Statistical Analysis on the Influence of Stack Thickness on the Tensile Property of Glass Fiber-Reinforced Polymer Laminates

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ABSTRACT
This work investigates the tensile testing of glass fibre-reinforced polymer (GFRP) composite material and its most influencing parameter. The GFRP constitutes bi-axial glass-fibre and epoxy-matrix. The three parameters considered for the tensile test are the load, elongation, thickness, and the experiment’s factorial design is L9 orthogonal array. The percentage contribution of load, extension, and thickness for stress and strain is calculated using variance (ANOVA) analysis. Optimizing parameters are made using response surface method (RSM). Since the solutions arrived at by this optimization process are promising, the optimized outcomes are high load, low elongation, and high thickness. Such works are beneficial for replacing concrete slabs constructed on the roads for rainwater harvesting. In such applications, non-crimp GFR panels with openings at regular intervals may replace concrete slab structures. A mathematical response surface model for the stress and strain parameters has been formulated. The model validation is done using the Pearson product-moment coefficient.

KEYWORDS
Fiber Reinforced, GFRP, Polymer Composite, Response Surface Methodology, Tensile Test

1. INTRODUCTION
Composites are a class of materials with the inherent and unique property of high strength to weight ratio. These materials are very light in weight with high stiffness and suitable corrosive property. Libonati and Vergani (2013) studied the non-crimp fabric with ±45º fibre orientation with ten laminate layers. Fabric density was 600 gsm. The predicted tensile strength was 142±3 MPa. The thermographic analysis showed the temperature impacts much during the tensile test. Composite’s fatigue behavior by identifying damage initiation stress was studied using thermographic technique (Colombo et al., 2012). Colombo and Vergani (2014) showed delamination decreased composite’s residual fatigue. Kuram et al. (2013) investigated the recycling number and injection parameters of glass fibre-reinforced nylon by Taguchi method. A carbon fibre-reinforced plastic waste to determine mechanical strengths with the failed specimen’s fracture morphology (Srinivasa et al., 2010). Mhalla et al. (2017) used response surface methodology (RSM) on tensile tests with 27 trials. The significant factors affecting the
composite’s tensile strength were fibre content and temperature. Makki et al. (2018) studied fibre content, stress loading and fibre angle as input factors. The output response stress concentration of carbon fibre-reinforced epoxy was analyzed using RSM-based mathematical model. It is helpful for material designers.

Penjumras et al. (2015) utilized RSM to optimize preparatory conditions of bio composites and developed a polynomial model. The optimum preparatory conditions were 165°C, 35 wt% cellulose loading, and 15min of mixing, which yielded a strength of 46.207MPa and 2.931 kJ/m², respectively. Talabari and Alaei (2019) investigated the vacuum infusion process parameters using RSM. The major factors considered for the process were viscosity, glass fabric weight, and fabric angle. The reinforcement angle was with high impact on mechanical properties; it decreased glass fiber-reinforced polymer (GFRP) strength/modulus.

Mhalla et al. (2018) predicted that GFR polyamide’s tensile strength through a probabilistic approach. They also proposed a model for determining the GFRP’s reliable strength. The authors concluded that with this empirical relationship, the damage threshold could be studied. Mirmohseni and Zavareh (2011) applied an RSM to optimize the impact strength of nanocomposite (epoxy/ABS/Clay/TiO₂). They showed the addition of particulate and layered nanofillers improved the impact strength. Rostamiyan et al. (2015) studied the nano-silica, nano clay, and fibres’ orientation on the tensile property and Izod impact strength of hybrid nanocomposite using RSM to optimize mechanical properties.

Priya and Vinayagam (2018a) investigated bi-axial glass fibre composites with nanoparticles (graphene platelet nanopowder). Different automated tests were carried out, such as tensile, compression, flexural, and high-velocity impact. The graphene platelet nanopowder samples had a better mechanical property than a parent sample. Priya and Vinayagam (2018b) investigated the drilling parameters on modified GFRP samples. The input factors were S (speed), F (feed), thickness and tool materials. The output responses were surface roughness (Ra), delamination, and the holes’ circularity. The RSM and Grey Relational Analysis results were compared, and they found that both the techniques yielded the same results. Shankar et al. (2018) developed a mathematical model for surface characteristics using RSM. John and Vinayagam (2011) studied a roller burnishing process to investigate surface characteristics, made an empirical model for surface roughness and hardness and validated using Pearson product-moment coefficient (PPMC).

Several researchers studied the stress-strain responses, transverse cracking, multiscale damage evolution and machining processes of GFRP (Ou et al., 2016; Guillamet et al., 2014; Montesano et al.,2015; Rao et al., 2019). He et al. (2020) studied the mechanical behavior of hybrid carbon/polyimide fibre composites. The authors investigated the tensile, compressive, and flexural modes of composite failures. The polyimide fibre had a remarkable improvement in failure strain and energy, while carbon fibre had improved tensile, compressive, and flexural properties. Wan Ramli et al. (2020) studied Napier fibre-reinforced composites’ tensile and flexural properties with and without alkali treatment. The epoxy used was modified with nano clay in different wt % such as 3, 5 & 10. The treated-NFR with modified epoxy (5 wt.% nano clay) had better tensile and flexural properties. The scanning electron microscope (SEM) images indicated an excellent adhesion between the reinforcement and the epoxy resin. Fontes et al. (2019) investigated the composite’s strength for loading (tensile, compressive), stacking sequence, and orientation of fibres in the loading direction. The samples aligned to ±45º had a decrease in their mechanical properties. However, composite behaves differently due to the reinforcement and matrix.

Haque et al. (2021) predicted and optimized the properties of cement concrete blended with rice husk ash and glass fibre using RSM. Experimentally, five responses were validated with the proportion of glass fibre (0.08%) and rice husk ash (16.05%). Both the methods yielded better results. Ragunath et al. (2021) optimized the mechanical properties, such as impact, the tensile and flexural strength of glass fibre – sisal hybrid composites. RSM was adopted to find the most significant factor. The analysis yielded sisal fibre to be the prominent factor. Palanikumar (2008) studied the machining characteristics of GFR plastics by applying Taguchi’s DOE. RSM was used to formulate the empirical relationship between the cutting parameters and the composite’s Ra (Surface roughness). Also, experimental values.
were validated with the predicted values of the composite. Kunnan Singh et al. (2018) investigated the strength, hardness, toughness, and stiffness of GF/POM/PTFE composites. The mechanical properties of the composites were optimized using RSM. The variables considered were PTFE with different wt% and etch times. The desirability index achieved was 87.5%, with PTFE etch time as 10 min and PTFE content as 6.5%, respectively. RSM is a statistical technique that involves mathematical relations used for building an empirical model. The experiment design is made carefully to optimize outputs (responses), influenced by input factors. An experiment with ‘n’ number of trials has been conducted by changing input factors to identify the output performance characteristic features. The statistical technique is not much applied to the GFRP composite material’s tensile test as per literature. Using statistical methods is essential to reduce the cost of experiments. Hence, the statistical approach is utilized to study the performances of the composite under tensile behavior.

From the literature, very few research works have been reported with the selected GFRP material, and the methodology adopted for manufacturing the composite was the hand layup technique. Bi-diagonal (bi-axial) glass fabric is used in the present work, and the laminates are prepared by vacuum-assisted resin transfer moulding, which is also a closed moulding technique. This material is tested for its tensile behavior incorporating the T-rosette strain-gauge to measure its change in resistance value in terms of strain. Then the mechanical properties are validated using RSM and an empirical relationship is developed combining the various input factors. Finally, PPMC is calculated for the composite.

2 EXPERIMENTATION

This study used a bi-axial glass cloth of 600 gsm (Easy Composites, UK) material for testing. Bi-axial non-crimp GFR with epoxy laminates is prepared using a vacuum-assisted resin transfer moulding method. Laminates were prepared by reinforcing fibres with epoxy resin (LY556) and hardener (HY951) in the ratio of 10:1 by weight. Initially, laminates were prepared to a size of (300mm x 300mm) for different thicknesses (2, 3 and 4mm) by varying the sequences such as [(±45)_{2s}], [(±45)_{3s}] and [(±45)_{4s}]. As per ASTM D 3518 (2007) standards, specimens are cut to a dimension of (250mm x 25mm) using an abrasive water jet cutting machine. Each test is performed on three samples.
The tensile test was performed on a WDW-50 (of capacity 50kN) computerized universal testing machine as per the factorial design of L₉ orthogonal array (Table 1). The accuracy grade of the universal tensile machine is 0.5. Each measurement is measured thrice, and the average is considered. The range between repeated readings is within 1%. Hence, the repeatability of the reading is 1%. Figure 1 shows the experimental setup along with the Max test software.

A T-rosette strain-gauge (Tokyo Sokki Kenkyujo Co. Ltd) was used to measure the strain. It is fixed on the specimen as per the manufacturer's instructions. Table 2 shows its specifications. Strain-gauges are connected to a 5-channel indicator and then to the data acquisition system (DAQ) NI 9222. The data acquisition device relates to the Lab-view software, where the longitudinal and transverse strains are indicated in volts. Fig 2 shows the attachment of the T-rosette strain-gauge to the specimen. The output voltage turned into apparent longitudinal strain (εₓ) and apparent transverse strain (εᵧ) using conversion factors. The formula used for calculations of corrected longitudinal strain and corrected transverse strain is given in Eqs. (1) – (2).

\[
\varepsilon_x = \frac{1 - \vartheta_0}{1 - k_t^2} \left( \varepsilon^1_x - k_x \varepsilon^1_y \right)
\]

(1)

\[
\varepsilon_y = \frac{1 - \vartheta_0}{1 - k_t^2} \left( \varepsilon^1_y - k_y \varepsilon^1_x \right)
\]

(2)

where, \(\varepsilon^1_x\) – Apparent longitudinal strain, \(\varepsilon^1_y\) – Apparent transverse strain, \(k_x\) – Transverse sensitivity factor, \(\vartheta_0\) - Poisson’s ratio.

<table>
<thead>
<tr>
<th>Exp.No</th>
<th>Load (kN)</th>
<th>Elongation (mm)</th>
<th>Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td>2</td>
<td>-1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>-1</td>
<td>1</td>
<td>1</td>
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<tr>
<td>4</td>
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<td>5</td>
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<tr>
<td>6</td>
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<td>7</td>
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<td>-1</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>1</td>
<td>0</td>
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</table>

Table 2. Specification of strain-gauge

<table>
<thead>
<tr>
<th>Specification</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gauge Factor</td>
<td>2.13</td>
</tr>
<tr>
<td>Gauge Resistance</td>
<td>120Ω</td>
</tr>
<tr>
<td>Transverse sensitivity</td>
<td>X=1.2%, Y=0.7%</td>
</tr>
<tr>
<td>Gauge length</td>
<td>2 mm</td>
</tr>
</tbody>
</table>
3. METHODOLOGY

3.1 Selection Of Process Parameters

This work’s main objective is to optimize three tensile test parameters of the non-crimp GFRP composite. The factors that have been considered for this parametric study are elongation, load, and thickness of the sample. Applying Taguchi’s design for three factors with three levels, L₉ orthogonal array has been selected. The range of each factor is coded in three different levels: (-1,0,1) using transformation equations Eqs. (3) – (5) for the input factors,

\[
\text{Load (kN)} = \frac{\text{Load (X₁)} - 5.5}{3} \quad (3) \\
\text{Elongation (mm)} = \frac{\text{Elongation (X₂)} - 4.07}{3.14} \quad (4) \\
\text{Thickness (mm)} = \frac{\text{Thickness (X₃)} - 3}{1} \quad (5)
\]

Table 3 shows the factors and corresponding level. Priya and Vinayagam (2021) studied the GFRP composites’ damages using the non-destructive technique (ultrasonic C-scan) and optical metrology. The methodology used for ultrasonic C-scan is of immersion pulse-echo method. In optical metrology, a He-Ne laser source is used to study the various failures in the composite samples. In both the techniques, the damages are compared with the parent samples. In the ultrasonic C-scan method, the damages are represented by amplitude signals and in optical metrology with different colour codes. Thus various damage-prone areas are identified, such as resin-rich areas, matrix cracking, fibre fracture, and delamination.

Table 3. Coded levels of tensile test

<table>
<thead>
<tr>
<th>Coded levels</th>
<th>-1</th>
<th>0</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load(kN)</td>
<td>2.5</td>
<td>5.5</td>
<td>8.5</td>
</tr>
<tr>
<td>Elongation(mm)</td>
<td>0.93</td>
<td>4.07</td>
<td>7.22</td>
</tr>
<tr>
<td>Thickness(mm)</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>
3.2. ANOVA Analysis

From Tables 4 and 5, the percentage contribution of the load is 91.55%, elongation is 8.18%, and the thickness is 0.05% for stress. While the load percentage is 72.6%, elongation is 23.53%, and thickness is 3.65% for strain. Table 4 shows the factors load, elongation, and thickness have significantly influenced responses (stress/strain). P-value preferred is < 0.05 (95% confidence-level). Therefore, the most prominent factor for the stress and strain of composite material is the load, followed by elongation and thickness. However, the P-value of thickness in Tables 4 and 5 is 0.830 and 0.057, slightly higher than P-value of 0.05. The thickness in the samples does not impact much in the tensile test of composite. A high R² value (99.77%) assures the reliability and accuracy of the experimental data.

Table 4. ANOVA for stress (Larger is better)

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Seq SS</th>
<th>Contribution</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load (kN)</td>
<td>2</td>
<td>5438.19</td>
<td>91.55%</td>
<td>5438.19</td>
<td>2719.10</td>
<td>403.42</td>
<td>0.002</td>
</tr>
<tr>
<td>Elongation (mm)</td>
<td>2</td>
<td>485.65</td>
<td>8.18%</td>
<td>485.65</td>
<td>242.82</td>
<td>36.03</td>
<td>0.027</td>
</tr>
<tr>
<td>Thickness (mm)</td>
<td>2</td>
<td>2.77</td>
<td>0.05%</td>
<td>2.77</td>
<td>1.38</td>
<td>0.21</td>
<td>0.830</td>
</tr>
<tr>
<td>Error</td>
<td>2</td>
<td>13.48</td>
<td>0.23%</td>
<td>13.48</td>
<td>6.74</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>8</td>
<td>5940.08</td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model</td>
<td>S</td>
<td>R-sq</td>
<td>R-sq(adj)</td>
<td>PRESS</td>
<td>R-sq(pred)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summary</td>
<td>2.59616</td>
<td>99.77%</td>
<td>99.09%</td>
<td>272.972</td>
<td>95.40%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5. ANOVA for strain (Smaller is better)

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Seq SS</th>
<th>Contribution</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load (kN)</td>
<td>2</td>
<td>142.838</td>
<td>72.60%</td>
<td>142.838</td>
<td>71.4191</td>
<td>330.90</td>
<td>0.003</td>
</tr>
<tr>
<td>Elongation (mm)</td>
<td>2</td>
<td>46.304</td>
<td>23.53%</td>
<td>46.304</td>
<td>23.1519</td>
<td>107.27</td>
<td>0.009</td>
</tr>
<tr>
<td>Thickness (mm)</td>
<td>2</td>
<td>7.179</td>
<td>3.65%</td>
<td>7.179</td>
<td>3.5895</td>
<td>16.63</td>
<td>0.057</td>
</tr>
<tr>
<td>Error</td>
<td>2</td>
<td>0.432</td>
<td>0.22%</td>
<td>0.432</td>
<td>0.2158</td>
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<tr>
<td>Total</td>
<td>8</td>
<td>196.753</td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Model</td>
<td>S</td>
<td>R-sq</td>
<td>R-sq(adj)</td>
<td>PRESS</td>
<td>R-sq(pred)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summary</td>
<td>0.464575</td>
<td>99.78%</td>
<td>99.12%</td>
<td>8.74113</td>
<td>95.56%</td>
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<td></td>
</tr>
</tbody>
</table>

4. RESULTS AND DISCUSSION

4.1 The Main Effects Plot for Signal To Noise (Sn) Ratio Of Stress

Figure 3 shows the main effect of the stress S/N. The formula used to calculate the SN ratio is as follows, considering higher the better condition for stress:

\[
\frac{S}{N} \text{ ratio} = -10 \log_{10} \left( \frac{1}{n} \sum_{i=1}^{n} \frac{1}{y_i^2} \right)
\]  (6)
Where \( y_i \) = observed response value and \( n \) = no. of replications.

The load is much more than elongation and thickness. The stress varies significantly due to a small-load change. The contribution of the load is 91.55%, the elongation is 8.18%, and thickness has 0.05%. The stress data points lie close to a better fit line (mean line) on the normal plot (Fig. 4). The data are reliable and standard. A slight deviation from normality can be neglected. It is also observed that the residues form a straight line, which implies that the errors are normally distributed. Fits and order plots also reveal no evidence of any unusual structure present in the data.
4.2 Contour And Surface Plots Of Stress

Figure 5(a-c) shows the contour plots and Fig 6 (a-c) shows the surface plots for the effect of thickness, elongation, and load on the stress distribution. Referring to these figures, how the range of input parameters affects the output parameters can be studied. From these figures, the user will identify load, thickness, elongation for a stress distribution required.

Figure 5. Contour plot: (a) Stress vs. elongation and load, (b) Stress vs. thickness and load, and (c) Stress vs. thickness and elongation

4.3 The Main Effect Plot For S/N Ratio of Strain

Figure 7 shows the main effect for the strain S/N. The formula used to calculate SN ratio is as follows considering Smaller the better condition for strain:

\[
\frac{S}{N} \text{ ratio} \left( \cdot \right) = -10 \log_{10} \left( \frac{1}{n} \sum_{i=1}^{n} y_i^2 \right)
\]  

(7)

where \( y_i \) = observed response value and \( n \) = no. of replications.

Figure 6. Surface plots: (a) Stress vs. elongation and load, (b) Stress vs. thickness and load, (c) Stress vs. thickness and elongation

Figure 7. Main effects plot for S/N ratio (Strain)
The plot infers the load is much more than elongation and thickness. The strain varies significantly for slight load change. The load effect on the response of 72.6% than elongation (23.53%) and thickness (3.65%), respectively. Figure 8 shows the residual plots for strain. The typical probability plot shows the strain values are close to a better fit. It is reliable and standard, and there is a small deviation from normality, which can be neglected. From the fits/order plots, there is no unusual data or pattern in the collected data.

4.4 Contour and Surface Plots of Strain

Figure 9(a-c) shows the contour plots and Fig 10 (a-c) shows the surface plots for the effect of thickness, elongation, and load on the strain distribution. The user can identify these plots’ required strain distribution for a given load, elongation, and thickness.

4.5 Response Optimization

The three parameters are optimized with an objective function where the stress is maximized and strain is minimized. The constraints for the objective functions are given in Eqs. (8) – (10)

6.24 <= Stress => 85

0.055 <= Strain => 14.45

where Stress, strain =>0

With the response surface optimization module of MiniTab software, the coded parameters are optimized. The optimized value of the tensile test is found to be: load=7.8268kN, elongation
Figure 9. Contour plot: (a) Strain vs. thickness and elongation, (b) Strain vs. elongation and load, (c) strain vs. thickness and load

Figure 10. Surface plots: (a) Strain vs. elongation and thickness, (b) Strain vs. elongation and load, (c) Strain vs. thickness and load
= 0.930mm, thickness = 4mm. Fig 11 shows the optimized plot of the tensile test parameters. The optimization of the stress and strain values are 59.43 kN/mm² and 5.835, respectively. Adjustment of the vertical red chain line shows variation in the output. The experiment has been conducted for the optimized values of RSM and the corresponding values are stress = 61.5 kN/mm² and strain = 6.82.

Using RSM, the most optimized parameter for the composite is 4mm thick, 0.93mm elongation and 7.8268 kN load with composite desirability of 63.58%. The optimality test has been carried out between the minimum and the maximum limiting values of the study’s three parameters. Under these conditions, the optimal desirability attainable is only 50%. But for this study, the achievable desirability has been found as 63.58%, which is more than a predicted value. It is about 14% more composite desirability. Therefore, the optimized parameters are very accurate and precise for this composite. Therefore these optimized parameters works out to be the best parameter for replacing concrete slabs constructed on the roads for rainwater harvesting. In such applications, non-crimp glass fibre composite panels with openings at regular intervals may replace concrete slab structures.

The stress and strain are modeled for the input parameters of load(X₁), elongation(X₂), and thickness(X₃) using RSM. The general governing equation for stress and strain is given in Eq. (11)

\[ Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{11} X_1^2 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{21} X_1 X_2 + \beta_{22} X_2 X_3 + \beta_{23} X_2 X_3 \]

where,

\[ \beta_0 \] Constant of RSM
\[ \beta_1, \beta_2, \beta_3 \] Coefficient of linear variables X₁, X₂, and X₃ respectively
\[ \beta_{11}, \beta_{12}, \beta_{13} \] Coefficient of squares of linear variables X₁, X₂, and X₃ respectively
\[ \beta_{21}, \beta_{22}, \beta_{23} \] Coefficient of interaction of linear variables X₁, X₂, and X₃ respectively

Figure 11. Optimization plot of tensile parameters
From experimental values, the regression equation coefficients and ANOVA of stress and strain are calculated using MiniTab software

\[
\text{Stress (kN/mm}^2\text{)} = -16.01 + 9.394X_1 - 0.5138X_2 - 2.428X_3 + 0.1674X_1^2 + 0.1256X_2^2 + 1.480X_3^2 + 0.2927X_1X_2 - 0.7988X_1X_3
\]  
\] (12)

\[
\text{Strain} = -1.980 + 0.8109X_1 - 0.4000X_2 + 0.3359X_3 + 0.03961X_1^2 + 0.1373X_2^2 - 0.2894X_3^2 + 0.02945X_1X_2 + 0.08612X_1X_3
\]  
\] (13)

PPMC used for validation of the predicted responses of Eq. (12) and Eq. (13) (Shankar et al., 2008; John and Vinayagam, 2011). The Pearson-coefficient is given in Eq. (14),

\[
\text{PPMC} = 3(\text{mean-median)/Standard deviation}
\]  
\] (14)

The PPMC values are 0.9434 and 0.999 for the stress and strain, respectively. Table 6 shows the experimental values, and the predicted values are close to each other. Therefore, the error and correlation coefficient percentage indicates that the RSM predicts accurately and precisely. The RSM and the experimental data are shown in Figures 12 and 13. Fig.14 all illustrates the SEM image of the healthy sample and Fig.14b illustrates the fractured surface, which is spiky shaped, and it also represents that such a failure has occurred due to brittle matrix cracking. The reinforcement fibres are highly resistant and take the loading capacity of the composite. The fibre/resin weight ratio of the composite is 75:25. Due to this proportion, the structural reinforcement behavior plays a significant role in load-bearing capability. Since the matrix is brittle, the crack gets initiated and propagates, yielding fibre breaking and delamination in the composite. The various damages are shown in the SEM image (Fig 14c) of the fractured sample. Also, the energy dispersion spectrum of the fractured sample is shown in Fig 14 (d). Therefore as the stacking thickness increases, the contribution of reinforcement increases which helps to withstand higher loads. Thus, the stacking thickness plays a major role in the composite laminates. Finally, the composite fractures into two halves with the fibre pull out that are visible. A large amount of matrix cracking is attributed to the epoxy resin’s brittleness and then

<table>
<thead>
<tr>
<th>S.No</th>
<th>Experimental Condition</th>
<th>Experimental reading</th>
<th>Calculated using RSM Stress</th>
<th>Calculated using RSM Strain</th>
<th>SNR (Stress)</th>
<th>SNR (Strain)</th>
<th>% of error</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Load</td>
<td>Elongation</td>
<td>Thickness</td>
<td>Stress</td>
<td>Strain</td>
<td>Stress</td>
<td>Strain</td>
</tr>
<tr>
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fibre breakage. Fibres improve load-bearing capacity and after withstanding the ultimate load in the tensile test, the specimen starts to fail with crack and propagation.

The optimized results are about the stress and strain considerations. The desirability index of 63.58% is obtained under a load of 7.82 kN, elongation of 0.93 mm and thickness of 4 mm. When the volume fraction of the reinforcement is higher, the load-bearing capacity will be higher because the fibres act as the load-carrying members. Therefore, the thickness of the composite automatically reaches a higher state. Due to this, the elongation happens minimally because these fibre reinforcements are highly denser in the state. The load plays a significant role, and the composite thickness has to be decided based on the loading conditions. Also, the density of the fabric is important because the reinforcement fibres take the load-bearing capacity of the composite. Therefore, if the density of the fabric is higher, then the load-bearing capacity is higher. Thus, it is witnessed from the experimentation and the optimized results.

Figure 12. Comparison of RSM and Experimental values of stress

Figure 13. Comparison of RSM and Experimental values of strain
5. CONCLUSIONS

This experimental study on GFRP composite material under the tensile test is conducted, and its most influencing parameter is determined. Three parameters considered for the tensile test are the load, elongation, and thickness using L9 orthogonal array. This work optimizes the tensile test parameters using the RSM, and the following are the key findings.

- Under tensile tests, the composite’s optimized parameter is 7.8268 kN load, 0.93 mm elongation, and 4 mm thickness. The load’s contribution is 91.55%, 8.18% elongation, and 0.05% thickness to the composite’s stress from the ANOVA analysis. The most influencing parameter of stress is the applied load.
- Similarly, ANOVA analysis of strain also depicts that load is a vital parameter. Each parameter’s contributing to the composite’s strain is 72.6% of load, 23.53% of elongation, and 3.65% of the thickness. Therefore, when comparing the contribution of each parameter, load plays a significant role in stress and strain. A margin of 15% contribution factor of elongation to the composite strain compared to the same material’s stress.
- While measuring the composite’s strain, the load is, and the composite’s elongation plays a significant contribution. The response surface model has been formulated for stress.
Thus, a new study has been made in the tensile test study using a statistical technique such as RSM. The optimized results have been validated using the Pearson correlation coefficient. Therefore, these non-crimp glass fibre composite panels are adequate replacements for concrete slab structures constructed for rainwater harvesting roads and load-bearing applications. The lightweight of the prepared slabs improves the handling easiness.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

**Infanta Mary Priya:** Conceptualization, Methodology, Investigation, Visualization, Writing - original draft.

**Ramalingam Senthil:** Data validation and curation, Writing - review & editing.

**K. Palanikumar:** Supervision, correction, Editing and Finalizing.

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DECLARATION OF COMPETING INTEREST

The authors declare that there are no competing interests.

DATA AVAILABILITY

The raw/processed data required to reproduce these findings cannot be shared at this time as the data also forms part of an ongoing study.

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REFERENCES


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