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PROCESS PARAMETER AND OPTIMIZATION OF NATURAL FIBER COMPOSITES BY USING TAGUCHI GREY RELATIONAL METHOD

Sivaperumal M,
Associate Professor, Jaya Engineering College, Chennai
Manikandan M,
Research Student, Jaya Engineering College, Chennai
Manikandan N,
Research Student, Jaya Engineering College, Chennai
Mukesh kannan S,
Research Student, Jaya Engineering College, Chennai

Corresponding Author:
shivaperumalmuthu@gmail.com

ABSTRACT
In recent times, environmental protection has become a crucial consideration in the development of engineering applications. Numerous composite materials have been introduced across agricultural, forestry, and energy sectors as effective alternatives to conventional materials. This research focuses on the fabrication of a composite material in which epoxy resin serves as the matrix. Glass fibres are employed as the reinforcing phase to produce a hybrid epoxy-based composite. The epoxy resin used in this investigation is LB011 (Lapox B_11), while Triethylenetetramine (TETA) is utilized as the curing agent. Composite laminates are fabricated with different weight percentages of glass fibres and subsequently evaluated for their mechanical characteristics. The laminate exhibiting the highest tensile strength is selected for further analysis of its machining behavior. Optimization of machining parameters is performed using Desirability Function Analysis (DFA), a robust and effective technique for solving problems.

Keywords:
Glass Fiber, Desirability function analysis, composites, delamination factor, surface Roughness.

INTRODUCTION
The preservation of the environment is now a significant concern for humankind. Many engineering applications utilize materials that pollute the environment once their useful lives are over. The creation of eco-friendly and biodegradable materials, such composite materials, has become more crucial in order to solve this problem. Natural fibers are becoming more and more popular in both academic and industrial settings. because of their superior mechanical qualities, affordability, ease of availability, and low weight. There is a large selection of both natural and synthetic fibers. including glass, basalt, jute, banana, carbon, and others. Composite materials are formed by combining two or more distinct constituents that are separated by a well-defined interface.
Design of Experiments (DOE) is employed to systematically plan experimental trials and evaluate the resulting responses. Nonlinear Regression analysis is used to create Mathematical models that represent these responses. Basalt fiber is made from extremely fine fibers derived from basalt rock and mainly consists of minerals such as plagioclase, pyroxene, and olivine. Basalt fibers possess mechanical qualities superior to those of carbon fibers and glass. In this study, LB011 epoxy resin (Lapox B_11) is used as the matrix material, and Triethylenetetramine (TETA) is used as a curing agent. The turning process parameters are optimized utilizing
Using Taguchi–Grey Relational Analysis (TGRA) is presented to identify the optimal machining conditions [1]. Additionally, the impact of fiber length on coir fiber-reinforced epoxy composites' mechanical performance is examined Previous studies have reported various investigations related to composite materials and their machining behavior. The machinability of glass fiber–reinforced polymer (GFRP) composites during end milling has been examined to identify optimal machining conditions [2,3]. Additionally, it has been noted that exposure to ultraviolet radiation influences FRP materials, leading to changes in the surface appearance of polymer composites [4]. Fibres extracted from coconut palm trees have been evaluated for multiple mechanical

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properties, including ultimate tensile strength, density, elongation, and dimensional characteristics [5]. Relationships between cutting parameters and machining responses have been established. Palm Kernel Fiber (PKF) has been found to exhibit favorable tensile strength and hardness characteristics [7]. Optimizing machining settings for CNC end milling of halloysite nano tube–reinforced aluminum epoxy hybrid composites has been effectively achieved using Taguchi-based design methodologies [8]. coconut palm trees demonstrate superior properties when compared with several materials [9]. Taguchi signal-to-noise ratios are commonly calculated based on performance metrics to assess process stability [10]. Because of their exceptional mechanical strength and thermal stability, natural fibers can be used in sports equipment manufacture, automotive engineering, and aerospace because of their superior [11–13]. Machining processes for GFRP composites have been extensively studied and optimized. Advanced optimization methods like Desirability Function Analysis (DFA) and Response Surface Methodology (RSM) have been employed to identify optimal machining parameters for composite laminates. Models in mathematics have been created and experimentally validated [14]. The best machining properties of laminated composites have also been identified using Grey Relational Analysis (GRA). Additionally experimental studies on mechanical properties and process Stir casting parameters in aluminum-silicon carbide composite have been optimized using Taguchi–Grey Relational Analysis. The biological and synthetic characterization of composites made of titanium boride and. Furthermore, frictions stir welding parameter improvement for hybrid metal matrix composites has been explored. Various researchers have employed RSM, Taguchi methods, and Grey Relational Analysis as instruments for optimization with multiple goals.

Fig 1

Experimental Setup

The method variables selected in this Fiber orientation angle, tool helix angle, spindle speed, and feed rate are among the variables under consideration. These variables are considered to be the most significant variables affecting the machining and fabrication performance of glass Laminate composites reinforced with fibers For it for strong interfacial connection between the reinforcement and the martial effective interfacial bonding between the matrix and the reinforcement, fiber orientation is necessary. While GFRP parts are being Processed Variables include helix angle, spindle speed, and feed rate are carefully considered, as they have a substantial impact on minimizing surface roughness, cutting forces, and delamination. Each process parameter is examined at three multiple tiers, which They are determined by recommendations from specialists in the industry and findings from past studies. The epoxy-based The technique is compression molding is used to create composite laminates. A total of four specimens are produced and evaluated for their mechanical properties. Glass fibres serve as the reinforcing phase in the hybrid epoxy composite and are supplied in mat form, as illustrated in Fig. 1. multiple layers of glass fibre mats are stacked sequentially, with epoxy resin uniformly applied across every layer to Apply the resigns

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Table 1. Experimental data

S. No	Fibre Orientation Angle (°)	Helix Angle (°)	Spindle Speed (rpm)	Feed Rate (mm/rev)	Surface Roughness (µm)	Machining Force (N)	Delamination Factor
1	15	25	2000	0.06	0.93	21.12	1.010
2	15	25	2000	0.06	0.95	22.35	1.008
3	15	25	2000	0.06	0.98	21.84	1.022
4	15	35	3500	0.08	0.88	24.62	1.027
5	15	35	3500	0.08	0.93	25.10	1.030
6	15	35	3500	0.08	0.90	23.96	1.020
7	15	45	5000	0.10	1.12	24.05	1.017
8	15	45	5000	0.10	1.01	24.58	1.019
9	15	45	5000	0.10	1.03	25.72	1.036
10	60	25	3500	0.10	1.07	28.55	1.034
11	60	25	3500	0.10	1.08	29.48	1.042
12	60	25	3500	0.10	0.99	32.14	1.025
13	60	35	5000	0.06	1.16	27.75	1.057
14	60	35	5000	0.06	1.21	26.25	1.038
15	60	35	5000	0.06	1.26	25.32	1.040
16	60	45	2000	0.08	1.08	28.44	1.048
17	60	45	2000	0.08	1.11	27.35	1.036
18	60	45	2000	0.08	1.14	26.21	1.047
19	105	25	5000	0.08	1.61	36.85	1.054
20	105	25	5000	0.08	1.69	37.64	1.060
21	105	25	5000	0.08	1.65	30.25	1.059
22	105	35	2000	0.10	1.57	30.64	1.073
23	105	35	2000	0.10	1.63	31.48	1.071
24	105	35	2000	0.10	1.70	30.15	1.067
25	105	45	3500	0.06	1.45	28.72	1.070
26	105	45	3500	0.06	1.53	30.65	1.089
27	105	45	3500	0.06	1.55	30.48	1.074

For each experimental trial, three measurements are recorded at different locations on the machined surface, and the mean value of these readings is regarded as the ultimate value of surface roughness. A Kistler dynamometer installed on the milling machine is used to measure the machining forces produced during the milling operation.
The total machining force consists of tangential, feed, and radial force components, all of which are captured simultaneously by the digital dynamometer during the machining of laminated composite specimens.
The delamination factor is evaluated using a high-resolution optical microscope. An L27, and a total of 27 machining trials are conducted at three different levels of fibre orientation angle, helix angle, spindle speed, and feed rate. The response values obtained from each experimental run are documented, and the
The full findings of the experiment are shown in
Table1.**Desirability Function Analysis**
Desirability Function Analysis (DFA), an efficient method for multi-response optimization issues, is used to optimize the machining settings. This study uses DFA to identify the best set of machining settings for milling fiber-reinforced epoxy composites based on the L27 orthogonal array The desirability function for each

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response characteristic is evaluated individually using the suggested mathematical formulation by Derringer, and the overall desirability is used to identify the optimum machining condition.

RESULTS AND DISCUSSION

The separate desirability values associated with each answer parameter are combined to get the overall (composite) desirability. To determine which machining factors have a major impact on the composite material's desirability, an analysis of variance (ANOVA) is performed. The ANOVA results for composite desirability are presented in Table 3. The analysis reveals that the fibre orientation angle has the most pronounced effect on composite desirability. This is followed, in descending order of influence, by spindle speed, feed rate, and helix angle. Based on the experimental findings, it is that variations in fibre orientation angle predominantly govern the overall machining performance of the composite.

Table 2. Individual and Composite Desirability

Run	Fibre Angle	Helix Angle	Speed (rpm)	Feed (mm/rev)	Roughness Desirability	Force Desirability	Delamination Desirability	Composite Desirability	Rank
1	15	25	2000	0.06	0.945	0.995	0.978	0.974	27
2	15	25	2000	0.06	0.889	0.872	0.995	0.920	26
3	15	25	2000	0.06	0.878	0.935	0.770	0.861	24
4	15	35	3500	0.08	0.995	0.785	0.770	0.846	23
5	15	35	3500	0.08	0.902	0.750	0.735	0.792	20
6	15	35	3500	0.08	0.980	0.828	0.858	0.887	25
7	15	45	5000	0.10	0.685	0.815	0.895	0.794	21
8	15	45	5000	0.10	0.868	0.782	0.870	0.838	22
9	15	45	5000	0.10	0.855	0.718	0.660	0.741	19
10	60	25	3500	0.10	0.785	0.552	0.685	0.668	17
11	60	25	3500	0.10	0.775	0.492	0.585	0.608	11
12	60	25	3500	0.10	0.878	0.328	0.795	0.612	13
13	60	35	5000	0.06	0.682	0.598	0.400	0.548	10
14	60	35	5000	0.06	0.578	0.682	0.645	0.636	16
15	60	35	5000	0.06	0.522	0.740	0.610	0.619	14
16	60	45	2000	0.08	0.785	0.558	0.510	0.609	12
17	60	45	2000	0.08	0.740	0.618	0.660	0.672	18
18	60	45	2000	0.08	0.660	0.688	0.525	0.621	15
19	105	25	5000	0.08	0.175	0.058	0.438	0.165	3
20	105	25	5000	0.08	0.005	0.003	0.362	0.005	1
21	105	25	5000	0.08	0.130	0.445	0.375	0.281	8
22	105	35	2000	0.10	0.223	0.425	0.202	0.270	7
23	105	35	2000	0.10	0.142	0.370	0.227	0.231	5
24	105	35	2000	0.10	0.062	0.448	0.275	0.198	4
25	105	45	3500	0.06	0.360	0.538	0.240	0.362	9
26	105	45	3500	0.06	0.258	0.422	0.005	0.005	1
27	105	45	3500	0.06	0.188	0.428	0.190	0.250	6

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Table 3. Analysis of Variance for Composite Desirability

Source	Degrees of Freedom	Sum of Squares	Mean Square	F-value	P-value
Fibre orientation angle	2	1.96784	0.98392	131.42	0.000
Helix angle	2	0.00273	0.00137	0.18	0.835
Spindle speed	2	0.03112	0.01556	2.08	0.154
Feed rate	2	0.00512	0.00256	0.34	0.712
Error	18	0.13482	0.00749	—	—
Total	**26**	**2.14163**	—	—	—

CONCLUSIONS

The application of epoxy-based composite materials contributes significantly to environmental sustainability. In the present study, an L27 orthogonal array is employed to investigate the influence of machining parameters during the milling of basalt fibre reinforced epoxy composites. The output responses evaluated in this work include surface roughness, machining force, and delamination factor.

A composite desirability index is determined by combining the individual desirability values obtained through Desirability Function Analysis (DFA). Analysis of variance (ANOVA) is performed to assess the adequacy of the developed models. The ANOVA results indicate a high level of model accuracy, with R^2 values of 96.29% for surface roughness, 90.28% for delamination factor, and 87.45% for machining force, demonstrating the strong predictive capability of the models.

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