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Multi-objective optimization of parameters in drilling of natural fibre Composites (Kenaf) using Taguchi and Grey relational analysis

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Abstract*— Taguchi and Grey Relational Analysis (GRA) are used in this study to reduce thrust force, torque, surface roughness, and roundness in drilling natural fibre composites. Drilling parameters, such as cutting speed, feed, point angle, and chisel angle, were used in this investigation. Experiments were conducted in accordance with Taguchi's experimental design using an L18 orthogonal array. Mathematical formula ANOVA was performed to determine how much each process parameter contributes to the responses. The results show that point angle, chisel edge width, feed, and speed have the greatest impact on the multi-performance characteristics.

I. INTRODUCTION

Natural composite materials have recently become more popular with researchers because of their advantages over conventionally reinforced alternatives. Low density and high specific qualities make these materials perfect for lightweight structural components such as door panels, seat backs and headliners as well as dashboard and other interior components in automotive. [1-4]. The natural fibres like sisal, jute, kenaf, Palmyra, etc., used for making natural composites are biodegradable, economically favourable, eco-friendly and have good specific, mechanical, thermal and acoustic properties [5]. In view of gaining importance for natural composites in engineering applications, now, these considered as an alternative to synthetic fibres [6-8]. Therefore, a detailed study of their machining characteristics is needed. Drilling is one of the common and complex machining processes which is widely used in various manufacturing industries including aerospace, automotive, machinery manufacturing, etc. An equation for torque and thrust forces could be difficult to draw if the cutting tool material, cutting process parameters, and their combinations are taken into account [9]. The tensile, compressive, and wear characteristics of hibiscus sabdariffa fibre reinforced polymer composites were studied in depth. When urea-formaldehyde was bonded with fibre, the mechanical characteristics were noticeably better. It was reported that the elastic modulus and strength properties of commodities were boosted by reinforcing the vinyl ester (VER) eco-composites and VER eco-nano-composites with both recycled cellulose fibre (RCF) and Halloysite nanotubes (HNTs) [10].

The short fibre reinforced polymer composite under investigation made with hibiscus cannabinus (kenaf) is very attractive because of their ease of fabrication, economy, good mechanical properties etc [11] [12]. This technology was used to improve the drilling process parameters for Al/Sic Metal matrix composites. [13] Taguchi technique was used to improve drilling process parameters for GFRP composites. Drilling process parameters such as spindle speed, feed rate, drill, and mica mass fraction can be optimised using Taguchi and Grey relational analysis based on the results of this study. According to the study's findings, feed rate and type of drill have a considerable impact on the drilling process [14].

The present study's purpose is to use Taguchi and Grey Relational Analysis to optimise multiple drilling process parameters on natural fibre composites in order to reduce thrust force, torque, surface roughness, and roundness.

II. METHODOLOGY

2.1 Selection of process parameters

The Taguchi technique makes use of orthogonal arrays derived from experiment design in order to examine the whole parameter space with fewer experiments. After an experiment has been completed, the data is translated into a signal-to-noise ratio (SNR). Compared to the desired values, the S/N ratio is a measure of quality [15].

In this study, the machining process parameters speed, feed, point angle, and chisel edge width were recognized. Three levels and four parameters were chosen for this study's L18 Taguchi orthogonal array [16]. Factors and their related levels can be shown in Table1.

Table.1: Levels of selected process parameters for drilling

Code	Variable	Level1	Level 2	Level3
1	Feed (mm/rev)	0.15	0.2	
2	Speed (rpm)	290.0	580	890
3	Point angle (deg)	98.0	108	118
4	Chisel edge width (mm)	1	1.5	2

2.2 Grey Relational Analysis

In his Grey theory, Dr. Deng proposes Grey relational analysis and Grey modelling as well as Grey prediction and decision-making for systems when the model is uncertain or the knowledge is insufficient [17]. A number of scholars have effectively applied this theory over the past two decades to a wide range of applications in the fields of business and social systems as well as ecological and the environment. [18-20]. Grey relational analysis, also known as Grey relational generation, is used to examine the data. The grey connection coefficient, which is based on normalised data, depicts the relationship between the expected and actual outcomes of an experiment. For each performance, the average of the Grey relational coefficients is utilised to get the Grey relational grade. The Grey relational grade calculated for each response determines the overall performance qualities of several responses. As a result of this strategy, the optimization of several responses is reduced to just one. The best parametric combination can be identified using Grey's highest relational grade. The normalised data for the Higher-the-Better (HB) criterion can be written as follows in grey relational generation.

$$x_i = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - \min y_i(k)} \tag{1}$$

Lower-the-Better (LB) criterion can be expressed as:

$$x_i = \frac{y_i(k) - \min y_i(k)}{\max y_i(k) - \min y_i(k)} \tag{2}$$

Nominal-the-better (NB) criterion can be expressed as

$$x_i = \frac{y_i(k) - y_0}{\max y_i(k) - y_0} \tag{3}$$

Grey relational generation produces xi (k) where xi (k) represents the data sequences and yi (k) reflects the values of yi (k) for the kth response. It is necessary to perform data processing prior to calculating the Grey relational coefficient (GRC).

The Grey relational coefficient ξ_i (k) can be expressef as

$$\xi_i(k) = \frac{\Delta_{\min} + \zeta\Delta_{\max}}{\Delta_{0i}(k) + \zeta\Delta_{\max}} \tag{4}$$

Where Δ_{0i}=||x_0(k)-x_i(k)|| = difference of the absolute value between x_0(k) and x_i(k)

ζ= distinguishing coefficient (0 ~1)

$\Delta_{min}=\forall j^{min} \in i\forall k^{min}$ || x_0(k)-x_j(k)|| = smallest value of Δ_{0i}

$\Delta_{max} = \forall j^{max} \in i\forall k^{max}$ || x_0(k)-x_j(k)|| = largest value of Δ_{0i}

The grey relational grade I is calculated using the following equation after obtaining the average of the grey relational coefficients.

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n}\xi_i(k) \tag{5}$$

Where γ_i is Grey relational grade and n is number of responses

The weight factor is assigned to the quality characteristics in the following condition

$$\sum_{i}^{n} W_i = 1 \quad (6)$$

The Grey relational grade is calculated by averaging the correlation coefficients for each response variable. Grey relational grades can be used to identify desirable process variables. In order to determine which factors have the most influence, an analysis of variance is carried out further onwards.

III. EXPERIMENTAL WORK

In this study, natural fibre reinforced polymeric (NFRP) composite was prepared using short fibre reinforced of kenaf fibre and isopthalic resin by hand lay-up process. Composite was used to cut the 50X100X8mm mm specimen size from the work piece material specimen. Following the L18 orthogonal array given in Table 2 on NFRP laminates with a 10-mm diameter HSS (M2) drill, the drilling experiments were conducted. Each experiment was repeated twice to reduce the possibility of an error in the data. In Fig. 1, the radial drilling machine is shown in operation as the experiment was conducted. The axial thrust and torque were measured using a syscon two-component tube strain gauge type drilling dynamometer. (model: SI-674). Thus, an amplified output signal was produced that corresponded with the amount of load being applied, which was supplied into the dynamometer's percentage voltage input (model SI–223 D). The database information on force and torque was recorded using digital amplifiers. Surtronic 3 and Taylor Hobson Talysurf surface profilo meters were used to measure the quality of drilling holes in relation to their final surfaces. CMM (model: BH 303) was used to gauge the amount of roundness that had been lost during the drilling process.

Fig. 1: Experimental setup

Table .2: The basic Taguchi L18 orthogonal array

Expt.	Control factors and Levels			
No	A	B	C	D
1	1	1	1	1
2	1	1	2	2
3	1	1	3	3
4	1	2	1	1
5	1	2	2	2
6	1	2	3	3
7	1	3	1	2
8	1	3	2	3
9	1	3	3	1
10	2	1	1	3
11	2	1	2	1
12	2	1	3	2
13	2	2	1	2
14	2	2	2	3
15	2	2	3	1
16	2	3	1	3
17	2	3	2	1
18	2	3	3	2

III. RESULTS AND DISCUSSION

3.1 Optimization of Process Parameters

Gray relational analysis is utilised in the following steps to optimise the drilling parameters. [16].

- Normalize the data.
- Grey relationship coefficients must be determined.
- Calculate the Grey relational grade
- Perform statistical analysis of variance (ANOVA).
- Select the optimum levels of process parameters

Table 3 shows the results of the thrust force, torque, surface roughness and circularity of each sample for varied process parameters. Quality increases with decreasing thrust force, torque, surface roughness and circularity of the machined surface. All responses were standardized using the Grey relational analysis approach using the LB criterion, which states that the lower the response, the better (LB).

Table. 3: Taguchi's L_{18} standard orthogonal array with responses

Expt. No	Thrust force	Torque (Kgf-m)	Surface roughness (μm)	Circularity (mm)
1	5.0	0.03	7.002	0.0857
2	9.2	0.04	4.544	0.0432
3	9.0	0.04	6.314	0.2168
4	5.0	0.03	7.157	0.0555
5	7.0	0.08	8.817	0.1482
6	10.0	0.07	9.554	0.0462
7	4.0	0.04	9.216	0.0671
8	4.6	0.06	10.004	0.0880
9	5.0	0.05	8.228	0.1209
10	4.0	0.07	6.284	0.1261
11	6.1	0.07	5.287	0.0545
12	5.1	0.16	8.300	0.3211
13	4.0	0.05	6.859	0.0625
14	5.1	0.07	8.118	0.1018
15	4.9	0.08	8.055	0.1547
16	5.0	0.07	6.668	0.1437
17	6.1	0.06	6.031	0.0960
18	6.1	0.07	3.642	0.0360

Table .4: Grey relational generation of each performance characteristics

Expt. No	Thrust force (Kgf)	Torque (Kgf-m)	Surface roughness (μm)	Circularity (mm)
1	0.1666	0.0000	0.5281	0.1743
2	0.8660	0.0769	0.1417	0.0252
3	0.8330	0.0769	0.4199	0.6341
4	0.1666	0.0000	0.5524	0.0683
5	0.5000	0.3846	0.8134	0.3935
6	1.0000	0.3076	0.9292	0.0357
7	0.0000	0.0769	0.8761	0.1090
8	0.1000	0.2307	1.0000	0.1823
9	0.1666	0.1538	0.7208	0.2977
10	0.0000	0.3076	0.4152	0.3160
11	0.3500	0.3076	0.2585	0.0648
12	0.1833	1.0000	0.7321	1.0000
13	0.0000	0.1538	0.5056	0.0929
14	0.1833	0.3076	0.7035	0.2307
15	0.1500	0.3846	0.6936	0.4163
16	0.1666	..3076	0.4756	0.3777
17	0.3500	0.2307	0.3755	0.2104
18	0.3500	0.3076	0.0000	0.0000

The data was normalised using Eq. (5) to obtain Grey relational generation. The normalised data and Δ_{0i} for each of the responses are presented in Table 4 and Table 5 respectively.

Δ_{0i} for each of the responses has been calculated as follows.

$\Delta_{01}(1) = (|x_0(k) - x_i(k)|| = ||1.0000-0.1666|| = 0.8334$

$\Delta_{01}(2) = (|x_0(k) - x_i(k)|| = ||1.0000-0.0000|| = 1.0000$

$\Delta_{01}(3) = (|x_0(k) - x_i(k)|| = ||1.0000-0.5281|| = 0.4719$

$\Delta_{01}(4) = (|x_0(k) - x_i(k)|| = ||1.0000-0.1743|| = 0.8257$

Therefore $\Delta_{01=}$ (0.8334, 1.0000, 0.4719, 0.8257)

Table 5 shows the outcomes from all i=1-18 studies that made use of a continuous contract. Everything that goes into conducting this study has an impact on the results. Because each performance criterion was given equal weight (=0.25), the Grey relational coefficients were calculated and reported in Table 6. As you can see, the Grey connection coefficient is calculated in this method.

$\Delta_{max}(k)$ and $\Delta_{min}(k)$ are taken as follows

$\Delta_{max}(k) = \Delta_{06}(1) = \Delta_{12}(2) = \Delta_{08}(3) = \Delta_{12}(4) = 1.000$

$\Delta_{min}(k) = \Delta_{10}(1) = \Delta_{01}(2) = \Delta_{18}(3) = \Delta 18(4) = 0.000$

$$\xi_{01}(1) = \frac{0.0 + 0.25 \times 1.0}{0..8338 + 0.25 \times 1.0} = 0.2307$$

$$\xi_{02}(1) = \frac{0.0 + 0.25 \times 1.0}{1.0 + 0.25 \times 1.0} = 0.2000$$

$$\xi_{03}(1) = \frac{0.0 + 0.25 \times 1.0}{0.4719 + 0.25 \times 1.0} = 0.3463$$

$$\xi_{04}(1) = \frac{0.0 + 0.25 \times 1.0}{0.8257 + 0.25 \times 1.0} = 0.2324$$

Table. 5: Evaluation of Δ_{0i} for each of the responses

Expt. No	Thrust force	Torque (Kgf-	Surface roughness	Circularity (mm)

	(Kgf)	m)	(μm)	
1	0.8334	1.0000	0.4719	0.8257
2	0.1340	0.9231	0.8583	0.9748
3	0.1670	0.9231	0.5801	0.3659
4	0.8334	1.0000	0.4476	0.9317
5	0.5000	0.6154	0.1866	0.6065
6	0.0000	0.6924	0.0708	0.9643
7	1.0000	0.9231	0.1239	0.8910
8	0.9000	0.7693	0.0000	0.8177
9	0.8334	0.8462	0.2792	0.7023
10	1.0000	0.6924	0.5848	0.6840
11	0.6500	0.6924	0.7415	0.9352
12	0.8167	0.0000	0.2679	0.0000
13	1.0000	0.8462	0.4944	0.9071
14	0.8167	0.6924	0.2965	0.7693
15	0.8500	0.6154	0.3065	0.5837
16	0.8334	0.6924	0.5244	0.6223
17	0.6500	0.7693	0.6245	0.7896
18	0.6500	0.6924	1.0000	1.0000

Table. 6: Grey relational coefficient of each performance characteristics

Expt. No	Thrust force (Kgf)	Torque (Kgf-m)	Surface roughness (μm)	Circularity (mm)
1	0.2307	0.2000	0.3463	0.2324
2	0.6510	0.2131	0.2255	0.2041
3	0.5995	0.2131	0.3011	0.4059
4	0.2307	0.2000	0.3583	0.2115
5	0.3333	0.2888	0.5726	0.2918
6	1.0000	0.2652	0.7793	0.2058
7	0.2000	0.2131	0.6686	0.2191
8	0.2173	0.2452	1.0000	0.2341
9	0.2307	0.2280	0.4724	0.2625
10	0.2000	0.2652	0.2994	0.2676
11	0.2777	0.2652	0.2521	0.2109
12	0.2343	1.0000	0.4827	1.0000
13	0.2000	0.2280	0.3358	0.2160
14	0.2343	0.2652	0.4574	0.2452
15	0.2272	0.2888	0.4492	0.2998
16	0.2307	0.2652	0.3228	0.2865
17	0.2777	0.2452	0.2858	0.2404
18	0.2777	0.2652	0.2000	0.2000

Grey relation coefficients were calculated using the same method for I = 1–18. Table 6 represents the conclusions of all of the studies. Each experiment's Grey relation grade was calculated based on the overall performance characteristic of all responses. With the Taguchi technique and Grey relational analysis, the multi-criteria optimization issue might be reduced to a single equivalent optimization problem for an objective. The higher the Grey relationship grade, the nearer the experiment's performance was to being optimal [21]. For each trial, the grey relation grade is shown in Table 7. Experiment 12 is revealed in Table 7 to have the maximum grey relationship grade.

Table. 7: Grey relational grade

Expt. No	Grade	Rank
1	0.2523	14
2	0.3234	7
3	0.3799	4
4	0.2501	16
5	0.3716	5
6	0.5625	2
7	0.3252	6
8	0.4241	3
9	0.2984	10
10	0.2580	13
11	0.2514	15
12	0.6792	1
13	0.2449	17
14	0.3005	9
15	0.3162	8
16	0.2763	11
17	0.2622	12
18	0.2357	18

The average Grey relational grade for each level of process parameter was calculated using the Taguchi technique response table in order to identify the best drilling parameters for thrust force, torque, surface roughness, and roundness. After sorting each column's Grey relationship grades corresponding to a separate process parameter's level of relevance, average them together was obtained [22]. First, the experimental runs in the orthogonal array numbered 1, 2, 3, 4, 5,6,7,8 and 9 had the feed parameter (F) set to level 1. It is these experimental runs with Grey relationship grades that correspond to F's grade Thus, the average Grey relationship grade for feed (F) at level 1 can be determined as follows:

F (level1) = (0.2523+0.3234+0.3799+0.2501+0.3716+0.5625+0.3252+ 0.4241+0.2984) /9= 0.354

F (level2) = (0.2580+0.2514+0.6792+0.2449+0.3005+0.3162+0.2763+ 0.2622+0.2357) /9=0.314.

Similar methods were used to calculate each drilling parameter's Grey relationship grade values. Table 8 and Fig. 2 show the grey relationship values for each level of parameter in respect with each other.

Table. 8: Response Table for Grey relational grade

Factors	Grey Relation grade			
	Level 1	Level 2	Level3	Max-Min
Feed	0.354	0.314	----	0.04
Speed	0.357	0.340	0.303	0.054
Point angle	0.268	0.322	0.412	0.144
Chisel edge width	0.272	0.364	0.367	0.095
Total mean Grey relational grade = 0.334				

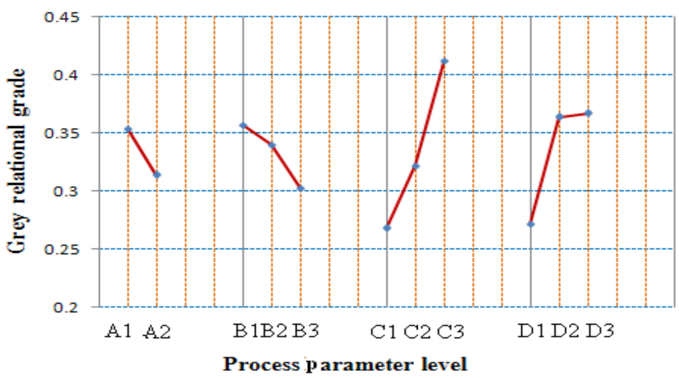

Fig .2: Grey relational grade graph

From the Table 8, the difference between the maximum and the minimum value of the Grey relational grade of drilling process parameters is 0.04 for feed, 0.054 for speed, 0.144 for point angle and 0.095 for chisel edge width. The significance of each controllable element can be assessed by examining these values. Maximum of these numbers is the most effective and measurable factor. The highest of these numbers is 0.144. According to this value, point angle is the most important process parameter for influencing multi-performance characteristics. As depicted in rational grade graph Fig.2 (the optimal combination of drilling parameters for reducing outcomes), site with the feed at level 1, speed at level 1, point angle at level 3 (1180) and chisel edge width at level 3 is the best combination of parameters (2 mm).

3.2 Analysis of variance (ANOVA)

Experimental data can be analysed with the analysis of variance (ANOVA), which is an established statistical approach for determining the relative contributions of various process parameters to the performance characteristics of significance. 'ANOVA' Overall Grey relational grade variability is achieved by summing squared deviations from the Grey relational grade total mean contributions from all process parameters and error [18]. The Pareto ANOVA technique was conducted and the results are presented in Table 9. It finds the most relevant parameters and determines the proportion of each parameter's effect on different responses. [16].

The overall S/N ratio is expressed from the S/N ratios as

$$\overline{S/N} = \frac{1}{18}\sum_{1}^{18}(S/N)_i \tag{7}$$

Here, $\overline{S/N}$ is the overall mean of S/N ratio

$(S/N)_i$ is the S/N ratio for ith parameter

The sum of squares due to variation about overall mean is

$$SS = \sum_{i=1}^{18}\left((S/N)_i - \overline{(S/N)}\right)^2 \tag{8}$$

where, SS is the sum of squares

The sum of squares due to variation about overall mean for the ith process parameter is

$$SS_i = \sum_{j=1}^{6}\left((S/N)_{ij} - \overline{(S/N)}\right)^2 \tag{9}$$

Where, SS_i is the sum of the square for ith parameter

$(S/N)_{ij}$ is the average S/N ratio of ith parameter of jth level

$$\% \text{ Contribution} = \frac{SS_i}{SS} \times 100 \tag{10}$$

Table 9 Contribution of process parameters

Process parameter	Sum of squares (SS_i)	% Contribution
Feed	0.769	8.2
Speed	0.563	6.0
Point angle	4.837	51.6
Chisel edge width	3.206	34.2

The ANOVA results indicate that point angle (51.6%) has the greatest influence on the responses followed by chisel edge width (34.2%), feed (8.2%) and speed (6.0%).

IV. CONCLUSION

As a conclusion of the Taguchi and Grey relational analysis, the cutting process parameters feed, speed, point angle, and chisel edge were all multi-optimized in drilling of natural fibre composites (Kenaf). At 0.15mm/rev feed rate (290 RPM), point angle of 1180 degrees (and 2mm edge width), these are the optimal processing parameters for drilling natural composites to minimise torque, thrust, surface roughness and roundness. The ANOVA results indicate that point angle (51.6%) is the most significant influence on the responses followed by chisel edge width (34.2%), feed (8.2%) and speed (6.0%).

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