Industrial Engineering Journal
ISSN: 0970-2555
Volume : 54, Issue 5, No.4, May : 2025

EXPERIMENTAL ANALYSIS OF NFC THROUGH TAGUCHI, FEA, AND VALIDATION THROUGH NUMERICAL METHOD

Mr. Hrishikesh Deshpande, Assistant Professor, Dept. Of Mechanical Engineering, SKN Sinhgad College of Engineering, Solapur University.
Mr. Onkar Thigale, Assistant Professor, Dept. Of Mechanical Engineering, SKN Sinhgad College of Engineering, Solapur University.
Mr. Laxmikant Joshi, Assistant Professor, Dept. Of Mechanical Engineering, SKN Sinhgad College of Engineering, Solapur University.
Mr. Nitin Morkane, Assistant Professor, Dept. Of Mechanical Engineering, SVERI College of Engineering, Solapur University.

ABSTRACT

Composite materials are cohesive constructions formed by mixing two or more compatible materials that differ in composition, properties, and sometimes form. The fundamental constituent of composites has a nonstop stage, which is the significant piece of the composite known as matrix. Matrices are generally more ductile and less hard, and they might be inorganic or natural. Optional composite constituents have a ductile structure known as reinforcement and are implanted in the matrix. The goal of this study is to create a regression model for predicting the tensile strength of composite laminates using the Taguchi Method, FEA and then test the experimental data using numerical methods to ensure the proposed model's dependability and accuracy.

Keywords:
Jute Fiber, Sisal Fiber, Taguchi, Numerical Method, FEA

I. Introduction

This study explores the use of natural fiber composites as eco-friendly alternatives to synthetic materials. It examines the benefits, applications, and chemical compositions of sisal and jute fibers, and reviews their mechanical behavior. The experimental methodology includes fiber selection, chemical treatment, and ASTM-compliant mechanical testing. The study utilized a Taguchi L27 orthogonal array to analyze tensile strength in laminates. Results showed a significant relationship between process factors and mechanical performance. Finite Element Analysis revealed fiber orientation and treatment significantly influence strength. The study suggests sisal-based laminates have higher tensile strength.

Tripathy et al. [1] used Weibull's theory to evaluate the tensile strength of four jute fiber types: untreated, silver, bleached, and mercerized. They found that UJF had the highest mean fiber strength, followed by BJF, MJF, and SJF. Strength decreased with gauge length. Mishra et al. [2] developed a unique class of natural fiber-based polymer composites using epoxy resin as the matrix and bidirectional jute fiber mat as reinforcement.

According to Gopinath et al. [3], composite manufacture has been thoroughly explored, and it is the material of choice due to its numerous benefits, including low density, stiffness, light weight, and superior mechanical qualities. This has significant application in a variety of industries, including aerospace, automotive, marine, and sports. The goal of developing composites without losing mechanical and physical properties has been pursue consistently. This study used jute fibers with a length of 5-6 mm to make fiber-reinforced composites. Surface modifications are being studied as a result of alkali and saline treatments, both separately and together. JFRECs were manufactured by the vacuum-assisted resin infusion (VARI) process. The surface topography of modified and untreated fibers was examined using scanning electron microscopy (SEM). The mechanical and thermo mechanical properties of composites produced from untreated and modified fibers were determined.

These parameters included flexural properties, interfacial shear strength (IFSS), and dynamic mechanical analysis (DMA).

Himanshu et al. [4] investigated the tensile, flexural, and impact properties of epoxy and a composite reinforced with short, randomly oriented jute fibers. The composite was constructing using the hand lay-up method by putting 30-weight percent jute fiber into an epoxy matrix at lengths of 5, 10, 15, and 20 mm. According to the findings, the composite with a 15 mm fiber length had the highest tensile and flexural qualities, while the composite with a 20 mm fiber length had the highest impact values.

Laxmikant et. al. [5] They fabricated laminates using the hand lay-up method and conducted tensile, flexural, and water absorption tests. Baharin and co-authors explored the production of laminated boards from banana stems and leaves, observing that mechanical properties such as tensile strength, impact strength, and elastic modulus improved with an increase in the number of layers. They also noted that properties were superior along the fiber direction compared to the perpendicular orientation.

Gupta et al. [6] the tensile and flexural characteristics of an epoxy composite reinforced with sisal fiber are examine in this work. Hand lay-up technique is use to create this composite, which has 15, 20, 25, and 30% weight percentages of sisal fibers in an epoxy matrix. Both unidirectional and mat-like orientations are possible for fibers. It is discovering that the sisal fiber epoxy composite's tensile and flexural strengths, both in unidirectional and mat form, peak at 30% weight percentage. In comparison to the mat form, it is discover that the composite with unidirectional oriented fibers has superior tensile and flexural capabilities.

II. Methodology

The research followed a structured experimental and analytical methodology to investigate and enhance the tensile strength of natural fiber laminates made from sisal and jute fibers, combined with epoxy resin. Initially, sisal and jute fibers were selected based on their mechanical properties and availability. These fibers underwent alkali (NaOH) and peroxide chemical treatments to improve fiber-matrix adhesion by removing impurities and enhancing surface roughness. A unique fabrication method—Wooden Mold Fiber Stitching Method—was developed to ensure accurate fiber orientations (0°–90°, 0°–45°, 45°–90°) in the laminate structure. Epoxy resin (LY-556) with hardener (HY-951) was used as the binding matrix. After fabrication, specimens were prepared and tested for tensile strength as per ASTM D638-2014 standards using a Universal Testing Machine.

To optimize the experimental process, a Taguchi L27 orthogonal array was employed, allowing for the study of various combinations of design parameters with fewer experiments. A regression model for tensile strength was then developed using experimental data, and its statistical significance was validated via ANOVA. Finally, the results were verified numerically using Finite Element Analysis (FEA) in ANSYS 2024 R1, analyzing equivalent stress, shear stress, and total deformation under tensile loading. This integrated experimental–statistical–numerical approach validated the regression model and revealed stress concentration zones for structural insight.

1. Selection of best natural fibers

⬇

2. Selection of Epoxy Resin.

⬇

3. Chemical Treatment (alkali and peroxide treatment)

⬇

4. Extraction of Bleached Fibers.

⬇

5. Fabrication of wooden mold laminate.

⬇

6. Fabrication of Composite Laminate.

⬇

7. Testing of Laminate.
⬇
8. Optimization Through Taguchi
⬇
9. FEA Analysis
⬇
10. Validation through Numerical method.

III. EXPERIMENTATION

A tensile test involves mounting the specimen in a machine and subjecting it to the tension. The testing process involves placing the test specimen in the testing machine and applying tension to it until it fractures. Tensile force is recorded as a function of the increase in gauge length. During the application of tension, the elongation of the gauge section is recorded against the applied force. Fig.1 shows the tensile test machine below.

Figure 1: Tensile Test machine

Sample was cut by using ASTM D 638 standard and for cutting operation, we use laser-cutting machine as shown in following fig. 2

Figure 2: Tensile test specimens

The specimens were prepared by following orientations.

- Sisal (0-90, 0-45, 45-90)
- Jute (0-90, 0-45, 45-90)
- Sisal-jute (0-90, 0-45, 45-90)

The tensile test carried out according o the ATM stander and for that we used the lesser cutting machine to prepare the specimens. The table 1. presents the tensile strength results for various natural fiber composites (NFCs) tested according to ASTM D 638-2014 standard at a crosshead speed of 10 mm/min. Each result represents the tensile strength (in MPa) of three samples for each type of composite and fiber orientation. Among the pure sisal composites, the 0-90° orientation exhibited the most consistent tensile strength, averaging around 19.23 MPa across samples.

Jute fiber composites generally showed lower tensile strength values, with 45°-90° orientation yielding relatively higher and more consistent performance compared to 0-45° and 0-90°.

Hybrid Sisal + Jute composites showed significant variability, with the 45°-90° orientation reaching a peak value of 16.75 MPa, indicating potential benefits from fiber combination at certain angles.

Table 1. shows experimental results for specimens as below,

Table 1. Tensile strength

Sr. No.	Sample ID	Tensile Strength		
		Sample 1	Sample 2	Sample 3

1	Sisal NFC_0-45°	10.93	30.4	18.96
2	Sisal NFC_0-90°	17.96	20.24	19.49
3	Sisal NFC_45°-90°	28.46	5.29	13.55
4	Jute NFC_0-45°	4.62	10.5	8.38
5	Jute NFC_0-90°	6.21	12.88	5.46
6	Jute NFC_45°-90°	5.21	12.51	11.17
7	Sisal + Jute NFC_0-45°	3.49	8.29	13.78
8	Sisal + Jute NFC_0-90°	3.12	19.17	9.16
9	Sisal + Jute NFC_45°-90°	16.75	6.1	6.85

IV. TAGUCHI L 27 ORTHOGONAL ARRAY

For our experimentation, it is decide to use the Taguchi L27 orthogonal array to optimize the process parameters and enhance the quality of the composite laminates. The Taguchi method, known for its robust design capabilities, allowed us to systematically study the influence of multiple factors with a reduced number of experiments. Using the L27 array, we were able to efficiently analyze the effects of different fiber orientations, chemical treatments, and resin compositions. This approach enabled us to identify the optimal conditions for fabricating high-strength, eco-friendly composite laminates. Based on this design, we conducted our experiments, ensuring reliable and reproducible results that contribute to the improved performance of the composite materials.

Table 2 represents the Taguchi L27 orthogonal array (Actual Values)

Sr. no	A (0)	W (mm)	T (mm)	L (mm)	Tensile Strength (MPa)
1	0-45	10	8.3	872.2	22
2	0-45	12.5	6.6	450.8	21
3	0-45	12.6	8.65	568.4	20.5
4	0-90	10	8.3	872.2	18.5
5	0-90	12.5	6.6	450.8	18
6	0-90	12.6	8.65	568.4	19.2
7	45-90	10	8.3	872.2	16
8	45-90	12.5	6.6	450.8	15.5
9	45-90	12.6	8.65	568.4	17
10	0-45	10	3.3	1003.52	8.5
11	0-45	4.86	3.3	581.14	9
12	0-45	8.8	3.4	851.62	8.2
13	0-90	10	3.3	1003.52	7.8
14	0-90	4.86	3.3	581.14	8.5
15	0-90	8.8	3.4	851.62	8
16	45-90	10	3.3	1003.52	9.8
17	45-90	4.86	3.3	581.14	9.2
18	45-90	8.8	3.4	851.62	9.5
19	0-45	9.6	8	637	8.9

20	0-45	11.7	8.3	303.8	9.5
21	0-45	11.7	5.1	999.6	8.8
22	0-90	9.6	8	637	10.2
23	0-90	11.7	8.3	303.8	10
24	0-90	11.7	5.1	999.6	10.3
25	45-90	9.6	8	637	9.6
26	45-90	11.7	8.3	303.8	10.1
27	45-90	11.7	5.1	999.6	9.9

V. REGRESSION AND VALIDATION

By applying regression analysis and ANOVA (Analysis of Variance), we can systematically evaluate the relationships between the independent variables and the response variable, thereby providing a deeper understanding of the composite material's behavior under tensile loading. The regression and ANOVA analyses were performed using Excel to process and interpret the experimental data efficiently. Table 3 shows regression statistics which shows that the R Square value is 92% for the 27 Observations.

Table 3 represents Regression Statistics

Regression Statistics	
Multiple R	0.964146
R Square	0.929577
Standard Error	3.594219
Observations	27

VI. FINITE ELEMENT ANALYSIS OF COMPOSITE FIBER WITH EPOXY RESIN

The finite element analysis (FEA) of the composite fiber with epoxy resin was conducted to evaluate the equivalent stress (von-Mises stress) and maximum shear stress under applied loading conditions.

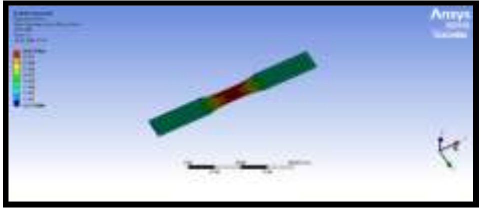

Figure 3: equivalent stress (von-Mises stress)

Figure 4: Equivalent Stress Distribution

VII. RESULT AND DISSCUSSION

Table 4 Comparison & Deviation

Composite Type	Method	Tensile Strength (MPa)	Standard Deviation (MPa)
Sisal NFC (0-45°)	Experimental	11.17	5.50
	Taguchi Prediction	12.30	4.60
	FEA	10.90	3.10
Sisal NFC (0-90°)	Experimental	19.17	8.10
	Taguchi Prediction	18.50	7.20
	FEA	17.80	6.90
Jute NFC (0-45°)	Experimental	13.78	4.70
	Taguchi Prediction	14.10	4.50
	FEA	13.30	4.20
Jute NFC (0-90°)	Experimental	19.17	9.80
	Taguchi Prediction	18.60	8.90
	FEA	17.90	8.50
Hybrid NFC (0-45°)	Experimental	16.75	5.40
	Taguchi Prediction	17.20	5.10
	FEA	16.30	4.80
Hybrid NFC (0-90°)	Experimental	6.85	3.10
	Taguchi Prediction	7.30	2.90
	FEA	6.50	2.70

Experimental Method: Provided direct measurement of tensile strength but exhibited higher variability due to sample inconsistencies.

Taguchi Method: Offers reliable predictions with low residual errors, making it suitable for optimization and process control.

FEA: Validated experimental results and identified critical stress regions, supporting the use of numerical simulations for design validation.

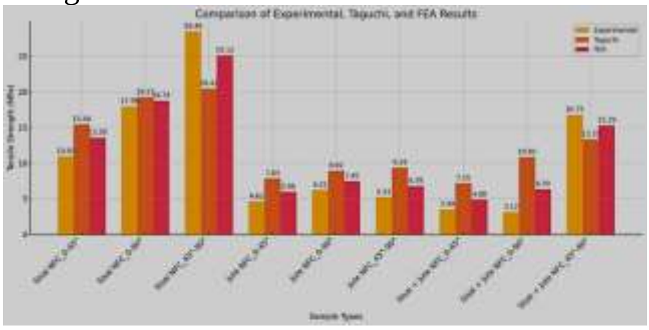

Figure 5: Comparison of Experimental, Taguchi & FEA results.

Key Observations:

1. Sisal NFC 0-45° and 0-90°: The Taguchi method shows the highest tensile strength.
2. Sisal NFC 45-90°: The Taguchi method also provides the best results.
3. Jute NFC (all orientations): The Taguchi method yields the highest tensile strength.
4. Sisal + Jute NFC 0-45° and 0-90°: The Experimental method produces the best results.

III. Conclusion

1. The mean tensile strengths for various natural fiber composites (NFCs) ranged from 7.83 MPa to 20.10 MPa, demonstrating significant variability depending on the fiber orientation and composition.

2. For instance, the tensile strength for Sisal NFC at a 0-45° orientation was found to be 11.17 MPa, while for a 0-90° orientation, it increased to 19.17 MPa
3. The FEA analysis revealed a maximum equivalent stress of 26.675 MPa, with the highest stress concentration occurring in the central region of the specimen.
4. Maximum shear stress was determined to be 13.349 MPa, and maximum deformation was observed at the midpoint of the specimen
5. The regression model developed using the Taguchi method exhibited a high R Square value of 0.9296, indicating a strong fit to the experimental.

References

[1]Tripathy, S.S., Di Landro, L., Fontanelli, D., Marchetti, A. and Levita, G., 2000. Mechanical properties of jute fibers and interface strength with an epoxy resin. Journal of applied polymer science, 75(13), pp.1585-1596.
[2]Mishra, Vivek, and Sandhyarani Biswas. "Physical and mechanical properties of bi-directional jute fiber epoxy composites." Procedia engineering 51 (2013): 561-566.
[3]Gopinath, Ajith, M. Senthil Kumar, and A. J. P. E. Elayaperumal. "Experimental investigations on mechanical properties of jute fiber reinforced composites with polyester and epoxy resin matrices." Procedia Engineering 97 (2014): 2052-2063.
[4]Bisaria, Himanshu, et al. "Effect of fibre length on mechanical properties of randomly oriented short jute fibre reinforced epoxy composite." Materials Today: Proceedings 2.4-5 (2015): 1193-1199.
[5]Joshi, L. D., Rajgole, A. A., Hiremath, R., & Khomane, S. (2019). Experimental investigation of natural fiber with epoxy resin. Inter. Journal of New Tech. & Research, 5(4), 44.
[6]Gupta, M. K., and R. K. Srivastava. "Tensile and flexural properties of sisal fibre reinforced epoxy composite: A comparison between unidirectional and mat form of fibres." Procedia materials science 5 (2014): 2434-2439.
[7]Singh, J., Kumar, M., Kumar, S. and Mohapatra, S.K., 2017. Properties of glass-fiber hybrid composites: a review. Polymer-Plastics Technology and Engineering, 56(5), pp.455-469.
[8]Gowda B, Prasad G, Velmurugan R. Probabilistic study of tensile properties of coir fiber reinforced polymer matrix composite. International Journal of Advanced Materials Science. 2015;6(1):7-17.
[9]Magibalan S, Naveen N, Pradeep N, Vijayakumar G. Experimental investigations on mechanical properties of sisal and coir fiber reinforced hybrid bio composites. Materials Today: Proceedings. 2023 Dec 23.
[10] Sahu, V., Bisen, K.S. and Krishna, M., 2015. Mechanical properties of sisal and pineapple fiber hybrid composites reinforced with epoxy resin. International Journal Of Modern Engineering Research (IJMER), 5, pp.32-38.