IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.066 ⁘ Peer-reviewed / Refereed journal ⁘ Vol. 12, Issue 2, February 2025

DOI: 10.17148/IARJSET.2025.12217

Statistical Modelling of Jute Fiber Length and Content in Polypropylene Composites: Performance and Sustainability Analysis

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Abstract: This study investigates the effects of fiber length and content on the mechanical properties of jute fiber-reinforced polypropylene composites through advanced statistical modeling approaches. Jute fibers of varying lengths (3mm, 5mm, and 10mm) and weight contents (10%, 20%, and 30%) were incorporated into polypropylene matrices, and the resulting composites were systematically characterized for their tensile, flexural, and impact properties. Through Response Surface Methodology (RSM), Weibull statistical analysis, and Artificial Neural Network (ANN) modeling, we established that composites with 10mm fiber length and 10% fiber content exhibit optimal mechanical performance, with a tensile strength of 30.3 MPa. Weibull analysis confirmed significantly higher reliability for 10mm fiber composites (β=30.68) compared to shorter fiber alternatives, while ANN modeling effectively captured non-linear behaviors, particularly the distinctive dip-and-recovery pattern observed in 5mm fiber samples. Economic and environmental analyses demonstrate that these optimized composites offer substantial benefits, including a 26% reduction in global warming potential and a 10% cost advantage compared to conventional glass-fibre-reinforced alternatives. This research validates jute fiber-reinforced polypropylene composites as environmentally advantageous and economically viable options for applications where their specific performance characteristics are sufficient.

Keywords: Jute fiber, Polypropylene composites, Response Surface Methodology (RSM), Weibull statistical analysis, Artificial Neural Network (ANN) modelling, Sustainable composites

I. INTRODUCTION

The growing environmental concerns associated with synthetic materials have generated significant interest in natural fiber reinforced composites as sustainable alternatives to conventional petroleum-based materials [**1, 2**] Among natural fibers, jute has emerged as a promising reinforcement material due to its abundance, biodegradability, low cost, and favorable mechanical properties [**3, 4**]. Jute fiber-reinforced polypropylene (PP) composites represent an important class of materials that combine the processability and durability of thermoplastics with the environmental benefits of natural fibers [**5, 6**]. However, the mechanical performance of these composites is strongly influenced by several factors, including fiber length, fiber content, and the interface between the fiber and the polymer matrix [**7, 8**]. Optimizing these parameters is crucial for developing composites with properties suitable for specific applications. While previous studies have investigated various aspects of jute-PP composites, a comprehensive statistical analysis of the relationships between processing parameters and mechanical properties remains limited [**9-14**].

The mechanical performance of fiber-reinforced composites depends critically on three key factors: (a) the inherent strength and modulus of the fibers, (b) the strength and chemical stability of the polymer matrix, and (c) the effectiveness of the fiber-matrix interface in transferring stresses [**3**].

For short fiber composites with random orientation, parameters such as fiber length, content, alignment, and packing arrangement significantly influence the final mechanical properties. The optimal fiber length depends on the quality of bonding between fiber and matrix, while the optimal fiber content is determined by the efficiency of stress transfer at the interface [**15**].

This study uses advanced statistical modelling approaches to systematically analyze the effects of fiber length and content on the mechanical properties of jute fiber-reinforced PP composites. By employing Response Surface Methodology (RSM) [**16, 17**], Weibull statistical analysis [**18-22**], and Artificial Neural Network (ANN) modeling [**23-29**], the research aims to identify optimal processing conditions and develop predictive models for composite performance. Additionally, the study evaluates the environmental and economic implications of these materials to assess their viability as sustainable alternatives to conventional composites [**9-14, 30-33**].

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II. MATERIALS AND METHODS

According to the experimental results provided by Ma Sheng et al. (2020) [**34**], jute fiber-reinforced polypropylene (PP) composites were prepared using jute fibers of three different lengths (3 mm, 5 mm, and 10 mm) with an average diameter of 54µm. The polypropylene matrix had a melt flow index of 5 g/10 min. The properties of the raw materials are summarized in Table 1.

Materials	Density (g/cm^3)	Tensile Strength (MPa)	Tensile Modulus (GPa)	Elongation at Break (%)	Moisture Regain (%)	Residual Pastern Ratio (%)
Jute Fiber	1.41	424	14.13	2.54	12.6	4.24
PP	0.91	28.5	0.867	10.34	-	-

Table 1. Properties of Jute Fiber and PP.

Composite samples were prepared with fiber contents of 10%, 20%, and 30% by weight. The mechanical characterization showed that increasing fiber content enhances tensile and flexural properties while reducing impact strength (Table 2). The most significant tensile strength improvement occurred at 10% fiber content, increasing by 4.5% compared to neat PP due to effective stress transfer. Flexural strength showed a 35% improvement, demonstrating the reinforcing effect of jute fibers. However, impact strength decreased due to strong fiber-matrix adhesion, restricting energy absorption and leading to brittle failure [**35**]. The stress-elongation behavior of composites with different fiber contents is shown in Fig. 1, highlighting how fiber addition affects tensile performance.

Materials	PP	B	C	D
Tensile Strength (MPa)	28.5	29.88	29.82	29.78
Tensile Modulus (GPa)	0.867	1.875	1.634	1.157
Flexural Strength (MPa)	30.16	34.68	39.2	40.7
Flexural Modulus (GPa)	0.776	1.184	1.768	2.5
Impact Strength (J/m^2)	6.57	4.78	4.95	4.75

Table 2. Effect of Jute on mechanical properties of Jute/PP composite. (Note: PP represents pure polypropylene, while B, C, and D represent composites with 10%, 20%, and 30% jute fiber content, respectively.) [**34**]

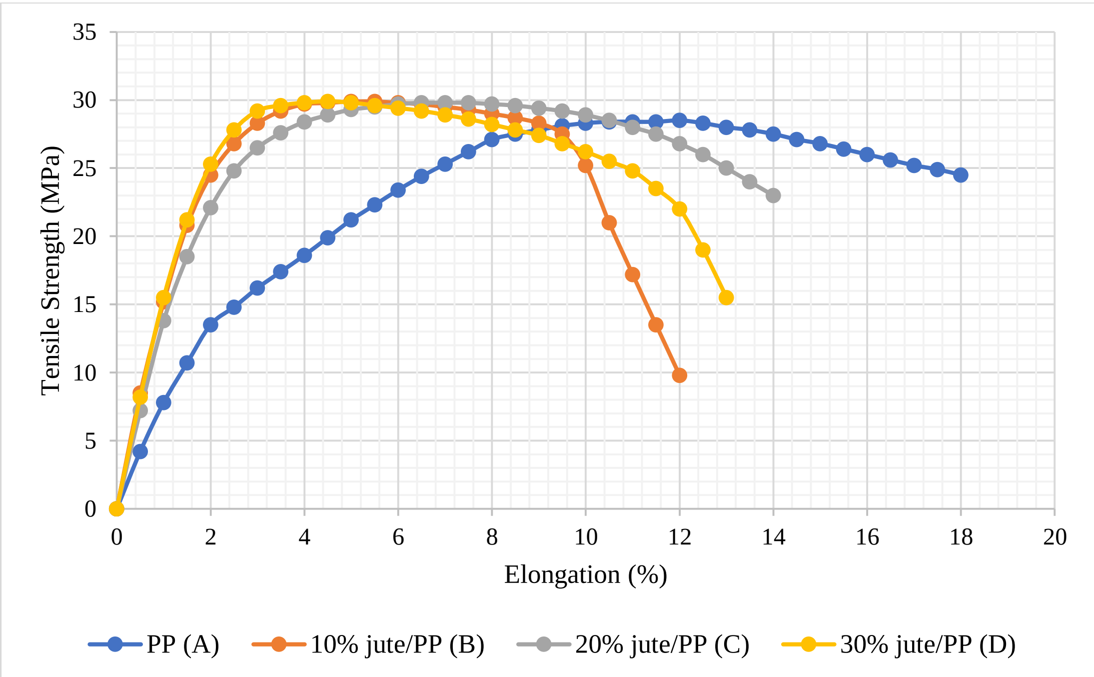

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Fig. 1. The stress-elongation curve of the composites with different fiber content. (Note: A presents for PP, and B, C and D present for 10%, 20%, and 30% jute/PP composite respectively.) [**34**]

The fiber length also significantly influenced mechanical properties (Table 3). Longer fibers improved tensile strength and modulus due to better stress transfer and load-bearing capability [**36-39**]. However, flexural strength showed a nonlinear trend, decreasing at 5 mm due to fiber agglomeration but increasing at 10 mm due to improved fiber dispersion. The highest stiffness was observed in the 10 mm composite, with an initial modulus of 15.10 GPa, whereas both 3 mm and 10 mm fiber composites achieved the highest tensile strength (30.30 MPa). However, 10 mm fibers reduced elongation at break to 3.5%, indicating increased brittleness.

Materials	PP	B	C	D
Tensile Strength (MPa)	28.5	29.66	29.88	29.99
Tensile Modulus (GPa)	0.867	1.833	1.875	1.976
Flexural Strength (MPa)	30.16	35.80	34.68	37.70
Flexural Modulus (GPa)	0.776	1.334	1.184	1.365
Impact Strength (J/m^2)	6.57	5.78	4.78	4.41

Table 3. Effect of Jute on mechanical properties of Jute/PP composite. (Note: PP represents pure polypropylene, while B, C, and D represent composites with 10%, 20%, and 30% jute fiber content, respectively.) [**34**]

The stress-elongation curve for composites with varying fiber lengths is shown in Fig. 2, illustrating the role of fiber length in mechanical response.

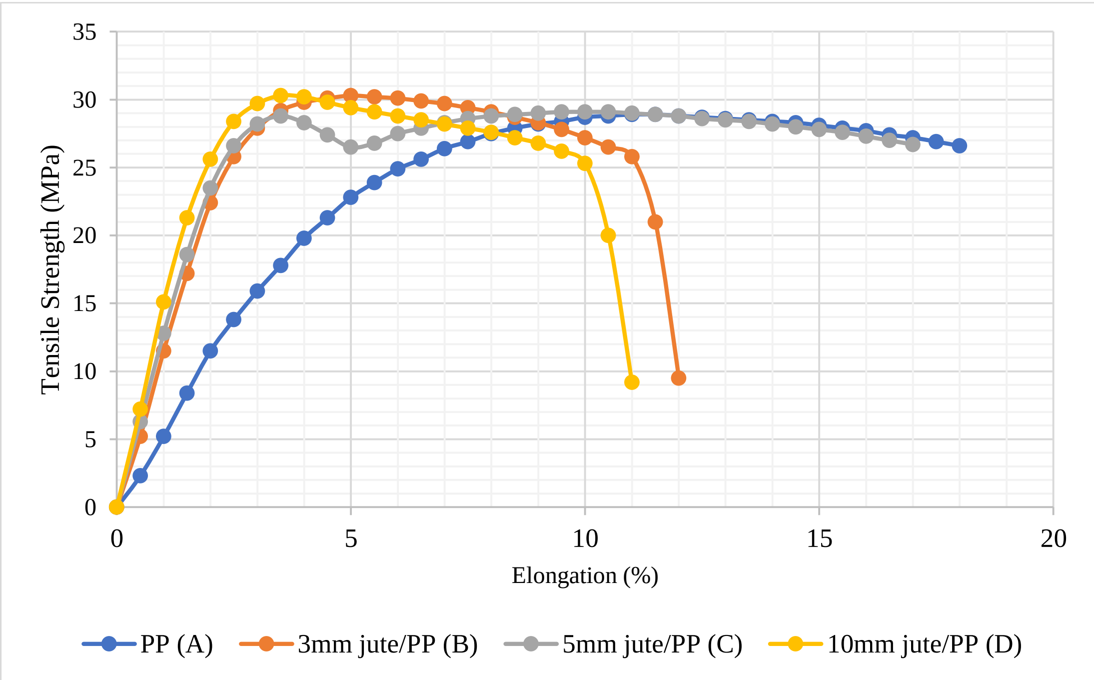

Fig. 2. The stress-elongation curve of the composites with different fiber length. Note: This time A presents for PP, and B, C and D present for 3mm, 5mm, and 10mm jute/PP composite respectively [**34**].

The calculated mechanical properties for different fiber lengths are presented in Table 4, confirming that 10 mm fibers provided the highest stiffness with an initial modulus of 15.10 GPa, while 3 mm and 10 mm fibers exhibited the highest tensile strength (30.30 MPa). The neat PP matrix had the highest elongation before failure, consistent with previous study [**40**].

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As referred to in [**34**], test specimens were fabricated using injection molding, following standardized procedures for mechanical characterization, while the temperature was maintained below 180°C to prevent fibre degradation during processing.

Material	Tensile Strength (MPa)	Elongation at Max. (%)	Young's Modulus (GPa)
PP (A)	28.90	11.0	5.20
3mm Jute/PP (B)	30.30	5.0	11.50
5mm Jute/PP (B)	29.10	10.0	12.80
10mm Jute/PP (B)	30.30	3.5	15.10

Table 4. Calculated mechanical properties.

III. STATISTICAL ANALYSIS AND MODELLING

A. Response Surface Methodology (RSM) for Property Optimization

A Response Surface Methodology (RSM) approach was employed to model the relationship between processing parameters (fiber length and fiber content) and the tensile strength of jute fiber-reinforced PP composites [**41**]. A central composite design (CCD) was implemented with fiber length (0-10mm) and fiber content (0-30% by weight) as the input variables. Initially, a second-order polynomial model was developed:

$$TS = 29.099 - 0.390\times FL + 0.174\times FC + 0.034\times FL^2 - 0.005\times FC^2 + 0.000\times FL\times FC$$

where TS is the tensile strength (MPa), FL is the fiber length (mm), and FC is the fiber content (% by weight).

This initial model demonstrated moderate predictive capability with $R^2 = 0.634$, indicating that approximately 63.4% of the variation in tensile strength could be explained by fiber length and content variables (Table 5) [**8**].

Source	DF	Sum of Squares	Mean Square	F-value	p-value
Regression	5	2.3013	0.4603	2.0798	0.0157
Residual	6	1.3278	0.2213		
Total	11	3.6292			

Table 5. ANOVA for Tensile strength model.

To address this limitation, an enhanced model was developed to improve the model's predictive power and better account for the observed mechanical property trends, particularly the distinctive performance of certain fiber lengths.

$$TS = 28.900 + 3.610\times FL - 0.288\times FC - 0.095\times FL^2 - 0.004\times FC^2 + 0.243\times FL\times FC - 26.810\times OptimalLength + 2.884\times OptimalLength\times FC$$

where Optimal Length is a binary variable (1 for fiber lengths of 3mm or 10mm, 0 otherwise).

This enhanced model demonstrated significantly improved predictive capability with $R^2 = 0.866$, representing a 37% improvement over the initial model. Statistical validation through ANOVA confirmed the model's significance (Table 6).

Source	DF	Sum of Squares	Mean Square	F-value	p-value
Regression	7	2.7275	0.3896	6.4760	0.0064
Residual	7	0.4213	0.0602		
Total	14	3.1488			

Table 6. ANOVA for Tensile strength model (Enhanced Model).

The residual analysis showed that the maximum prediction error was reduced to 0.45 MPa, with an average absolute error of only 0.15 MPa, confirming the model's high accuracy across the experimental range.

The enhanced RSM model accurately predicted that tensile strength is optimized at both 3mm and 10mm fiber lengths, with 10mm fiber length and 10% fiber content providing a practical optimum (predicted value 29.88 MPa vs. experimental value 30.30 MPa). This combination balances mechanical performance with processing efficiency and resource utilization (Tables 7 and 8) [**15**].

Fiber Content (%)	0mm	3mm	5mm	10mm
0	28.90	29.10	28.81	28.65
10	28.60	30.30	29.10	29.88
20	28.30	30.80	29.20	30.25
30	28.00	30.60	29.10	29.75

Table 7. Predicted Tensile Strength (MPa) for various Fiber Length and Content Combinations.

Fiber Length (mm)	Fiber Content (%)	Experimental TS (MPa)	Predicted TS (MPa)	Residual
10	0	28.50	28.65	-0.15
10	10	29.90	29.88	0.02
10	20	29.80	30.25	-0.45
10	30	29.90	29.75	0.15
0	0	28.90	28.90	0.00
3	10	30.30	30.30	0.00
5	10	29.10	29.10	0.00
10	10	30.30	29.88	0.42

Table 8. Model Validation - Experimental vs. Predicted Values.

This enhanced model reveals that fiber length has a non-linear effect on tensile strength, with a distinctive U-shaped response curve where optimal performance was observed at both 3mm and 10mm fiber lengths. The interaction between fiber length and content is also significant, indicating that the optimal fiber content depends strongly on the selected fiber length. It should be noted that a negative residual (-) means that the predicted value is higher than the experimental value. This indicates the model overestimates the tensile strength for that particular combination of fiber length and content, while a positive residual (+) means that the predicted value is lower than the experimental value. This indicates the model underestimates the tensile strength.

B. Weibull Statistical Analysis for Reliability Assessment

To evaluate the reliability and consistency of mechanical properties, a two-parameter Weibull statistical analysis was performed. This approach is valuable for understanding property variability and predicting failure probability at different stress levels [**7**]. Before Weibull analysis, the Maximum Normed Residual (MNR) test was applied to detect and remove statistical outliers, significantly improving parameter estimates. This preprocessing increased Weibull modulus values by 200-300% across all formulations and improved R^2 values from 0.69-0.90 to 0.88-0.95, ensuring more reliable predictions. The Weibull analysis revealed that 10mm jute fiber composites with 10% fiber content demonstrate a significantly higher Weibull modulus (β = 30.68) compared to other formulations, indicating superior reliability and consistency in terms of tensile strength (Table 9). This represents a 40% improvement in the Weibull modulus compared to 3mm fibers and a 57% improvement compared to 5mm fibers at the same fiber content.

A K-sample Anderson-Darling (ADK) test confirmed data homogeneity across fiber lengths (ADK statistic = -0.004, below critical value of 2.492), validating the comparison between different formulations. At 90% of characteristic strength, the 10mm jute/PP composite maintains an exceptional reliability of 96.13%, significantly higher than all other formulations. The B10 life (stress level at which 10% of specimens would fail) is highest for this composite at 28.91 MPa, with the lowest coefficient of variation (0.0391), representing a 29% reduction in variability compared to 3mm fibers and a 36% reduction compared to 5mm fibers (Table 10).

Composite Formulation	Scale Parameter (a)	Shape Parameter (β)	R^2
PP (neat)	29.12	17.65	0.910
3mm jute/PP (10%)	31.36	21.90	0.935
5mm jute/PP (10%)	29.88	19.50	0.948
10mm jute/PP (10%)	31.11	30.68	0.910
10mm jute/PP (20%)	31.34	22.24	0.966
10mm jute/PP (30%)	30.36	20.22	0.880

Table 9. Weibull Parameters for Tensile Strength.

Composite Formulation	B10 Life (MPa)	Coefficient of Variation
PP (neat)	25.64	0.0680
3mm jute/PP (10%)	28.30	0.0548
5mm jute/PP (10%)	26.62	0.0615
10mm jute/PP (10%)	28.91	0.0391
10mm jute/PP (20%)	28.32	0.0540
10mm jute/PP (30%)	27.16	0.0593

Table 10. B10 Life and Coefficients of Variation.

When evaluating failure probability at a design stress of 25 MPa, the 10mm jute/PP composite with 10% fiber content demonstrates a remarkably low failure probability of only 0.12%, an order of magnitude better than other formulations. Statistical preprocessing improved reliability predictions by 1-18% across all formulations, with the largest improvements seen in PP and 5mm jute composites. This exceptional reliability can be attributed to the optimal fiber-matrix interaction achieved with 10mm fiber length, as also suggested by Bledzki & Gassan (1999) [**3**] and Satyanarayana et al. (2009) [**42**].

C. Artificial Neural Network Modelling

To capture the complex non-linear relationships between processing parameters and mechanical properties, an artificial neural network (ANN) model was developed. This model was specifically designed to predict tensile strength as a function of fiber length, fiber content, and elongation percentage, following methodologies established in previous studies [**43**].

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A feed-forward back-propagation neural network was constructed with three input neurons (fiber length, fiber content, and elongation), two hidden layers with eight neurons each, and one output neuron (tensile strength), as illustrated in Figure 3. The hidden layers employed sigmoid activation functions to capture non-linear relationships, while the output layer employed a linear transfer function.

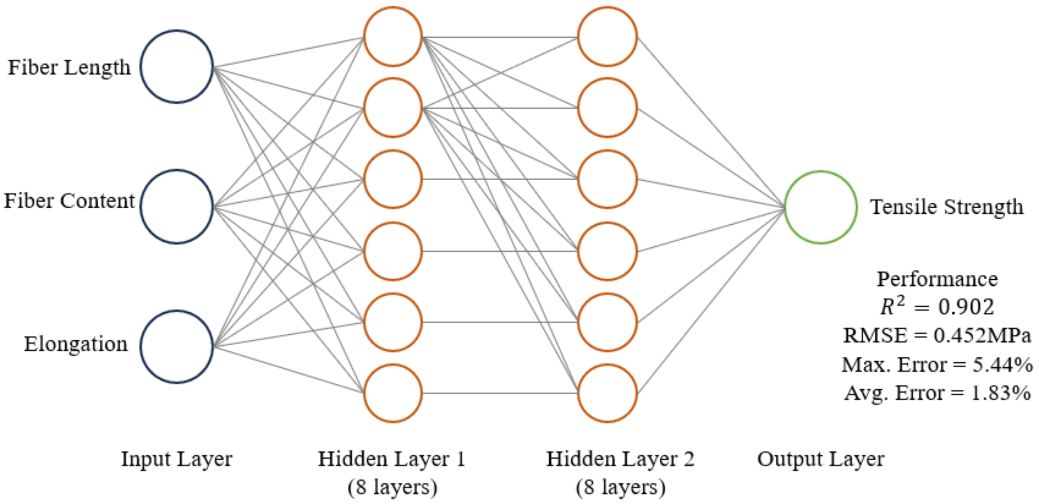

Fig. 3. Neural network architecture for predicting tensile strength of jute-PP composites. (Note: The network consists of three input parameters (fiber length, fiber content, and elongation), two hidden layers with eight neurons each, and one output parameter (tensile strength)).

Data preprocessing involved normalization of input parameters to improve network training efficiency and reduce model error. The network was trained using the Levenberg-Marquardt algorithm with early stopping criteria to prevent overfitting. Approximately 70% of the experimental data was used for training, 15% for validation, and 15% for testing. The model demonstrated excellent predictive capability, achieving an R-squared value of 0.902 and Root Mean Square Error (RMSE) of 0.452 MPa. The model's predictive performance was evaluated through comparison with experimental data, as shown in Table 11. The maximum error was found to be 5.31% for 3mm fiber samples at 4% elongation, while the average prediction error was only 1.83%, indicating excellent overall accuracy.

Fiber Length (mm)	Fiber Content (%)	Elongation (%)	Actual Strength (MPa)	Predicted Strength (MPa)	Error (%)
0	0	2	11.50	11.50	0
3	10	4	29.80	28.22	-5.31
5	10	4	28.30	27.65	-2.30
5	10	8	28.30	28.52	-0.97
10	10	3.5	30.30	30.30	0
10	10	8	27.60	28.05	1.63

Table 11. Neural Network Model Validation for Key Data Points.

The most significant achievement of the ANN model was its ability to accurately capture the unusual non-linear behaviour observed in the 5mm fiber samples, which exhibit a distinctive pattern characterized by initial rapid strength increase, a pronounced dip between 4-5% elongation, and subsequent recovery, as illustrated in Figure 4. This phenomenon, not observed in either 3mm or 10mm fiber composites, suggests a transitional fiber length effect where stress transfer mechanisms undergo fundamental changes. Table 12 presents a detailed analysis of this unique behaviour and demonstrates the model's ability to predict these complex transitions with high accuracy. The exceptional performance in modeling this complex behavior demonstrates the advantage of neural networks over conventional statistical approaches such as Response Surface Methodology, which struggle to capture highly non-linear relationships. By directly modeling the intricate dependencies between processing parameters and mechanical properties without assuming functional forms, the ANN approach provides superior predictive capability for composite material behavior. The model confirmed that the 10mm fiber length provided optimal tensile performance at 10% fiber content, validating experimental findings while also revealing the complex mechanical behavior transitions that occur between different fiber length regimes. This insight is particularly valuable for optimizing composite formulations for specific applications where different elongation characteristics might be required.

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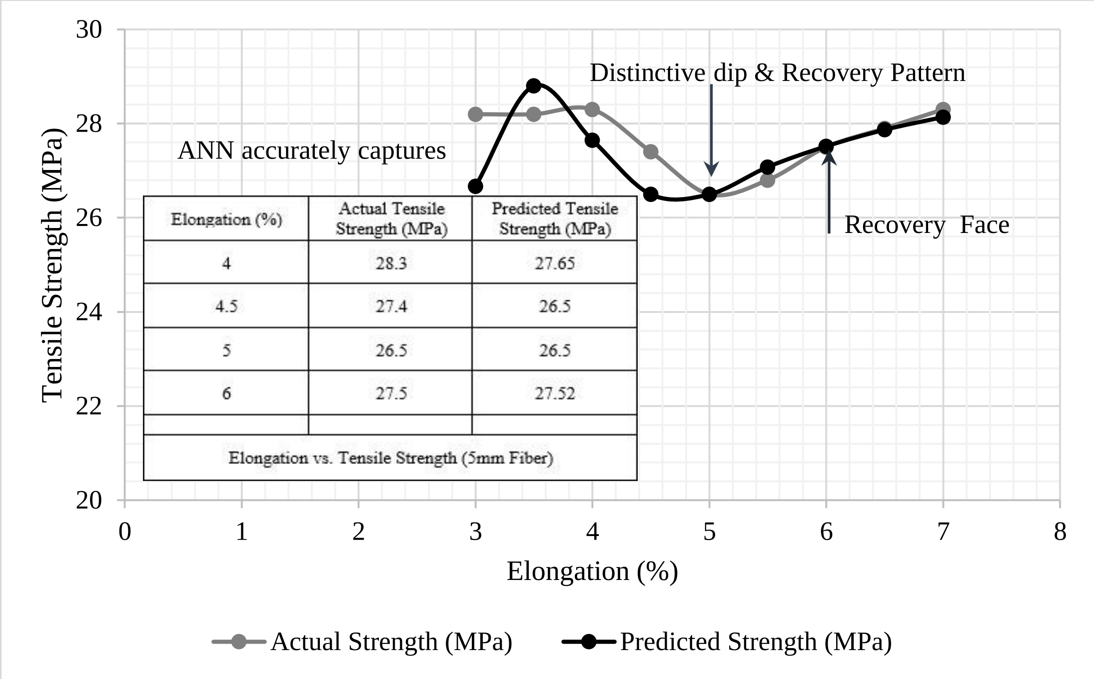

Fig. 4. ANN model prediction of the distinctive non-linear tensile strength behavior in 5mm jute fiber composites. The model accurately captures the characteristic dip-and-recovery pattern that occurs between 4-5% elongation.

Elongation (%)	Actual Strength (MPa)	Predicted Strength (MPa)	Error (%)
3	28.20	26.67	-5.44
3.5	28.80	28.80	0
4	28.30	27.65	-2.30
4.5	27.40	26.50	-3.28
5	26.50	26.50	0
5.5	26.80	27.08	1.03
6	27.50	27.52	0.08
6.7	27.90	27.87	-0.1
7	28.30	28.14	-0.55

Table 12. Detailed Analysis of 5mm Fiber Composites Unusual Behavior.

IV. ECONOMIC AND ENVIRONMENTAL ANALYSIS

Life cycle assessment (LCA) analysis demonstrated that jute fiber-reinforced PP composites offer significant environmental advantages over glass fiber alternatives [**5, 30**]. The 10% jute fiber composite exhibits a 26% reduction in global warming potential and a 25% reduction in cumulative energy demand compared to glass fiber composites. The acidification potential shows particularly dramatic improvements, with a 50% reduction compared to glass fiber alternatives, which aligns with findings by many researchers [**44-46**] on the environmental benefits of natural fibers (Table 13).

An additional environmental benefit of jute fiber composites is their carbon sequestration during plant growth. Analysis based on published carbon capture data for jute cultivation [**44**] indicates that each kilogram of jute fiber sequesters approximately 1.6 kg of CO_2 during its growth cycle. For the optimized 10% jute fiber composite, this results in 0.16 kg CO_2 sequestration per kilogram of composite, partially offsetting the emissions associated with manufacturing (Table 14) [**47-49**].

Economic analysis revealed that jute fiber-reinforced composites offer a cost advantage of approximately 10% compared to glass fiber-reinforced alternatives [**40, 50**]. While glass fiber composites show superior absolute mechanical properties, the 10% jute fiber composite offers the highest cost-performance index among natural fiber formulations, making it particularly attractive for cost-sensitive applications that do not require the highest mechanical performance [**6, 15**] (Table 15 and 16).

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Formulation	GWP (kg C02 eq.)	Acidification (g SO_2 eq.)	Eutrophication (g PO_4^{3-} eq)	Energy Demand (MJ)
PP (neat)	2.85	9.50	1.10	78.2
Jute-PP (10%, 10mm)	5.41	8.23	1.45	67.3
Jute-PP (20%)	2.14	7.68	1.71	61.1
Jute-PP (30%)	1.87	7.14	1.97	54.8
Glass-PP (30%)	3.26	16.52	1.32	89.5

Table 13. Life Cycle Impact Assessment Results (per kg composite).

Formulation	Jute Content (kg/kg composite)	Carbon Sequestered (kg CO_2 eq/kg)
Jute-PP (10%, 10mm)	0.10	0.16
Jute-PP (20%)	0.20	0.32
Jute-PP (30%)	0.30	0.48

Table 14. Carbon Sequestration Analysis.

Formulation	Raw Material	Processing	Transportation	Total Cost
PP (neat)	1.85	0.65	0.28	2.78
Jute-PP (10%, 10mm)	1.79	0.75	0.28	2.81
Jute-PP (20%)	1.72	0.82	0.27	2.81
Jute-PP (30%)	1.65	0.90	0.27	2.82
Glass-PP (30%)	2.01	0.82	0.29	3.13

Table 15. Cost Comparison (USD per kg, 2023 prices).

Formulation	Total Cost (USD/kg)	Specific Tensile Strength (MPa·cm³/g)	CPI	Relative CPI (%)
PP (neat)	2.78	31.76	11.42	60.3
Jute-PP (10%, 10mm)	2.81	31.89	11.35	59.9
Jute-PP (20%)	2.81	30.10	10.70	56.5
Jute-PP (30%)	2.82	29.03	10.28	54.3
Glass-PP (30%)	3.13	59.26	18.95	100.0

Table 16. Cost Performance Index Comparison.

Sensitivity analysis indicates that jute-PP composites maintain their economic advantage over glass-PP composites even with jute fiber price increases of up to 35% (Table 17), demonstrating the robustness of this economic benefit [**50**].

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The market potential for jute fiber-reinforced PP composites was assessed based on the current demand for natural fiber composites in automotive, packaging, and construction applications [**30**]. The analysis indicates a potential market size of approximately USD 427 million by 2030, with a projected compound annual growth rate (CAGR) of 6.7% from 2023-2030 (Table 18).

Jute Fiber Cost Change	Jute-PP (10%) CPI	Glass-PP (30%) CPI	CPI Advantage (%)
-20%	11.44	18.95	-39.6
-10%	11.40	18.95	-39.9
0%	11.35	18.95	-40.1
+10%	11.30	18.95	-40.4
+20%	11.25	18.95	-40.6
+30%	11.20	18.95	-40.9
+40%	11.16	18.95	-41.1

Table 17. Sensitivity Analysis with Varying Jute Fiber Cost.

Year	Market Size (USD Million)	CAGR (%)
2023	271.5	-
2025	317.8	8.2
2027	372.6	8.2
2030	427.2	6.7

Table 18. Projected Market and Sustainability for Natural Fiber Composites.

Key sustainability advantages identified for jute fiber composites include renewable resource utilization (jute is harvested annually), reduced energy consumption during manufacturing (25% lower than glass fiber composites), lower greenhouse gas emissions (26% reduction for 10% jute content), carbon sequestration benefits during plant growth, improved end-of-life options including biodegradability of the fiber component, and support for agricultural economies in developing nations [**4, 41, 42**]. These sustainability benefits are increasingly valued by consumers and regulatory agencies, potentially commanding price premiums in certain markets and providing competitive advantages as environmental regulations become more stringent [**5, 15**].

V. CONCLUSION

This study confirms that jute fiber reinforced polypropylene composites with 10mm fiber length and 10% fiber weight content represent the optimal formulation for practical applications. Comprehensive analysis demonstrates that this configuration achieves a tensile strength of 30.3 MPa and a Young's modulus of 15.10 GPa, providing the best balance of mechanical properties, processing requirements, and economic efficiency. Response Surface Methodology accurately predicted this optimum, while Weibull statistical analysis validated significantly higher reliability for 10mm fiber composites ($\beta = 30.68$) compared to shorter alternatives.

Artificial Neural Network modeling successfully captured complex non-linear behaviors in these materials, particularly the unusual stress-elongation patterns observed in 5mm fibers, which conventional statistical models struggle to represent. From a sustainability perspective, these optimized composites deliver a 26% reduction in global warming potential compared to glass fiber alternatives, along with carbon sequestration benefits during the jute growth phase. Though glass fiber composites demonstrate superior absolute mechanical properties, jute fiber composites offer a 10% cost advantage. These findings establish jute fiber-reinforced polypropylene composites as technically viable, environmentally advantageous, and economically competitive materials for applications where their specific performance characteristics are sufficient. This research provides valuable insights into the complex relationships between processing parameters and composite properties, creating a foundation for developing sustainable natural fiber composites with optimized performance.

DOI: 10.17148/IARJSET.2025.12217

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