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Optimization of Drilling Parameters for GFRP Composite Using Taguchi method

Abeer S. Eisa

Lecture, Production Engineering & Mech. Design Dept., Faculty of Engineering, Menoufiya University, Egypt.
Drabeer78@yahoo.com

Abstract: ***The surface roughness (Ra) and delamination factor (df) are vital problems in any drilling operation of (GFRP) Composite materials. These elements cause structural integrity reduction and poor assembly as well as the potential for long-term performance deterioration. In this research, the optimization of drilling parameters using Taguchi technique, to obtain minimum both of surface roughness (Ra) and delamination factor (df). ANOVA uses to analyze the data obtained from the experiments and determine the optimal parameters in the drilling of GFRP composite materials.***

The results of these techniques revealed that; the delamination factor (df) increases with the increase of drilling speed (2250rpm-2750rpm) and increases with the feed rate (100mm/min to 125mm/min). Increasing the drilling speed and reducing feed rate can reduce the delamination factor (df) and the use of high feed rate and high spindle speed can be increasing the delamination factor (df) within limits of specified speed and feed rates. Feed rate is the more influential factor on delamination than the other parameters. The results for very low feed rate i.e. 25mm/min and high drilling speed 2750 rpm show an obvious decrease in surface roughness (Ra). Feed rate and drilling speed are the more influential factors on surface roughness (Ra) than the other parameters.

Keywords: Optimization, Taguchi Method, ANOVA, Composite Materials, GFRP, Delamination, Surface Quality, Machining processes, Fiber orientation.

1. Introduction

Polymer matrix composites (PMCs) are one of the widely known composites because of their superior properties such as high strength, stiffness, and corrosion resistance. GFRPs are strong and light, showing resistance characteristics like metallic materials. Also, it is widely used in different fields such as automotive, aircraft, aerospace and oil industries due to their specific properties.

For most purposes, which GFRPs is used, drilling is one of the widely used machining processes. Drilling of composite materials is a difficult task due to the number of problems, such as surface delamination, fiber pullout associated with the characteristics of the material and the cutting parameters that appear during the machining process.

Surface roughness has a great influence on the functional properties of the product. It is an important aspect of mechanical engineering design depending on the application of the component in usage. Friction, wear and power transmission depends on PMCs material surface and contact environment and due to the stress condition, precision fits, smooth motion, etc.

Finding the rules that how the process and environment factors affect the values of surface roughness will help to set the process parameters of the future and then improve production quality and efficiency. Therefore, optimization methods are considered being a very important tool for continual improvement of output quality in processes and for obtaining high product quality. Also, to control and optimize several drilling parameters. Taguchi method is a tool of finding the best combination of an input (cutting parameters, cutting condition, workpiece and cutting tool material properties) for producing a high quality of product and services. In addition, it is used on developing the design of the manufacturing process for creating high quality product compared to statistical process control that tries to control the factors that affect the product quality. The optimization of process parameters; feed rate, cutting speed, tool point angle and chisel edge width in the drilling of glass fiber reinforced polymer (GFRP) composites using Taguchi method is presented in the work of Vinod Kumar Vankanti, Venkates warlu Ganta [1]. An L9 orthogonal array is used to study the influence of various process parameters on the resultant hole quality. The significance of each parameter on drilling is determined by the analysis of variance (ANOVA) test. From the results of this work, it is obvious that feed rate is the most significant factor influencing the thrust force followed by speed, chisel edge width, and point angle .Also, the optimum process parameters of the used range in the drilling of GFRP composites are; the speed of 500 rpm, the feed rate at 0.04 mm/rev, point angle at 90◦ and chisel edge width of 0.8 mm for thrust force. But for torque; speed at 500 rpm, feed rate of 0.06 mm/rev, point angle at 95◦ and chisel edge width of 1.6 mm are found to be optimum values. In addition, Sumesh A S, Melvin Eldho Shibu [2] conducted work to optimize the process parameter such as cutting speed, feed, and drill diameter by using Taguchi methods. This technique is using to obtain minimum surface roughness (Ra) of the drilled hole when used HSS twist drills. To determine the most significant control factors affecting the surface roughness, the Analysis of variance (ANOVA) is also used. The cutting parameters such as cutting speed, feed rate and drill diameter are select as a control factor. The drilling parameters are optimizing with respect to multiple performances to achieve a good quality of drilled holes and after nine experimental trials that, the drill diameter is the most significant factor for the surface roughness. From the analysis, it is identified that a spindle speed of 80 rpm, drill diameter of 4mm and a feed rate of 0.1 mm/rev is the optimal combination of drilling parameters that produced a high value of S/N ratios of hole roughness. In addition to the previous works, G. Srikanth Reddy, Ranjith Kumar [3] presented an experimental investigation to optimize process parameters in drilling operation of composite materials. The influence of tool point

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angle, spindle speed and feed rate on material removal rates are study and analyzed. Drilling operations are conduct on the carbon fiber with 6.5 and 10.2mm diameter drills (118° and 120°-point angles) with different cutting parameters. The input parameters, which considered are; 6.5 and 10.2mm diameter drill bits with 118°- and 120°-point angles, spindle speeds 1000, 1500 and 2000rpm with feed rate 30mm/min. Different combinations from the above parameters are used to get the maximum value of MRR. From the analysis of this work, the time taken for drilling is less for 1180 and 6.5mm diameter drill and the stresses are more for 1200 angle and 6.5mm diameter drill. The material removal rate is increasing with the increase of the drill diameter and spindle speed. İlknur Çavuşoğlu, et al. [4] conducted a workshop on the optimization of drilling parameters of glass fiber reinforced plastics via Taguchi method. In this work, the analysis and evaluation of the delamination factor is investigating in the GFRP using high precision metrology techniques. The optimum values with the minimum of delamination are determined by using Taguchi DoE. Consequently, with these values in all sectors use of free of damage and delayed damage will be achieved. Rajiv Chaudhary, et al. [5] conducted a workshop to study the critical constraints such as surface roughness, tolerances and nominal size for the selection criteria of the parts. Whereas the Taguchi method systematically reveals the complex, cause and evolves the relationship between design parameters along with taking consideration of performance. When using Taguchi technique, the significant factors are developed such as optimum machining conditions and improving performance characteristics. In addition, the multiple performance characteristics such as tool life, cutting force, surface roughness as well as the overall productivity can be improving. From the results, it is essential to determine the optimal cutting conditions for a given tool–workpiece combination. From the analysis, the used of large cutting speeds with smaller feed rate, good surface quality along with dimensional accuracy can be achieved. Amarnath R. Mundhekar, et al. [6] presented a work on optimization of drilling process by studying the influence of various drilling parameters (spindle speed, feed rate, drill diameter, drill point angle, etc.) on the performance parameters (surface roughness, material removal rate, thrust force, etc.) during drilling process. The relationship between the input process parameters and the output responses is studied to optimize the process parameters. The main object of this work is to determine the region of critical process control factors. These factors are; drill diameter, material thickness and the drill point angle. This leads to desired output or responses with acceptable variations that will ensure a low cost of manufacturing through optimization. Also, this may be used to face the challenge of higher productivity and quality of the product. Bala Swapna, et al. [7], investigates the optimization of drilling parameters for minimum surface roughness using the Taguchi method. From the present work, the effect of input parameters on the MRR, surface roughness, hole diameter error, burr height is studied and analyzed. It is obvious that MRR is mainly influenced by cutting speed and drill diameter. The surface roughness is mainly influenced by drilling material, drill diameter and cutting speed. Nevertheless, the burr height is affected mainly by feed rate and cutting speed. The Optimization of drilling process parameters on surface roughness and material removal rate by using the Taguchi method is presented by S.V. Alagar Samy, et al. [8]. This method is used to investigate the effects of drilling parameters such as cutting speed, feed rate and depth of cut on the resultant surface roughness and material removal rate in drilling and to find the optimal cutting parameters. A series of experiments based on L16 orthogonal array are conducting using CNC vertical machine. To determine the most significant control factors affecting the surface roughness and material removal rate, the analyses of variances is employed. For MRR, Analysis of Variances (ANOVA- S/N ratio) indicated that the depth of cut is majorly contributing of about 56.96% in obtaining optimal MRR followed by feed rate 20.11% and depth of Cut 3.56%. But for surface roughness, ANOVA clearly indicated that the cutting speed has a large effect in obtaining optimal surface roughness (about 28.65%) followed by feed rate of (10.20%) and depth of cut of (8.12 %). K. Palanikumar [9] presented an application of Taguchi and response surface methodologies to analyze and evaluate the surface roughness in machining glass fiber reinforced plastics by PCD tooling. The design of experiments has been conducted using Taguchi's experimental design technique. The influence of cutting process such as; cutting speed, feed rate and depth of cut on the resultant surface roughness is evaluated and the optimum cutting condition for minimizing the surface roughness is determined. Also, a second-order response surface model for surface roughness has been developed from the observed data. From the analysis of the results, the most significant machining parameter for surface roughness is feed rate followed by cutting speed. The developed model can be effectively used to predict the surface roughness in the machining of GFRP composites. Verification test results revealed that the determined optimal combination of machining parameters satisfy the real requirements of a machining operation in the machining of GFRP composites. Murthy B.R.N., et al. [10] presented a work to optimize the effect of process parameters such as spindle speed, feed rate, drill diameter, tool point angle, and material thickness on the generated thrust force and torque during drilling of Glass Fiber Reinforced Polymer (GFRP) composite material using solid carbide drill bit. Full Factorial Design of Experiments (DOE) has been adopted and the results indicated that, the spindle speed is the main contributing parameter for the variation in the thrust force, but drill diameter is the main contributing factor for variation in torque. It must be noticed that the results in this work are based on the preselected range values of; spindle speed, feed rate, material thickness, drill diameter and drill point angle, and therefore, the inferences drawn cannot be completely generalized. From the analysis, the thrust force is significantly influenced by spindle speed, and they are inversely proportional. Due to the use of a bigger drill diameter, the thrust force increased, and the cutting torque is significantly influenced by drill diameter. It

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is obvious from the results that, the thrust force and cutting torque are increased with the increase in feed rate and the material thickness. The used methods indicated the values of response, through which, process parameter selection.

Ahmet Can, Ali Ünüvar, [11] presented workshop on the optimization of process parameters in the drilling of SMC composites using the Taguchi method to discuss the machinability in the drilling of SMC (Sheet Mold Compound) A-Class composite materials. The studied objects are; the thrust forces, surface roughness and push-out - peel-up delamination behavior in drilling process. In addition, ANOVA is used to evaluate the effect of the different parameters on machinability outputs of drilling process. The optimum parameters show a reduction in thrust force by 9,8 %, surface roughness by 33,3 %, push-out delamination by 2,5 % and peel-up delamination by 1,38 %.

Kilickap E. [12] studied the influence of the cutting parameters, such as cutting speed, feed rate and tool point angle on the delamination produced when drilling a GFRP composite. The damage generated associated with drilling GFRP composites is observed, at both the entrance and the exit during the drilling. The results indicated that the feed rate and the cutting speed are the most influential factors on the delamination respectively. The evaluation of the surface roughness and geometric accuracies in the drilling process performed using U-drills without a pilot hole is presented by Evren Kabakli, et al, [13]. For evaluating the effects of; the feed rate, peripheral speed, hole diameter and hole depth, the response parameters which studied are the surface roughness, perpendicularity and cylindricity. The performance characteristics and various signal-noise ratios are calculating with the Taguchi method. To identify the optimum drilling conditions for U-drills, ANOVA is performed and the effects of the controlled factors at different levels are analyzed. From the results, the hole diameter and the feed rate have a large effect on the resultant surface roughness of the drilled hole. The hole diameter plays a vital role in the resultant surface roughness. The perpendicularity also is influenced by the hole diameter and feed rate with the percentage contributions of 9.70 % and 11.31 %. Also, the most important variable affecting the perpendicularity is the hole depth with a percentage contribution of 75.18 %. This analysis of the results confirmed that, with the optimum parameter combination selected with the Taguchi design, the desired performance characteristics could be achieved in actual drilling conditions. The optimization of drilling parameters using Taguchi method to obtain minimum surface roughness and maximum tool life is presented in the paper of Kadam Shirish, M. G. Rathi [14]. The experiments of drilling are conducted using the L9 orthogonal array on a CNC vertical machine using uncoated M32 HSS twist drills under dry cutting conditions. The cutting speed, feed rate and depth of the hole are selected as control factors and Signal to Noise (S/N) ratio are employed to optimize these factors. From the analysis of the results, better surface finish in dry drilling resulted when used high cutting speed, low feed rate and low depth of cut. V. N. Gaitonde, S. R. Karnik [15] presented a work to minimize burr size at the exit of holes in drilling at the manufacturing stage. A multi-response optimization method has been employed to determine the best combination values of; cutting speed, feed rate, tool point angle and lip clearance angle for specified drill diameters to simultaneously minimize burr height and burr thickness during drilling. To measure the performance characteristics, the experiments are planned as per L9 orthogonal array and multi-response signal to noise (S/N) ratio is applied. For determine the optimal levels and to identify the level of important parameters, Analysis of means (ANOM) and analysis of variance (ANOVA) are performed. The best combination values of process parameters for simultaneously minimizing the burr height and burr thickness at the exit of the holes in drilling are determined using Taguchi's quality loss function approach. Nevertheless, the relative significance of the process parameters is determined by ANOVA. The optimal values of cutting speed and lip clearance angle are at low level, i.e. 8 m/min and 8° respectively, for all drill diameters specified. ANOVA indicates that, tool point angle has a significant effect in reducing the burr size for 4 mm and 10 mm drill diameters. On the other side, the lip clearance angle has a major contribution in controlling the burr size for 16, 22- and 28-mm drill diameters. B. Shivapragash, K. Chandrasekaran [16], presents the use of Multiple Response Optimizations in the drilling using Taguchi and Grey Relational analysis. The main object of this work is to minimize the damage events occurring during the drilling process for Al-TiBr2 composite when used radial drilling machining with dry conditions. To optimize the machining parameters with multiple performance characteristics in the drilling of MMC Al-TiBr2, Taguchi method with grey relational analysis are used. From the analysis of the results, the optimum cutting parameters for minimization surface roughness are spindle speed (low level -1000 rpm), feed rate (maximum level -1.5 mm/min) and depth of cut (middle level - 6 mm).

Based on the previous literature review there are big variations between the results and the conclusions of most researches and need more investigations to understand the defects of drilling glass fiber reinforced plastics (GFRPs) accurately.

The present research is conducted on the optimization of dry drilling conditions on GFRP composite laminates. Taguchi method is used, because it is a good tool of finding the best combination of an input (cutting parameters, cutting condition, workpiece and cutting tool geometry) for producing a high quality of product and services.

The objective of the present research is to study the influence of three sets of fiber orientation angles, HSS twist drill, five feed rates and five of cutting speeds on the resultant surface roughness and delamination of drilled hole. The design of experiments has been conducted using the Taguchi's experimental design technique. The influence of cutting process on the resultant surface roughness and delamination is evaluated and the optimum cutting condition for minimizing the surface roughness and delamination is determined.

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2- Experimental Procedure

2.1-Design of experiment

Design of Experiment is a powerful approach to improve product design where it can be reduced cycle time required to develop new product or processes. In addition, the design of experiments (DoE) dictates a series of steps to follow for the experiment to yield an improved understanding of product or process performance. The independently controllable machining parameters which are having greater influences on surface roughness and delamination while drilling conditions of GFRP composite laminates are as follow, 1) drilling speed, 2) feed rate, 3) fiber orientation angles, 4) tool geometry and with fiber volume fraction ratio. These parameters and their levels are shown in Table (1).

Table (1) Parameters and their Levels.

Process parameters	Unit	1	2	3	4	5
drilling speed	rpm	750	1250	1750	2250	2750
Feed rate	mm/min	25	50	75	100	125
Volume fraction ratio	%	60	60	60	60	60
Fiber orientation angles	Degree	0/0/0/0		0/45/45/0	0/90/90/0	
Used Tools	HSS twist drill (diameter ϕ 8 mm and point angle 90°)					

3. Experimental Setup

3.1. Materials, Process Parameters and Tools

In this work, glass fiber is used as reinforcement in the form of bidirectional fabric (Standard E-Glass Fiberglass) and polyester with catalyst addition as a matrix for the composite material. The material used is a typical composite plate of dimensions (200×40×20 mm) with fiber volume fraction ratio of 60%. The specimen is constituted by four layers with different fiber orientation angles as follow; Set (1): [/0/0/0/0], Set (2): [0/45/45/0] and Set (3): [0/90/90/0]. During the manufactured of specimens, the orientation of the fibers on the workpiece has been set. The plates fabricated by hand lay-up process followed by a curing process under constant pressure. The mechanical properties of the used composite are calculated analytically using the mixture rules. The material properties presented in [17].

3.2. Drilling operation setup

The Machine, which used in drilling operations, is an Extron M218, LH, CNC Machine. The feed rate and drilling speed are controlled by a program, which was written specifically for drilling of composites. High-speed steel (HSS) tool of φ 8 mm is used for the drilling operations. The tips of the drills are ground to have drill point angles of, (90°). To prevent the effect of twist drill wear on the results of the experiments; each of them is used for drilling five holes only. The specifications of the used drilling machine presented in [17].

3.3. Surface roughness measurement and calculation of delamination factor

The machined holes are prepared for measurements and the measurements of surface roughness are perform using SJ-201P surface test. The measurements are made after the calibration of the instrument and with the cut-off length of (0.8mm) according to (ISO 4287-1997). The surface roughness of the hole is measured at entry, middle and exit of the drilled hole and the average value of surface roughness is considered for the investigation. The results of measurements are tabulated for every hole and classified all results into groups related to the following; drilling speed, feed rate and fiber orientation angles.

From [20 and21], it can be calculating the delamination factor (df) which is used to determine the extent of delamination as follows;

df = D max/D

Where:

D max = the maximum diameter created due to delamination around the hole.

And, D = the hole or drill diameter.

4. Results and Discussion

4.1.Optimization of drilling conditions of GFRP composites

When using Taguchi method, there are three categories of quality characteristics in the analysis of the S/N ratio, i.e., the – lower – better, the – higher – better, and the – nominal – better. The S/N ratio for each level of the process parameter is compared based on the S/N analysis. Regardless of the category of the quality characteristic, a greater S/N ratio corresponds to better quality characteristics. Therefore, the optimal level of the process parameters is the level with the greatest S/N ratio. In addition, the use of statistically significant with the S/N, the optimal combination of the process parameters can be predicting. Now, a confirmation experiment is conducting to verify the optimal process parameters obtained from the parameter design. The experimental design consists of three replications. 1) The term "signal" represents the desirable value, 2) Noise (represents the undesirable value), and 3) The formulae for signal – to- noise ratio [18] and [19]. It can be always select the largest factor level setting to optimize the quality characteristic of an experiment due to the designed formulae for the signal to noise ratio. Now, the Smaller-The-Better, which required in this research, is determined as follow;

The Signal-To-Noise ratio for the Smaller-The-Better is:

S/N = -10 *log (mean square of the response);

$$\zeta = -10\log\left[\frac{1}{n}\right]\sum_{i=1}^{n} y_i^2 \; ..... \; \textit{for smaller the better}$$

Where n = number of measurements in a trial/row, in this

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case, n=1, 2…, 9 and Yi is the (i th) measured value in a run/row. i =1, 2…, 25.

4.1.1. Planning for experiments

Taguchi parameters design begins with the selection of orthogonal array with the number of levels, which must use in this research. The drilling parameters, which effect on the resultant surface roughness and delamination will discuss using the analysis of variance. The orthogonal array L25 for the two responses, [surface roughness (Ra)and delamination factor (df)] is presented in Table (2).

Table (2) the orthogonal array L25.

A	B	C	D	E
1	1	1	1	1
1	2	2	2	2
1	3	3	3	3
1	4	4	4	4
1	5	5	5	5
2	4	3	2	1
2	5	4	3	2
2	1	5	4	3
2	2	1	5	4
2	3	2	1	5
3	2	5	3	1
3	3	1	4	2
3	4	2	5	3
3	5	3	1	4
3	1	4	2	5
4	5	2	4	1
4	1	3	5	2
4	2	4	1	3
4	3	5	2	4
4	4	2	5	3
5	4	5	1	2
5	5	1	2	3
5	1	2	3	4
5	2	3	4	5
5	3	2	4	5

4.2. Analysis of Variance

4.2.1. Analysis of Variance for surface roughness

Analysis of variance is a method of portioning variability into the identifiable source of variation and the associated degree of freedom in an experiment. The frequency test (F-test) is utilized in statistics to analyze the significant effects of the parameters, which form the quality characteristics. Table (3) shows the results of the ANOVA analysis of the S/N ratio for surface roughness. This analysis is carried out for a level of significance of (5%), i. e., for (95%) a level of confidence. The last column of the table shows the "percent "contribution (P) of each factor as the total variation, indicating its influence on the result.

In Table (3), the F – values of the used parameters are presented. Form this table, it is obvious that, the F – values of drilling speed, feed rate and fiber orientation angles have statistical and physical significance on the surface roughness/13/.

Table (3) Analysis of variance for surface roughness.

Source	DF	Seq SS	MS	F-Test	P
drilling speed	6	54.876	46.595	12.30	4.7
Feed rate	4	129.667	16.012	19.27	30
Volume fraction ratio	6	23.099	5.099	2.30	50
Fiber orientation angles	8	5.825	1.081	0.80	5.1
Used Tools	4	3.773	0.693	0.51	9.2
Error	2	2.699	1.350	--	7
Total	24	227.967	--	--	100

Where: DF: degree of freedom, Seq SS: Sum square, MS: Mean square and
P: Percentage of contribution.

4.2.2. Analysis of Variance for delamination

In Table (4), the F – values of the used parameters are presented. Form this table; it is apparent that, the F – values of drilling speed, feed rate and fiber orientation angles have statistical, physical significance on the delamination factor.

Table (4) Analysis of variance for delamination.

Source	DF	Seq SS	MS	F-Test	P
drilling speed	3	64.376	50.395	13.30	5.7
Feed rate	2	39.667	18.012	16.27	40
Volume fraction ratio	6	43.039	6.112	1.30	40
Fiber orientation angles	8	7.845	1.081	0.80	6.1
Used Tools	4	2.663	0.234	0.51	9.2
Error	1	3.499	1.340	--	7
Total	24	227.967	--	--	100

Where: DF: degree of freedom, Seq SS: Sum square, MS: Mean square and
P: Percentage of contribution.

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4.3. Determination of optimum factor level for surface roughness

Figure (1) shows five graphs, each represents the mean response and the mean S/N ratio for cutting speed, feed rate, fiber orientation angles and volume fraction ratio. The values in the graphs have been tabulated in Tables (5, and 6), based on the S/N ratio and ANOVA analysis. The optimum cutting conditions for surface roughness shown in Table (5) are; A2, B5, C3, D1 and E3.

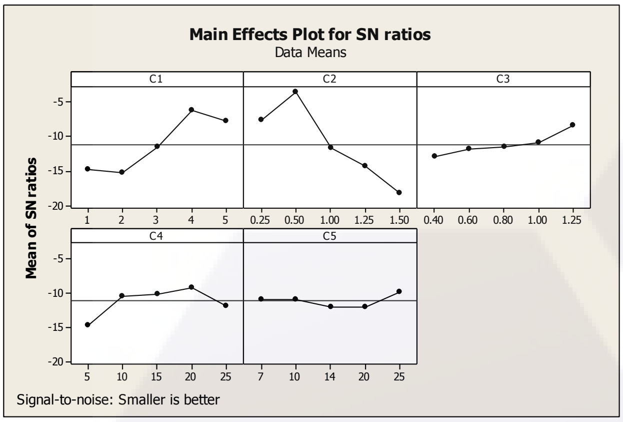

Fig. (1) Determination of optimum factor using ANOVA

Table (5) Response table for the signal to noise ratio of surface roughness (Smaller is better) (*Optimum level).

Level	Drilling speed rpm (A)	Feed rate mm/min (B)	Volume fraction ratio (C)	Fiber orientation angles (D)	Used Tools (E)
1	-14.822	-7.731	-12.952	-14.690*	-10.873
2	-15.237*	-3.629	-11.931	-10.518	10.978
3	-11.566	-11.651	-13.157*	-10.100	-12.075*
4	-6.244	-14.395	-10.911	-9.178	-12.002
5	-7.872	18.336*	-8.407	-11.828	-9.814
Delta	8.993	14.707	8.929	5.513	2.261
Rank	2	1	3	4	5

Table (6) Response table for means surface roughness.

Level	Drilling speed rpm (A)	Feed mm/min	Volume fraction ratio (C)	Fiber orientation angles (D)	Used Tools (E)
1	4.168	2.559	1.631	3.824	2.965
2	7.935	1.867	3.373	2.568	4.144
3	3.368	5.017	3.175	1.509	2.284
4	5.023	2.389	7.227	6.736	6.644
5	2.996	4.658	3.806	8.999	8.453
6			1.627		
7			7.363		
Delta	2.939	7.791	5.004	4.088	1.139
Rank	3	1	2	4	5

4.4. Determination of optimum factor level for delamination

Figure (2) shows five graphs, each represents the mean response and the mean S/N ratio for one of the used parameters. The values in the graphs have been tabulated in Tables (6, and 7), based on the S/N ratio and ANOVA analysis. The optimum cutting conditions for surface roughness shown in Table (6) are; A4, B1, C3, D5 and E2.

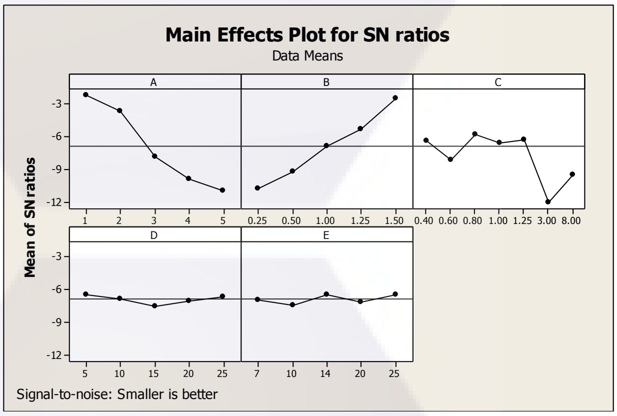

Figure (2) Determination of optimum factor using ANOVA

Table (7) Response table for the signal to noise ratio of delamination (Large is better) (*Optimum level).

Level	Drilling speed rpm (A)	Feed mm/min	Volume fraction ratio (C)	Fiber orientation angles (D)	Used Tools (E)
1	5.128	4.339*	1.631	2.444	1.335
2	3.455	1.557	2.553	1.778	3.664*
3	2.368	2.227	2.475*	1.219	1.224
4	6.223*	1.559	6.337	7.446	5.664
5	2.496	3.558	4.806	8.669*	5.113
6			1.527		
7			6.223		
Delta	2.439	1.791	4.004	4.088	1.139
Rank	2	1	3	4	5

Table (8) Response table for means delamination.

Level	Drilling speed rpm (A)	Feed mm/min	Volume fraction ratio (C)	Fiber orientation angles (D)	Used Tools (E)
1	1.245	2.559	1.631	3.824	2.965
2	8.124	1.867	3.373	2.568	4.144
3	3.12	5.017	3.175	1.509	2.284
4		2.389	7.227	6.736	6.644

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5	2.996	4.658	3.806	8.999	8.453
6			1.627		
7			7.363		
Delta	2.939	7.791	5.004	4.088	1.139
Rank	3	1	2	4	5

In Table (9) the experimental results and predicted values of surface roughness (Ra) are presented. The deviation between the experimental results and the predicted value is between (0.0 and 0.1 µm).

Table (9) Measured and predicted the surface roughness of (ANOVA) technique.

Reading number	Surface roughness of experimental (Ra)	Predicted by ANOVA	Deviation
1	1.16	1.17	-0.01
2	1.19	1.20	0.01
3	1.22	1.22	0
4	1.25	1.24	0.01
5	1.26	1.25	0.01
6	1.36	1.35	0.01
7	1.09	1.09	0
8	1.10	1.11	- 0.01
9	1.12	1.13	- 0.01
10	1.14	1.15	-0.01
11	1.15	1.16	-0.01
12	1.16	1.16	0
13	1.13	1.12	0.01
14	1.16	1.15	0.01
15	1.19	1.20	-0.01
16	1.22	1.23	- 0.01
17	1.23	1.22	0.01
18	1.16	1.17	-0.01
9	1.19	1.20	- 0.01
20	1.22	1.23	-0.01
21	1.25	1.25	0
22	1.26	1.25	0.01
23	1.34	1.35	-0.01
24	1.09	1.09	0
25	1.25	1.26	- 0.01

In Table (10), the experimental results and predicted values of the delamination are presented using (ANOVA) technique. The deviation between the experimental results and the predicted value is between (0.0 and 0.1).

Table (10) Measured and predicted delamination of (ANOVA) technique.

Reading number	Delamination experimental (df)	Predicted by ANOVA	Deviation
1	1.13	1.14	-0.01
2	1.16	1.15	0.01
3	1.19	1.20	0.01
4	1.22	1.23	0.01
5	1.25	1.25	0
6	1.34	1.35	0.01
7	1.07	1.09	0
8	1.09	1.11	- 0.01
9	1.10	1.13	- 0.01
10	1.12	1.11	-0.01
11	1.14	1.13	-0.01
12	1.12	1.13	0.01
13	1.10	1.11	0.01
14	1.13	1.13	0.01
15	1.16	1.15	-0.01
16	1.19	1.20	- 0.01
17	1.22	1.22	0.01
18	1.13	1.14	-0.01
9	1.16	1.17	- 0.01
20	1.19	1.20	-0.01
21	1.22	1.22	0
22	1.25	1.25	0
23	1.22	1.21	-0.01
24	1.07	1.07	0
25	1.09	1.10	- 0.01

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5. Discussions

Taguchi technique and ANOVA are used to obtain minimum both of surface roughness (Ra) and delamination factor (df). The results obtained has been calculated and plotted as response curves when they change from one level to another and analyzed in a standard step as discussed. The response curves are the average value of the characteristic and average S/N values versus the level of drilling parameters. The response curves are used to analyze the parametric effect on selected quality characteristics.

The ANOVA identifies the significant parameters and quantifies their effect on the selected quality characteristics. The S/N response curve is used to keep in the selection of the optimal level of response process parameters for individual quality characteristics. From the previous results, the optimum values for Surface roughness (Ra) and Delamination factor (df) are presented in Table (11).

Table (11) the optimum values for Surface roughness (Ra) and Delamination factor (df).

Used parameters	Ra	df
Cutting speed rpm (A)	15.237*	6.223*
Feed mm/min(B)	18.336*	4.339*
Volume fraction ratio (C)	13.157*	2.475*
Fiber orientation angles (D)	14.690*	8.669*
Used Tools (E)	12.075*	3.664*

6. Conclusions

This research has presented the optimization of drilling parameters using Taguchi technique, to obtain a minimum of both surface roughness (Ra) and delamination factor (df). From the deep analysis of the results, it can be concluded that:

1-The analysis of experimental results is carried out using Taguchi's orthogonal array and analysis of variance. The optimum levels of the cutting parameters on the drilling induced minimum of both surface roughness (Ra) and delamination factor (df) are determined by using ANOVA.

2-The delamination factor(df) is increased with the increase of cutting speed (2250rpm-2750rpm) and increases with feed rate (100mm/min to 125mm/min).

3-The results for very low feed rate i.e. 25mm/min and high cutting speed 2750 rpm show an obvious decrease in surface roughness (Ra).

4- The higher values of delamination factor (df) at cutting speed 2750 rpm may be due to; when the drill speed increases, the thrust force increases and severe heat generation in the drilling area. As a result, fiber cutting becomes harder for the cutting edges of the drill and drilling thrust force increases further causing more delamination.

5-The higher values of delamination factor (df) at the feed rate 25 mm/min may be due to the increase of generated heat between the tool and hole wall and transferred to the laminate in the drilling area and causes local thermal destruction of the workpiece with undesirable results on delamination.

6- The results of ANOVA reveal that the feed rate is the main cutting parameter, which has the greater influence on the delamination factor.

7- Predicted values of delamination at optimized process parameters are in good agreement with the test results.

8- The feed rate is the more influential factor on delamination factor (df) than the other parameters.

9-Feed rate and cutting speed are the more influential factors on surface roughness (Ra) than the other parameters.

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