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Optimization of Drilling Parameters for GFRP with Full Factorial Method

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Abstract: Drilling is the most commonly applied method for hole making of fiber reinforced materials owing to the need for structure joining. GFRP is required a high quality drilling parameters due to its application in research and development, aerospace, marine, delegate furniture, roof, bridge construction, etc. This study had been given a new approach to optimize the drilling parameters such as thrust force and delamination through DOE by using full factorial design. The purpose of this study is to investigate the influence of drilling parameters, such as cutting speed, feed and Thickness of material on torque, thrust force and delamination produced when drilling different a thickness of GFRP composite sheet. It had been regression analysis and ANOVA to analyze and optimize the process parameter of drilling. From the results it has been observed that the significant effect of thickness, speed and feed on the responses thrust force, torque and circularity. It has been concluding that the minimum thickness, speed and feed given the optimum result of thrust force. The minimum speed, thickness and median feed given a optimum result for torque. The maximum speed median feed and minimum thickness given optimum result for circularity.

Key words: *GFRP, drilling, delamination, thrust force, torque*

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1.1. Introduction

Glass Fiber Reinforced Polymers are a proven and thriving alternative that have abundant compensation over traditional reinforcement methods, giving structures a longer examine life. The GFRP rebar is a structural corrugated reinforcing bar made of high strength and rust resistant glass fibers that are impregnated and bound by a tremendously durable polymeric epoxy resin. This arrangement equals an engineered material system consequential in unique attributes that change and supersede typical materials such as galvanized, epoxy coated and stainless steel rebar. Its attribute properties are ideal for any harsh and corrosive environments. GFRP is everlastingly resistant to chemical acids and alkaline bases, therefore extra concrete cover up, anti-shrink additives, and even cathodic guard are not necessary. GFRP considerably improves the durability of engineering structures where corrosion is a key factor.

1.2. Objectives and Goals:

- Improve the hole quality of E-Glass FRP composite and make it easy to the manufacturing industries.
- To increase drilling efficiency of GFRP composite laminates with the least waste and damages, it is essential to understand the drilling behavior by conducting a number of drilling experiments and drilling parameters such as feed rate and spindle speed should be optimized.
- Find out the significance effect of same parameters for different thickness of GFRP and study the Thrust, Torque and delamination for helping to the GFRP Production line long machining life given. This study guides to the mass production of different thickness of GFRP in current developing industries.

1.3. Problem definition:

During the global development in industries and machining operations it is necessary to reduce the time for drilling of different thickness of GFRP material because of widely usage. The optimization is required for same parameter of drilling on GFRP sheets.

It is required to increase the drilling efficiency of GFRP composite laminates with the least waste and damages, it is essential to understand the drilling behavior by conducting a number of drilling experiments and drilling parameters should be optimized.

2.1. Literature Survey

An Experimental Investigation of the Crack Growth Phenomenon for Drilling of Fiber-Reinforced Composite Materials
by
Dipaolo g, kapoor G and devor r. E

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They studied the crack growth experience that occurs while drilling fiber-reinforced composite materials (FRCM), purposely unidirectional (UD) carbon fiber/epoxy resin. It used an investigational setup that exploits the technology of video to understand the absolute crack growth phenomenon as the drill emerges from the exit side of the workpiece.	Important damage mechanisms are experiential and defined, and correlations between the average exit drill forces and the crack tip situation are shown. On the spot forces as they vary along the direction of the cutting edges are recognized in terms of their role to the crack propagation.
Some Experimental Investigations In The Drilling Of Carbon Fiber-Reinforced Plastic (Cfrp) Composite Laminates By Wen-Chou Chen	
They studied the concept of delamination factor Fd is proposed to analyze and compare easily the delamination degree in the drilling of carbon fiber-reinforced plastic (CFRP) complex laminates. Experiments were performed to investigate the variations of cutting forces with or lacking onset of delamination during the drilling operations. The effects of tool geometry and drilling parameters on cutting force variations in CFRP composite materials drilling were also experimentally examined.	The investigational results shown the delamination-free drilling processes may be obtained by the proper selections of tool geometry and drilling parameters. The effects of drilling parameters and tool wear on delamination factor are also obtainable and discussed.
Drilling carbon fiber-reinforced composite material at high speed by S. C. Lin, I. K. Chen	
They studied the effects of rising cutting speed on drilling characteristics of carbon fiber-reinforced compound materials. The effects of rising cutting speed ranging from 9550 up to 38 650 rev min−1 (from 210 to 850 m min−1) on average thrust force, torque, tool wear and hole quality for both multifaceted drill and twist drill are studied.	It was found that increasing cutting speed will accelerate tool wear and the thrust force increases as drill wear increases. This is because relatively small feeds are used in this test. It was concluded that tool wear was the major problem encountered when drilling carbon fiber reinforced composite materials at high speed.

A Neural Network Thrust Force Controller To Minimize Delamination During Drilling Of Graphite epoxy Laminates by R. Stone and K. Krishnamurthy	
They studied the linear-elastic fracture mechanics theory which proposed critical cutting and thrust forces in the various drilling regions that can be used as a guide in preventing crack growth or delamination. Using these critical force curves as a guide, a thrust force controller was developed to minimize the delamination while drilling a graphite epoxy laminate. A neural network control scheme was implemented which required a neural network identifier to model the drilling dynamics and a neural network controller to learn the relationship between feed rate and the desired thrust force.	Experimental results verifying the validity of this control approach as well as the robustness of the design are presented. Visual measurements of the delamination zones were used to compute the benefits of the thrust force controlled drilling process versus the conventional stable feed rate drilling process.
Investigations into the effect of geometry of a trepanning tool on thrust and torque during drilling of GFRP composites by J. Mathew,N.Ramakrishnan and N. K. Naik	
They studied that thrust is a major factor responsible for delamination and it mainly depends on tool geometry and feed rate. The models for forecast of critical thrust and critical feed rate at the onset of delamination during trepanning of uni-directional composite based on rupture mechanics and plate theory also have been presented. Mathematical models correlating thrust and torque with tool diameter and feed rate have been developed through statistically designed experiments and effect of various parameters on them have been discussed.	It is observed that sub-laminate thickness is the most decisive parameter from the viewpoint of significant feed rates.

2.2. Summary of Literature Survey:

From the above literature studies it has been observed that the GFRP sheets are largely used in the current market and due to its global demand in manufacturing industries and high quality interior and exterior development machining optimization are most powerful challenges. Fabricators are facing a problem with different thickness of sheets drilling with single drilling machine and required a good quality of hole for some special applications and as per demanding of the customer. Drilling of this type of material plays an important role and that's why its drilling parameter optimization is required.

3.1 Design of Experiments

- Experiments assist us in understanding the performance of a (mechanical) system.
- Data collected by logical variation of influencing factors helps us to quantitatively explain the fundamental phenomenon or phenomena.

The aim of any experimental action is to get the maximum information about a system with the least number of fine designed experiments. An experimental agenda recognizes the major "factors" that influence the outcome of the experiment. The factors may be recognized by looking at all the quantities that may affect the result of the experiment. The most significant among these may be identified using a few examining experiments or from past experience or based on some fundamental theory or theory. The next thing one has to do is to choose the number of levels for each of the factors. The facts will be gathered for these values of the factors by performing the experiments by maintaining the levels at these values.

Experiments repeated with a particular set of levels for all the factors constitute replicate experiments. Statistical validation and repeatability concerns are answered by such replicate data.

3.2. Full factorial design:

A full factorial design of experiments consists of the subsequent:

- Vary one factor at a time
- Perform experiments for all levels of all factors
- Hence perform a large number of experiments that are needed!
- All interactions are captured (as will be shown later)

4.1. Research Methodology

In the first session the area of selection and literature has been collected for the study. The method should be identified and studied for the research purposes. Collect some required knowledge of related software such as MINITABE 17. From the whole literature it has been conclude that the optimization is needed for mare accuracy with DOE method for same parameter. In the middle of the stage collect a required GFRP material.

FACTORS at point angle 90°	**LEVELS**		
Speed of Spindle(rpm)	900	1200	1500
Feed(mm/min)	75	110	150
Sheet Thickness(mm)	4	6	8

Properties of GFRP	
Fibre content (% by weight)	50-80
Density (kg/m3)	1600-2000
E (Long.) (GPa)	20-55
Tensile strength (MPa)	400-1800

Full factorial Method has been used for the minimizing the hole expansion in the drilling of GFRP sheet Taguchi recommends analysing the mean response for each run in the inner array and he also suggests analysing variation using an appropriately chosen signal-to-noise ratio (S/N). These S/N ratios are derived from the quadratic loss function, and three of them are considered to be standard and widely applicable. These are:

(1) Lower is best,

(2) Higher is best,

(3) Average is best

Our target is to achieve minimum hole expansion so we have used lower is best which is;

(2) There lower S/N ratio corresponds to a better performance. So, the optimal level of the process parameters is the level with the lowest S/N value.

Three machining parameters were selected as control factors, and each parameter was designed to have three levels, denoted by 1, 2, and 3. The experimental design was based on L27 (3*3*3) orthogonal array for RSM method. Minitab 17 software was used for graphical analysis of the obtained data. Total 27 experimental runs will be carried out in study. Responses measured will measure thrust force and Circularity.

There three level designed for different factors for GFRP sheet[10] spindle speed 900-1200 – 1500 rpm, feed rate 75-110 - 150 mm/min and thickness of 4mm-6mm - 8mm of GFRP sheet with solid carbide drill tool point angle 90°. Delamination, Torque and Thrust force as output will be observed. This study will be carried out for the influence of the cutting tool geometry, material thickness, feed and speed on the thrust force and delamination produced when drilling a glass fibre reinforced composite. Sample of data will be obtained from the dynamometer for HSS tools are compared and computed. Each sheet of GFRP (300 x 600 x 4 / 6 / 8 mm) will have drilling operation carried out on vertical machining centre. Hole size will measured by Universal Measuring Microscope. From this study it will be optimizing the results of drilling parameter for GFRP composites in Minitab 17.

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5.1 Experimental Setup

Literature has been reviewed for the CFRP, GFRP, FRP composites and on drilling parameter optimization. Design an orthogonal array for the experiment. The levels of the machining parameters input are being taken from the review after study. Drill bit using during this experiment is having a 90 degree point angle and 8mm diameter HSS twist drill. There are three different thicknesses (4, 6, 8 mm) of E-GFRP sheets as composite purchased for the three level design of experiment. It is cutting in the form of 1.5” x 4” rectangle block for easy handling during experiment. The speed and feed also set for three level design at 900, 1200 & 1500 rpm and 75, 110 & 150 respectively. Design an orthogonal array for the full factorial experiment of L27. Responses will be recorded and insert in to the software for the analysis by analysis of variance. Torque and thrust force will recording with the help of drill tool dynamometer which is placed on the machine bed and workpiece is fixed on the top of the dynamometer by fixture. Drill the holes as followed by the designed array. Delamination of the drilled hole will measuring and recording with the help of 3D – Electron microscope. It will generate a regration line and create a mathematical model in the form of regration equations for the each response. Then analyse and optimizing the predicted results for drilling of GFRP composite.

Figure 5.1 Experimental Setup with Drill tool dynamometer and drill tool arrangement, Experimental work piece 1 and 2 of GFRP

Experimental Run

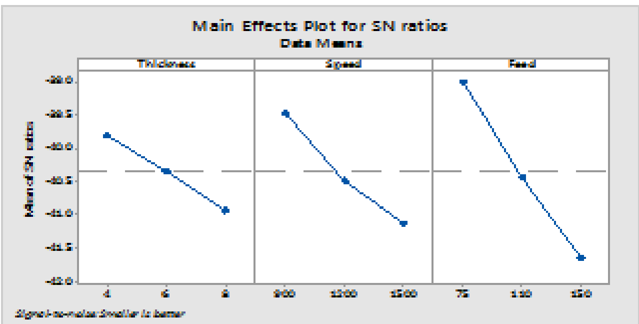

Figure 7.1 Mean plot of SN Ratios Vs Thickness, Feed, Speed

Figure 7.1 shows the SN Ratios chart Vs Thickness, feed and speed. From the above results observation the value of R-Sq is 95% and R-Sq(Adj.) is 93.5%. This has been a very close and acceptable parameter result. The graph has been shown effect of variable thickness, feed and speed of spindle on the SN Ratio with smaller is batter result.

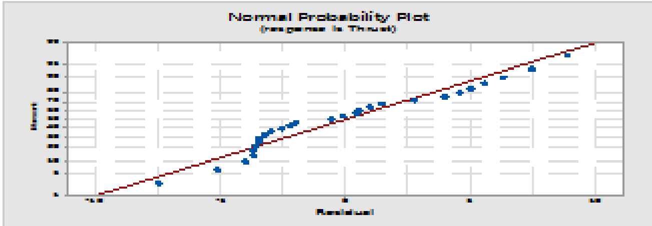

Figure 7.2 Response Plot of Thrust Force

Figure 7.2 shows the result of response plot of normal probability for thrust force. From the above chart it has been observe that most of the collected data are very nearer to the regration line and it had been given acceptable results for the drilling parameter aspect.

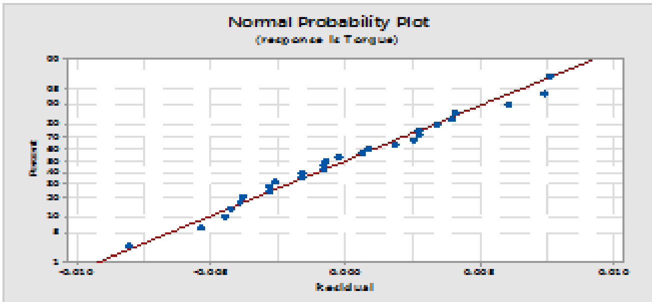

Figure 7.3 Response Plot of Torque

Figure 7.3 shows the result of response plot of normal probability for Torque. From the above chart it has been observe that most of the collected data are very nearer to the regration line and it had been given acceptable results of Torque for the drilling parameter aspect.

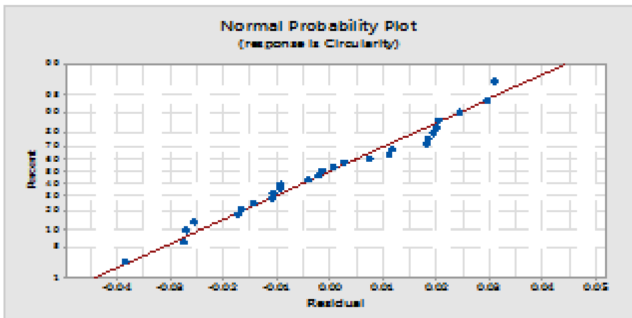

Figure 7.4 Response Plot of Circularity

Figure 7.4 shows the result of response plot of normal probability for Circularity force. From the above chart it has been observe that most of the collected data are very nearer to the regration line and it had been given acceptable results of circularity for the drilling parameter aspect.

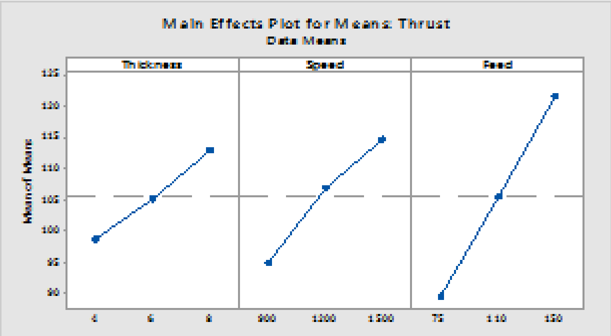

Figure 7.5 Mean plot of Thrust force Vs Thickness, Feed, Speed

Figure 7.5 shows the Mean effect for mean chart of thrust force Vs Thickness, feed and speed. From the above results observation the value of R-Sq is 93.9%, and R-Sq(adj) is 92.1%. This has been a very close and acceptable parameter result. The graph has been shown effect of variable thickness, feed and speed of spindle on the Thrust Force with smaller is batter result.

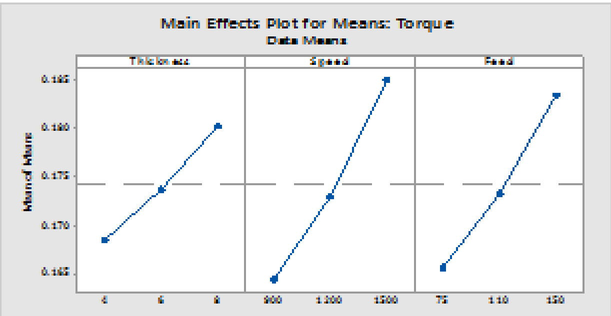

Figure 7.6 Mean plot of Torque Vs Thickness, Feed, Speed

Figure 7.6 shows the Mean effect for mean chart of Torque Vs Thickness, feed and speed. From the above results observation the value of R-Sq = 90.9% R-Sq(adj) = 88.2%. This has been a very close and acceptable parameter result. The graph has been shown effect of variable thickness, feed and speed of spindle on the Torque with smaller is batter result.

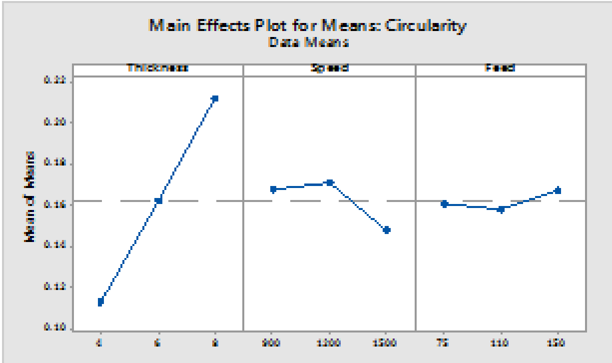

Figure 7.7 Mean plot of Circularity Vs Thickness, Feed, Speed

Figure 7.7 shows the Mean effect for mean chart of Circularity Vs Thickness, feed and speed. From the above results observation the value of R-Sq is 85.7%, and R-Sq(adj) is 81.4%. This has been a very close and acceptable parameter result. The graph has been shown effect of variable thickness, feed and speed of spindle on the Circularity with smaller is batter result.

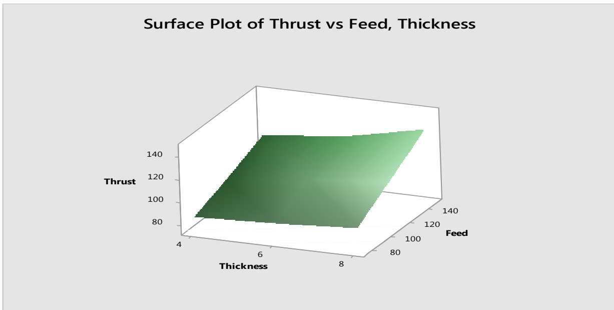

Figure 7.8 Surface Plot of Thrust Force Vs Feed, Thickness

Figure 7.8 shows the surface plot for thrust force vs thickness vs feed. Form this figure it has been observed that the optimum value of thrust force gain low thickness and minimum feed. It has been conclude that the increase the thickness the thrust force is increased and at the minimum feed thrust force is optimum.

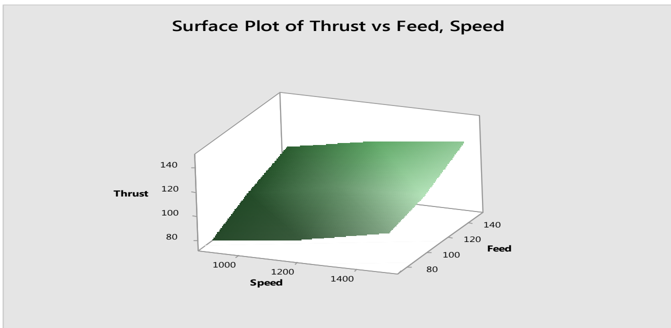

Figure 7.9 Surface Plot of Thrust Force Vs Feed, Speed

Figure 7.9 shows the surface plot for thrust force vs Speed vs feed. Form this figure it has been observed that the optimum value of thrust force gain low speed of spindle and minimum feed rate. It has been conclude that the increase the speed the thrust force is increased and at the minimum feed thrust force is optimum.

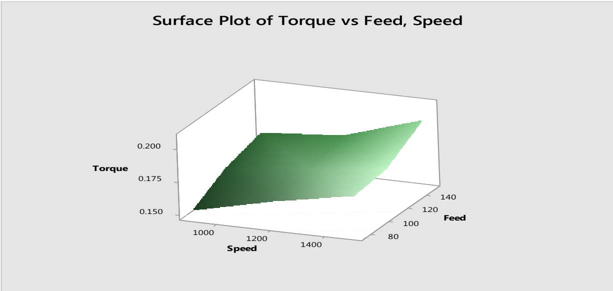

Figure 7.10 Surface Plot of Torque Vs Feed, Speed

Figure 7.10 shows the surface plot for torque vs speed vs feed. Form this figure it has been observed that the optimum value of torque gain at low speed and median feed. It has been conclude that the increase the thickness the torque is increased and at the minimum feed torque is optimum.

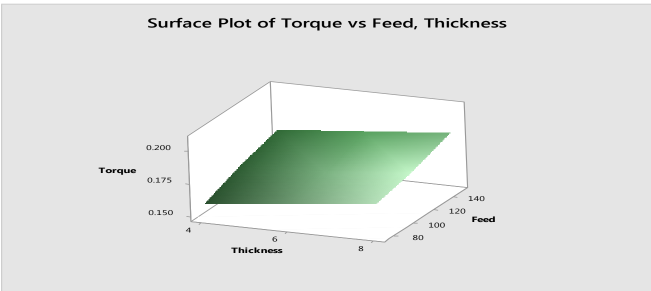

Figure 7.11 Surface Plot of Torque Vs Feed, Thickness

Figure 7.11 shows the surface plot for torque vs thickness vs feed. Form this figure it has been observed that the optimum value of torque gain low thickness and minimum feed. It has been conclude that the increase the thickness the torque is increased and at the minimum feed torque is optimum.

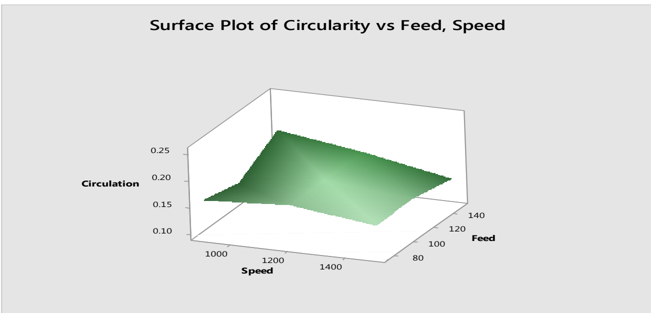

Figure 7.12 Surface Plot of Circularity Vs Feed, Speed

Figure 7.12 shows the surface plot for circularity vs speed vs feed. Form this figure it has been observed that the optimum value of circularity gain maximum speed and median feed. It has been conclude that the increase speed the circularity is reduced and at the minimum feed circularity is optimum.

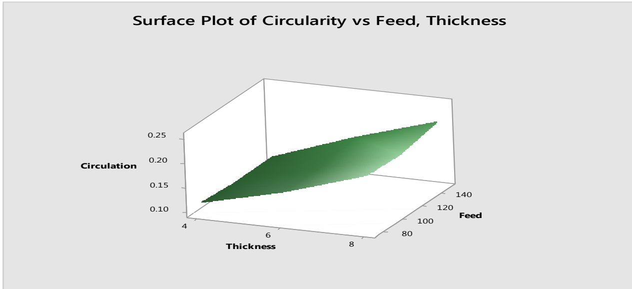

Figure 7.13 Surface Plot of Circularity Vs Feed, Thickness

Figure 7.13 shows the surface plot for circularity vs thickness vs feed. Form this figure it has been observed that the optimum value of circularity gain minimum thickness and minimum feed. It has been conclude that the increase thickness the circularity is increased and at the minimum feed circularity is optimum.

2nd Test results with same factors

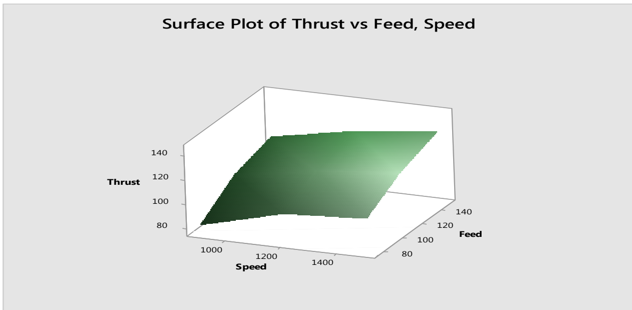

Figure 7.14 Surface Plot of Thrust Force Vs Feed, Speed

Figure 7.14 shows the surface plot for thrust force vs Speed vs feed. Form this figure it has been observed that the optimum value of thrust force gain low speed of spindle and minimum feed rate. It has been conclude that the increase the speed the thrust force is increased and at the minimum feed thrust force is optimum.

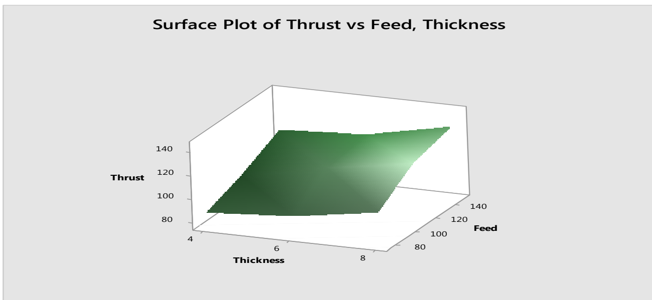

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Figure 7.15 Surface Plot of Thrust Force Vs Feed, Thickness

Figure 7.15 shows the surface plot for thrust force vs thickness vs feed. Form this figure it has been observed that the optimum value of thrust force gain low thickness and minimum feed. It has been conclude that the increase the thickness the thrust force is increased and at the minimum feed thrust force is optimum.

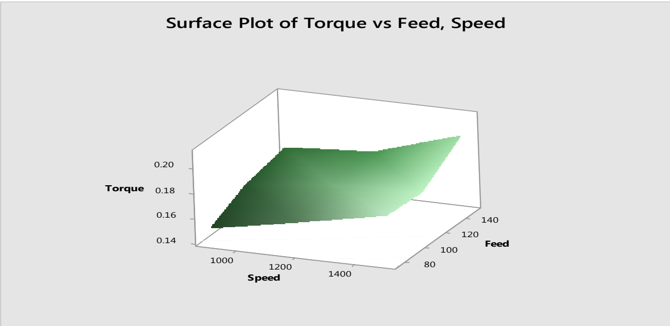

Figure 7.16 Surface Plot of Torque Vs Feed, Speed

Figure 7.16 shows the surface plot for torque vs speed vs feed. Form this figure it has been observed that the optimum value of torque gain at low speed and minimum feed. It has been conclude that the increase the thickness the torque is increased and at the minimum feed torque is optimum.

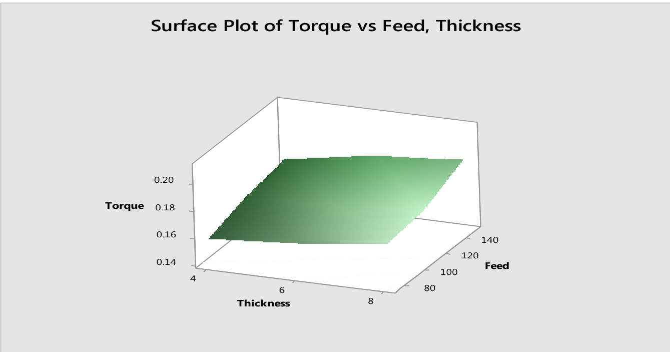

Figure 7.17 Surface Plot of Torque Vs Feed, Thickness

Figure 7.17 shows the surface plot for torque vs thickness vs feed. Form this figure it has been observed that the optimum value of torque gain low thickness and minimum feed. It has been conclude that the increase the thickness the torque is increased and at the minimum feed torque is optimum.

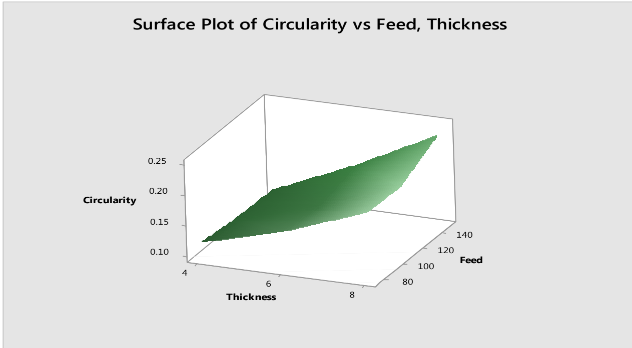

Figure 7.18 Surface Plot of Circularity Vs Feed, Thickness

Figure 7.18 shows the surface plot for circularity vs thickness vs feed. Form this figure it has been observed that the optimum value of circularity gain minimum thickness and minimum feed. It has been conclude that the increase thickness the circularity is increased and at the minimum feed circularity is optimum.

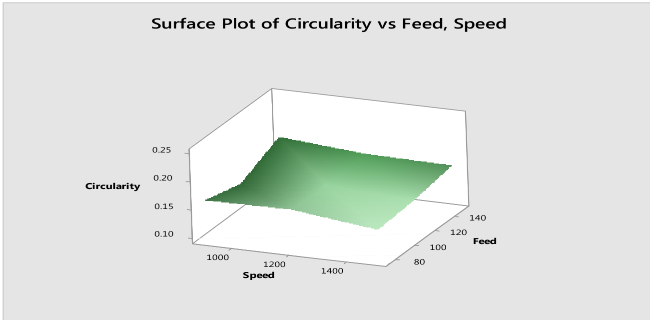

Figure 7.19 Surface Plot of Circularity Vs Feed, Speed

Figure 7.19 shows the surface plot for circularity vs speed vs feed. Form this figure it has been observed that the optimum value of circularity gain maximum speed and midian feed. It has been conclude that the increase speed the circularity is reduced and at the minimum feed circularity is optimum.

8.1 Conclusion and Future Scope

From the above experiment it has been conclude that the response data are very close to the regration line and it had been acceptable results. SN ratio, normal probability plot, mean plot and surface plot had been observed.
It has been concluding that the minimum thickness, speed and feed given the optimum result of thrust force. The minimum speed, thickness and median feed given a optimum result for torque. The maximum speed mediam feed and minimum thickness given optimum result for circularity.

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