OPTIMIZATION OF TENSILE PROCESS PARAMETERS OF BI-AXIAL GLASS FIBRE REINFORCED EPOXYCOMPOSITE USING TAGUCHI METHOD

I Infanta Mary Priya\textsuperscript{1} and B K Vinayagam\textsuperscript{2}

\textsuperscript{1}Asst Professor, Mechanical Department, SRM University
\textsuperscript{2}Professor, Mechatronics Department, SRM University

E-mail: infanta.i@ktr.srmuniv.ac.in

Abstract: The aim of this work is to optimize the parameters namely load, elongation and thickness in tensile test of glass fibre reinforced polymer (GFRP) composites. In the present work, experiments were carried out as per the Taguchi experimental design and an L9 orthogonal array was used to study the influence of various combinations of parameters on stress and strain factors of the composite using MINITAB 17. Analysis of variance (ANOVA) test was conducted to determine the significance of each parameter on stress and strain value of the composite. The results indicate that load is the most significant factor influencing the stress, and also it is the most significant factor inducing the strain of the composite. This work is useful in selecting the optimum values of various parameters that would, not only maximize the stress in the composite but also reduces the strain to a minimum level and improve the strength of the composite by acquiring a higher load bearing capacity.

Key Words: Glass Fibre Reinforced Polymer (GFRP), L9 orthogonal array, analysis of variance (ANOVA), stress, strain.

1. Introduction

Composite materials are widely used in many fields of automobiles and aerospace industries due to their high strength to weight ratio, lightweight, high stiffness, corrosive property and low thermal expansion, etc. Most of the literature [1-3] reported on Taguchi experimental design and an L9 orthogonal array was used to study the influence of various parameters. According to Taguchi method, engineering optimization of a process must be carried out in three different stages: system, parameter and tolerance design [4]. Also Taguchi method uses orthogonal arrays to study a large number of variables with a minimum number of experiments by using design of experiments theory. Therefore orthogonal arrays reduce the experimental configurations in number that is to be studied. The conclusions drawn by these small number of experiments are within the entire experimental region by the usage of control factors and the settings[5]. Taguchi modified the usage and provided standard orthogonal arrays in tabulated sets with the corresponding linear graphs to fit specific conditions of the project[6].
In this work, process parameters are optimized in the tensile test of GFRP composites using Taguchi design of experimental technique and the results are analysed using ANOVA technique to know the percentage contribution of each parameter on stress and strain of the composite. In this present work, statistical analysis software MINITAB 17 is used for the design and analysis of experiments to perform the Taguchi and ANOVA analysis and also to establish regression models.

2. Methodology

2.1. Taguchi Design of Experiment

Taguchi design of experiment consists of orthogonal arrays to study all the parameters of the project with a minimum number of experiments only. Then the results of the experiments are transformed into a signal-to-noise (S/N) ratio. It considers the S/N ratio to be a measure of quality characteristics that are deviating from or nearing to the required values. There are three different stages of quality characteristics in the analysis of the S/N ratio, i.e. the lower the better, the higher the better, and the nominal the better. The formula used for calculating S/N ratio is given below.

Smaller the better: It is used where the smaller value is required.

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

Where \( y_i \) = observed response value and \( n \) = number of replications.

Nominal the best: It is used where the nominal or target value and variation about that value is minimum.

\[
\frac{S}{N} \, ratio(\eta) = -10 \log_{10} \left( \frac{\mu^2}{\sigma^2} \right)
\]

Where \( \mu \) = mean and \( \sigma \) = variance.

Higher the better: It is used where the larger value is required.

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

Where \( y_i \) = observed response value and \( n \) = number of replications.

2.2 Selection of process parameters

In this study, tensile test parameters like load, elongation and thickness of the specimen were considered. According to the Taguchi’s design of experiments for three parameters and three levels L9 Taguchi orthogonal array was selected. The number of factors and their corresponding levels are shown in table 1.

| Code | Variable | Level1 | Level2 | Level3 |
|------|----------|--------|--------|--------|

Table 1 – Selected variable levels for the tensile test of GFRP
2.3. ANOVA Analysis

The ANOVA technique identifies the important parameters and calculates the influence of percentage of each parameter on different quality characteristics. The S/N ratios are calculated for the stress and strain responses and it is represented in table 2 and table 3 respectively.

**Table 2 – Response table for S/N ratios for stress**

| Level | Load(KN) | Elongation(mm) | Thickness(mm) |
|-------|----------|----------------|---------------|
| 1     | 21.98    | 27.18          | 28.63         |
| 2     | 32.66    | 31.37          | 31.00         |
| 3     | 37.45    | 33.54          | 32.46         |
| Delta | 15.47    | 6.36           | 3.84          |
| Rank  | 1        | 2              | 3             |

**Analysis of Variance**

| Source            | DF | Adj SS  | Adj MS  | F-Value | P-Value |
|-------------------|----|---------|---------|---------|---------|
| Load(KN)          | 2  | 5379.23 | 2689.62 | 884.73  | 0.001   |
| Elongation(mm)    | 2  | 505.01  | 252.50  | 83.06   | 0.012   |
| Thickness(mm)     | 2  | 5.35    | 2.68    | 0.88    | 0.532   |
| Error             | 2  | 6.08    | 3.04    |         |         |
| Total             | 8  | 5895.67 |         |         |         |

**Model Summary**

| S  | R-sq  | R-sq(adj) | R-sq(pred) |
|----|-------|-----------|------------|
| 1.74357 | 99.90% | 99.59%   | 97.91%     |

**Table 3 – Response table for S/N ratios for strain**

| Level | Load(KN) | Elongation(mm) | Thickness(mm) |
|-------|----------|----------------|---------------|
| 1     | 9.1382   | -0.9389        | -4.9295       |
| 2     | -13.7873 | -6.9035        | -7.6916       |
| 3     | -20.3110 | -17.1177       | -12.3390      |
| Delta | 29.4492  | 16.1788        | 7.4095        |
| Rank  | 1        | 2              | 3             |

**Analysis of Variance**

| Source            | DF | Adj SS  | Adj MS  | F-Value | P-Value |
|-------------------|----|---------|---------|---------|---------|
| Load(KN)          | 2  | 142.838 | 71.4191 | 330.90  | 0.003   |
| Elongation(mm)    | 2  | 46.304  | 23.1519 | 107.27  | 0.009   |
| Thickness(mm)     | 2  | 7.179   | 3.5895  | 16.63   | 0.057   |
| Error             | 2  | 0.432   | 0.2158  |         |         |
| Total             | 8  | 196.753 |         |         |         |
Model Summary

| S   | R-sq | R-sq(adj) | R-sq(pred) |
|-----|------|-----------|------------|
| 0.464575 | 99.78% | 99.12%    | 95.56%     |

2.4. Experimentation

In this work, bi-axial glass fibre reinforced plastic composite laminate specimens with 50% fibre volume ratio were prepared with E-glass fibre using epoxy resin by vacuum infusion process. The specimen size of 250 x 25 x 2 mm was cut from a laminate using abrasive water jet cutting. The tensile test was carried out according to the ASTM D3518 standards. The experimental setup along with the software is shown in figure 1.

![Figure 1 - Experimental set up](image)

Tensile test was conducted according to Taguchi’s L9 orthogonal array as shown in table 4 on the bi-axial GFRP specimens.

Table 4 – Taguchi L9 orthogonal array

| Expt.No | Control factors and their levels |
|---------|----------------------------------|
|         | A | B | C |
| 1       | 1 | 1 | 1 |
| 2       | 1 | 2 | 2 |
| 3       | 1 | 3 | 3 |
| 4       | 2 | 1 | 2 |
| 5       | 2 | 2 | 3 |
| 6       | 2 | 3 | 1 |
| 7       | 3 | 1 | 3 |
| 8       | 3 | 2 | 1 |
| 9       | 3 | 3 | 2 |

3. Results and discussion
The experimental results for all the responses using the S/N ratio values are presented in table 2 and table 3. Similarly the main effect for the mean and S/N ratio is plotted in figure 2 and figure 3.

**Figure 2** – Main effects plot for S/N ratio (Stress)

From the figure 2 and the table 2, the most influencing parameters on the stress are obtained as A3, B3, C3. It is clearly understood from the response table for stress, that the maximum values are achieved at level 3 for all the three factors. Also from the figure 3 and table 3, the influencing parameter on the strain of the component are obtained as A1, B1, C1. It is very clear that for strain of the specimen, the minimum values are achieved at level 3 for load, elongation and thickness.

**Figure 3** – Main effects plot for S/N ratio (Strain)
After conducting ANOVA analysis, to verify the normality assumption of the residuals, residual plots were plotted. Figures 3 and 4 represent the normal probability plots of the residuals. From both the figures it is revealed that almost all the residuals follow a straight line pattern.

The regression equation for the stress and strain are given below:

Stress (KN/mm$^2$) = -22.26 + 9.976 Load (KN) + 2.648 Elongation (mm) + 0.84 Thickness (mm)

Strain = -2.27 + 1.5872 Load (KN) + 0.8031 Elongation (mm) - 1.157 Thickness (mm)

| Load(KN) | Elongation(mm) | Thickness(mm) | Stress(KN/mm$^2$) | Predicted stress(KN/mm$^2$) | %Error |
|----------|----------------|---------------|-------------------|----------------------------|--------|
| 2.5      | 0.839          | 2             | 6.24              | 6.581672                   | -5.475512821 |
| 2.5      | 2.573          | 3             | 13                | 12.013304                  | 7.589969231 |
| 2.5      | 7.226          | 4             | 25.22             | 25.174448                  | 0.180618557 |
| 5.5      | 0.839          | 3             | 35.04             | 37.349672                  | -6.59152968 |
| 5.5      | 2.573          | 4             | 45.12             | 42.781304                  | 5.183280142 |
| 5.5      | 7.226          | 2             | 50.06             | 53.422448                  | -6.716835797 |
| 8.5      | 0.839          | 4             | 65.02             | 68.117672                  | -4.764183328 |
| 8.5      | 2.573          | 2             | 75                | 71.029304                  | 5.294261333 |
4. Conclusion

This work presents optimizing the parameters namely the load, elongation and thickness of the specimens in the tensile test of glass fibre reinforced polymer composites using the Taguchi design of experiments and followed by ANOVA analysis. The following conclusions are drawn:

- Stress is maximum at load 8.5KN, elongation of 7.226mm and 3mm of thickness specimen
- Strain is minimum under 2.5KN load, elongation of 0.84mm and 2mm thickness specimen
- The percentage of error between the experimental stress value and the predicted stress is below 10%. It is also the same, while comparing the experimental strain and the predicted strain value from the table 5 and 6.
- From the main effect plot it is clear that the most influencing parameter of the tensile test is the load.
- ANOVA analysis reveals more than 95% confidence level for the responses.

References

[1] Manna A and Bhattacharyya B 2006 *Int J Mach MachMater* 14 488-99
[2] Abrao AM, Faria PE, Campos Rubio J C and Paulo Davim J 2007J Mater Process Technology 186 1–7
[3] Gopalsamy B, Mondal B and Ghosh S 2009 *J SciInd Res* 68 686–95
[4] Taguchi G 1986 *Introduction to quality engineering* Asian Productivity Organization Dearborn MI: Distributed by American Supplier Institute Inc
[5] Phadke S M 1989 *Quality engineering using robust design* Englewood Cliffs NJ: Prentice Hall
[6] ASI 1989 *Taguchi methods: implementation manual* Dearborn MI USA: American Supplier Institute Inc