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EXPERIMENTAL AND STATISTICAL INVESTIGATION LOAD BEARING CAPACITY RELATED TO NOMINAL TENSILE STRENGTH OF NOTCHED HYBRID FIBER-REINFORCED COMPOSITE

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Abstract
The chief motive for the development of hybrid natural fiber-reinforced composites is to earn carbon credits with better mechanical properties. Within that, Banana/Glass fiber yarn reinforced composite material (BGRFC) was developed by hand layup method in the present study. Single-edge-notched tension (SENT) specimens were designed to investigate load-bearing capacity with four fiber orientations, three thicknesses, and three sizes (Width). The influence of fiber orientation, thicknesses, and specimen size on load-bearing capacity has also been predicted using second-order polynomial regression models. Results predicted by the regression models are in good agreement with experimental results. From load-bearing capacity, nominal tensile strengths(σ_N) were calculated. The calculated Tensile strength can use to provide a reference to estimate the failure behaviour of BGFRC Material.

Keywords: Hybrid natural fiber reinforced composite, Tensile strength, Load Bearing Capacity, Regression Method

1 Introduction

The composites (Fiber-Reinforced) are made from natural or synthetic fibers reinforced with a polymer matrix. Fiber provides strength and stiffness while the matrix protects the fiber from external damage and the environment. Users mainly use composites in the form of a laminate. Therefore, it is foremost important to examine its strength and failure mechanism [2,6,9,10,14,15,17].

Natural fibers are increasingly being used in composite materials because they are more environmentally friendly, found easily, and have outstanding qualities like low weight and affordability that advised appeal to the building, automobile, aerospace, and other technical industries. Exploration and attempts to extract plant-based fibers with desirable mechanical properties are being made by scientists [4,5,12]. Banana fiber yarn is utilized in this project as reinforcement. Each banana plant only produces fruit once, and the pseudo stem is used to make banana fiber yarn out of agricultural waste. When compared to other natural fibers, this is one of the key advantages of banana fibers. In terms of strength, dimensional stability, mechanical characteristics, usefulness, affordability, biodegradability, and environmental sensitivity, banana fibers have been determined to be excellent. Banana fibers are being utilized in a variety of applications as a composite reinforcement material [16]. In contrast, because of their superior mechanical qualities and inexpensive cost, synthetic fibers like glass and carbon are utilized as reinforcement in various applications, including those in the automotive, aerospace, leisure, and home appliance industries.

Hybridization of natural fibers with glass fibers in composite materials is highly recommended for improving mechanical qualities with an environmentally friendly structure. To enhance the mechanical, thermal, tribological, and wear resistance qualities of composite materials, many researchers have created hybrid composite materials which demand an extensive study of their mechanical properties and failure behaviors [8,11,16] of them. Nowadays, the mechanical performance of fiber-reinforced composites can be enhanced by changing fiber orientation and fiber volume, fiber selection, extraction, chemical treatment, interfacial engineering as well as composite processing. Michael Corbin experimentally studied the effect of fiber orientation on the mechanical properties of

polypropylene–lyocell composites and reported that E-modulus and tensile strength depend strongly on fiber orientation [7]. Romi Sukmawan also observed the effect of fiber content on the mechanical properties and fracture characteristics of the composites of bamboo fiber[13].
In the present study, the composite was made using banana fiber yarn reinforced with E-glass fiber yarn of different fiber orientations and different thicknesses and sizes. Tensile tests were performed to assess the maximum load-bearing capacity for each fiber orientation. Based on experimental results, the regression analysis was done and statistical models were developed to predict the load-bearing capacity. Tensile strength was calculated from load-bearing capacity.

2 Experiment

2.1 Materials and Material Properties

Banana Fiber yarn (Reinforcement Material): Banana fiber yarn was procured from Bio Natural Organic Farm, Telangana. The mechanical properties of banana/glass fiber-reinforced composite material depend mainly on the properties of the fibers. The strength of fiber yarn depends on the count, tenacity, and manufacturing process used. So, banana fiber yarn was tested on the yarn testing machine at the textile testing laboratory -MANTRA, Surat. Banana fiber yarn's properties are listed in Table 1.

Table 1: The unique physical characteristics of banana fibers

Parameter	Properties
Yarn Type	100% Natural Banana Yarn
Tenacity	2.02gf
Count	60
% Max Elongation	9.04
Maximum Load	190 gf

E-Glass Fiber yarn (Reinforcement Material): E-Glasss Fiber fiber yarn was procured from Om Industrial Fabrics, Ahmedabad. The properties of E-Glass fiber yarn are listed in Table-2.

Table 2: The unique physical characteristics of E-glass Fiber Yarn

Parameter	Properties
Yarn Type	E-glass Fiber Yarn
Tenacity	50 Cn/Tex
Count	40
% Max Elongation	2.2-2.5
Tensile Modulus	73Gpa

2.2 Experimental Process

Banana Fiber reinforced composite laminates were fabricated by hand lay-up technique with banana and glass fiber yarn as reinforcement and epoxy as matrix material. To study the effect of fiber orientation, thickness, and size on load-bearing capacity, the material was laid up in a 304.8 mm * 304.8 mm plate with four different layups and three different thicknesses as shown in Figure-1.

Table 3: SENT Test specimen matrix for various layups and thicknesses

	Fiber Orientation			
Thickness(mm)	Uni-directional ply	30^o Angle Ply	45^o Angle Ply	Cross-ply
3	$[0]_{2s,}$	$[\pm30]_s$	$[\pm45]_s$	$[0/90]_s$
4	$[0]_{3s}$	$[+30/-30/+30]_s$	$[+45/-45/+45]_s$	$[0/90/0]_s$
5	$[0]_{4s}$	$[\pm30]_{2s}$	$[\pm45]_{2s}$	$[0/90]_{2s}$

Three groups of single-edge notched tension (SENT) specimens, each with a thickness of 5mm, 4mm, and 3mm, were created. Table 3 displays the test specimen preparation matrix. Each group contained three specimens of each size that had been mathematically reduced down into two dimensions (Figure-4) 1:2:4 was examined (Table 2). This aids in examining how specimen size (width) and fiber orientation affect strength at a constant thickness. To reduce fiber damage, a single edge notch of a =

D/5 was cut using the laser cutting technique, where D is the specimen width as illustrated in Fig. 2. For the purpose of grasping, a consistent 38 mm long tab length was used to produce all SENT specimens.

On TINIUS OLSEN/L-series H50KL at a strain rate of 1 mm/min, all specimens were tested. The machine's software recorded the specimen's load (in N) and displacement (in mm).

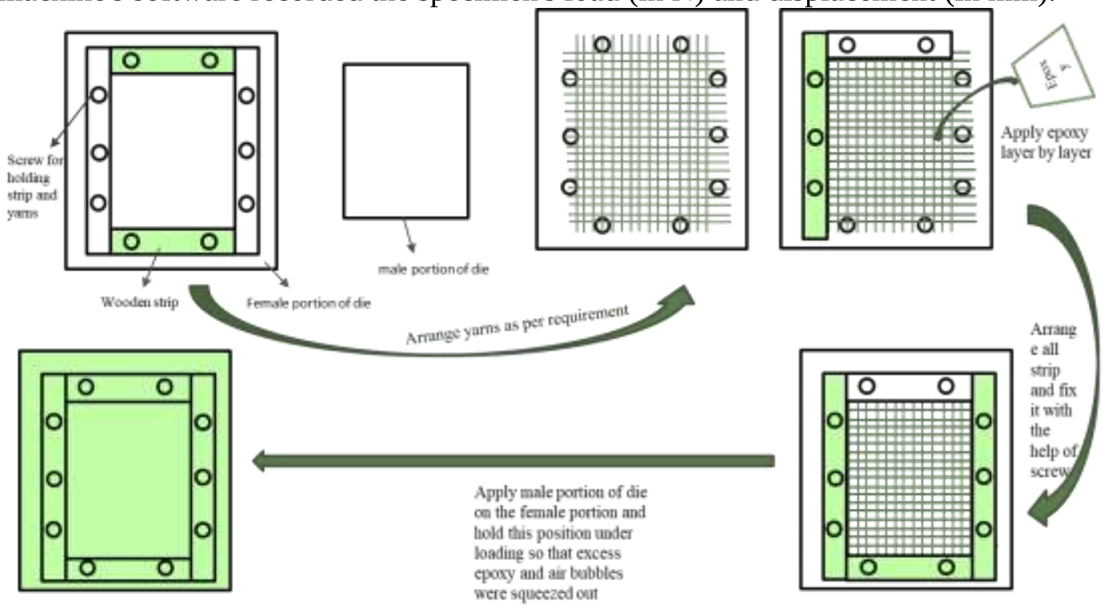

Fig. 1. Hand Layup Method

2.3 Determination of Tensile strength of SENT specimen

The strength of the notched specimen can be calculated from equation -1.

$$\sigma_N = \frac{P}{D*t} \qquad \text{-----(1)}$$

Where P = Max. load, D= width of the specimen, t= thickness of the specimen

2.4 Regression Analysis

Regression is the statistical method for finding fitting models to the data. In statistics, polynomial regression is a form of linear regression that gives the relationship between independent variable x with dependent variable y and is generated nth-order

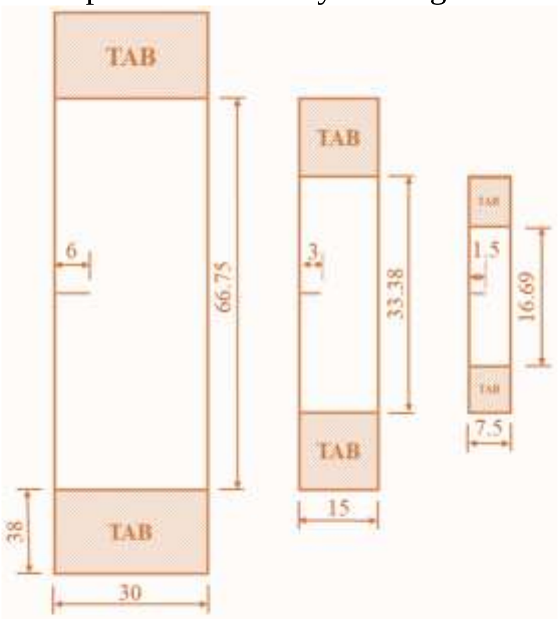

Fig. 2. Dimensions of SENT specimens

Table 4: Dimensions of SENT specimens
(All dimensions are in mm)

Size	Width (D)	Gauge Length (L)	Overall Length	Crack Length (a)
1	7.5	16.69	92.69	1.5
2	15	33.39	109.38	3
3	30	66.75	142.75	6

polynomial. In the present work, second-order polynomial regression was modeled for each

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fiber orientation using MS Excel for deriving the relationship between load-bearing capacity with specimen size and specimen thickness.

In this model, load-bearing capacity was taken as the dependent variable whereas specimen size and thickness were taken as the independent variable. Regression model of the current work is given as

$$y=\beta_0+\beta_1 x_1+\beta_2 x_2 \qquad \text{-----(2)}$$

where, y is the predicted outcome; β_1 and β_2 are the regression coefficients; β_0 is the intercept of the regression equation,.

3 Result and Discussion

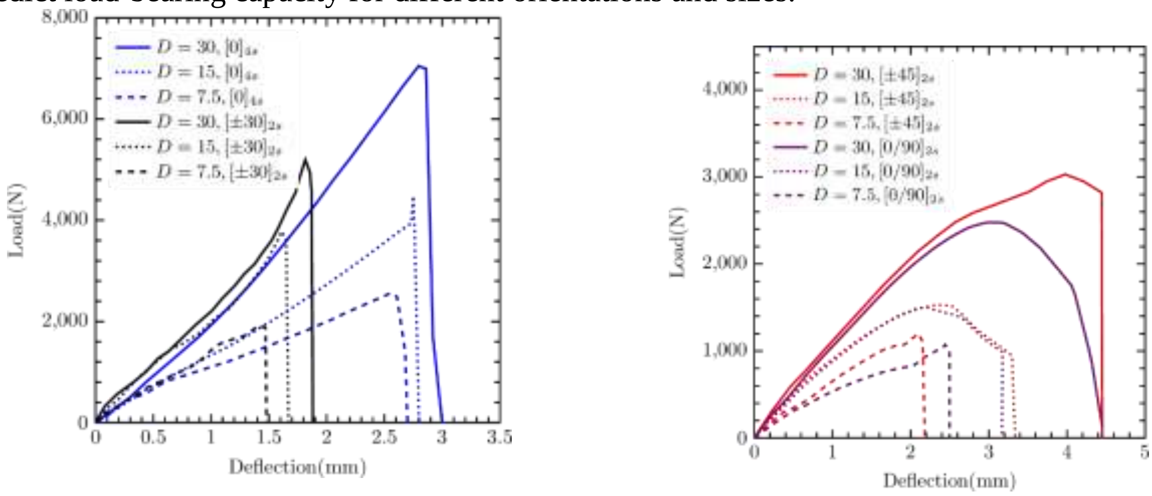
3.1 Analysis of Load displacement curve

To determine maximum load-bearing capacity, careful experimentation was performed, yielding reliable results for a variety of specimen sizes, fiber orientations, and thicknesses. Load displacement curves for all BGFRC notched specimens were obtained by test, as shown in Fig. 4. SENT specimens exhibit the same behavior in any fiber orientation of each group. It is also linear up to a strain level of 25%. It can be concluded that material properties in all sizes for the same fiber orientations and thicknesses are the same. When the samples reached at maximum bearing capacity, the crack expands, and the load drops rapidly. In all cases, the crack occurs at the tip of the prefabricated notch and propagates perpendicular to the loading directionIn all cases, because the stress was concentrated at the crack tip and created fracture.

3.2 Analysis of Load bearing capacity and Tensile strength

The average load-bearing capacity of 3 sets of specimens for each parameter is listed in Table-4. Table 4 shows that load bearing capacity of BGFRC depends on the thickness of the material. The material having 5 mm thickness has a maximum load bearing capacity than 4mm and 3mm thickness specimens because the fiber volume of banana and glass fiber yarn is maximum in thicker material which increases the load bearing capacity of the material.

The average nominal tensile strength of the SENT specimens was calculated and Table 4 shows that the unidirectional BGFRC material strength values are higher than other orientations and the strength is decreasing with increasing angle of the fiber. So it can be concluded that unidirectional layup is less notch sensitive than other orientations. That's why unidirectional layups are preferable in many technical applications. Notch length, gauge length, and width of the specimen are scaled at a constant thickness (i.e. 3mm, 4 mm, 5 mm) and the same *a/D* ratio. Nominal tensile strength decreases (≈30-50%) with increasing specimen width (i.e 15-30 mm). It demands crucial consideration of size while predicting the strength of larger structures from small laboratory specimens. The sizing effect and fracture of material should be considered which fully depends on load-bearing capacity so it is required to predict load-bearing capacity for different orientations and sizes.



(a) Group-1 : 5mm Thickness

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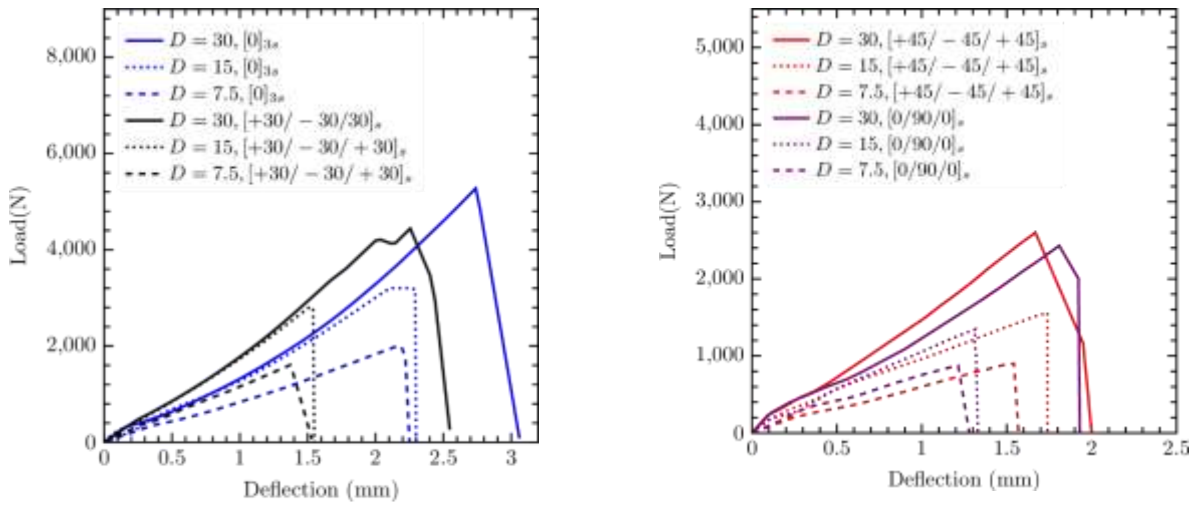
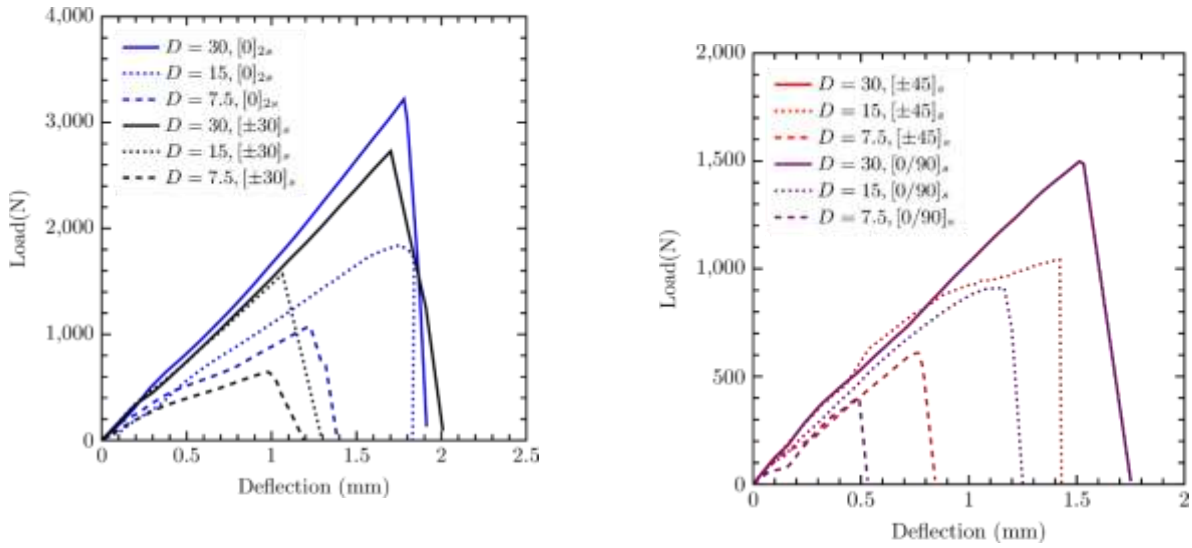


(b) Group-2 : 4 mm Thickness



(c) Group-3 : 3mm Thickness

Fig. 3. Load-Deflection Curve for different layup and thickness of SENT specimen

Table 5: Experimental average values of load-bearing capacity and tensile strength of BGFRC

Fiber orientations	Thickness (mm)	Tensile strength (MPa) Size(mm^2) (Width* Gauge Length)			Load bearing capacity (N) Size(mm^2) (Width* Gauge Length)		
		30*66.75	15*33.39	7.5*16.69	30*66.75	15*33.39	7.5*16.69
$[0]_{4s}$	5	47	59.74	68.26	7050	4481	2560
$[\pm30]_{2s}$		34.62	48.4	51.466	5193	3630	1930
$[\pm45]_{2s}$		20.2	24.70	32	3030	1853	1200
$[0/90]_{2s}$		17.2	23.06	28.56	2580	1730	1071
$[0]_{3s}$	4	43.80	58.3	66.56	5257	3500	1997
$[+30/-30+30]_s$		33.58	46.66	53.46	4030	2800	1604
$[+45/-45/+45]_s$		21.29	24.2	30	2555	1452	900
$[0/90/0]_s$		16.75	22.41	27.5	2010	1345	825
$[0]_{2s}$	3	40	51.11	57.77	3600	2300	1300

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$[\pm30]_s$		30.33	34.8	40	2730	1566	900
$[\pm45]_s$		17.5	23.17	27.02	1575	1043	608
$[0/90]_s$		15.55	21.77	26.66	1400	980	600

3.3 Analysis of the Regression Model

For predicting load bearing capacity of BGFRC, a statistical model for each orientation is given in the table. The values of the coefficient of correlation (R), coefficient of determination (R^2), and significance F (P-value, P.05) are also given in Table 6. The coefficient of correction (R) gives a relation between actual value with predicted values. Here, R value is more than 0.93 (93%), indicating exactness in results between the predicted and actual values. The coefficient of determination method is used to predict and explain the future outcomes of a model. The coefficient of determination values is more than 0.95 means the accuracy of the model is appreciable. It can also be seen that the values of "significance F" (P-value of model) in the ANOVA table are less than 0.05 (5%), indicating that models are significant. The experimental results are compared with the results predicted by the statistical model, shown in Tables 5 and 6 along with the percentage of error. The percentage of error is less than 8% in the major of its cases. It is found more for small specimens due to gripping issues. Hence, quadratic regression models appear to be suitable for predicting the correct outcomes and this result provides a reference to understand failure behavior, fracture properties, and size effect law for BGFRC [1,3,8,20].

Table 6: Statistical model for different fiber layups

	Statistical models	Coefficients of correction (R)	Coefficient of determination (R^2)	F-test	Significance F
Uni-directional ply	$Y=145.47X_1+1148.5X_2-3579.33$	0.9435	0.9713	50.15	0.000179
30^o Angle Ply	$Y=108.04X_1+926.16X_2-2886.17$	0.9446	0.9719	51.21	0.000169
45^o Angle Ply	$Y=65.46X_1+476.16X_2-1470.67$	0.9500	0.9746	57.01	0.000125
Cross-ply	$Y=50.51X_1+400.16X_2-1091.17$	0.9484	0.9739	55.23	0.000137

Table 7: Percentage of error

Fibre layups	Thickness (mm)	Load bearing capacity (N)			Load bearing capacity (N)			Percentage of error (%)		
		Experimental value			Predicted value by the statistical model					
		Size(mm^2) (Width* Gauge Length)			Size(mm^2) (Width* Gauge Length)			Size(mm^2) (Width* Gauge Length)		
		30*66.75	15*33.39	7.5*16.69	30*66.75	15*33.39	7.5*16.69	30*66.75	15*33.39	7.5*16.69
$[0]_{4S}$	5	7050	4481	2560	6527.54	4345.35	3254.26	-7.41	-3.02	27.11
$[\pm30]_{2s}$		5193	3630	1930	4985.90	3365.28	2554.97	-3.98	-7.29	22.38

[±45]$_{2s}$		3030	1853	1200	2873.97	1892.07	1401.11	-5.14	2.10	16.57
[0/90]$_{2s}$		2580	1730	1071	2425	1667.33	1288.5	-6.00	-3.62	20.30
[0]$_{3s}$	4	5257	3500	1997	5257	3500	1997	2.32	-8.66	5.44
[+30/-30+30]$_s$		4030	2800	1604	4059.73	2439.11	1628.81	0.73	-12.88	1.54
[+45/-45/+45]$_s$		2555	1452	900	2397.81	1415.90	924.95	-6.15	-2.48	2.77
[0/90/0]$_s$		2010	1345	825	2024.83	1267.16	888.33	0.73	-5.78	7.67
[0]$_{2s}$	3	3600	2300	1300	3600	2300	1300	17.51	-10.94	-26.36
[±30]$_s$		2730	1566	900	3133.57	1512.95	702.64	14.78	-3.38	-21.92
[±45]$_s$		1575	1043	608	1921.64	939.73	448.78	2.20	-9.90	-26.18
[0/90]$_s$		1400	980	600	1624.66	867	488.16	16.05	-11.53	-18.63

4 Conclusion

The production of novel materials using natural resources is the focus of recent innovations. The main drawback of natural fiber-reinforced composite materials is their moderate mechanical strength. Changes in fiber orientation, fiber volume fraction, and effective chemical treatment and hybridization can all help to overcome it. In this study, the effect of the fiber orientation, volume, and size of composite materials on their tensile strength and load-bearing capacity is experimentally studied, and concluded that the orientation of the fibers as well as the thickness and size of the specimen are important parameters to determine the failure and fracture of the material.

From the experimental results, it can be observed that the strength of the unidirectional BGFRC material is greater than that of other layups, and it diminishes with increasing fiber angle. The unidirectional layup is therefore less notch sensitive than other layup materials and has a wide range of engineering uses. Due to the higher fiber content, thicker materials can support greater load-bearing capacity than thinner ones. It is important to understand the scaling effect for composite materials since the nominal strength of BFRC material has a strong scaling impact in test specimens of various layups and thicknesses, with a strength drop of (30–50%) when the width is increased from 7.5 mm to 30 mm. The developed statistical models exhibit good agreement with experimental findings and can reasonably forecast the load-bearing capacity of BGFRC. For different sizes and thicknesses, the load-bearing capacity of BGRFC may be accurately predicted, and this serves as a guide to understanding the material's fracture and failure behaviour.

Statement and Declaration

The Authors declare that there is no conflict of interest.

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