

Optimization of process parameters in drilling of fibre hybrid composite using Taguchi and grey relational analysis

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Abstract. Nowadays quality plays a vital role in all the products. Hence, the development in manufacturing process focuses on the fabrication of composite with high dimensional accuracy and also incurring low manufacturing cost. In this work, an investigation on machining parameters has been performed on jute-flax hybrid composite. Here, the two important responses characteristics like surface roughness and material removal rate are optimized by employing 3 machining input parameters. The input variables considered are drill bit diameter, spindle speed and feed rate. Machining is done on CNC vertical drilling machine at different levels of drilling parameters. Taguchi's L16 orthogonal array is used for optimizing individual tool parameters. Analysis Of Variance is used to find the significance of individual parameters. The simultaneous optimization of the process parameters is done by grey relational analysis. The results of this investigation shows that, spindle speed and drill bit diameter have most effect on material removal rate and surface roughness followed by feed rate.

1. Introduction

In present days, composites processed from natural fibres are increasingly useful and preferred in the field of automotive, aircraft and construction industries. Natural fibres provide an additional advantage over synthetic fibres due to their low cost, biodegradability and eco-friendly properties. Consumption of synthetic fibre has been reduced in aircraft and military application due to high cost even though they have good mechanical properties. El Tayeb [1] has investigated and acknowledged the fact that the composites reinforced with natural fibres and polymer matrices have better mechanical properties. Malkapuram et al. [2] studied the adhesion between the fibre and matrix surface and concluded that the mechanical properties can be improved by chemical modification methods and novel processing techniques. Various natural fibres like jute, flax, sisal, kenaf, abaca and acacia are used for commercial purposes [3]. An investigation shows that jute-flax hybrid composite has better tensile and shear properties than flax-fiber mono composite but flax composite is superior to hybrid composites in flexural and impact properties [4]. Srinivasan *et al* [5] have experimentally tested and proved that



hybrid composite with glass fibre reinforced composite (GFRP) have better thermal properties and also shows higher resistance under impact and flexural loading when compared to single fibre composite. Vijaya Ramnath *et al* [6, 7] have fabricated abaca-jute hybrid composite and evaluated various mechanical properties. They concluded that hybrid natural fibre composites have better tensile, flexural, impact and shear properties when compared with mono fibre composite. Wong *et al* [8] has studied the fracture characteristics of short bamboo fibre reinforced polyester composite and concluded that fracture toughness of all types of composites are higher compared to mere polymer composite. Koenig *et al* [9] has studied the various factors affecting machining of FRP's and concluded fibre orientation also affects machining. Teti [10] and Abrao *et al* [11] have concluded that various characteristics of composite lamination such as non-homogenous, anisotropic, high abrasiveness make them difficult to be machined. Ali *et al* [12] has performed comparative study of drilling and milling process in hole making of GFRP composites. They concluded that milling process has been more suitable than drilling at higher cutting speed and lower feed rate. Sonbaty *et al* [13] have performed the drilling operation on GFRP with twist drills of various diameters with constant rotational speeds and found that with increase in drill diameter and feed rate, thrust force and torque has been increased. Khashaba [14] has studied the influence of drilling variables and material variables on thrust force and torque and concluded that the feeds and fiber volumes have direct effects on thrust forces and torques. Ariffin *et al* [15] has performed optimization of drilling process using design of experiments on aircraft composite. It has been concluded that minimum and maximum damage length of 0.05mm and 0.44mm was obtained when performed at 3000rpm and feed rate of 80.2 mm/rev for high speed steel. Tsao and Chiu [16] have investigated the influence of cutting velocity, feed rate and drill diameters on thrust force and found that cutting velocity, feed rate are the most influential among a group of five control factors. Yang *et al* [17] has conducted end milling on high purity graphite and optimized the various parameters such as cutting speed, feed rate and depth of cut. Strenkowski *et al* [18] has described a model for determining thrust force and torque in drilling. This model has been applicable for general drill geometries under various cutting condition. Hocheng and Tsao [19] have studied the effects of special drill bits on drilling induced delamination of composite material and reviewed the application of special drill bits and non-traditional machining methods and they have also concluded that the drilling thrust force varies with feed rate and has devised a feed rate strategy that avoids delamination due to high thrust force in drilling. Jin *et al* [20] has concluded that the thrust force have been influenced by thickness of drilling plates and also thrust force increases with feed rate and number of holes drilled. Marta *et al* [21] has studied drilling of carbon epoxy using one shot drill bit and the results showed the influence of tool wear and thickness of the work piece on the thrust force and torque in the drilling process. Duraoa *et al* [22] and Hocheng *et al* [23] have analyzed the effects of drilling parameters on composite plate's damage. The study inferred that lower feed rates and conservative cutting speed are most suitable for drilling of the composite plates. Jeykrishnan *et al* [24-28] have done experiments on non-traditional machining processes such as electro-discharge machining (EDM) and electro-chemical machining (ECM) and have optimized their input variables using traditional techniques like Taguchi method in obtaining the best feasible output characteristics such as material removal rate (MRR), tool wear rate (TWR) and surface roughness (R_a) in materials like steels, nickel alloys etc., and have also concluded that certain parameters like applied current, inter-electrode gap between tool and the workpiece impacts the responses, significantly.

However, the task of optimizing a particular parameter has been a tedious and time consuming process. Taguchi principles and grey relational analysis (GRA) are used nowadays to optimize the process parameters. Chen *et al* [29] has discussed the integration of Taguchi method with GRA for resolving multi-quality characteristic into grey relational grades and obtained the results by comparing these grades. Tzeng *et al* [30] has made use of Taguchi method and GRA to optimize the input parameters for CNC turning process and concluded that the depth of cut (DOC) and cutting speed has the maximum influence on roughness and roundness. Hasani *et al* [31] has performed GRA to find optimum process parameters in end spinning process of yarns and concluded that rotor diameter has

most significant impact. Upinderkumar and Deepak Narang [32] have optimized the cutting parameters in high speed turning by GRA. They have employed Taguchi method and analysis of variance (ANOVA) for individual character optimization in the machining of medium carbon steel in dry conditions while varying the different input characteristics like cutting speed, feed and depth of cut for obtaining the optimal values of surface roughness and material removal rate (MRR). Sardinias *et al* [33] has performed a genetic algorithm (GA) based multi objective optimization technique on cutting parameters in turning process. The results were analyzed for various production conditions and also discussed the advantage of multi –objective optimization approach. Hassan *et al* [34] have used Taguchi's L27 orthogonal array (OA) for optimizing MRR in turning process and concluded that MRR was affected by cutting speed and feed rate, significantly.

2. Materials

Natural fibres are substances produced by plants and animals and they are environment friendly. The added key advantages are their strength, high stiffness to weight ratio, acoustic isolation, high damping and rapid production. The following natural fibers namely jute and flax have been used in this work.

2.1 Jute fibre

Jute which is called as “The golden fibre” mainly because of its colour and high cash value comes under the family name of Sparrmanniaceae. Jute fibres are 100% bio-degradable and recyclable. They are environmental friendly. They are the 2nd most available vegetable fibre. They also have good tensile strength and low extensibility.

2.2 Flax fibre

Flax is biologically named as *Linum Usitatissimum* belong to the family called Linaceae. Flax fibres are thermo regulating, non-allergenic, antistatic and anti-bacterial.

2.3 Glass Fibre Reinforced Polymer (GFRP)

They are made up of strands of silica glass fibre. Glass fibres have high strength, light weight, good resistance, low maintenance and high durability. They also have high strength to weight ratio. The main function of GFRP is to protect the fibre from atmosphere moisture.

2.4 Resin and Hardener

The main purpose of Resin and Hardener are to bind various layers of fibre. Epoxy resins have excellent mechanical strength, resistance to heat, adhesive strength and low curing contraction. These resin and hardener are used at room temperature to achieve better results. Epoxy LY558 Resin and Araldite HY951 hardener are used for fabrication of composite in this work.

3. Fabrication of composite

Hand layup process is used to fabricate Jute Flax based GFRP composite. Initially, the fibres are allowed to dry in sunlight for complete removal of moisture. Combing is done to separate small flakes present in jut fibre. A releasing agent (Poly Vinyl Alcohol) is spread over flat surface of mold for easy removal of composites. Resin hardener mixture is applied between layers of fibers for binding purpose. GFRP is used as laminate on outer side of composites so that it covers the composites on both sides. Here, the jute fibers are arranged in vertical orientation and flax fibers are arranged at 45° to jute fiber. The composite consists of 5 layers of fibers at different orientation as shown below.

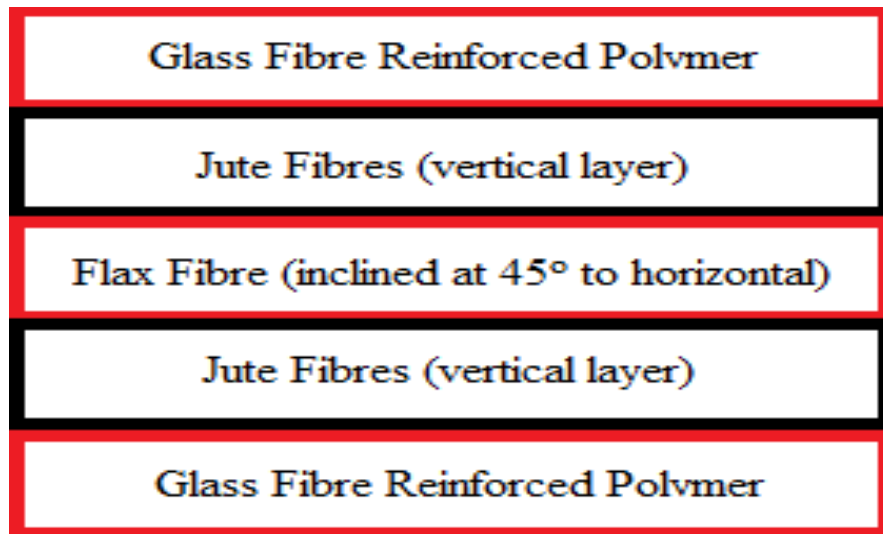


Figure 1. Schematic diagram of Jute+Flax+GFRP composite

4. Experimental setup

4.1 Machining setup

In this work, a hole was drilled on hybrid composite laminate. The following machines are used for drilling and also for measuring R_a .

4.1.1 Drilling machine

In this work, drilling was done on a vertical CNC machine, BMV TC24 manufactured by BFW as shown in figure 2. Initially, test drill was performed to ensure that the work piece is clamped properly. The drill was performed under varying combination of cutting parameters namely drill bit diameter, spindle speed and feed rate. The drill bit was made up of K20 Carbide.



Figure 2. CNC drilling machine

4.1.2 Surface Roughness testing machine

Surface roughness was measured using Surfcontour-1500 as shown in figure 3 has been manufactured by Zeiss THK (Tokyo Seimitsu, Japan). In order to achieve good results, the measurement was carried out at a speed of 0.3mm/s for a length of 4mm.



Figure 3. Surfcontour-1500

4.2 Measurement procedure

The following machined work piece parameters are considered in this work.

4.2.1 Material removal rate (MRR)

The rate at which the material is removed from the work piece is termed as Material Removal Rate. It depends on Diameter of drill (D), speed of the spindle (N), feed rate (f_r). Though high MRR rate reduces the cost of production and also the machining time, it increases the rate of tool wear as well as surface roughness. MRR is calculated from the formula as shown in eqn 1.

$$MRR = (\pi D^2 / 4) (N * f_r * 60) \quad (\text{mm}^3/\text{sec}) \quad (1)$$

4.2.2 Surface roughness

Surface roughness is defined as the degree of waviness present on the surface of the machined material. If the surface finish is good, the machined material is said to have a smooth surface. It is measured either in R_a or RMS. R_a is called as arithmetic mean roughness value. Since, the machined surface must have better finish, this work prefers the smaller values of surface roughness.

5. Optimization of machining parameters

5.1 Design of Experiment

Taguchi method is mainly used to study the effect of all the parameters with minimum possible number of experiments. Initially, a proper orthogonal array must be selected based on the number of parameters. Since, this work is aimed to analyze the effect of machining parameter more accurately, signal to noise ratio are calculated. The contribution of each parameter can be clearly obtained using ANOVA method.

5.2 Taguchi approach

Taguchi approach is a statistical method. The experiments were performed using Taguchi approach which is used to investigate the effect of different parameter affecting the mean and variance of a process performance characteristic that define the outcome of the product with less number of experiments.

There are 3 quality characteristic of Signal-to-Noise ratios for an optimization problem:

(I) Smaller the better

$$SN_s = -10 \log (\Sigma y^2/n) \quad (2)$$

(II) Larger the better

$$SN_L = -10 \log (\Sigma (1/y^2)/n) \quad (3)$$

(III) Target the better

$$SN_T = 10 \log (\bar{y}^2/s^2) \quad (4)$$

Where,

SN	- Signal to Noise ratio
n	-Number of observation in a trail
y	- Observed value of the response
$\bar{y}$	- Average of observed value

Since, this work mainly focuses on finding the optimum parameters that are required to achieve maximum material removal rate and minimum surface roughness, the quality characteristic namely Larger the better and Smaller the better are used. In this work, multi-performance optimization of process parameters are also performed using GRA.

6. Experimental plan and details

Table 1. Levels and process parameters

Symbol	Drilling Parameter	Level 1	Level 2	Level 3
D	Drill bit Diameter (mm)	6	8	10
N	Spindle speed (rpm)	600	1200	1800
F _r	Feed rate (mm/rev)	0.1	0.2	0.3

Three major factors that are affecting the material removal rate and surface roughness are selected and each factor is designed to have three different levels to perform the process of optimization. The parameters and their levels are shown in table 1. After reducing the number of experiments with Taguchi method, statistical method ANOVA and GRA are applied to find optimal process parameter for drilling.

Table 2. Design of experiment and calculation

EX. No	D (mm)	N (rpm)	f _r (mm/rev)	MRR(mm ³ /sec)	Ra (μm)
1	6	600	0.1	28.26	7.68
2	6	1200	0.2	113.04	10.052
3	6	1800	0.3	254.34	6.472
4	8	600	0.2	100.48	10.576
5	8	1200	0.3	301.44	4.749
6	8	1800	0.1	150.72	4.418
7	10	600	0.3	235.5	8.31
8	10	1200	0.1	157	7.012
9	10	1800	0.2	471	9.178

Table 2 shows the calculated value of MRR and surface roughness for all the experiments conducted based on L9 orthogonal array. These found values are analysed to find the optimal machining condition.

7. Results and discussion

In drilling process, the material removal rate and surface roughness are important features. In order to find the factors which significantly affect them, ANOVA method is used. Response table shows the optimum condition of machining.

7.1 Effect of process parameter on material removal rate

Table 3 and 4 shows the ANOVA and response table for MRR. It can be seen from the relation that MRR is directly depends on all the three parameters. Table 3 shows the amount of contribution of each parameter on MRR. From table 3, it is seen that the speed contributes about 31.75%, while the diameter of drill and the feed rate has approximately equal amount of contribution. Response table 4 ranked the parameters based on their contribution.

Table 3. ANOVA table for mean of MRR

Source	Degree of Freedom (DF)	Sum of Squares (SS)	Mean of Squares (MS)	F-test	P-test	Contribution (%)
D	2	37797	18899	1.95	0.339	27.159
N	2	44186	22093	2.28	0.305	31.750
F _r	2	37797	18899	1.95	0.339	27.159
Error	2	19386	9693			13.930
Total	8	139167				

Table 4. Response table for MRR

Level	Drill bit Diameter	Spindle speed	Feed rate
1	131.9	121.4	112
2	184.2	190.5	228.2
3	287.8	292	263.8
Delta	156	170.6	151.8
Rank	2	1	3

From table 4 and table 1, it is concluded that the optimal machine settings for maximum MRR are drill bit diameter 10 mm, spindle speed 1800 rpm and feed rate 0.3 mm/rev.

7.2 Effect of process parameter on surface roughness

Table 5 and 6 shows the ANOVA table and response table for surface roughness. It can be seen from the table 5 that the feed rate has the major contribution among the three parameters of 64.81%. It is also clear that the drill diameter does not play a significant role in the outcome of surface roughness.

Table 5. ANOVA table for surface roughness

Source	DF	SS	MS	F	P	C
D	2	4.735	2.368	4.72	0.175	12.547
N	2	7.54	3.77	7.51	0.117	19.978
fr	2	24.462	12.231	24.38	0.039	64.816
Error	2	1.004	0.502			2.659
Total	8	37.741				

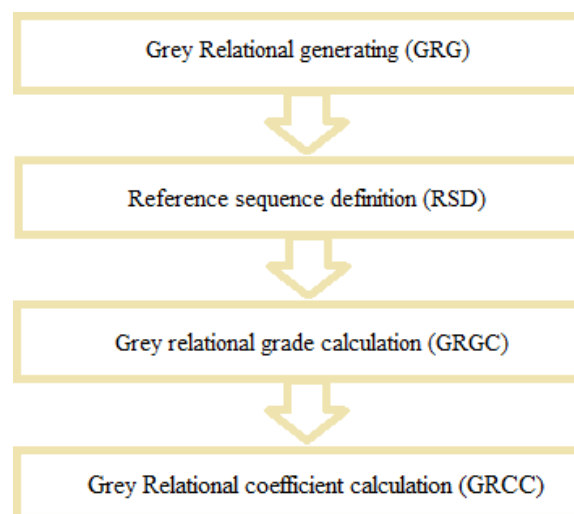
Table 6. Response table for surface roughness

Level	Drill bit Diameter	Spindle speed	Feed rate
1	8.068	6.855	6.37
2	6.581	7.271	9.935
3	8.167	6.689	6.51
Delta	1.586	2.166	3.565
Rank	3	2	1

From table 6 and table 1, it is concluded that the optimum machine settings for getting good surface finish are drill bit diameter of 8mm, spindle speed of 1800 rpm and feed rate of 0.1 mm/rev.

8. Grey relational analysis

Since, the experimental results are not unique and optimum, grey relational analysis (GRA) is employed to find the unique optimal machine setting. GRA uses a specific concept of information where situation with zero information is called as black and concept with required information called as white. Situation between these extremes are termed as Grey. In GRA, the quality characteristic are first normalized ranging from zero to one in which zero being the worst condition and one being the best condition. The procedure of GRA is shown in figure 4 as flow chart.

**Figure 4.** GRA flow chart

The S/N ratio, GRG and GRGC are calculated for each experiment and furnished in table 7. In this paper the distinguishing coefficient was set at 0.5, from which the required grey relation coefficient can be calculated.

Table 7. Grey relational analysis calculations

Ex. no.	Mean Values		S/N ratio		GRG		GRGC	
Xo	MRR	Ra	MRR	Ra	MRR	Ra	MRR	Ra
1	28.26	7.68	29.02	-17.707	0	0.47	0.33	0.49
2	113.04	10.052	41.06	-20.045	0.19	0.085	0.38	0.35
3	254.34	6.472	48.11	-16.221	0.51	0.666	0.51	0.6
4	100.48	10.576	40.04	-20.486	0.16	0	0.37	0.33
5	301.44	4.749	49.58	-13.532	0.62	0.946	0.57	0.90
6	150.72	4.418	43.56	-12.905	0.28	1	0.41	1
7	235.5	8.31	47.44	-18.392	0.47	0.368	0.48	0.44
8	157	7.012	43.91	-16.917	0.29	0.579	0.41	0.54
9	471	9.178	53.46	-19.255	1	0.227	1	0.39

Table 8 shows the grey relational coefficient calculated after giving equal weight age to each parameter. S/N ratio was calculated for the mean of GRG and they are ranked based on larger being the best.

Table 8. Grey relational grade calculation

Ex. No.	GRGC		Grade		Rank
	MRR	Ra	Mean	S/N ratio	
1	0.33	0.49	0.41	-7.76	7
2	0.38	0.35	0.37	-8.69	8
3	0.51	0.60	0.55	-5.15	4
4	0.37	0.33	0.35	-9.03	9
5	0.57	0.90	0.73	-2.68	1
6	0.41	1.00	0.70	-3.04	2
7	0.48	0.44	0.46	-6.69	6
8	0.41	0.54	0.48	-6.41	5
9	1	0.39	0.70	-3.14	3

8.1 Combined influence of the process parameter

Table 9 and 10 are made after the process of converting multi objective into single objective result. Table 9 represents the ANOVA for the mean of grey relational grade which shows that the maximum contribution among the three parameters is the speed at which the spindle is working which accounts about 49.02%. The next most influencing factor is the diameter of the drill bit which is 20.61%. The response table 10 shows the overall ranking of all the three parameter and their amount of influence.

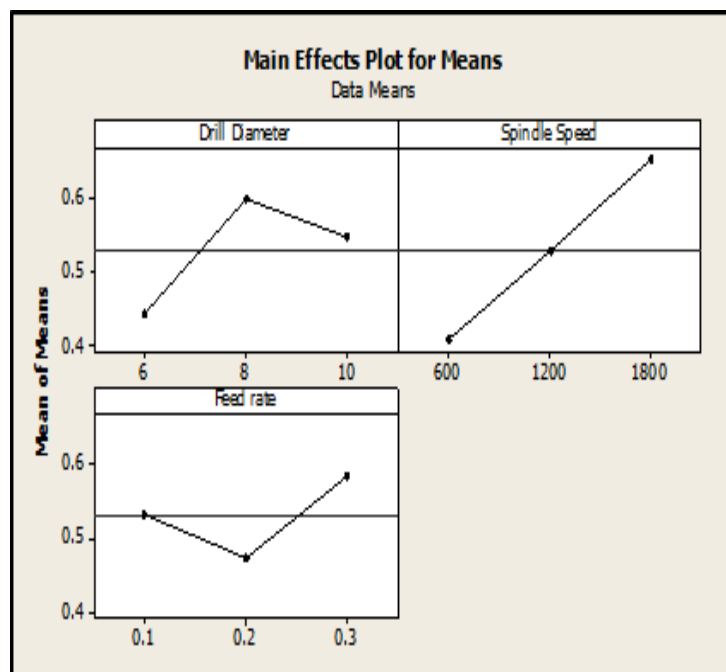
Table 9. ANOVA for mean of grey relational grade

Source	DF	SS	MS	F	P	C
D	2	0.037	0.018	1.03	0.49	20.61
N	2	0.088	0.044	2.45	0.29	49.02
F _r	2	0.018	0.009	0.51	0.66	10.25
Error	2	0.035	0.018			20
Total	8	0.179				

Table 10. Response table for means of grey relational grade

Level	Drill bit Diameter	Spindle speed	Feed rate
1	0.443	0.409	0.531
2	0.598	0.527	0.473
3	0.546	0.651	0.584
Delta	0.154	0.242	.111
Rank	2	1	3

From table 10 the optimum process parameter to have maximum MRR and minimum surface roughness are drill bit diameters 8mm, spindle speed 1800rpm and feed rate 0.3mm/rev.

**Figure 5.** Main effects plot for means

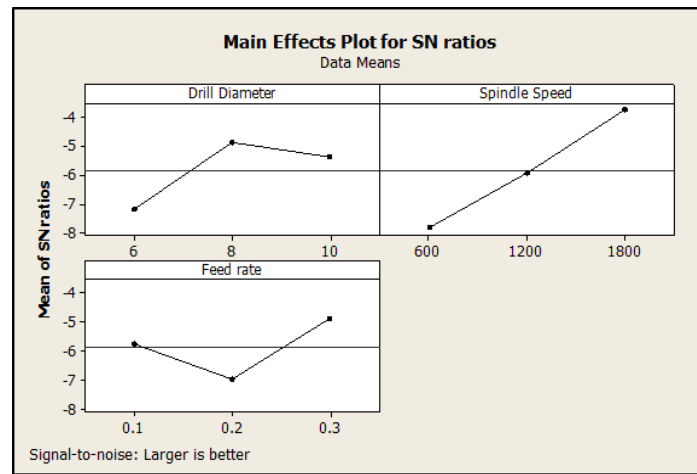


Figure 6. Main effects plot for SN ratio

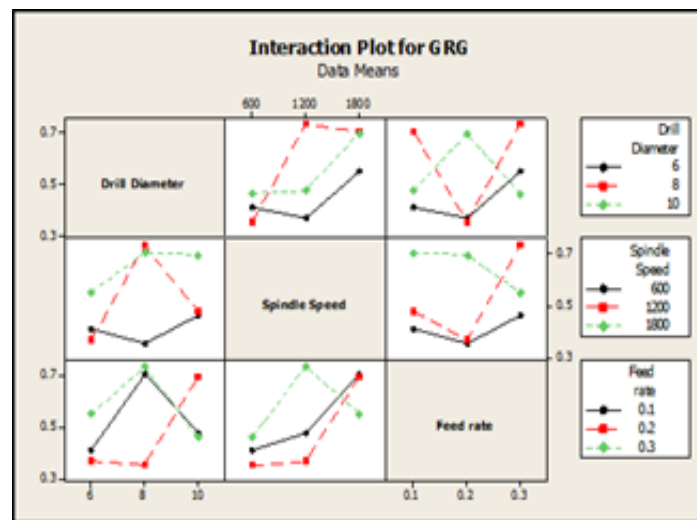


Figure 7. Interaction plot for grey relational grade

8.2 Main effects plots and interaction plot

A “main effect” is the effect of one of the selected independent variable on the dependent variable, ignoring the effects of all other independent variable. Figure 5 shows the main effects plot for mean and figure 6 shows the main effects plot for S/N ratio. S/N ratio is always high at optimum condition. So, from the figure 7 it can be seen that the optimum combination is diameter 8mm, spindle speed 1800 rpm and feed rate 0.3 mm/rev.

An interaction is present when the combined effect of two or more factors is bigger or smaller than the sum of their individual effect. It means that the factors are affecting each other as well as the product of process performance. This Interaction plot of grey relational grade and the three process parameters which are considered is clearly shown in the figure 6.

9. Conclusion

In this work, the three machining parameter like drilling, spindle speed, feed rate and their interactions are evaluated using ANOVA and also with GRA. The following conclusions are arrived in this study;

Spindle speed contributes more for MRR and surface roughness than the other two parameters. MRR increased with drill diameter, feed rate and spindle speed.

The influence of drill bit diameter is very less when compared to the feed rate for surface roughness. GRA is used to find combined output and optimum machine setting.

By GRA, it is found that drill diameter of 8 mm, spindle speed of 1800 rpm and Feed rate of 0.3 mm/rev should be preferred in drilling of Jute –Flax fibre reinforced composite for getting optimum MRR and surface roughness.

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