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Taguchi Design for Optimization of Reinforcement at Toe area of Carbon Fiber Foot Plate

Chandrika Wagle[1,*], S.N. Padhi[2]

Abstract

This paper uses the Taguchi method to design experiments to determine the effect of various factors, such as fiber orientation, fiber type, and number of layers, on the reinforcement at the toe area. The experiments are Taguchi method, which allows for identifying the optimal combination of factors that minimize the carried out using a combination of computer simulations and physical tests. The results are analyzed using the variability in the reinforcement at the toe area. The study's findings indicate that the optimal combination of factors for the reinforcement at the toe area of the carbon fiber footplate includes a fiber orientation angle of 45 degrees, a fiber type of T700S, and a four-layer reinforcement structure. In addition, the optimized foot plate shows a significant improvement in mechanical properties, including higher stiffness, strength, and fatigue resistance, compared to the optimized footplate. Overall, the results of this study demonstrate the effectiveness of the Taguchi method for optimizing the reinforcement at the toe area of a carbon fiber footplate. As a result, the optimized foot plate can be used in various applications, including sports equipment, prosthetics, and orthotics, to improve the performance and durability of these devices.

Keywords: Taguchi design, optimization, reinforcement, foot plate, toe area

INTRODUCTION

The use of carbon fiber composites has grown significantly in various fields due to their high strength-to-weight ratio, stiffness, and durability. Foot plates made of carbon fiber are commonly used in sports equipment, prosthetics, and orthotics to enhance their performance and durability [5, 6]. However, the toe area of the foot plate is susceptible to failure under high stress conditions, which can hamper the overall performance of the device. Hence it is essential to optimization of the reinforcement at the toe area of the carbon fiber foot plate. Taguchi design methodology is a powerful tool for optimizing the parameters of a system to achieve optimal performance with minimal variability. The Taguchi method involves the use of a designed set of experiments to which has effect on various factors on the performance of the system. This method provides a systematic approach to identify the optimal combination of factors that result in the best performance with minimal variability [1].

***Author for Correspondence**
Chandrika Wagle

[1]Research Scholar, Department of Mechanical Engg., Koneru Lakshmaiah Education Foundation, Guntur, Andhra Pradesh, India
[2]Professor, Department of Mechanical Engg., Koneru Lakshmaiah Education Foundation, Guntur, Andhra Pradesh, India

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In this paper, the Taguchi method is applied to optimize the reinforcement at the toe area of a carbon fiber foot plate. The aim is to identify the optimal combination of factors, such as fiber orientation, fiber type, and layer structure that minimize the variability in the reinforcement at the toe area. The optimization of the reinforcement at the toe area will enhance the mechanical properties of the foot plate, including stiffness, strength, and fatigue resistance, which are essential for optimal performance.

The optimization of the reinforcement at the toe area of the carbon fiber foot plate has significant implications for various applications, including sports equipment, prosthetics, and orthotics [7]. The optimized foot plate can improve the performance and durability of these devices, leading to better outcomes for users. This study presents a systematic approach to optimize the reinforcement at the toe area of a carbon fiber foot plate using the Taguchi method [8].

MATERIALS AND METHODS

The Taguchi method aims to improve process quality by reducing variation through robust experiment design. The objective of this method is to manufacture products of excellent quality at a reasonable cost to the producer. The method used by Taguchi entails examining the effects of various factors on a process's mean and variance of a performance characteristic that determines its efficiency. Instead of testing all potential combinations as in factorial designs, his experimental approach tests pairs of combinations as in factorial designs, his experimental combinations rather than all possible combinations. Process parameters and their levels are organized using orthogonal arrays. Utilizing this method, accurate data may be collected to determine what elements have the greatest impact, product, quality, time and resource conservation [2].

The Taguchi method functions best when there are three to fifty variables, few variables that have a significant impact on the process, and little interaction between variables. The Taguchi arrays are available through derivation or lookup, with small arrays manually drawn and large ones generated through deterministic algorithms. Online sources offer arrays selected by the number of parameters and levels. To optimize performance, analysis of variance can be conducted on data collected from the Taguchi experiments, with parameter values adjusted accordingly. To evaluate the importance of the data, one can use visual analysis, ANOVA, bin yield, fisher’s exact test, or chi-squared test. While the Taguchi method is a systematic approach to experiment design and analysis, primarily intended for optimizing a single performance characteristic, it has recently become a valuable tool in enhancing research and development productivity, enabling the manufacture of high-quality products at a low cost. However, further research is required to optimize multiple performance characteristics using the Taguchi method, as this involves vector objective optimization.

The Taguchi method emphasizes the optimization of process parameters to achieve high-quality outcomes without raising costs. This is because enhancing process parameters can lead to improved performance characteristics. Traditional process parameter design is intricate and challenging to implement, requiring numerous experiments when dealing with a high number of parameters. The Taguchi technique makes use of orthogonal arrays as a solution to this problem, enabling thorough process parameter space analysis with a limited number of tests Taguchi recommends employing this loss function to identify the difference between desired and experimental values and to measure performance characteristics [3].

TAGUCHI METHOD DESIGN OF EXPERIMENTS

The steps followed in Taguchi Method are below.

1. Create a process goal by specifying a target value for a process performance metric, like flow rate or temperature. The loss function for the process is established using the performance characteristics divergence from the desired value. The performance measure’s minimization, maximization could also be the goal.
2. Identify the easily controllable design factors, such as temperature or pressure, that have an impact on the process. Indicate how many levels each parameter should be modified at, however doing more trails will be necessary as the number of levels at which a parameter can be changed.
3. For the parameter design, create orthogonal arrays that list the number of experiments and the details of each trial. The number of parameter and the degree of variation for each parameter are used to determine which orthogonal arrays to use.
4. Run the tests suggested in the orthogonal array to collect information on how the settings affect the performance metric.

5. Examine the gathered information to ascertain the effects of the different parameters on the performance metric. The steps of problem solving is represented as flow diagram in Figure 1.

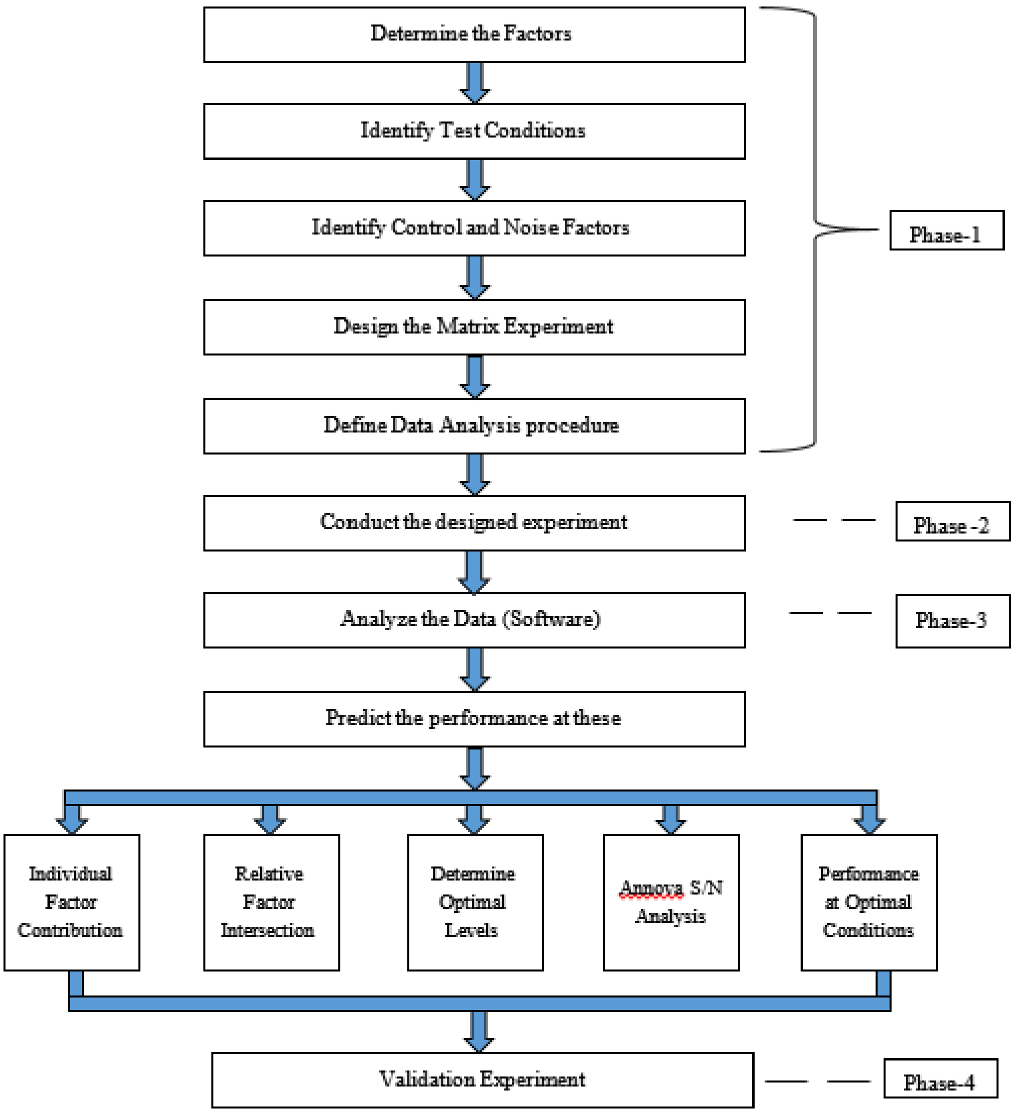

Figure 1. Flow diagram used for problem solving.

ORTHOGONAL ARRAY PARAMETER DESIGN CALCULATION

To investigate how different parameters affect a process' performance throughout the course of a condensed set of tests, Taguchi proposed utilising an orthogonal array experimental design. Once the parameters that can be managed have been determined, the levels at which these parameters should be updated must be specified based on information of the process, including the minimum, maximum, and current values of the parameter. When a parameter's range is wide, it is possible to test more values or more distant values, whereas when the range is narrow, it is possible to test fewer values or values that are closer together. The array selector in Table 2 can be used to choose an appropriate orthogonal array once the parameters and levels have been fixed. The column and row that correspond to the number of variable and stages can be used to determine the name of relevant array. The preconfigured array may then be located by looking for the name's subscript, which stands for the number of trials to be finished. These arrays were developed by Taguchi using a method that enables equal testing of all variables and settings. The array selector table provides links to several of the preconfigured arrays.

After conducting the experiments according to the chosen design, the impact of various parameters can be analyzed by examining the measured performance characteristic of each trial. Although any type of array can be used for this purpose, L9 array will be used to illustrate the data analysis process[4]. It should be noted that the Taguchi technique does not only rely on repeated trials, but also permits the insertion of a noise matrix that takes into account outside influences that affect the outcome of the process. To ascertain the effect of each variable on the result of each experiment, the signal-to noise ratio (SN ratio) must be estimated. After calculating the SN ratio for each experiment, the average SN value for each factor and level is determined. Each parameter's range (R = high SN low SN) is established and entered into the table once these SN ratio values are tabulated. The more significant the R value for a parameter, the larger the impact that parameter has on the process as a given change in signal has on the output variable being measured.

DESIGN OF EXPERIMENT

Modelling and examining the impact of process variables on response variables can be done effectively and analytically using the Design of Experiments (DoE) technique. The parameters that can be used as input parameters in welding operations include welding speed, beam diameter, and power. Designers can use DoE to analyse the individual and interaction effects of numerous variables that may have an impact on the output of any design. Designers are then able to rectify these issues and build robust and higher yield designs before going into production by identifying the sensitive components and locations in designs that lead to yield problems. To implement Taguchi's strategy, multiple values of each control component are systematically varied and tested using Design of Experiments methodologies, notably Orthogonal Arrays (OAs). In comparison to haphazard or unplanned experiments, well-designed experiments frequently require fewer runs and can yield noticeably more information.

To facilitate the use of DoE, the Minitab 17 software is used. Minitab 17 is a statistical analysis software package that allows for the ease of conducting analyses of data. It is an interactive program that responds instantaneously to any commands given to it. Worksheets are files made consisting of data, whereas projects are files made up of commands and graphs. The two primary types of files in the software are projects and worksheets. In the business world, devised experiments can be used to methodically study the factors in a process or a product that affect product quality. Based on the results, production circumstances can be changed to improve a product's ability to be manufactured, its dependability, its quality, and its performance in the field.

Design of Experiment (Doe) By Using Taguchi Technique in Minitab 16

The notations used in above Power (KW) table for different parameters and levels are explained here.

The data from above Table 1 is put into the orthogonal array, which is formed by using Taguchi Design and this table containing actual values of input parameters are used while performing Experiment. In this project there are three input parameters, out of that three parameters are having 3 levels and deformation being considered as the output parameter. So from the available designs in Minitab (Taguchi) we have chosen L4 array. The design is as follow as shown in Table 2.

Table 1. Parameter set of Reinforcement.

Parameters	**Levels**	
	1	**2**
Percentage Reinforcement	10	15
Thickness of Reinforcement	0.8	1.0

Taguchi Design

Taguchi Orthogonal Array Design
L9(3^2)
Factors: 2

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Runs: 9
Columns of L9(3^4) Array
1 2

Table 2. Orthogonal Array of Taguchi Lw (Coded).

R-Percentage	T-Thickness	Deformation
10	0.8	0.73
10	1.0	0.75
10	1.2	0.75
15	0.8	0.76
15	1.0	0.74
15	1.2	0.73
18	0.8	0.75
18	1.0	0.75
18	1.2	0.76

RESULT AND DISCUSSION

The main effect plots of Means in Figure 2 shows that Reinforcement percentage of 15%, thickness of 1.2 mm will yield the minimum deformation. The main effect plots shown in Figure 3 of SN ratios shows that Reinforcement percentage of 15%, thickness of 0.8 mm will yield the minimum deformation.

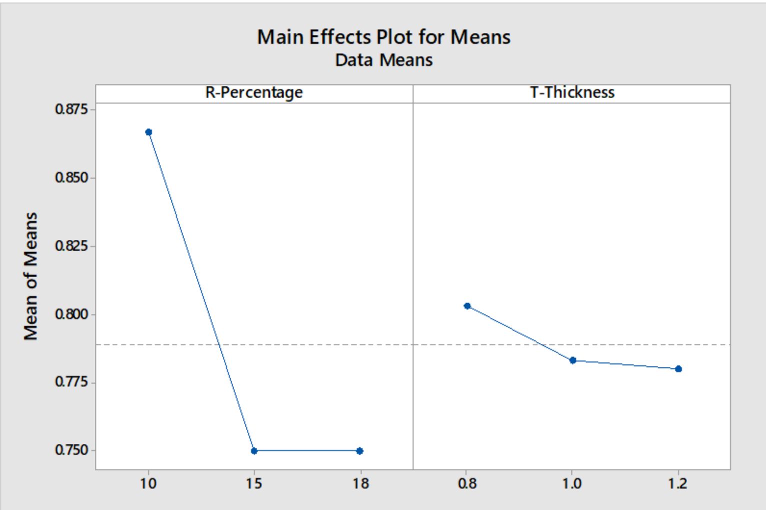

Figure 2. Plot For Means For Main Effects.

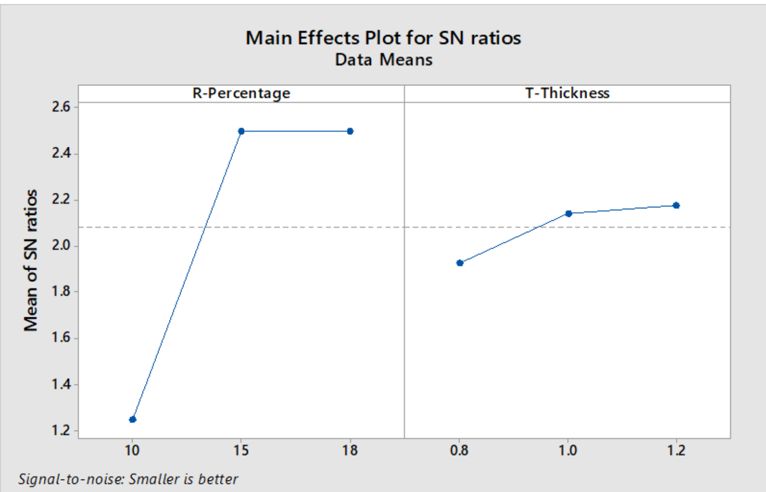

Figure 3. Main Effects Plot For SN Ratios.

CONCLUSION

By utilizing Taguchi's parametric approach, the experiments solely focused on evaluating the main effects of individual parameters. Through the use of the statistical program MINTAB17, an analysis of variance (ANOVA) was carried out to evaluate the sufficiency and viability of the experimental results. ANOVA enables the estimation of the percentage contribution of various process parameters, providing crucial information on the significance of each process parameter's effect on the performance characteristics of interest.

The results of the test showed the following results:

1. Maximum load considered was 40 kg.
2. The main effect plots of Means shows that Reinforcement percentage of 15%, thickness of 1.2 mm will yield the minimum deformation.
3. The main effect plots of SN ratios shows that Reinforcement percentage of 15%, thickness of 0.8 mm will yield the minimum deformation.
4. The effect of width increment of reinforcement was not seen to effect the deformation thus the optimal width of the reinforcement is 15mm and thickness of 1.2 mm is optimal for development of foot plate.

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