Multi Response Optimization of Process Parameters in Drilling Operation for Jute and Basalt Fabric Composite Material

M. Indira Rani, Ajmeera Ramesh, K. Ramu, N.V. Srinivasulu

Abstract**:** ***Natural fabric Reinforced polymer (NFRP) composites are the materials by a matrix and a reinforcement of natural fibre. NFRPs are the materials with low density, high molding flexibility, environmentally friendly and have wide range of applications extending from products of commodity to aerospace, defence, automobile spare parts, and bicycle frames applications. In this work the effect of cutting parameters in drilling Natural fabric reinforced composites were studied. Experiments were conducted to study the effect of drill bit diameter, spindle speed and feed rate on Material Removal Rate (MRR), Surface Roughness, Circularity of Hole and Delamination Factor. Theoretical calculations are done to calculate Material Removal Rate and Delamination Factor. Surface Roughness and Circularity of Hole measured by Surface Roughness Tester and Coordinate Measuring Machine (CMM) respectively. The input parameters considered were 6mm, 8mm and 10mm diameter drill bits, spindle speeds of 600rpm, 1200rpm & 1800rpm, feed rates of 0.1rev/min, 0.2rev/min and 0.3rev/min. Experiments were carried as per Taguchi Experimental Design (L_9) to get the optimum values of MRR, Surface Roughness, And Circularity Of Hole and Delamination Factor. Optimization was done using Taguchi Analysis, Grey Taguchi Analysis and Multi Attribute Decision Making (MADM) Method. The optimal solution for the multiple response system of drilling of NFRP were diameter of drill bit of 10 mm, Spindle speed 600 rpm and at 0.3 mm/rev feed rate. MADM process concluded that, Circularity of Hole was most preferred response than followed by Material Removal Rate, Surface Roughness and Delamination Factor.***

Key words**:** ***Circularity, Coordinate Measuring Machine (CMM), Delamination Factor,*** **Grey relation analysis,** ***Natural Fabric Reinforced Polymer (NFRP),*** **Surface roughness.**

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I. INTRODUCTION

Development of thermosetting natural and synthetic fabric composites has drawn attention of the researchers all over the globe, owing to the availability and biodegradability of natural and synthetic fibric [1-3]. Composite materials are abundantly from conventional materials. The dimensions of the stimulation regulate its susceptibility of contributively its characterized [4]. Fibers are really potent in improving the trauma resistivity of the matrix since a reinforcement having an advance to failure, particularly with toffee matrices. A fibre is considered by its length presence some better compared to its dimensions. Jute fibers are fully bio-degradable, recyclable and environmentally friendly [4-6]. Hybrid is the flexible system with unique properties in which combined two or more fibers types to design composite materials that overcome the drawbacks of individual fibers composites [7-8]. It is also having better tensile strength and less extensibility. Measured the devotion between the fibre and matrix surface and determined that the mechanical properties can be enhanced by chemical methods and new processing techniques [8-11]. Several natural and synthetic fibres are like flax, jute [5], oil palm [16,18], basalt, cotton [15], Kevlar, coir [14] carbon [20], Americana kenaf, sisal [13], glass [17] and banana are used for commercial purposes. Basalt fabric is a material prepared from extremely fine fibers of basalt. It is parallel to Glass fibers, having better physic mechanical properties than E-Glass fibers, but being expressively low cost than other synthetic fibers. Currently, hybridizing natural fibers with synthetic fibers, getting innovative consideration, to prepare a composite with improved properties, such as low cost, light weight, ease of fixing. Among several types of natural fibres, jute fibre has a high content of cellulose which considers an attractive option for the special engineering materials such as construction structures, building, automotive, aerospace, biomedical materials, in an eco-friendly manner [3-12]. In last decade, natural fiber reinforced epoxy resin composites have attracted growing research benefits owing to their potential as a substitute for composites reinforced with synthetic fibers like basalt, glass, Kevlar or carbon [13-20]. Jute fibers exhibit excellent properties, such as cheapness, high specific modulus, light weight, good thermal, good acoustic insulating, lower energy requirements, less wear and tear in processing, abundant worldwide, biodegradability. Because they have a wide range of physical and mechanical characteristics, they are utilized increasingly reinforced both thermoset and thermoplastic polymer composites which extended their wider applications. Due to its high mechanical properties' jute fibers are considered as a substantial and alternative to glass and carbon fibers [13-16]. The total dimensions and its compositional reliability are substantial in better value of the fiber and the sum of these parameters is serving of the fiber finding a new investigation on drilling of GFRPs in which L orthogonal array was used for determining delamination as well as surface roughness [6-9]. The process parameters are spindle speed, feed rate and tool point angle were combined to identify the optimal process parameters. Grey Relational Analysis (GRA) was completed to observe the effect of parameters and its interaction. Testing results showing that spindle speed and tool were found as the most important factor while point angle take to the least. have experimentally tested and proved that hybrid composite with jute and glass fibres reinforced composite (GFRP) have enhanced other properties and also developed under tensile, impact and flexural loading when compared to single fibre composite. Studied on jute and basalt hybrid composite has improved tensile properties than jute-fiber mono composite but jute composite is higher to hybrid composites in tensile, flexural, impact and water absorption properties [7-14].

Fig. 1. Jute and basalt fabric

II. EXPERIMENTAL DETAILS

2.1. Materials Used in Composite Preparation

- **Fixing Percentage of Epoxy Resin and Fabric Material**

Composite material generally consists of some layers of fabric held together with the help of a resign. Suppose the composite material is of 100 % by weight, 40 % by weight is made of fabric and remaining 60 % by weight constitutes the epoxy resign. Accordingly, the weights of fabric and epoxy resin are 750 grams and 1125 grams respectively.

epoxy Resin Mixture

Epoxy resin is made up of resin and hardener. Resin and hardener are taken in a ratio of 10:1 for obtaining epoxy resin mixture.

- **Fabric**

The thickness of composite material is initially fixed as 10 mm. Basalt and jute are used as fabrics for preparing composite material. For this purpose, 16 layers of jute fabric having 0.4 mm thickness and 8 layers of basalt fabric having 0.4 mm thickness are utilized. Of the 16 layers of jute fabric, 8 layers are perpendicular and remaining 8 layers are inclined (i.e. 45 degrees to horizontal)

2.2. Composite Preparation

The composite material is prepared by stacking layers of fabric and epoxy resign. So, it generally has a layer of fabric followed by resign which in turn is followed by another layer of fabric. This stacking is continued till all the fabric layers are arranged. So here the typical stacking layers are of the form Jute perpendicular – resin – jute 45 – resin – basalt–resin–jute perpendicular – resin etc. Once all the ingredients for composite preparation are fixed, the process is started by selecting a suitable space for the preparation. First, peel-ply is applied over the selected space. On the peel-ply layer, jute perpendicular fabric is placed and epoxy resin is uniformly applied over it. On this epoxy resin layer, jute fabric with 45 to horizontal is placed. Again, epoxy resin is uniformly applied over it. The epoxy resin layer is followed by a layer of basalt fabric and a layer of uniformly applied resin. This method of placing fabric followed by a layer of resin is continued for 24 fabrics. The above-mentioned methodology can be easily depicted from the following Table 1.

Table 1Arrangement of Fabric Layers

1	J +	13	B +
2	J X	14	J x
3	B +	15	J +
4	J +	16	B +
5	J X	17	J x
6	B +	18	J +
7	J +	19	B +
8	J X	20	J x
9	B +	21	J +
10	J +	22	B +
11	J X	23	J x
12	B +	24	J +

- **Preparation of Sealed Bag**

Sealed bag is prepared in order to achieve an air tight space. Upon the composite release fabric is placed followed by breather fabric and vacuum bag film. Vacuum bag film is nothing but a plastic cover cut in size to cover the entire composite. Then sealing tape is applied over all the edges of the vacuum bag film to prevent any air leakage.

- **Air Suction**

A provision for air suction is made in the sealed bag. From this provision using a vacuum pump all the air is sucked out. This process is carried out for about six hours. During this time, all the air contained in between the layers is evacuated and final composite is obtained. This process is shown in the figure 2 After completion of total processes remove the vacuum bag film, breather fabric and release fabric and then composite material is taken out. Using sawing machine cut the all sides of material to get rectangular shape as shown below figure 3.

Fig.2.Preparation of Composite Material

Fig 3. Final Composite Material

Table 4 Results of performance measure

Exp. No	MRR (mm^3/sec)	Ra(µm)	Circularity of hole	Delamination factor
1	28.26	8.4	0.1854	1.0007
2	113.04	9.4	0.1242	1.0060
3	254.34	10.8	0.1565	1.0015
4	100.48	13.1	0.1291	1.0171
5	301.44	11.0	0.0905	1.0099
6	150.72	12.8	0.1539	1.0056
7	235.50	9.2	0.1509	0.9508
8	157.00	11.8	0.2288	0.9522
9	471.00	14.0	0.1629	0.9512

III. EXPERIMENTAL ANALYSIS

3.1 *Design of Experiments*

Taguchi method is the technique of laying out the conditions of experiments including multiple factors. The technique is commonly known as factorial design of experiments. A complete factorial design will identify all possible combinations for a specified set of factors. This technique uses a different set of arrays called orthogonal arrays. These arrays stipulate the way of conducting minimum number of experiments which could give complete data of all the factors that mark the performance parameter. In the present work three different drill bit diameters, speeds and feeds have been considered as three factors in three different levels. The three levels of drill bit diameters (mm) are: 6, 8 & 10; speed (rpm) are 600, 1200, 1800 and feed (rev/min) 0.1, 0.2, 0.3. The experiment is conducted under nine different experimental conditions using Taguchi method and as shown in the Table 2,3 and 4.

Table 2 Drilling Process Parameters and Their Levels

S. no	Process parameters	Unit	Level 1	Level 2	Level 3
1	Drill bit diameter	mm	6	8	10
2	Speed	rpm	600	1200	1800
3	Feed	rev/min	0.1	0.2	0.3

Table 3 Experimental Design Matrix

Exp.no	Drill bit diameter (mm)	Speed (rpm)	Feed (rev/min)
1	6	600	0.1
2	6	1200	0.2
3	6	1800	0.3
4	8	600	0.2
5	8	1200	0.3
6	8	1800	0.1
7	10	600	0.3
8	10	1200	0.1
9	10	1800	0.2

IV. DETERMINATION OF OPTIMUM MACHINING PARAMETERS

4.1*Optimum Machining Parameters for Material Removal Rate*

Table 5 Response table of MRR

Level	Diameter(mm)	Speed(rpm)	Feed(mm/rev)
1	39.40	38.83	38.83
2	44.40	44.86	44.86
3	48.27	48.38	48.38
Delta	8.87	9.54	9.54
Rank	3	2	1

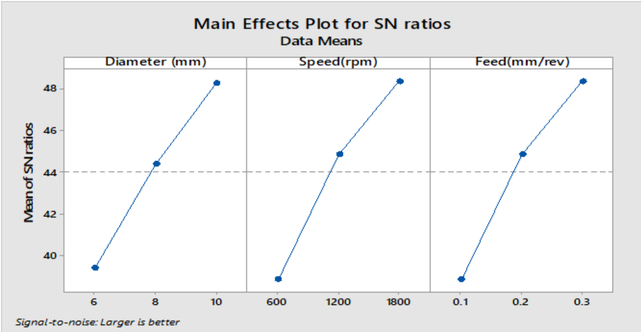

Fig 4. S/N Ratio of MRR

It is observed that from table 4 the order of effect of input process parameters are diameter of drill bit, speed and feed. From the above table 5and graph, it is observed that the optimum process parameters for the MRR are diameter 10mm, speed 1800 rpm and feed are 0.3 mm/rev since the optimum S/N ratio for MRR is Larger the better

4.2 *Optimum Machining Parameters for Surface Roughness*

Table 6 Response table Of Surface Roughness (Ra)

Level	Diameter (mm)	Speed (rpm)	Feed (mm/rev)
1	-19.54	-20.04	-20.69
2	-21.77	-20.58	-21.58
3	-21.21	-21.91	-20.26
Delta	2.23	1.88	1.32
Rank	1	2	3

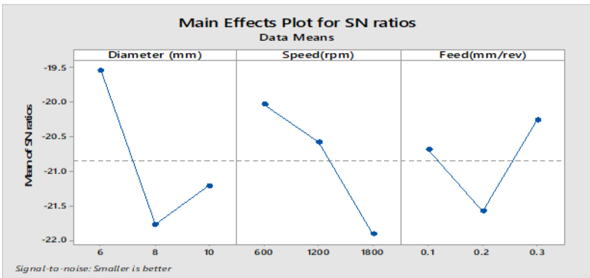

Fig 5 S/N Ratio of Surface Roughness

It is observed that from table the order of effect of input process parameters are diameter of drill bit, speed and feed. From the graph and table, it is observed that the optimum process parameters for surface roughness are diameter 8 mm, speed 1800 rpm and feed 0.2 mm since the optimum S/N ratio for surface roughness is smaller the better.

4.3 *Optimum Machining Parameters for circularity of hole*

Table 7 Response table of Circularity of hole

Level	Diameter (mm)	Speed (rpm)	Feed (mm/rev)
1	19.24	16.28	16.23
2	18.30	18.93	17.22
3	16.66	18.99	20.75
Delta	2.57	2.71	4.52
Rank	3	2	1

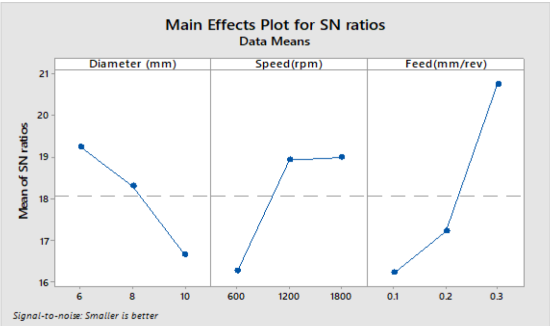

Fig 6 S/N Ratio of Circularity of Hole

It is observed that from table the order of effect of input process parameters are diameter of drill bit, speed and feed. From the table and graph, it is observed that the optimum process parameters for circularity are diameter 10 mm, speed 600 and feed is 0.1 mm since the optimum S/N ratio for circularity is smaller the better.

4.4 *Optimum Machining Parameters for Delamination Factor*

Table 8 Response table Of Delamination Factor

Level	Diameter (mm)	Speed (rpm)	Feed (mm/rev)
1	-0.02021	0.09970	0.12798
2	-0.08919	0.09916	0.07934
3	0.4369	0.12813	0.11967
Delta	0.52558	0.02897	0.04864
Rank	1	3	2

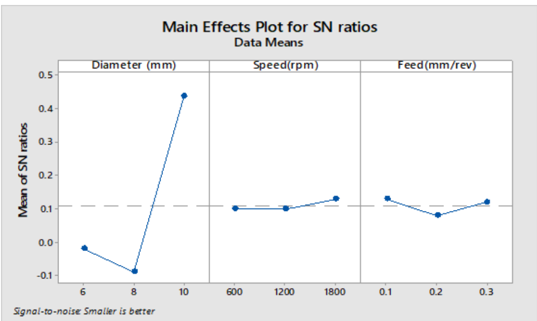

Fig 7 S/N Ratio of Delamination Factor

It is observed that from table the order of effect of input process parameters are diameter of drill bit, speed and feed. From the above table and graph, it is observed that the optimum process parameters for delamination factor are 8 mm, speed 600 rpm and feed rate is 0.2 mm/rev since the optimum S/N ratio for delamination factor smaller the better.

4.4 Grey Relation Analysis (GRA)

Grey Relation Grade are used to prepare a relation between the sequence of factor and decrease the distance between these sequences.

Normalization of different responses:

'Higher the better (HTB)' or 'Lower the better (LBT)' condition is chosen for each response based on the desired objective. For this experiment HBT and LBT were chosen for MRR and SR respectively. For HTB, For LTB the equation of normalization is

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

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

Where y_i (k) is the **ith** normalized response value and x_i (k) is observed value for the **ith** run of the **kth** response.

- ***Grey Relation Coefficient (GRC):***

Grey Relation coefficient ξ_i (k) is finding by using the following expression

$$\zeta_i(k) = \frac{\Delta_{\min} + \zeta_i \Delta_{\max}}{\Delta_i(k) + \zeta_i \Delta_{\max}}$$

- ***Grey Relation Grade (GRG):***

Presentation of the multi response is estimated by GRG. It is the total weighted of all the GRC'S and it is finding by the following equation

$$\gamma = \frac{1}{n}\sum_{i=1}^{n} \zeta_i(k)$$

n = number of response parameters, ξ_i (k)is Grey relation coefficient, ϒ is the grey relation grade

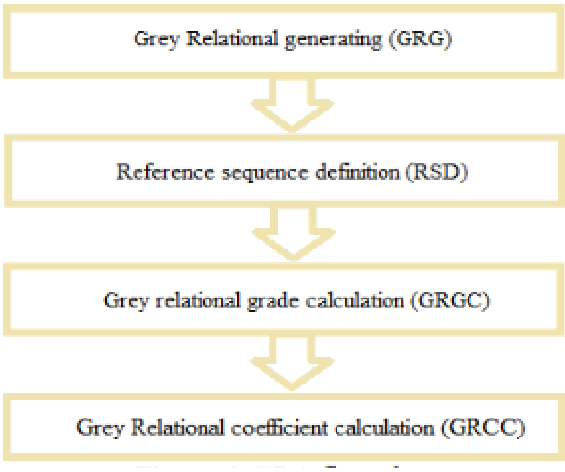

Figure 8. GRA flow chart

Table 9 Evaluation of grey relational coefficient and grade values

Exp no	Grey relation coefficient				Grey relation grade	Rank
	MRR (mm^3/sec)	Ra(μm)	circularity	Delamination		
1	0.66	1.0	0.3	0.40	0.610	3
2	0.38	0.7	0.5	0.37	0.512	7
3	0.50	0.5	1.0	0.39	0.609	4
4	0.37	0.37	0.5	0.33	0.405	9
5	0.56	0.51	0.7	0.36	0.540	6
6	0.40	0.38	0.4	0.37	0.411	8
7	0.48	0.77	0.4	1.00	0.684	1
8	0.41	0.45	0.3	0.94	0.570	5
9	1.0	0.3	0.4	0.97	0.670	2

According to performed experiment design, it is clearly observed from Table No 9 that the 'drilling process parameters' setting of experiment no. 7 has the highest grey relation grade. Thus, the seventh experiment gives the best multi-performance characteristics among the 9 experiments

4.6 AHP *Methodology*

There are four (4) steps of calculation that are considered in AHP and these are

1. Construction of Structural Hierarchy
2. Construction of Comparative Judgments (Pair-Wise Comparison Matrices)
3. Weight Determination through Normalization Procedure

4.7 Synthesis of Weight and Consistency Test

		Ranks
MRR	1.64696603	2
SR	0.35590538	3
COH	1.80354262	1
DF	0.33826724	4

Fig 9 Ranking Matrix in AHP Process

Conclusion

In this experimental work of drilling operation for natural fabric composite material the process parameters Diameter of drill bit (D**)**, Spindle speed(N), Feed rate(f) are considered as variables.

- The maximum Material Removal Rate is occurring for, when input parameters are diameter of drill bit 10 mm, speed 1800 rpm and feed rate is 0.3mm/rev
- The minimum Surface Roughness is occurring for, when input parameters are diameter of drill bit 8 mm, speed 1800 rpm and feed rate is 0.2mm/rev.
- The minimum Circularity of Hole is occurring for, when input parameters are diameter of drill bit 10 mm, speed 600 rpm and feed rate is 0.1mm/rev.
- The minimum Delamination Factor is occurring for, when input parameters are diameter of drill bit 8 mm, speed 600 rpm and feed rate is 0.2 mm/rev.

Using grey relation analysis parameters are optimized for selected performance measures namely material removal rate, surface roughness, circularity of hole and delamination factor table gives the GRG for various sets

From the table 3 and 9 it can be observed that diameter = 10 mm, spindle speed = 600 rpm, feed rate = 0.3 mm/rev at which performance measures are optimum. At these optimum parameters, the performance measures MRR = 235.5(mm3 /sec), surface roughness = 9.2 (μm), circularity of hole = 0.1509 and delamination factor = 0.950.

MADM analysis is carried out to study each parameter influence on selected performance measures. Fig 9 gives the MADM analysis. From this figure it can be illustrated that circularity of hole has more preference than followed by Material Removal Rate, Surface Roughness and Delamination Factor.

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