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Analysis and Optimization of Surface Roughness in GFRP Drilling Through Integration of Taguchi and Response Surface Methodology

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Abstract

The purpose of this paper is to study the effect of process parameters such as spindle speed and feed rate, drill diameter and point angle, and material thickness on the surface roughness of the drilled hole in drilling of Glass Fibre Reinforced Polymer (GFRP) composite laminate using solid carbide drill bits. Full factorial Design of Experiments (DOE) has been adopted to estimate the number of runs and the combination of independent variables for each run. The data obtained from the experimentation was analyzed using Taguchi Method. The analysis indicate that material thickness is the main contributing parameter for the variation in the surface roughness of the drilled hole compared to other parameters and the least contributing parameter is spindle speed. The analysis results reveal that, except the spindle speed, the rise in the level of the other independent parameters increases the surface roughness. But as spindle speed increases, the surface roughness decreases. The correlation between thrust force and the surface roughness is also predicted. The optimum combination of process parameter settings has been found out using the integration of Taguchi method and Response Surface Methodology (RSM).

Keywords: GFRP composite drilling, surface roughness, DOE, RSM, Taguchi method.

Introduction

In recent days fibre reinforced plastics find wide application in all manufacturing fields due to their distinct properties such as low weight, high strength and stiffness[1]. Compared to all other machining process, drilling is the widely used process in the fabrication of the composite products. The performance of these products is mainly dependant on surface quality and dimensional accuracy of the drilled hole. The quality of the hole drilled is influenced by the cutting conditions, tool material and geometry[2]. The material anisotropy resulting from fibre reinforcement considerably influences the quality of the drilled hole. Hence, precise machining needs to be performed to ensure the dimensional stability and interface quality[3]. The good surface finish is one of the aspects of quality hole. The surface roughness of the drilled hole depends on the thrust force and torque generated during drilling, which in turn is affected by the factors such as tool geometry, speed, feed etc. Good numbers of research works are conducted to investigate the influence of above listed process parameters on the surface roughness[4-10]. Many researchers are tried to minimize the surface roughness through various optimization techniques.

It is evident through these researches that significant contribution has already been made on optimization of surface roughness on the basis of specific tool or machining conditions. Further, most of the researchers have adopted either Taguchi method or RSM for optimization, but very little work has been undertaken for a combination of tool and work material using a combination of both of these methods. In the present work, the analysis and optimization has been done by using both Taguchi and Response Surface Methodology (RSM) to supplement each other for the given material and tool combinations.

Objectives of research: The main purpose of this research is to optimize the process parameters during the drilling of GFRP using Solid carbide drill, based on minimum cutting energy criterion by Taguchi method and RSM. To accomplish this purpose, the following objectives are formulated: i. Identify the process parameters, which influence the thrust force and torque in drilling. ii. Apply DOE and arrive at the number of experiments, based on full factorial design, for the given set of factors and levels. iii. Using the standard set-up, conduct the experiment and analyze the significance of influence of process parameters on thrust force and torque. iv. Optimize the process parameters using Taguchi Method and RSM and compare.

Hypothesis testing: Based on the contemporary research, a number of exogenous factors have been indentified, which are supposed to influence the surface roughness of the drilled hole. The list includes: material thickness, volume fraction of fiber, type of fiber, tool diameter, drill point angle, spindle speed, and feed rate. As the research focus is to find the significance of influence of these exogenous factors on the surface roughness of the drilled hole, the following two hypotheses have been formulated.

Ho1: There is no significant influence of exogenous factors on surface roughness.
Ha1: There is a significant influence of exogenous factors on thrust force.

Material and Methods

Machine: The experiment has been carried out on the TRIAC CNC vertical machining centre which enables high precision machining. The laminate composite specimen was rigidly held by the fixture which is attached to the dynamometer mounted on the machine table. The thrust force generated during cutting was measured with the help of KISTELER dynamometer. The data collected was transferred to a computer for analysis. Solid carbide drills have been used for the present experimental study because they offer better heat and wear resistance properties and are widely used in machining GFRP composites. The experimental set-up is shown in figure 1.

Figure-1
Experimental set-up

Work piece: Drilling experimentation has been carried out on GFRP composite material which is manufactured by hand layup method. Chopped strand mat made of E-glass fiber having the density of 2590 kg/ m^3 and modulus of elasticity of 72.5 GPa is used as reinforcement material. Matrix system consists of general purpose polyester resin [GP] and a room temperature curing accelerator catalyst is used. The hardener used is the methyl ethyl ketone peroxide (MEKP).

Table-1
Factors and levels

Factors	Levels	Output Parameter
DA (Degree)	90, 103, 118	Surface Roughness (Ra)
DD (mm)	6, 8, 10	
MT (mm)	8, 10, 12	
SPEED (rpm)	900, 1200, 1500	
FEED (mm/min)	75, 110, 150	

Required numbers of mats were stacked to give the intended thickness (variable) and the weight fraction of the composite is (0.44), which was validated by burn test method. Full-Factorial design for three levels has been followed. Factors and their levels of the experiment are presented in table 1.

Taguchi Method: Taguchi express the quality of a product in terms of the losses that are imparted by the product to the society during the shipment of the product to the consumer. Among these losses, some are occur due to the variation in the product's functional characteristics from its desired value and these are named as functional variations. The factors which are uncontrollable and cause the functional characteristics of a product to deviate from their original value are noise factors.

Taguchi suggested analyzing the data means and S/N ratio by graphing the effects and identifying significant factors visually without using ANOVA, which makes the analysis simple. The characteristics of the S/N ratio are given by the following equations.

Larger the better characteristic: $\frac{S}{N} = -\log \frac{1}{n}\left(\sum \frac{1}{y^2}\right)$

Nominal is the better characteristic: $\frac{S}{N} = 10\log \frac{\bar{y}}{S^2 y}$

Smaller is the better characteristic: $\frac{S}{N} = -10\log \frac{1}{n}\left(\sum y^2\right)$

Response Surface Methodology (RSM): RSM is a collection of statistical and mathematical methods which are used for the modeling and analyzing problems related to engineering. The objective of the response surface analysis is to determine the global optimization of process parameter. The prime purpose of this technique is to optimize the response surface that is influenced by several process parameters.

Surface roughness (Ra) measurement: Surface roughness was measured by Surtronic +3 roughness measurement instrument. This instrument is capable of measuring surface roughness with high precision.

Figure-2
Ra measurement set up

The instrument is powered by a 9- volt alkaline battery or through an optional main adaptor. The set-up surface roughness measurement is shown in figure 2.

Results and Discussion

Statistical Analysis of Surface roughness using Taguchi Method: The ANOVA for surface roughness is shown in table 2. From the table, it is clear that all the chosen process parameters have significant influence on roughness (P value <= 0.05; 95% confidence level). It is clear from the ANOVA for thrust force that all the chosen process parameters have significant influence on thrust force (P value <= 0.05; 95% confidence level) and hence, the null hypothesis (Ho1) stands rejected.

Table-2
ANOVA for Surface roughness

Source	DF	SS	MS	F	P
DA	2	1.516	0.758	141.28	0.000
DD	2	0.672	0.336	62.66	0.000
MT	2	3.636	1.818	338.86	0.000
SPEED	2	0.111	0.055	10.43	0.000
FEED	2	0.321	0.160	30.00	0.000
DA*DD	4	0.036	0.009	1.71	0.150
DA*MT	4	0.489	0.122	22.82	0.000
DA*SPEED	4	0.023	0.006	1.08	0.370
DA*FEED	4	0.076	0.019	3.56	0.008
DD*MT	4	0.065	0.016	3.03	0.019
DD*SPEED	4	0.023	0.005	1.09	0.361
DD*FEED	4	0.027	0.006	1.28	0.281
MT*SPEED	4	0.040	0.010	1.89	0.114
MT*FEED	4	0.256	0.006	1.20	0.314
SPEED*FEED	4	0.028	0.007	1.35	0.255
ERROR	192	1.030	0.005		
TOTAL	242	8.126			

According to the table, the most contributing parameter for the variation in the roughness of the drilled hole is material thickness. Second most significant parameter for the roughness is drill point angle which is followed by drill diameter and feed rate. According to the table among the considered parameters, the least contributing parameter for the roughness is spindle speed.

The main effect plots for data means of surface roughness are shown in figure 3. This graph also indicates that material thickness and drill angle are very significant design factor influencing the surface roughness. And according to the graph least dominating parameter is spindle speed.

Correlation between roughness and the thrust force: For the present experimentation conditions, the correlation between the thrust force and the surface roughness is shown in figure 4. From the figure it is observed that surface roughness is directly proportional to the thrust force generated during drilling. Hence to have good surface finish it is necessary to keep the thrust force generated at the lower level.

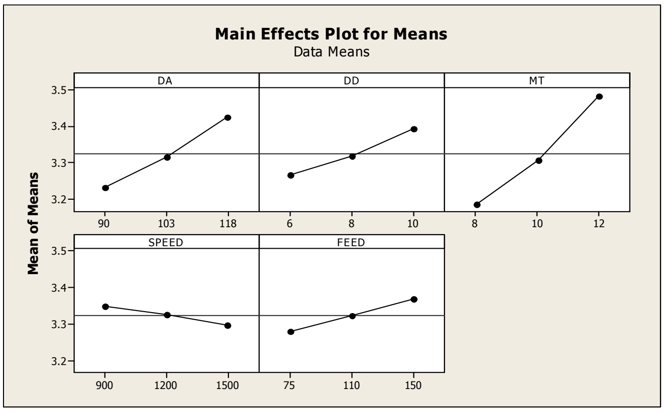

Figure-3
Main effect plot for data means

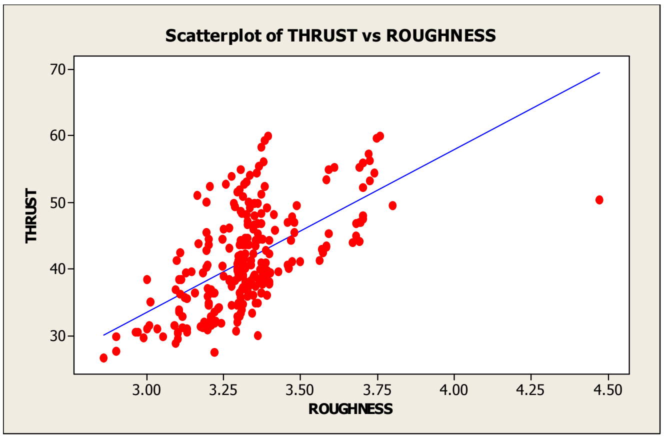

Figure-4
Correlation between roughness and thrust force

Effects of process variables on the surface roughness: Material thickness: During drilling process of composite materials large amount of heat will be generated due to cutting action of hard and brittle reinforcement material and about 90% of heat is liberated to the surrounding through drill and remaining through the work piece. The amount of heat liberated to the surrounding is depends on the thermal conductivity of that particular material. In the present case the thermal conductivity of matrix and the reinforcement materials is less than the drill bit material. It was observed that, as the depth of the hole increased, the heat produced also increased. Due to this the temperature of drill bit material increases rapidly and the gives rise to more thrust generation. This might be the reason to increase in the surface roughness of drilled hole.

Drill diameter: As the drill diameter increases, the material removal rate will also increases, which will increase the amount of thrust force generation during drilling and this increase in thrust force is the responsible for the variation in roughness.

Drill point angle: From the experimentation it is observed that change in the point angle of the drill bit, causes variation in the generation of the thrust force during drilling. Due to this there is a rise in the surface roughness as the point angle rises.

Feed rate: When the feed rate is increased the machining time decreases which reduces the time for the heat dissipation to the surrounding through the drill bit which will increase in the temperature of the tool and causes the rise in the generation of thrust force which will rise the surface roughness value.

Spindle speed: In the present experiment, the rise in the level of spindle shows the reduction in thrust force generated. Since the roughness is directly proportional to the thrust force a reduction in the surface roughness is noticed.

Optimization of surface roughness using Taguchi analysis: Taguchi recommends analyzing the means and S/N ratio using conceptual approach which involves graphing the effects and visually identifying the factors which are appear to be significant without using ANOVA table, thus making the analysis simple. The response table for data means and signal to noise ratio of surface roughness is presented in table 3. According to the table raking, the most dominating design factor is material thickness followed by the drill point angle and the least contributing parameter is spindle speed.

Table-3
Response Table for Means

Level	DA	DD	MT	S. Speed	Feed
1	3.231	3.263	3.184	3.349	3.280
2	3.302	3.316	3.304	3.324	3.322
3	3.424	3.391	3.482	3.297	3.369
Delta	0.193	0.128	0.298	0.053	0.089
Rank	**2**	**3**	**1**	**5**	**4**

From the response table we can select the combination of parameters to obtain the low surface roughness and the combination is presented in table 4.

Table-4
Optimum combinations of parameters

Factors	Levels
Drill angle	90^0
Drill diameter	6 mm
Material Thickness	8 mm
Speed	1500 rpm
Feed	75mm/min

However, Taguchi method only identifies the optimum process parameters, but does not indicate value of surface roughness corresponding to the optimum combination specified. Hence, it is required to go for RSM to identify the Thrust force corresponding to this optimum combination.

Analysis of surface roughness by RSM: Contour plots: Contour plots of response with various design parameters are shown in the figures 5a-5j. Figure (5a) indicates that at any particular drill diameter, the low surface roughness is obtained when low point angle drill bit is used. Figure (5b) indicates that for any value of drill point angle, the low surface roughness is observed on the lesser material thickness. Figure (5c) indicates that for any particular drill angle, the low surface roughness can be obtained at high spindle speed condition. Figure (5d) shows that, for any particular drill angle, the good surface can be achieved at low feed rate. From figure (5e) it is clear that, for a particular thickness of the material, the low amount of surface roughness can be obtained using smaller diameter drill bits. Figure (5f) shows that, for any particular drill diameter, the less surface roughness will be obtained at high spindle speed condition. Figure (5g) indicates that, for a particular drill diameter, the low surface roughness will be obtained with low feed rate. From figure (5h) it is clear that, for a given material thickness, at higher spindle speed yield low surface roughness. Figure (5i) show that, for a given feed rate, the lower amount of surface roughness will be obtained on low material thickness. Figure (5j) shows that, for a particular feed rate, low surface roughness will be produced at high spindle speed.

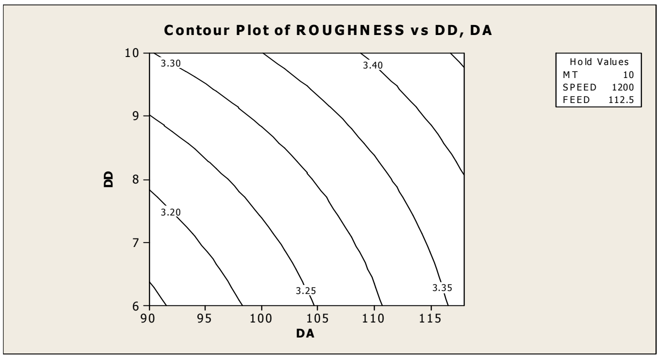

Figure-5a
Ra v/s Drill diameter, Drill angle

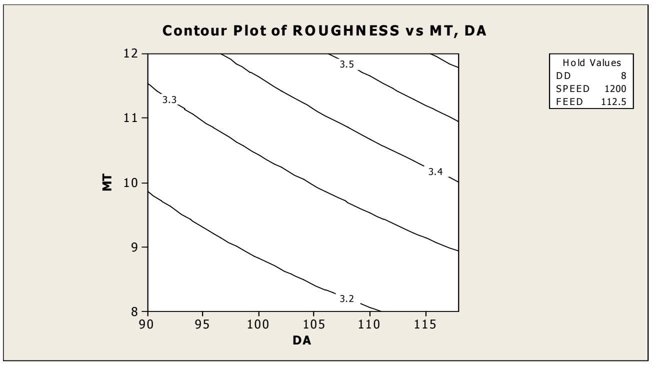

Figure-5b
Ra v/s material thickness, Drill angle

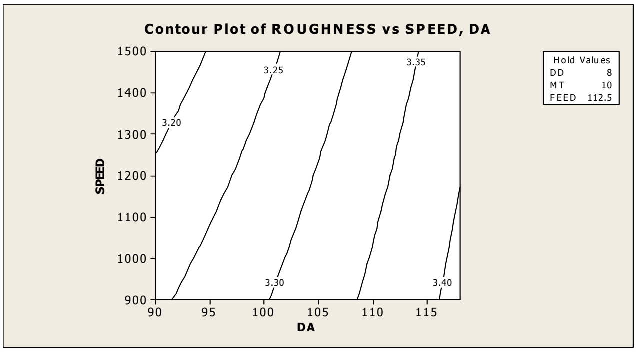

Figure-5c
Ra v/s spindle speed, Drill angle

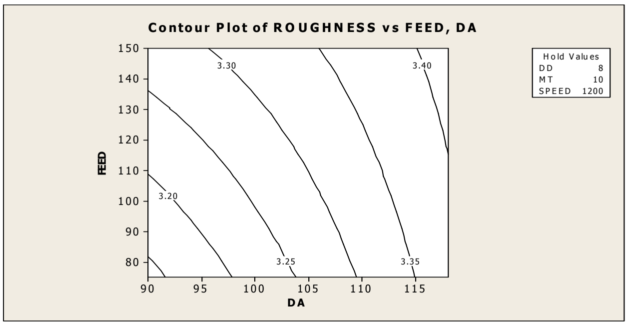

Figure-5d
Ra v/s feed rate, Drill angle

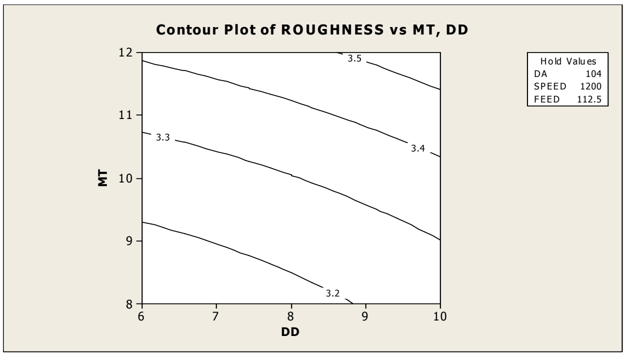

Figure-5e
Ra v/s material thickness, drill diameter

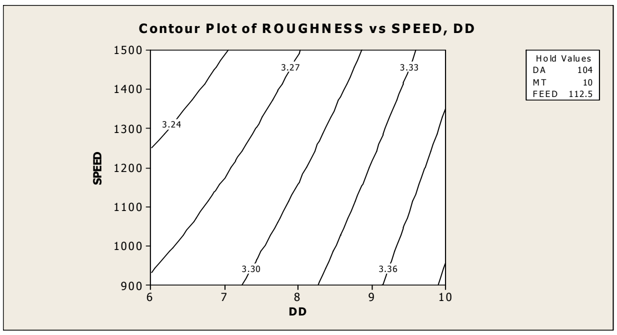

Figure-5f
Ra v/s spindle speed, drill diameter

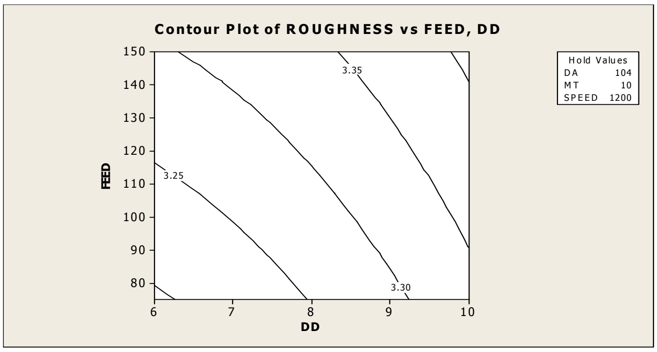

Figure-5g
Ra v/s feed rate, drill diameter

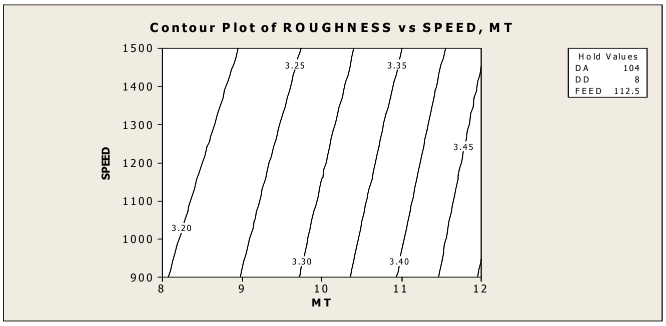

Figure-5h
Ra v/s spindle speed, material thickness

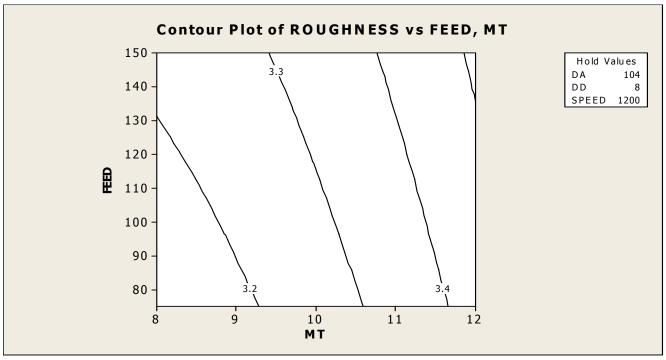

Figure-5i
Ra v/s feed rate, material thickness

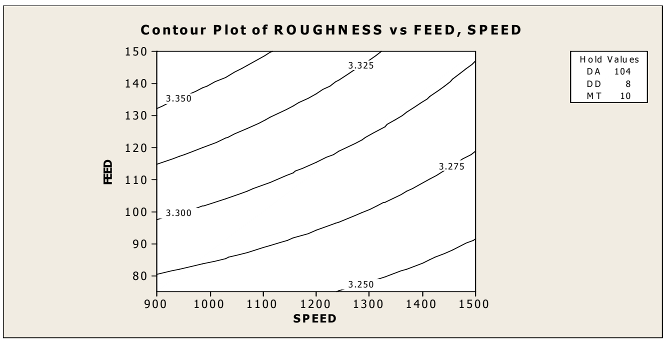

Figure-5j
Ra v/s feed rate, spindle speed

Surface roughness optimization by RSM: It can be observed that except for the spindle speed, the roughness increases for the increase in all the parameters under consideration (figure 6). But the roughness decreases with the increase in spindle speed. The roughness that can be obtained under optimum machining condition is 2.971 µm and the optimized values of process parameters are: Drill point angle is 90^0, Drill diameter is 6mm, Material thickness is 8 mm, Speed is 1500 rpm and the feed rate is 75 mm/min. The optimized process combination is same as Taguchi method. The advantage of RSM optimization method is associated with the possibility of changing the value of any input parameter. Hence, it is possible to estimate the roughness value for any combination. The roughness value for standard drill point angle when all other parameters are remains same is: 3.2654 µm (figure 7). In the same way by changing the input value of any parameter one can predict the roughness value produced.

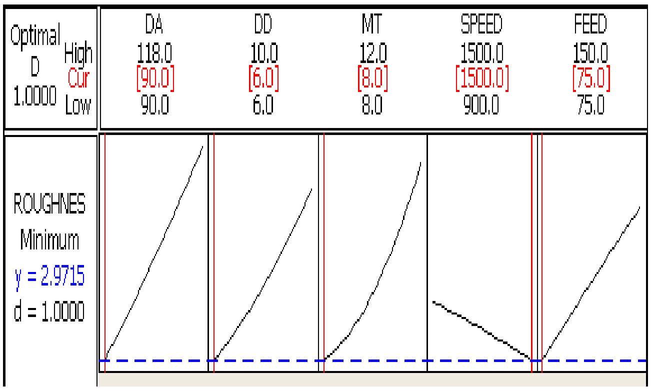

Figure-6
Optimized combination of parameters for Ra by RSM

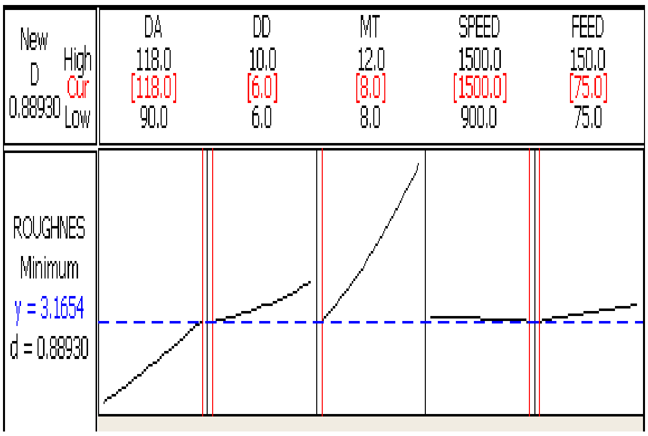

Figure-7
Optimized combination of parameters for Ra when point angle is 118^0

Conclusion

The roughness is significantly influenced by all considered parameters and except with speed, they are directly proportional. Hence, while working on Glass Fiber Reinforced Composites by using Solid Carbide drills, higher spindle speed are recommended for process parameter ranges under consideration. Integrating Taguchi method and RSM can be very effective in process parameter optimization, as combining of the results of the two methods can not only optimize the parameters, but also, indicate the values of response, through which, process parameter selection can be refined and results justified. The results are based on the preselected range of values of speed, feed, material thickness, drill diameter and drill point angle, and hence, the inferences drawn cannot be completely generalized. However, statistical procedures very clearly reveal significant influence of all the process parameters on the surface roughness. As the objective of this research has been mainly on optimization of the process parameters, deeper analysis on the significance of influence has not been carried out for a wide range of process parameters including volume fraction and fiber type.

References

1. Jain S., Yang D. and C.H., Delamination-free drilling of composite laminates *Trans. ASME, Journal for Engg and Industry,* **(116),** 475-481 **(1994)**
2. Hocheng H. and Tsao C.C., Comprehensive analysis of delamination in drilling of composite materials with various drill bits, *Journal of Material Processing and Technology,* **(140),** 335-339 **(1993)**
3. Mohan N.S., Kulkarni S.M. and Ramachandra, A Optimization of process parameters during drilling of Glass-Fiber-Polyester reinforced composite using DOE and ANOVA *IIUM Journal,* **(7),** 13-21 **(2006)**
4. Krishnaraj V., Vijayaraghavan S., Suresh G., An investigation on high speed drilling on glass fiber reinforced plastics, *Indian Journal of Engineering and Material Science,* **12,** 189-195 **(2005)**
5. Tsao C.C. and Hocheng H., Evaluation of thrust force and surface roughness in drilling composite material using Taguchi analysis and neural network, *Journal of materials processing technology*, **203,** 342–348 **(2008)**
6. Won M.S. and Dharan C.K.H., Chisel edge and pilot hole effects in drilling composite laminates" *Transactions of the ASME, Journal of Manufacturing Science and Engineering,* **124,** 242–247 **(2002)**
7. Jamal Y., Sheikh Ahmad, *Book of Machining of Polymer composites,* Springer Publication
8. Uwe Heisela, Pfeifrothb, Influence of Point Angle on Drill Hole Quality and Machining Forces when Drilling CFRP" 5th CIRP Conference on High Performance Cutting, 488–493 **(2012)**
9. Won M.S., Dharan C.K.H., Chisel edge and pilot hole effects in drilling composite laminates, *Transactions of the ASME, Journal of Manufacturing Science and Engineering,* **124,** 242–247 **(2002)**
10. Vijayan Krishnaraj, Effects of Drill Points on Glass Fibre Reinforced Plastic Composite While Drilling at High Spindle Speed, *Proceedings of the World Congress on Engineering,* Vol II WCE, July 2 - 4, London, U.K. **(2008)**