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A Statistical Analysis on Tensile behaviour of Single Edge Notched Jute Hybrid Composites

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Abstract: *In this work, a statistical model was developed using Taguchi technique to study the factors influencing the tensile strength of single edge notched jute hybrid composites. Standard uniaxial tensile tests were conducted to evaluate tensile strength of single edge notched jute hybrid composite specimens, with different fiber orientations, glass volume fractions and notch sizes, in accordance with ASTM D3039 standards. It is observed that as glass volume fraction increases, tensile strength increases. As notch size increases, tensile strength decreases. The tensile strengths of specimens in fiber direction (0°/90°) were higher than those in off fiber direction (±45°). The forecast model indicates that the major parameters that impact the tensile strength were glass volume fraction and fiber orientation. Notch size had lesser impact on tensile strength. The optimum value of the tensile strength is observed for specimen with 0/90 fiber orientation, 45% glass volume fraction, 2mm notch size and from the confirmation test, the model results were observed to be near to the experimental values.*

Keywords: Taguchi analysis, Glass and Jute fiber, volume fraction, orientation, notch size, tensile strength, single edge notch

I. INTRODUCTION

Nowadays, natural fiber composites have gained increasing interest due to their ecofriendly properties. A lot of work has been done by researchers based on these natural fibers. Natural fiber reinforced composites have raised great attentions and interests among materials. Scientists and Engineers in recent years due to the considerations of developing an environmental friendly material, partly replacing currently used glass or carbon fibers in fiber reinforced composites. They are high specific strength, modulus, low price materials, recyclable and easily available in some countries [1]. The mechanical properties like tensile, compressive, flexural, impact, in plane, interlaminar shear strengths and hardness of jute fiber, jute fabric and woven jute fabric reinforced polyester composites fabricated by hand layup method, were evaluated experimentally as per standards. From the results, jute fiber and the composites made by reinforcing it with suitable polymer was proposed as substitute for low strength and relatively low cost components in domestic, indoor and automotive applications [2].

Jute/glass fibers in 40:0, 40:00, 35:05, 30:10, 25:15, 20:20 wt% ratios, reinforced with 60 wt% polypropylene and subjected to mechanical tests. The tensile strength, tensile modulus, flexural strength, flexural modulus, impact strength and hardness of 20:20 wt% jute/glass-PP composite was found to be maximum. From the observations, these properties increased with increase in glass fiberswt% [3]. The elastic properties of woven jute and jute-glass fabric hybrid composites have been evaluated using rule of hybrid mixtures. The effects of hybridization of glass fibers and hole size on notched sensitivity of woven jute and jute-glass fabric hybrid composites were investigated analytically and experimentally [4].

The effect of a hybrid composite specimen subjected to in-plane tensile and compressive loading were studied. The laminated specimens were fabricated using steel and nylon bi-directional mesh as reinforcements and polyester as the binder, as per ASTM standards. The various volume fractions and fiber orientations were used in which the percentage of polyester (40%) was maintained constant. From the investigations, it is revealed that the specimens with a higher percentage of steel sustain greater loads & also the strengths are superior in case of 0/900 oriented specimens. A relationship between the tensile/compressive strength, fiber content and orientation has been established [5]. The potential of sisal, banana and roselle fiber reinforced composites has been explored, mechanical and material characterization was studied. The final composite material coated by calcium phosphate and hydroxyapatite (hybrid) composite can be used for both internal and external fixation of fractured bone in the human body [6].

The mechanical properties of banana fiber reinforced epoxy composites have been measured, and it was observed that tensile strength increased with increase in fiber length. It was also found that the void, fiber length and interfacial adhesion between fiber & matrix can affect mechanical properties of composite [7]. The effect of replacing glass fiberswith jute fibers was studied, found that glass fiber reinforced composite was stronger than jute reinforced composite. Even it was observed that the composites made by replacing glass fibers with jute fibers partly, its strength was lower than glass fiber reinforced composites. However, the cost is reduced by replacing glass with jute fibers and they can be conveniently used in low strength applications [8].

Tensile and flexural tests were conducted on pure oil palm empty fruit bunch (EFB) fiber reinforced composites, jute reinforced composites and EFB/jute fiber reinforced hybrid composites. The tensile and flexural strengths were tabulated and compared. The hybridization of EFB fibers with jute fiber, improved the tensile and flexural strengths. From these results and observations, hybrid composites were proposed alternative to synthetic fibre composites used in engineering applications [13]. The significance of these results wereanalyzed by ANOVA-one way statistical method and SEM micrographs of fractured surfaces of tensile test specimens [9]. Taguchi designs are employed in robust parameter design, with the primary purpose of finding factor values that reduce response variation while modifying (or keeping) the process on track. Taguchi designs are a powerful and effective way to create things that perform consistently and optimally under a variety of scenarios [10].

To investigate the mechanical behaviour of the composites, tensile and flexural tests are done at three different speeds. In their study, six different percent filler contents were used to produce sundi wood dust reinforced epoxy composites. Experiments using the Taguchi L18 orthogonal array were carried out with two design characteristics in mind: speed and percent filler weight. Using the Taguchi optimization method, the experimental data was examined. The process parameters for load, tensile, and flexural stress were set to their optimal values. The optimal sets of values for the various parameters were displayed after statistical analysis of the experimental data. The relevant parameters for load, tensile, and flexural stress were determined using an analysis of variance (ANOVA) technique. Speed is the most important factor impacting load and tensile stress values, but percent filler wt. is the most important factor at the 95 percent confidence level for flexural stress. A confirmation test was conducted to verify the optimised findings, and it was discovered that the S/N ratios had improved from the initial to the optimal setting [11]. Using the Taguchi technique, an attempt was made to investigate and extract the optimal combinations of process parameters involved in fabrication of silica fly ash filled polymer matrix composites to improve mechanical qualities including hardness, flexural strength, and moisture absorption. Input process parameters included the proportion of fly ash, mixing duration, and filler size. To validate the model and confirm the most significant parameter, an analysis of variance was performed. Ball milling hours, which are important in determining the size of FA particles, have been found to have the greatest impact on the performance parameters of the produced polyester composite [12].

The main aim of this paper is to develop forecast model using Taguchi technique and study the factors influencing the tensile strength of single edge notched jute natural hybrid composites subjected to uniaxial tension.

II. OPTIMIZATION TECHNIQUE

The Taguchi methodology for quality systems and system engineering is widely used and tested. This approach was effectively applied in the research of polymer matrix composites [9-13]. The process parameters used in the study were Fiber Orientation (O), Glass volume fraction (%), and Notch size (mm). Table 1 shows the parameters and its levels.

TABLE 1: Process parameters and its Levels

Factors	Level 1	Level 2	Level 3
Fiber Orientation (O)	1 (0°/90°)	2 (45°)	-
Glass volume fraction (%)	15	30	45
Notch size (mm)	2	4	6

III. Experimental Procedure

Epoxy resin was chosen as the base matrix material, Jute and Glass fiber mats were added as the reinforcements. The laminated specimens in accordance with ASTM D3039 [13] standards were fabricated using glass, jute bi-directional mesh as reinforcements and epoxy resin as the binder. The various fiber orientations (0°/90°, ±45°), jute/glass fiber % volume fractions (45:15, 30:30, and 15:45), and notch size (2, 4 and 6mm) were used in which the percentage of epoxy resin (40%) was maintained constant. Hand layup method is used to prepare the specimens. The standard uniaxial tension tests were conducted by universal testing machine as shown in Figure 1 (a) and the test specimen configuration is shown in Figure 1 (b). The load and the corresponding deformations are recorded. From the ultimate load values, tensile strengths were evaluated. The effect of fiber orientation (O), Notch type, glass volume fraction (%), and notch size (mm) on tensile strength was studied.

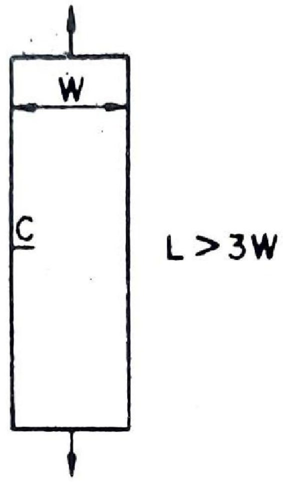

Figure 1: (a) Universal Testing Machine (b) Specimen configuration [14]

IV. Result and Discussion

The results of tensile strengths for all 18 combinations were tabulated (Table 2). Using Minitab software, the tensile strength assessment parameters were analyzed, using L18 Taguchi orthogonal array design. The S/N ratios for all combinations were listed below. For all possible combinations of the factors and levels the signal to noise ratios have been calculated and tabulated.

TABLE 2: Experimental Results for L18 orthogonal array with S/N ratio

Sl No	Fiber Orientation (O)	Glass volume Fraction (%)	Notch Size (mm)	Tensile Strength (MPa)	S/N Ratio
1	1	15	2	76.38	37.66
2	1	15	4	66.01	36.39
3	1	15	6	55.37	34.86
4	1	30	2	112.27	41.01
5	1	30	4	97.05	39.74
6	1	30	6	80.04	38.07
7	1	45	2	129.08	42.22
8	1	45	4	122.98	41.80
9	1	45	6	112.65	41.03
10	2	15	2	60.12	35.58
11	2	15	4	52.32	34.37
12	2	15	6	50.04	33.99
13	2	30	2	75.98	37.61
14	2	30	4	65.15	36.28

15	2	30	6	62.79	35.96
16	2	45	2	89.69	39.06
17	2	45	4	80.08	38.07
18	2	45	6	76.87	37.72

V. Influence of Each Factor on Tensile Strength

An average of all tensile strength values was taken for each level of the individual parameter. Table 3 shows these values. The difference between the maximum and minimum average value (Delta) was calculated for each parameter. The greater the Delta value, the higher the tensile strength of the composite is influenced by that parameter. Tensile strength corresponding to the parameter level has been plotted for each parameter and is shown in Figure 2.

Table 3: Response Table for Means

Level	Fiber Orientation (O)	Glass volume fraction (%)	Notch size (mm)
1	94.65	60.04	90.59
2	68.12	82.21	80.60
3	-	101.89	72.96
Delta	26.53	41.85	17.63
Rank	2	1	3

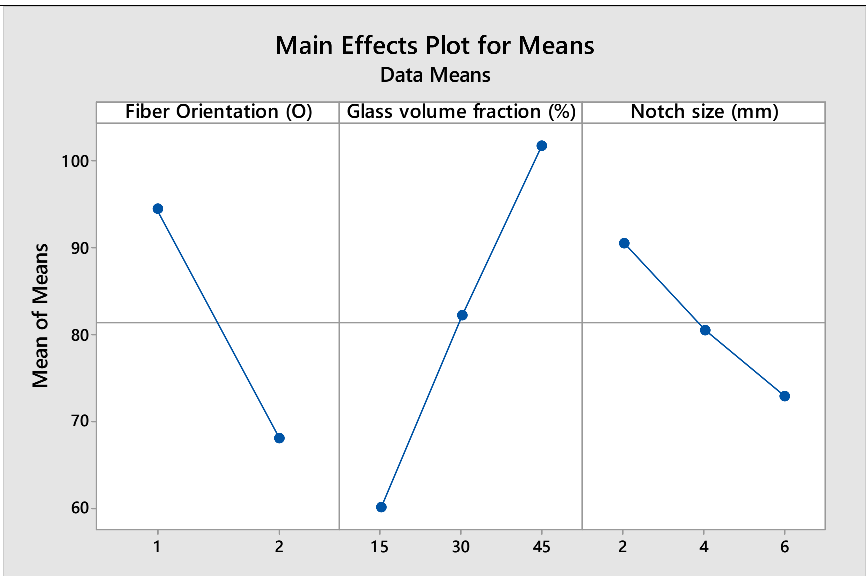

Figure 2: Main effects plot for means

Using S/N Ratios, similar calculations were made. The response table for S/N ratios for various combinations was shown in table 4. It is tabulated for larger the better method of calculating the tensile strength since it is considered to be as large as possible for the given combination of the parameters. Tensile strength corresponding to the parameter level has been plotted for each parameter and is shown in Figure 3.

Table 4: Response Table for Signal to Noise Ratios -Larger is better

Level	Fiber Orientation (O)	Glass volume fraction (%)	Notch size (mm)
1	39.20	35.48	38.86
2	36.51	38.11	37.78
3		39.98	36.94
Delta	2.68	4.51	1.92
Rank	2	1	3

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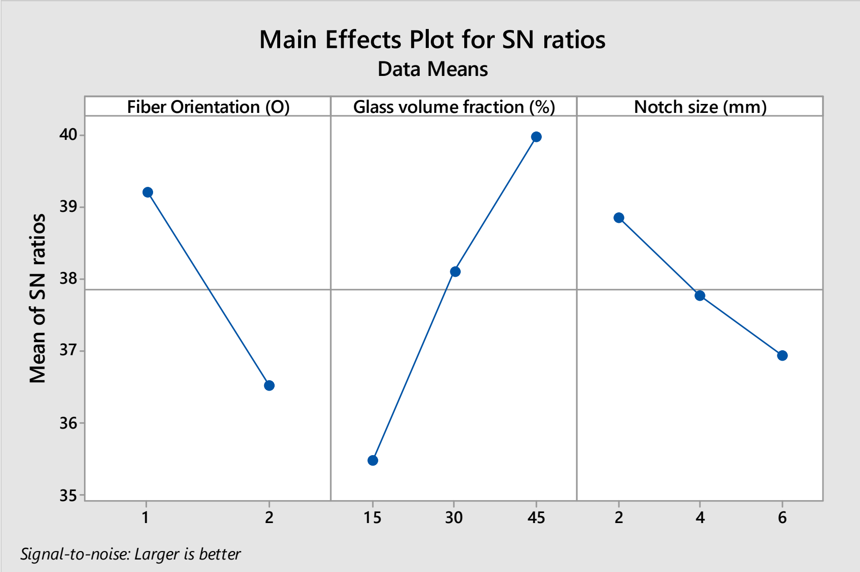

The tensile strengths of specimens with fiber direction (0°/90°) were higher than those with off fiber direction (±45°) because the fiber reinforcement has more load carrying capacity along its axis. It is observed that when jute fiber is replaced with strong glass fiber, as glass volume fraction increases from 15% to 45%, tensile strength increases. A crack or defect in a structure reduces its strength and as notch size increases from 2mm to 6mm, tensile strength decreases.

VI. Analysis of Variance

The result of analysis of variance (ANOVA) for tensile strength is shown in Table 5. ANOVA is also used to determine each input parameter's percentage contribution. This helps to find out the parameter that contributes most among all the sources that are responsible for the response variation. It should be noted from table 5 that fiber orientation has greater influence on tensile strength (51.93%), followed by glass volume fraction (31.26%), and they were major dominant factors. Notch size had contribution of 9.27% on tensile strength, which is less dominant factor. The error of 7.54% is well within the limit.

Table 5: ANNOVA of Tensile Strength Estimation

Source	DF	Adj SS	Adj MS	F-Value	% Contribution
Fiber Orientation (O)	1	3167.6	3167.58	49.71	31.26
Glass volume fraction (%)	2	5261.3	2630..65	41.28	51.93
Notch Size (mm)	2	937.8	468.91	7.36	9.27
Error	12	764.7	63.72		7.54
Total	17	10131.4			100

VII. Regression Analysis and Confirmation Test

Based on the experimental outcomes, a regression model was created, which creates a correlation between the important parameters. The regression equation for tensile strength is as follows:

Tensile Strength (MPa) =

96.95 - 26.53 Fiber Orientation (O) + 1.395 Glass volume fraction (%) -4.41 Notch size (mm)

It was noted from the above equation that the Fiber Orientation and Notch size coefficients were negative. This reveals that the tensile strength of composites decreases as fiber orientation changes from 0°/90° to ±45° and notch size increases from 2mm to 6mm. The coefficient associated with the glass volume fraction of the reinforcement was positive. This indicates that the tensile strength increases as glass volume fraction increase from 15% to 45%. Confirmation experiment was performed to validate the findings gained from the study and a comparison was made between the experimental values and the predicted values created from the regression model. The confirmation experiment and its outcomes are presented in Table 6. Based on the confirmation experiment, it is observed that the error with experimental values and calculated values was minimal (3.8% for 0°/90°). The regression model thus acquired from the L18 array can be efficiently used to predict the tensile strength of notched jute/glass natural hybrid composites with excellent precision.

TABLE 6: Results for Confirmation Experiment

Sl NO	Fiber Orientation (O)	Glass volume fraction (%)	Notch size (mm)	Experimental Tensile Strength (MPa)	Regression Tensile Strength (MPa)	Error in %
1	0°/90°	45	2	129.08	124.39	3.77

VIII. CONCLUSION

Hybrid Polymer Composites specimens have been fabricated by Hand Layup method with Jute/Glass fiber mats as reinforcements and Epoxy resin as matrix. Experiments were performed on the basis of Taguchi's technique and it was noted that Glass volume fraction (51.93%) had the greatest contribution towards the tensile strength prediction followed by Fiber Orientation (31.26%) and Notch size (9.27%). From the S/N ratio plot, it was found that 45% Glass Volume fraction and 2mm Notch size provides maximum Tensile Strength for specimens with 0°/90° fiber orientation. An equation of regression was developed to predict the Tensile Strength for the current model. To validate the theoretical values, confirmation test was conducted and the results are matched with minimal error of 3.77%. Thus, Taguchi's technique was efficiently used to forecast the Tensile Strength of Jute Hybrid composites.

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