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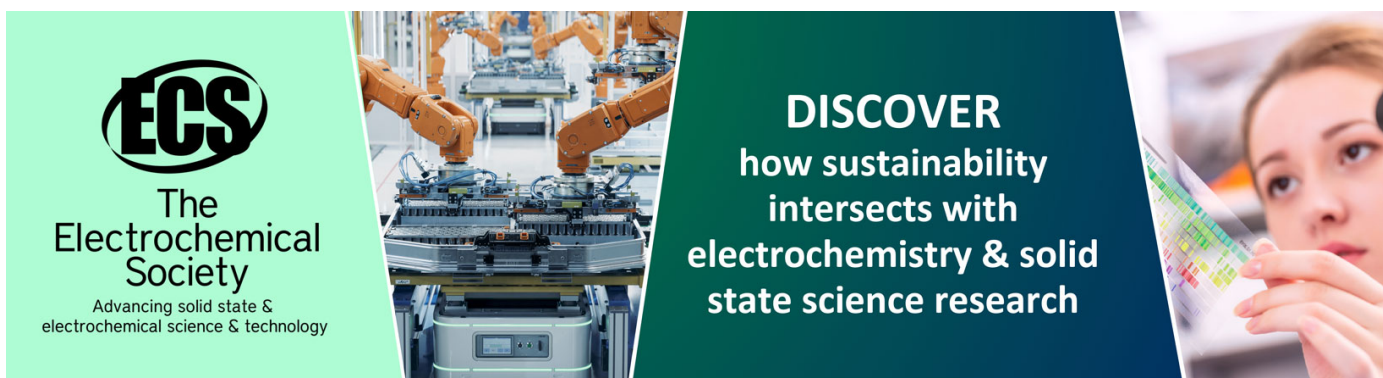
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Influence of Drilling Parameters on Torque during Drilling of GFRP Composites Using Response Surface Methodology

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Abstract: Polymer based composites have marked their valuable presence in the area of aerospace, defense and automotive industry. Components made of composite, are assembled to main structure by fastener, which require accurate, precise high quality holes to be drilled. Drilling the hole in composite with accuracy require control over various processes parameters viz., speed, feed, drill bit size and thickness of specimen. TRIAC VMC machining center is used to drill the hole and to relate the cutting and machining parameters on the torque. MINITAB 14 software is used to analyze the collected data. As a function of cutting and specimen parameters this method could be useful for predicting torque parameters. The purpose of this work is to investigate the effect of drilling parameters to get low torque value. Results show that thickness of specimen and drill bit size are significant parameters influencing the torque and spindle speed and feed rate have least influence and overlaid plot indicates a feasible and low region of torque is observed for medium to large sized drill bits for the range of spindle speed selected. Response surface contour plots indicate the sensitivity of the drill size and specimen thickness to the torque.

1. Introduction

The Importance of composite structure materials has been in successfully replacing the conventional materials. These materials have many applications with lightweight and high strength properties. Composite material structures are basically made up of two or more micro-constituents with different physical state and chemical composition and those constituents are insoluble in each other [1]. The main objective of having two or more constituents is to obtain several advantages of the superior properties of both constituents. In a glass fiber reinforced composite [GFRP] structures, fibers take the majority of applied load and matrix assists in transferring the applied load [2]. The usage of such GFRP composite structures are very well noted in the field aircraft, marine, industrial, defense and transportation, etc. Assembly of these components to main structure involve material cutting, drilling, or contouring GFRP laminates [3].

Therefore drilling is one of the most commonly used processes to fix fasteners for assembly of complex shaped laminates. In most of the machining processes, the quality of the assembled composite structures components are highly influenced by the machining conditions, cutting tool geometry, tool material, specific machining process, types chip formation, work piece material, cutting tool wear etc., [4]. Therefore, the specific machining process needs to be performed to ensure the dimensional stability and interface quality [5]. Therefore for these conditions, there have been research developments with



the objective to optimize the cutting parameters in order to achieve a better productivity in drilling operations. Hence productivity of the work piece involves the specific “metal removal rate (MRR)” and “life of cutting tool”, result in the minimum rejection of the composite material components [6]. Therefore, in material machining processes, selection of an improper cutting conditions result in dimensional irregularities with rough surfaces [7]. Therefore, it becomes necessary to identify the important parameters which influence the quality of drilling [8]. Therefore, it is very much necessary to optimize [9] the influence of torque on tool life and quality of hole in composite [10].

It is necessary to understand the relationship among the various controllable parameters and to identify the important parameters that influence the quality of drilling [11]. Moreover, it is necessary to optimize the cutting parameters to obtain an extended tool life and better productivity [12], which are influenced by machining parameters, material parameters and machine tool parameters [13]. The approach is based on a combination of Design of experiment, Taguchi’s experimental analysis technique and response surface optimization criterion [14]. The optimization objective includes the contributing effects of the drilling performance measures, surface roughness, delamination factor, drilling thrust force and torque [15]. The Design of experiment [DOE] is used to determine the influence of various known process parameters over unknown process variables. This current work is focused on harnessing the features of “DOE” for process optimization of torque in drilling process on GFRP composites.

2. Methodology

2.1. Preparation of GFRP specimen

Composites are prepared by using chopped E-glass fiber as reinforcement and polyester resin as matrix material. Composite laminate slabs of size 200 X 200 mm² are prepared by contact moulding process. E-glass with 72.5 GPa modulus and density of 2590 kg/m³ and polyester resin with modulus of 3.25 GPa and density 1350 kg/m³ are used.

2.2. Machine set-up

“Carbide-coated” drill bits are used to drill holes with diameter 3, 6, 10 and 12 mm. CNC TRIAC VMC is used for drilling operation. Figure 1 shows the overall setup of machine to collect data. The machine is enabled with the dynamometer to measure force–torque on drill bit and fixture. The specimen is fixed on a fixture, which is enabled with the dynamometer. The fixture is fixed on the machine table of CNC machine. The acquired machining signals of torque and thrust force are amplified through an amplifier converter on a digital computer.

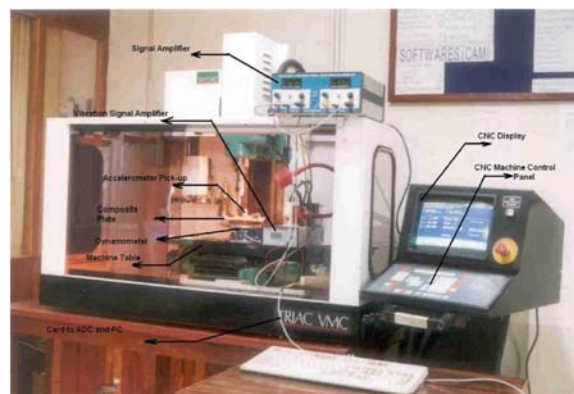


Figure 1. Experimental setup

2.3. Design of experiment (DOE)

DOE of MATLAB software is a versatile tool for analyzing the influence of process parameters over some unknown function of specific variable viz., force and torque. The most vital stage of DOE is to select the control variable factors. Normally, the thrust force and cutting torque are widely depend on the parameters like, cutting speed, feed, cutting tool and its geometry, etc,. The detail of the various variables considered for the experiment is shown in table 1. The selection of variables is aimed to show

the variability related to their machining parameters and to carry out the comparative analysis. The main effects plotted in figure 2, indicates the selection of specimen parameters, thickness [3 mm], drill size [3mm], feed rate [100 mm/min] and highest speed [1500 rpm] F3N4T1D1. Also, it indicates the superlative combination to measure the lower torque during drilling operation within all the range of selected experiments.

Table 1 Levels of variables used in the experiment

Variables	Lowest	Low	Center	High
Thickness, mm	3	6	10	12
Speed, rpm	600	900	1200	1500
Feed rate, mm/min	50	75	100	125
Drill size, mm	3	6	10	12

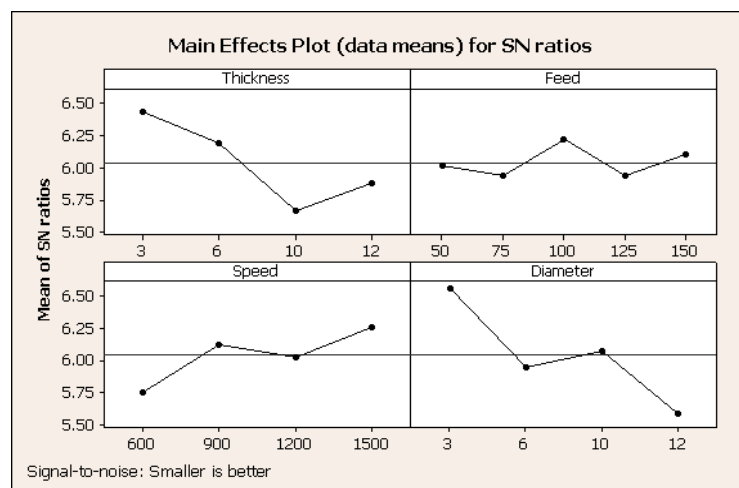


Figure 2 Main effects plot for S/N Ratio

3. Experimental results and analysis.

The main purpose of selected experiment is to investigate the important parameters and combination of factors influence the drilling operation to attain the lower torque, by using the smaller value is the better characteristic of DOE. Table 2 indicates the result of variance analysis and it shows that thickness, feed, speed and diameter are important parameters which influence the drilling torque. The feed rate has ranked 4th, so it has lesser significance. To obtain higher MRR, feed value can be set high and to get more tool life, feed value can set for nominal value respectively.

Table 2. Response surface Table for Signal to Noise Ratios Smaller is better

Variables	Lowest	Low	Center	High
1	6.012	5.753	6.432	6.557
2	5.934	6.126	6.190	5.951
3	6.217	6.030	5.670	6.073
4	5.942	6.260	5.877	5.588
Delta	0.283	0.506	0.762	0.968
Rank	4	3	2	1

3.1 Analysis of Torque using Response surface methodology.

One of methodologies for obtaining the optimum is response surface technique. Response surface methodology is a collection of statistical and mathematical methods that are useful for the modeling and analyzing engineering problems. In this technique, the main objective is to optimize the response surface that is influenced by various process parameters. Response surface methodology also quantifies the relationship between the controllable input parameters and the obtained response surfaces. The objective of this analysis is to determine optimum values of parameter levels where results in the lowest torque during drilling of GFRP composites. Therefore, the optimum level for a parameter is the level that gives the highest value of S/N ratio in the experimental range of experiments. The main objective of response surface methodology is to optimize the response surface that is influenced by various design parameters. This analysis also quantifies the relationship between the controllable input parameters and the obtained response surfaces.

Figure 3 response surface plots indicate that at any particular spindle speed, the low torque force is observed during drilling in the middle range of feed rates. Contour plot indicates the sensitivity of drill size over the range of feed rate selected. Therefore, specimen thickness is observed to be very sensitive and the influencing parameter for the low torque also indicates that for any speed of the spindle, low torque is observed in the small sized drill bits and similarly for any specimen thickness, the optimum torque is observed in the low range of drill sizes. Response surface contour plots indicate the sensitivity of the drill size and specimen thickness to the torque. Overlaid plot indicates a feasible and low region of torque is observed for medium to large sized drill bits for the range of spindle speed selected.

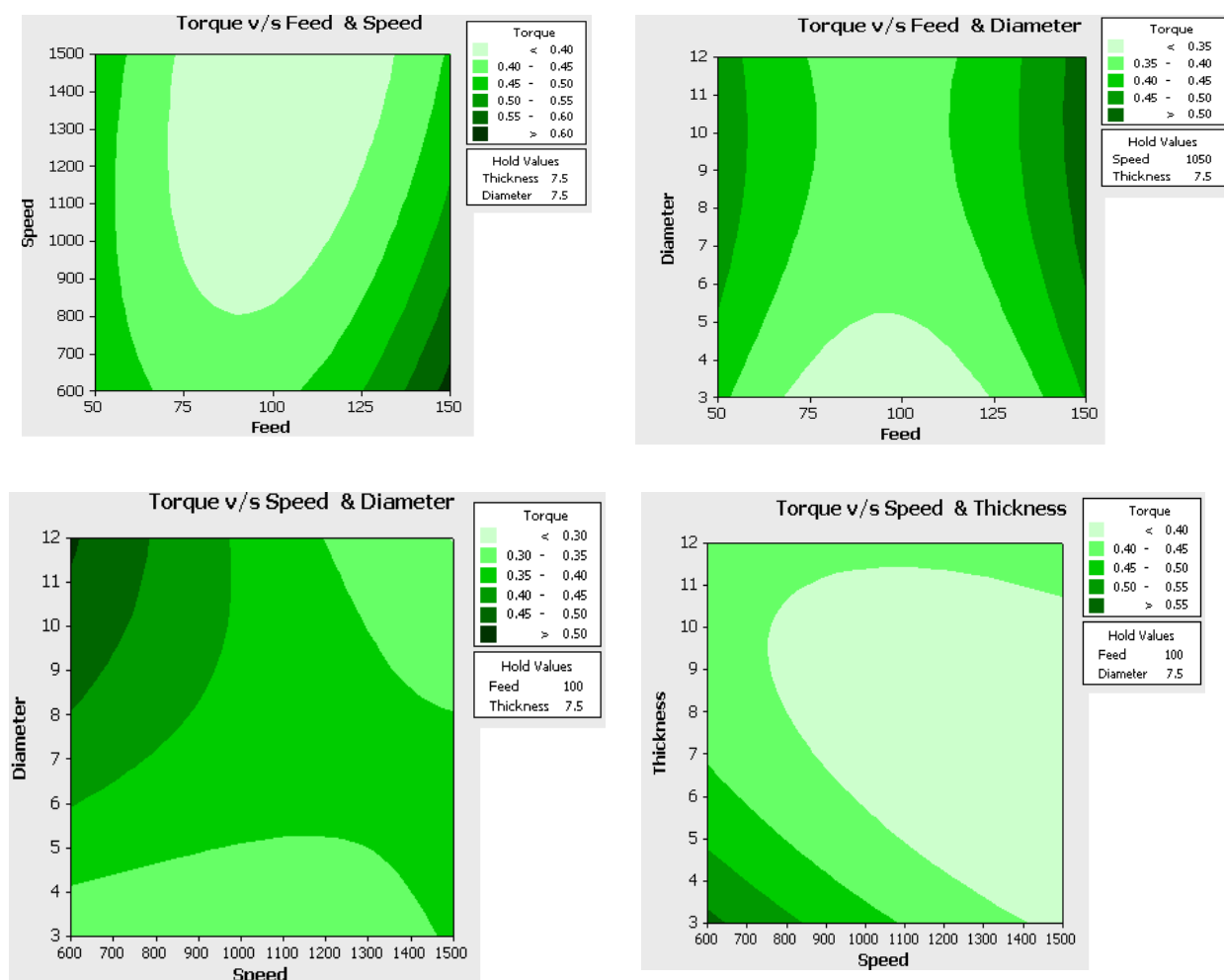


Figure 3. Response surface plots

From the overlaid plot of diameter over feed rate, the plot figure 4 indicates that high torque is observed in low feed values over the range of drill bit sizes. A feasible and low region of torque is observed for medium to high size drill bits over the range of spindle speed. Over laid plot of drill size with specimen thickness indicates that over the range of thickness and diameter, the torque is quite high and it is evident that these parameters are very significant factors influencing the torque.

3.2 Optimization of torque using response surface methodology.

The main objective of response surface analysis is to optimize the responses those are having significant influence of various design parameters. Response surface methodology also quantifies the relationship between the controllable input parameters and the obtained response surfaces. The optimum torque can be obtained by suitably redefining the feed rate and speed. From the over laid plot of torque with feed and speed for the optimum condition F3N4T1D1, for all whole speed conditions, torque appears to be high in the low feed range and be feasible on the wide range of feeds.

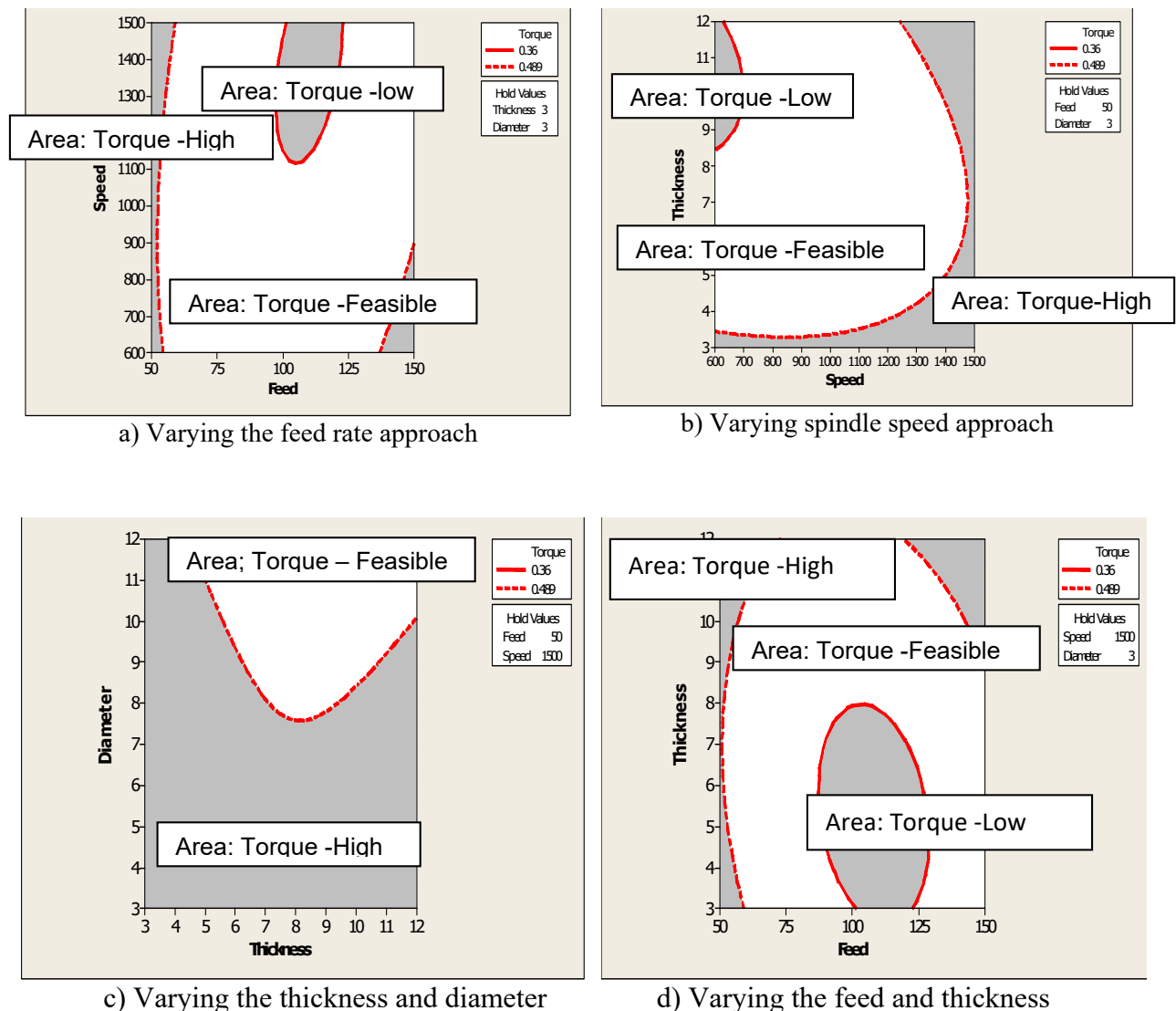


Figure 4. Overlaid plots

Feed rate and thickness the plot indicates that torque force is low and feasible in the medium range of design parameters. It is assumed that the independent variables are continuous and controllable by

experiments with negligible errors. Usually a second-order model is utilized in plot Figure 5 (a) and (b) indicates that response 'y' can have value of 0.3545 Kgf.m at feed 113 mm/min and 0.3576 Kgf.m at speed 1325.56 rpm.

3.3 Optimization of high Torque condition during drilling.

Machining conditions for the high torque of the peak value, 0.738 Kgf.m is being observed during drilling condition $F_2N_1T_3D_4$. Using response surface optimization plot, figure 5, a reduction of torque value from this peak value, 0.738 Kgf.m to the predicted torque of 0.487 Kgf.m for drilling on 12 mm thick specimen with 6 mm drill bit. Therefore, reduction in torque of 34 % being predicted from the optimized graph Figure 6 and this can be achieved by selecting the optimized conditions at feed rate 98 mm/min and spindle speed 1500 rpm. The torque rises slowly during initial engagement of drill bit with the work piece and followed with significant increase until cutting lips start to engage in drilling operations.

In contrast to thrust, the torque increases up to the maximum value over the drilling cycle followed by a gradual drop in torque up to certain value, which is normally called as frictional torque. The experimental result conducted at the above optimized condition result measure torque of value 0.514 Kgf.m and hence, this confirming to 94.74% of confidence with the predicted value.

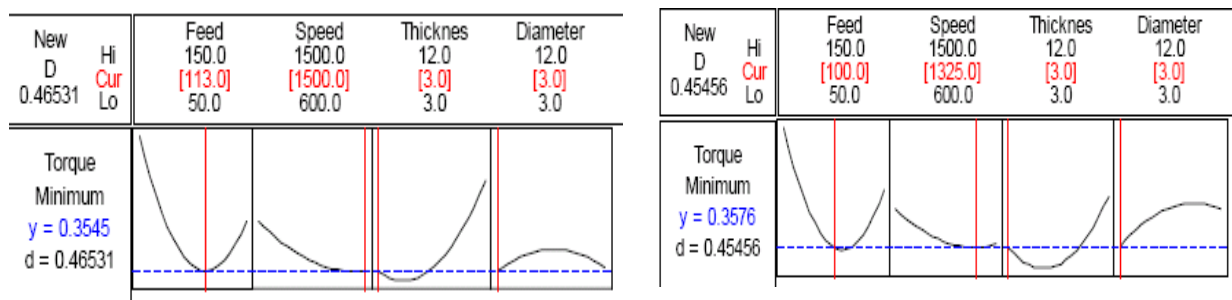


Figure 5. Optimized response surface plots for the torque.

Machining conditions for the high torque of the peak value, 0.738 kgf.m is being observed during drilling condition $F_2N_1T_3D_4$. Using response surface optimization plot, figure 6, a reduction of torque value from this peak value, 0.738 kgf.m to the predicted torque of 0.487 kgf.m for drilling on 12 mm thick specimen with 6 mm drill bit. Therefore, reduction in torque of 34 % being predicted from the optimized graph Figure 5.25 and this can be achieved by selecting the optimized conditions at feed rate 98 mm/min and spindle speed 1500 rpm. The experimental result conducted at the above optimized condition result measure torque of value 0.514 kgf.m and hence, this confirming to 94.74% of confidence with the predicted value.

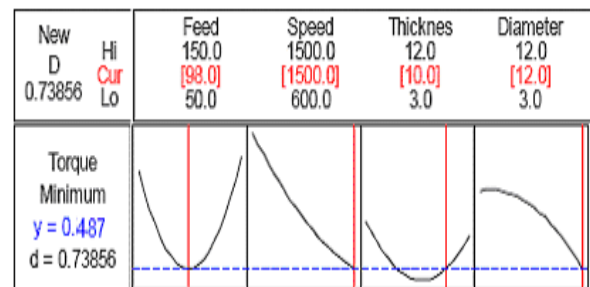


Figure 6. Optimized response surface plot at the high torque value.

4. Conclusions.

From the analysis of result using “conceptual S/N ratio approach” and “Taguchi method” gives simple, systematic and efficient method to optimize the process parameters. In this work, it is observed that thickness of specimen, speed, feed and diameter of dill are significant parameters of torque. Among the

torque significant parameters, thickness of specimen and drill diameter are more significant than the speed and feed. The main effects plot obtained for optimum torque condition indicates the selection of feed (100 mm/min), higher speed (1500rpm), lower thickness of specimen (3 mm) and lower drill diameter (3 mm) resulted in the best combination of drilling parameters to obtain the lowest torque while drilling within the selected experiments range. From the over laid plots figure 4 of torque with feed and speed for the optimum condition F3N4T1D1, for all whole speed conditions, torque appears to be high in the low feed range and be feasible on the wide range of feeds. Therefore again it looks evident that feed rate and speed does not have significant influence on the low torque force value. From over laid plot of torque with feed rate and thickness the plot indicates that torque force is low and feasible in the medium range of design parameters.

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