix, filler and fibre the mechanical properties of the composites increase. Adding of hardener to the mixture with light combining, then the mixture is poured from one corner into the mould (to avoid bubble formation that causes cast damage) and also the uniform running is sustained till the mould is stuffed to the desired level [11].

Taguchi methodology of research is used to cut down the total range of experiments. The experimental data is analyzed using Taguchi method for optimal conditions of input parameters. ANOVA can be dispensed on experimental information to search out the numerous effects of the input parameters.

Taguchi methodology of design of experiments, genetic algorithmic rule and artificial neural network are the vital tools used for strong design to provide top quality merchandise quickly and at low price. Taguchi methodology relies on acting analysis or experiments to check the sensitivity of a group of response variables to a group of control parameters (or freelance variables) by considering experiments in "orthogonal array" with associate aim to achieve the optimum setting of the management parameters. Orthogonal arrays offer a best set of well balanced (minimum) experiments. The S/N ratios, which are log functions of desired output, serve as the objective functions for optimization, help in data analysis and the prediction of the optimum results. There are 3 types of S/N magnitude relation that are of common interest for optimisation of static issues 1. Smaller-the-better, 2.Larger-the-better and 3.Nominal-the-best. Different factors affect the strength at a different degree. A better feel for the relative effect of the different factors is obtained by the decomposition of variance, which is commonly called as analysis of variance[12-13].

The experimental result were analyzed using Taguchi optimisation methodology. Corn fibre polypropylene (PP) composites were prepared and tested for their mechanical properties. Maleic compound grafted polypropylene (MAPP) is supplementary to matrix and also the mechanical properties of MAPP corn fibre composites was found and the results of investigation are compared with those of PP composites. Experiments were planned using Taguchi L12 orthogonal array considering the 2 design parameters viz. weight fraction of the fibre and treatment. The experimental results were analyzed using Taguchi optimisation methodology. Analysis of variance (ANOVA) obtains the numerous values of lastingness, flexural strength and impact strength at ninety five percent confidence level [14].

Experiments are conducted using Taguchi L12 orthogonal array considering the 2 design parameters viz. weight fraction of the fiber and treatment. Vakka fibre polypropylene (PP) composites are fabricated and tested for mechanical properties. Maleic compound grafted polypropylene (MAPP) is supplementary to matrix and also the mechanical properties of MAPP Vakka fibre composites are found and compared with those of PP composites. Experiments are conducted using Taguchi L12 orthogonal array considering the 2 design parameters viz. weight fraction of the fiber and treatment. The experimental results were analyzed using Taguchi optimisation methodology. Analysis of variance (ANOVA) obtains the numerous values of lastingness, flexural strength, and impact strength at ninety five percent confidence level. Multiple regression analysis technique is applied to get the mathematical model for tensile, flexural and impact strengths [15].

II. EXPERIMENTAL

2.1. Materials

The Pine apple leaf fibre is extracted manually. The Pine apple leaf fibre is cut with the dimension. The Pine apple leaf fibre organic constituents are Cellulose, Hemicelluloses and Lignin. The carbon powder is collected from the nearest seller. The polyester resin contains the ester functional group in their chain and the polyester is in polymer category. Methyl ethyl ketone peroxide [MEKPO] is the hardener used for the polyester resin.

2.2 Processing

Manually extracted fibres are cleaned and dried. The composite samples are prepared by using the Taguchi's L9 orthogonal array to reduce the no of experiments. 9 rows and 3 columns in the L9 orthogonal array with 9 degrees of freedom. As per the L9 orthogonal array each parameter is sated. The experimental results further transferred into S/N ratio using MINITAB17 software. When response is to be maximized (Larger-the-better), Taguchi uses the following formula for S/N ratio (η) is in equation-1.

$$\eta = -10 \log_{10} \left(\frac{1}{n} \sum_{i=1}^n \frac{1}{y_i^2} \right) \quad - (1)$$

Table-1 Selected factors and their level

S.NO	PARAMETER	CODE	LEVELS		
1	WEIGHT % OF PINE APPLE	X	2	4	6
2	WEIGHT % OF	Y	2	4	6

	CARBON POWDER				
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The most suitable orthogonal array for experimentation is L9 array as shown in Table-2. Therefore a total nine experiments are to be carried out.

Table-2 Orthogonal Array(OA) L9

S.NO	CONTROL FACTORS	
	WEIGHT % OF PINE APPLE	WEIGHT % OF CARBON POWDER
1	1	1
2	1	2
3	1	3
4	2	1
5	2	2
6	2	3
7	3	1
8	3	2
9	3	3

2.3 Conducting the matrix experiment

Experiments will conduct with their factors and their levels as mentioned in table-1. The experimental layout with the selected values of the factors shown in table 3. For each of the above 9 experiments were conducted 5 times (45 experiments in all) to account for variations that may occurs due to the noise factors.

Table-3 The experimental layout with the selected values of the factors.

S.NO	CONTROL FACTORS	
	WEIGHT % OF PINE APPLE	WEIGHT % OF CARBON POWDER
1	2	2
2	2	4
3	2	6
4	4	2
5	4	4
6	4	6
7	6	2
8	6	4
9	6	6

2.4 Tensile Testing of composite

The tensile properties of the composite were measured as per the test method. By using the electronic tensometer find the tensile properties of the composite specimens. The tensile testing composite specimens are prepared as per the ASTM-D-638M. Test specimens having the dimensions like 160 mm length, 12.5 mm wide and 3 mm thickness. 5 specimens were tested for each composition.

2.5 Flexural Testing of composite

For flexural 3-point bend testing specimens are prepared as per the ASTM-D790M. By using the electronic tensometer find the flexural properties of the composite specimens. Test specimens having the dimensions like 100 mm length, 25 mm wide and 3mm thickness for each composition 5 samples is tested.

2.6 Impact Testing of composite

By using the Izod impact test machine find the impact properties of the composite test specimen. The impact test specimens are prepared as per the ASTM-D-256M. Test specimen having the dimensions like 63.5 mm length, 12.7 mm wide and 10 mm thickness. For each composition 5 samples is tested.

III. RESULTS AND DISCUSSION

3.1 Tensile, flexural and impact strength results

The different tensile, flexural and impact properties were found with the different weight percentages of Pine Apple fibre and Carbon powder. For each composition 5 five composite samples are tested to achieve the repeatability in results. The variations of tensile, flexural and impact strength with the weight percentage of fibre are in table- 4 and also in fig-1.(a),(b) and (c) respectively.

Table-4 Tensile, flexural and impact strength values.

SPECIMEN NO	WEIGHT % OF PINE APPLE	WEIGHT % OF CARBON POWDER	TENSILE STRENGTH (N/mm ²)	FLEXURAL STRENGTH (N/mm ²)	IMPACT STRENGTH (J/mm)
1	2	2	22.47	138.12	20.35
2	2	4	23.21	140.42	24.74
3	2	6	24.18	140.35	30.53
4	4	2	29.67	142.78	32.67
5	4	4	28.47	138.94	34.24
6	4	6	27.24	137.75	32.47
7	6	2	24.47	144.05	26.37
8	6	4	22.02	139.70	28.54
9	6	6	23.24	142.84	30.36

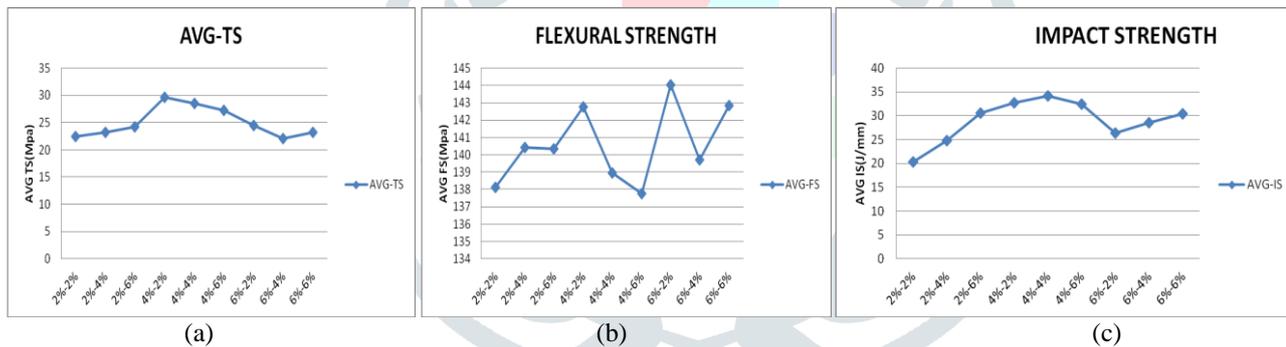


Fig-1.(a) Tensile strength vs weight % of fibres; (b)Flexural strength vs weight % of fibres; (c) Impact strength vs weight % of fibres;

Table-5 Experimental results of tensile strength along with S/N ratio.

WEIGHT % OF PINE APPLE	WEIGHT % OF CARBON POWDER	TENSILE STRENGTH	SNRA
2	2	36.49	31.36
2	4	44.406	33.03
2	6	45.598	33.13
4	2	48.592	30.15
4	4	54.922	34.74
4	6	64.4012	36.21
6	2	49.12	31.009
6	4	42.9	31.19
6	6	38.46	34.795

Table-6 Experimental results of flexural strength along with S/N ratio.

WEIGHT % OF PINE APPLE	WEIGHT % OF CARBON POWDER	FLEXURAL STRENGTH	SNRA
2	2	79.84	31.13
2	4	95.18	32.855
2	6	131.92	33.03
4	2	143.082	30.21
4	4	180.6	34.66
4	6	185.82	36.19
6	2	164.86	30.81
6	4	154.954	29.50
6	6	147.78	34.76

Table-7 Experimental results of Impact strength along with S/N ratio

WEIGHT % OF PINE APPLE	WEIGHT % OF CARBON POWDER	IMPACT STRENGTH	SNRA
2	2	26.02	28.35
2	4	28.86	30.93
2	6	32.96	32.90
4	2	36.69	32.66
4	4	38.26	33.31
4	6	33.96	32.63
6	2	30.89	30.98
6	4	32.46	31.06
6	6	34.84	32.61

3.2. Taguchi analysis for tensile and flexural strength

Experiment results for tensile strength, flexural strength and S/N ratio for each combination parameters is calculated and shown in table The time scale plots for S/N ratio and predicted S/N ratio presented in Figure Analysis of the influence of control factors (weight fraction of fibre (X) and weight fraction of filler (Y)) on the responses are obtained from the response tables of mean S/N ratio and the results are listed in table 8 and 9 respectively. Larger value of S/N ratios corresponds to better quality, so optimal combination of design parameters can be obtained as X_1Y_1 for tensile and flexural strength.

Table-8 Response Table for S/N ratio for tensile strength

LEVEL	WEIGHT FRACTION OF FIBER	WEIGHT FRSCATION OF FILLER
1	30.38	27.32
2	27.95	27.04
3	26.95	27.18
Delta	1.42	0.42
Rank	1	2

Table-9 Response Table for S/N ratio for flexural strength

LEVEL	WEIGHT FRACTION OF FIBER	WEIGHT FRSCATION OF FILLER
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1	43.03	40.26
2	40.39	40.96
3	40.49	40.39
Delta	0.29	0.24
Rank	1	2

Table-10 Response Table for S/N ratio for Impact strength

LEVEL	WEIGHT FRACTION OF FIBER	WEIGHT FRSCATION OF FILLER
1	30.43	28.31
2	29.39	28.58
3	28.85	29.87
Delta	2.17	1.16
Rank	1	2

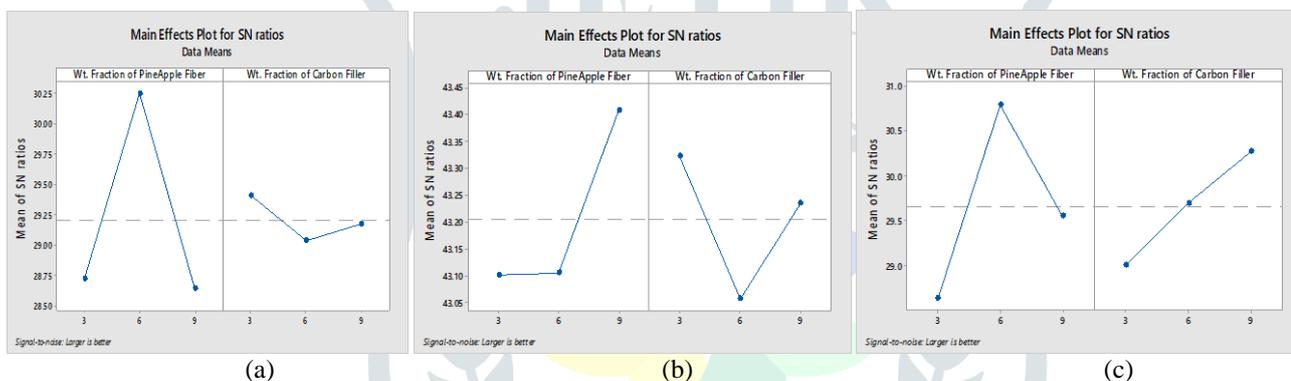


Fig-2. Main affects plot of S/N ratio for (a) tensile strength; (b) flexural strength; (c) Impact strength;

3.3 Analysis of variance

The purpose of the statistical analysis of variance is to investigate which design parameter significantly affects strength of the composites. The analysis carried out for the level of significance of 5% (the level of confidence is 95%). Two-way ANOVA allow comparing population means when the populations classified according to two (categorical) factors (weight fraction of the fiber (X), weight fraction of the filler (Y). Analysis of variance results are listed in table 11, 12 and 13 respectively.

From ANOVA it can conclude that the weight fractions of the fibre-1 (X) are significant for tensile strength, flexural strength and impact strengths.

Table-11 ANOVA table for tensile strength

SOURCE	DF	SEQ SS	CONTRIBUTION	ADJ SS	ADJ MS	F-VALUE	P-VALUE
Wt. Fraction of Pine Apple FIBER	2	4.2112	81.42%	4.2112	2.15562	22.18	0.005
Wt. Fraction of carbon FILLER	2	0.1153	14.02%	0.1153	0.10766	1.008	0.316
Error	4	0.2655	4.56%	0.2655	0.08137		

Table-12 ANOVA table for flexural strength.

SOURCE	DF	SEQ SS	CONTRIBUTION	ADJ SS	ADJ MS	F-VALUE	P-VALUE
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Wt. Fraction of Pine Apple FIBER	2	0.18543	60.72%	0.18543	0.092714	11.47	0.022
Wt. Fraction of Carbon FILLER	2	0.10919	28.40%	0.109119	0.054595	6.76	0.052
Error	4	0.03232	10.88%	0.03232	0.008080		
Total	8	0.32694	100.00%				

Table-13 ANOVA table for flexural strength

SOURCE	DF	SEQ SS	CONTRIBUTION	ADJ SS	ADJ MS	F-VALUE	P-VALUE
Wt. Fraction of Pine Apple FIBER	2	6.972	61.94%	6.972	3.4859	7.31	0.046
Wt. Fraction of Carbon FILLER	2	2.375	21.10%	2.375	1.1876	2.49	0.198
Error	4	1.908	16.95%	1.908	0.4770		
Total	8	11.255	100.00%				

3.4 Mathematical model using multiple regression analysis

Multiple regression analysis is done using the statistical software package MINITAB-18. The fitted line plots for tensile strength, flexural strength and Impact strength are shown in Figure-3(a), (b) and (c) respectively. These graphs show trends of tensile strength, flexural strength and Impact strength. Three are varying linearly.

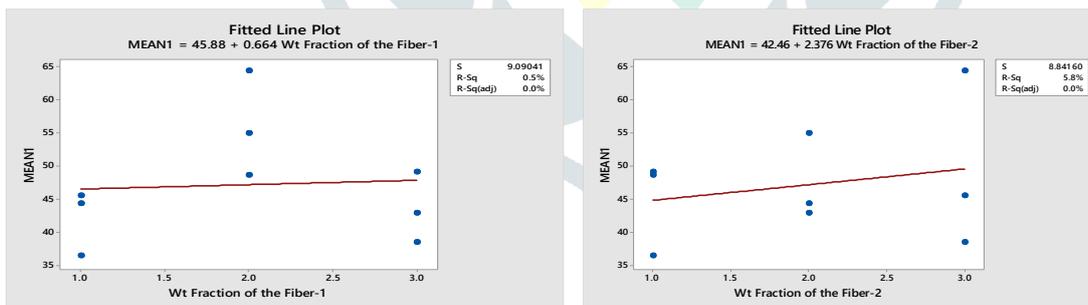


Figure 3(a)

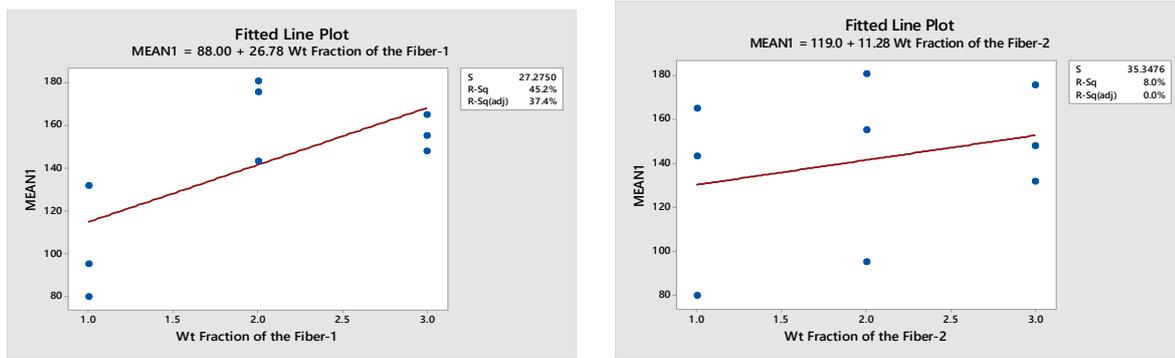


Figure 3(b)

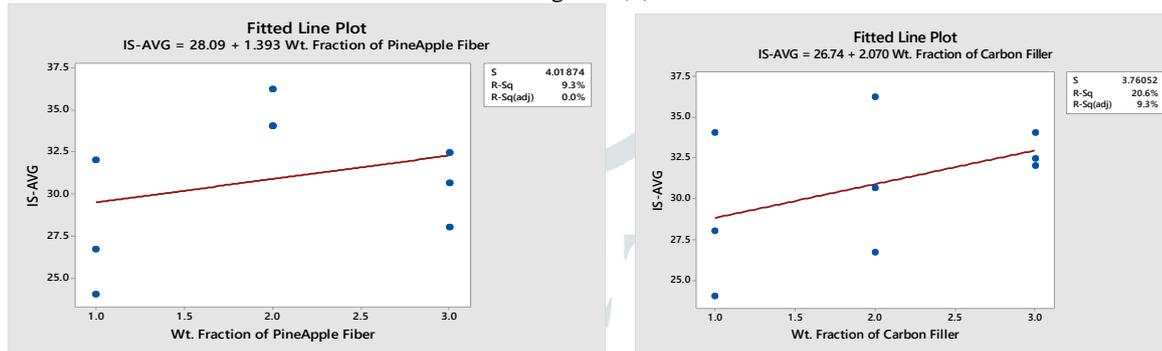


Figure 3(c)

Fig-3 Fitted line plots for (a) tensile strength; (b) flexural strength;(c) Impact strength

Mathematical models have been developed to evaluate the relationship between input and output parameters. The output values of tensile strength, flexural strength and impact strength have been used to construct the mathematical models. The functional relationship between dependent output parameter with the input parameters could be postulated using the following equation (2).

$$Z = A * (X)^a * (Y)^b \quad (2)$$

where Z is dependent output variable such as tensile strength, flexural strength and impact strength; X and Y are independent input variables such as weight fraction of the fiber and treatment respectively; a and b are the exponents of input parameters. The above nonlinear equation converted into linear form by logarithmic transformation and can write as equation (3).

$$\log(Z) = \log(A) + a * \log(X) + b * (Y) \quad (3)$$

Minitab 18 statistical analysis software has been used to estimate the parameters of the above first order model. The data regression constants are calculated by performing multi parameter linear regression analysis which are shown in tables 14, 15 and 16 for tensile strength, flexural strength and impact strength respectively.

Table-14 Data regression constants for tensile strength.

TERM	COEF	T-VALUE	P-VALUE
Constant	1.1625	41.94	0.000
LN(X)	0.0221	0.29	0.768
LN(Y)	-0.0217	-0.26	0.772

Table-15 Data regression constants for flexural strength.

TERM	COEF	T-VALUE	P-VALUE
Constant	2.06440	431.86	0.000
LN(X)	0.0139	1.24	0.263
LN(Y)	-0.0109	-0.99	0.362

Table-16 Data regression constants for Impact strength.

TERM	COEF	T-VALUE	P-VALUE
Constant	1.3614	39.44	0.000
LN(X)	0.1095	1.38	0.217
LN(Y)	0.1208	1.51	0.182

The equations of logarithmic transmission of tensile strength, flexural strength and Impact strength are shown in (4), (5) and (6) respectively.

$$\text{Log (tensile strength)} = 1.1625 + 0.0221 \text{ LOG(X)} - 0.0217 \text{ LOG(Y)} \quad - \quad (4)$$

$$\text{Log (Flexural strength)} = 2.06440 + 0.0139 \text{ LOG(X)} - 0.0109 \text{ LOG(Y)} \quad - \quad (5)$$

$$\text{Log (Impact strength)} = 1.3614 + 0.1095 \text{ LOG(X)} + 0.1308 \text{ LOG(Y)} \quad - \quad (6)$$

After taking antilog on both the sides for the equations (4), (5) and (6), the modified equations for tensile strength and flexural strength are shown in (7), (8) and (9).

The predicted values of tensile strength, flexural strength and impact strength calculated from equations (7), (8) and (9), which to be compared with experimental values for which error must be calculated. The predicted error percentage between predicted and measured output values at each experimental condition calculated by using the equation (8)

Table-17 Error percentage for experimental and predicted values of tensile strength.

WEIGHT% OF FIBER	WEIGHT% OF FILLER	TENSILE STRENGTH	PREDECTED TENSILE STRENGTH	ERROR (%)
1	1	22.47	27.01	-6.95
1	2	23.21	26.85	-5.06
1	3	24.18	26.42	-0.21
2	1	29.67	27.24	12.70
2	2	28.47	27.01	9.47
2	3	27.24	26.67	8.96
3	1	24.47	27.74	-3.84
3	2	22.02	27.52	-11.71
3	3	23.24	27.10	-5.91

$$\text{Tensile strength} = 1.5379 * (X)^{0.004} * (Y)^{0.400} \quad - \quad (7)$$

$$\text{Flexural strength} = 1.5356 * (X)^{-0.037} * (Y)^{0.395} \quad - \quad (8)$$

$$\text{Impact strength} = 26.387 (X)^{0.1195} * (Y)^{0.1308} \quad - \quad (9)$$

Table-18 Error percentage for experimental and predicted values of flexural strength.

WEIGHT% OF FIBER	WEIGHT% OF FILLER	FLEXURAL STRENGTH	PREDECTED FLEXURAL STRENGTH	ERROR (%)
1	1	138.12	144.21	-1.27
1	2	140.42	142.81	0.68
1	3	140.35	142.21	1.23
2	1	142.78	145.23	0.48
2	2	138.94	144.31	-1.32
2	3	137.75	143.13	-1.21
3	1	144.05	146.47	1.13

3	2	139.70	145.03	-1.32
3	3	142.84	144.71	1.23

Table-19 Error percentage for experimental and predicted values of flexural strength

WEIGHT% OF FIBER	WEIGHT% OF FILLER	IMPACT STRENGTH	PREDECTED IMPACT STRENGTH	ERROR (%)
1	1	20.35	24.24	-9.15
1	2	24.74	26.45	-8.07
1	3	30.53	28.42	4.19
2	1	32.67	26.34	14.38
2	2	34.24	29.21	12.09
2	3	32.47	31.24	2.25
3	1	26.37	28.45	-5.96
3	2	28.54	30.12	-7.06
3	3	30.36	32.21	-6.88

$$\text{Error}(\%) = \left(\frac{\text{experimental value} - \text{predicted value}}{\text{experimental value}} \right) * 100 \quad - \quad (10)$$

Tables 17, 18 and 19 show the comparison of predicted values and experimental values of tensile strength and flexural strength respectively along with error (%). For tensile strength, 90.231% of the points are within 20% of the error and for flexural strength, 92.638 % of the points are within 20% of the error and impact strength which is acceptable. It can be seen that experimental and predicted values are very close and hence the mathematical model is suitable.

IV. CONSLUSIONS

The experimental results supported the successful fabrication of pineapple fibre and carbon powder reinforced polyester resin composites and confirmed the fact that pineapple leaf fibre and carbon powder can be used as fibre/filler to improve the mechanical properties of the composite with polyester. It can be concluded from S/N ratio that, optimal combination of design parameters are 4% pine apple leaf fiber and 2% carbon powder weight fraction for tensile strength, 6% pine apple leaf fiber 2% carbon powder weight fraction for flexural strength, and 4% pine apple leaf fiber 6% carbon powder weight fraction for impact strength. It can be concluded from ANOVA that weight fraction of the fibre is significant for tensile test, flexural and impact tests. The results of present work indicate better mechanical properties for pineapple-carbon polyester, which makes it better suited for the automotive applications.

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