International Journal of Emerging Trends in Science and Technology
5 (2), December 2019, 24-30
http://www.publishingindia.com/ijetst

Optimization of Machining Parameters on Surface Roughness and MRR in Drilling AISI 429 Steel Using Response Surface Method

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Abstract: This paper mainly focuses on the drilling parameter optimization by introducing Response Surface Methodology (RSM). RSM is the most effective methods to modeling and find optimum results. In this study, three parameters such as cutting speed, feed rate and point angle has been selected as input parameters and surface roughness, torque, thrust force and material removal rate (MRR) are taken as the responses. The experiments are carried out over the AISI 429 steel plate with the dimension of 100×100×10 mm by using HSS 8 mm drill bit. The input parameters are predicted by using response surface methodology (RSM). From the results that can be observed clearly the predicted parameters speed and feed rate are the most important to get good surface integrity and maximum material removal rate.

Keywords: AISI, Drilling, Material removal rate, Response surface methodology, Surface roughness.

I. Introduction

Drilling is the hole making process which enables mating two parts with the help of fasteners. While drilling number of holes over the hard material there is chance to drill bit and its cutting edges damage. Sometimes chips formed during drilling operation may stick with drill bit due to heat generated during operation. So this may lead lack of hole quality. That is why we have to make some changes in the input parameters such as drill diameter, point angle, speed, feed rate, etc. Many studies shows speed and feed rate plays a vital role to get hole quality and reduce drill bit damage. Amran *et al.* [1] investigated the effect of drilled hole in various speed, feed also observed in surface roughness using numerical approaches. The study shows there are interactions among parameters and also it shows that less surface finish because of to increase in speed, feed and drilled hole diameter of tool. Gaurav Chaudhary *et al.* [2] studied the effect of drilling parameters on aluminium matrix composites and hybrid aluminium metal matrix composites by using Response Surface Method (RSM). Erol Kilickap *et al.* [3] studied the effect of surface finish in drilled hole in AISI 1045 material using Response surface methodology (RSM) and Genetic algorithm (GA). Nam *et al.* [4] discussed to achieve the drilled hole and selection of speed, feed also nanofluid volumetric concentration in micro-drilling using RSM and GA. Nihattosun *Outcomeparameters* [5] introduced grey relational analysis to determine optimum parameters for multi-objective characteristics in drilling. In this study, three different materials such as HSS, TiN coated HSS and carbide drill bits are used to make hole on AISI 4140 steel work piece. Hamzeh Shahrajabian *et al.* [6] conducted the experiment on carbon fiber reinforced epoxy composite to get surface roughness, delamination factor and thrust force. Erol Kilickap *et al.* [7] conducted the experimental investigation of burr height in drilling on Al-7075 by integrating response surface method (RSM) and Taguchi method. The surface integrity and burr height. Ademcicek *et al.* [8] studied the effect of drilling parameters on AISI 304 steel with cryogenically treated HSS drill bit by integrating Taguchi technique and response surface method (RSM). Control factors considered in this study are spindle speed, feed rate and full factorial design has been chosen. HSS drill bits are cryogenically treated which means drill bits kept at -195 ºC for 24 hr. J. P. Davim *et al.* [9] investigated the effect of parameters on delamination of medium density fiberboard (MDF) using response surface method. Also shows that the increase in speed reduces the cutting force and materials soften due to increase in speed, it minimizes delamination. K. Palanikumar *et al.* [10] study the effect of drilling parameter cutting speed, feed rate and various point angles on medium density fiber board using response surface method.

II. Material Selection

A. Processing of AISI 429

AISI 429 stainless steel is used in domestic, construction and chemical industries. AISI 429 steel is a martensitic stainless steel which is smallest group among stainless steel groups. It has excellent mechanical properties in addition to good corrosion resistance due to which the stainless steel finds extensive application in chemical vessels manufacturing. Martensitic stainless steel has highest tensile strength and lowest elongation which depends upon the heat treatment process. Raw material of the stainless steel is prepared from stainless steel scrap and alloying elements are added based on the properties required.

B. Composition of AISI 429 Stainless Steel

Table I: Composition of AISI 429 Stainless Steel

Elements	% of Composition
Carbon (C)	0.03
Silicon (Si)	0.47
Manganese (Mn)	0.54
Phosphorous (P)	0.016
Sulphur (S)	0.013
Nickel (Ni)	0.14
Chromium (Cr)	15.39
Molybdenum (Mo)	0.029
Copper (Cu)	0.085
Titanium (Ti)	0.003
Cobalt (Co)	0.032

Mechanical Properties of AISI 429

Fig. 1: AISI 429 Stainless Steel

III. Tool Selection

A. Drill Bit

Nowadays drilling is the most appropriate operation to fasten two components than any other joining process. Drill bit is used to make a hole over the material which is a solid rod and it has helical groove over its body called flute which is also carries chips away. There is lot of materials exist to drill hard materials and high strength materials, drill bit type is selected based on the hole size and type of hole. These grooves guide the chip to get out from cutting edge to hole top. Twist drill bit is preferred for all kind of work materials, even if super alloys and high strength materials. Normally, the helix angle varies between 18 ºC to 30 ºC which two times bigger than point angle.

B. Selection of Tool Material

High Speed Steel (HSS) is the most commonly used tool material, due to its low cost and high wear resistant; it is preferred in many industries to drill high strength alloys and ductile materials. Cobalt steel, TiN coated HSS and carbide drill bits are preferred to drill stainless steel material. While coming to the point of their cost, they are costlier than high speed steel. That is why we have decided to make hole on stainless steel material by means of high speed steel 8 mm M42 drill bit. In this study, we have decided to vary point angle of the drill bit which is mentioned in input parameters.

Fig. 2: AISI M30 Drill Bit

Soft annealing is carried out at the temperature of 850–900 ºC and kept it for 3 hrs. Then slowly cooled at the temperature of 10 ºC per hour until 700 ºC reached, then stress is relieved at the temperature of 600–700 ºC kept 2 hrs. Hardness is increased by preheating at the temperature of 450–500 ºC and 580–900 ºC.

IV. Experimental Details

A. Selection of Input Factors and Matrix Design

This investigation concentrates on the input parameters feed rate, spindle speed and point angle, this factors selected for three levels. Response surface method is done using Minitab17; optimum results are obtained by applying response surface method. Three levels such as maximum, medium and minimum are selected.

Table II: Selection of Input Parameters

Factors	Parameters	Levels		
		-1	0	1
A	Point Angle (deg)	110	118	126
B	Speed (rpm)	500	750	1000
C	Feed Rate (mm/rev)	0.075	0.1625	0.25

B. Material Preparation

AISI 429 steel material is widely used in chemical industries to reduce corrosion; due to its hardness it is difficult to machining.

Experiments were carried out over the AISI 429 stainless steel 200×200×10 mm using HSS straight shank drill bit with 8 mm diameter at various feed rate and spindle speed under dry condition. Stainless steel plate is cut into four pieces with the dimension of 100×100×10 mm by using cutter grinder. HSS drill bits are prepared at various point angles, the point angles are obtained by grinding. The materials are shown in Fig. 3. Excessive burr appears on the work material during cutting is removed from it by grinding the work material. Materials are prepared by grinding its surface to check its chemical composition; chemical composition results are confirmed that the chosen material is AISI 429 steel. Chemical composition test is carried out by optical emission spectroscopy (OES).

Fig. 3: Prepared AISI 429 Stainless Steel

The parameter material removal rate, torque, thrust force and surface roughness has been taken as the responses. Recommended spindle speed, feed rate and point angle has been taken from the machinability data book. Studies show that the speed rate and feed rate is most influential parameter while considering better surface integrity. While machining hardest material some parameters has to be consider to get better quality hole. AISI 429 is a ductile material so lowest feed rate and highest speed has been considered.

Experiments are designed by using Minitab17 and optimization is done in response surface method (RSM), Box-Behnken method of optimization. The experiments are carried out in dry environmental condition. Thrust force and torque noted down for each process and graph is drawn in the computer itself. One piece of plate is fixed on the table and point angle 110º is mounted in spindle, drilling made on the work piece based on is speed and feed rate. Another piece is mounted on the table and point angle 118º is fitted in spindle. Likewise, each material selected for making hole for each point angle. Chips are collected for every hole and it is cleaned by means of brush, hole number is noted down on the work material.

Fig. 4: Various Drill Bit Angles

C. Design of Matrix and Observed Values

During machining process machining time, torque and thrust force is measured as responses. A dynamometer is used to measure thrust force and torque, computer is used to plot graph. Thrust force is also called cutting force, hardest material requires more cutting force and torque. Three parameters and three levels are selected based on studies and these selected parameters are uploaded in response surface method and optimum values are tabulated. Experimental sequence is shown in Table III. Design table depicts experimental sequence which is carried out during machining process. Minimum parameter value is taken as -1, medium value is taken as 0 and maximum value is taken as +1. Medium speed is entered in program command, maximum feed and point angle is considered for first hole, for same speed minimum feed and point angle is selected. Minimum and maximum speed is selected respectively for medium and minimum feed and point angle combination.

Table III: Observed Values

Sr. No.	Speed (RPM)	Feed Rate (mm/rev)	Point Angle (Deg)	Thrust Force (N)	Torque (Nm)
1	750	0.25	126	3.312	9.36
2	750	0.075	110	1710	4.79
3	1000	0.1625	110	3184	7.77
4	500	0.25	118	3172	9.79
5	750	0.25	110	4250	10.74
6	750	0.1625	118	3087	7.81
7	750	0.1625	118	3019	8.8
8	750	0.075	126	1609	4.11
9	1000	0.075	118	1806	4.98
10	500	0.1625	126	2597	7.39
11	500	0.075	118	1744	3.62
12	1000	0.1625	126	2306	6.68
13	750	0.1625	118	3198	8.77
14	500	0.1625	110	2897	8.12
15	1000	0.25	118	4305	11.37

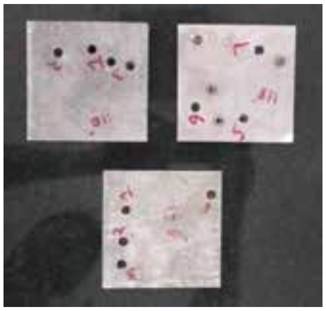


Fig. 5: Drilled Materials

D. Material Removal Rate (MRR)

Material removal rate is defined as the amount of material removed from work material per unit of time. Material removal rate defines quality of hole, if material removal rate is higher, then quality of hole is lesser. MRR values for this experiment are shown in Table IV. Material removal rate is calculated from the formula given below,

$$MRR = \frac{A}{t} \times L \ \ (\text{mm}^3/\text{Sec})$$

Where,

A- Area of the hole (mm^2), L- Length of the hole (mm), t- Time (Sec)

$$A = \frac{\pi}{4} D^2$$

Where,

D - Diameter of the hole (mm)

Material removal rate calculation

Area of hole (A) = $\frac{\pi}{4}$ $(8)^2$ = 50.24 mm^2

Surface roughness calculation

Average = $\frac{T1+T2+T3}{3}$ µm

E. Surface Roughness

Surface roughness is defined as the surface waviness or deviation of height on profile of hole or any machined components. Surface roughness of the hole is measured using SURFTEST SJ-210 roughness tester manufactured by Mitutoyo. SURFTEST SJ-210 roughness tester setup is shown in Fig. 6.

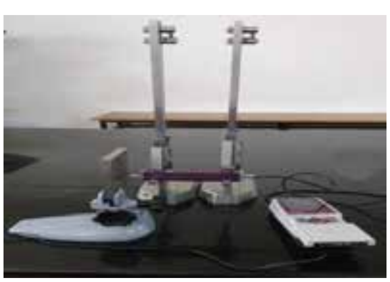


Fig. 6: Surface Roughness Tester Setup

Two vernier height gauges is used to support surface roughness tester, tester is placed over height gauge scribe. Work material is placed on the fixture by tightening screw, before placing roughness tester; reference is taken by reference specimen shown in Fig. 6. Calibration is most important to check accurate value, it can be vary based on roughness required.

Table IV: MRR and Surface Roughness Values

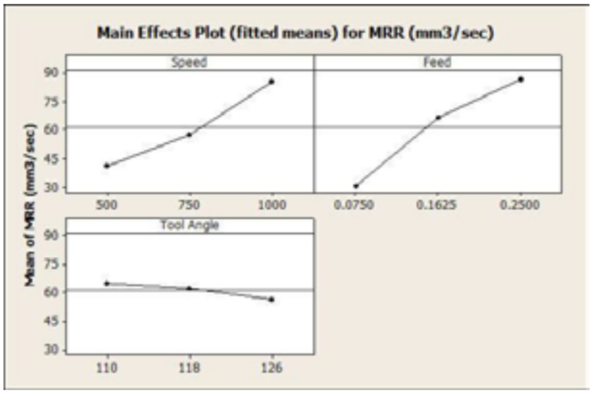
Sr. No.	Speed (RPM)	Feed Rate (mm/rev)	Point Angle (Deg)	MRR (mm^3/min)	Surface Roughness (µm)
1	750	0.25	126	71.771	3.823
2	750	0.075	110	31.4	3.057
3	1000	0.1625	110	100.48	1.181
4	500	0.25	118	62.8	1.856
5	750	0.25	110	83.733	1.684
6	750	0.1625	118	62.8	2.226
7	750	0.1625	118	62.8	3.03
8	750	0.075	126	29.552	2.236
9	1000	0.075	118	38.646	1.296
10	500	0.1625	126	41.867	4.136
11	500	0.075	118	20.096	3.03
12	1000	0.1625	126	83.733	2.157
13	750	0.1625	118	66.105	2.553
14	500	0.1625	110	45.672	1.521
15	1000	0.25	118	125.6	3.803

V. Results and Discussion

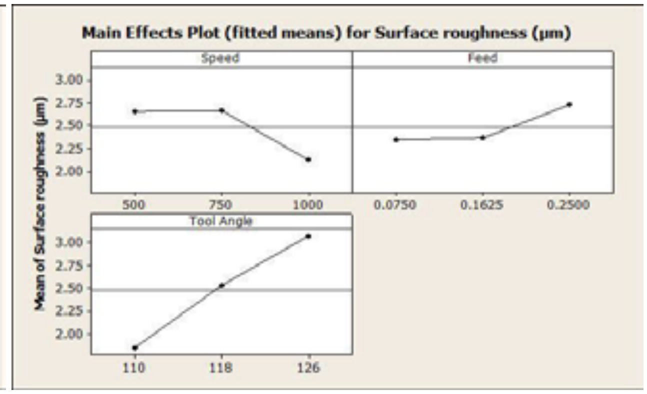
Drilling is carried out over three samples of stainless steel AISI 429 with dimensions of 100×100×10 mm using HSS 8 mm drill bit under dry condition. Three different speeds, feed rate and point angle is selected to drill the material. Selected speed rate is 500, 750 and 1000 rpm, feed rate is 0.075, 0.1625 and 0.75 and point angle is 110º, 118º and 126º.

A. Outcome Parameters of MRR

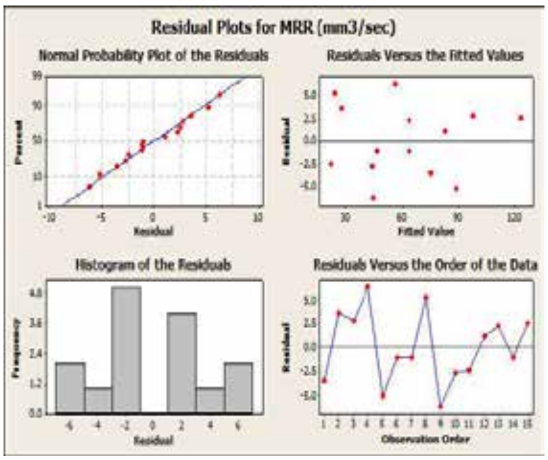
Material removal rate is defined as the amount of material removed from the work material. Quality of machining process defines the amount of material removal rate, it may affects the hole quality. Fig. 7 (a, b, c, d, e, f) shows effect of parameters on MRR.



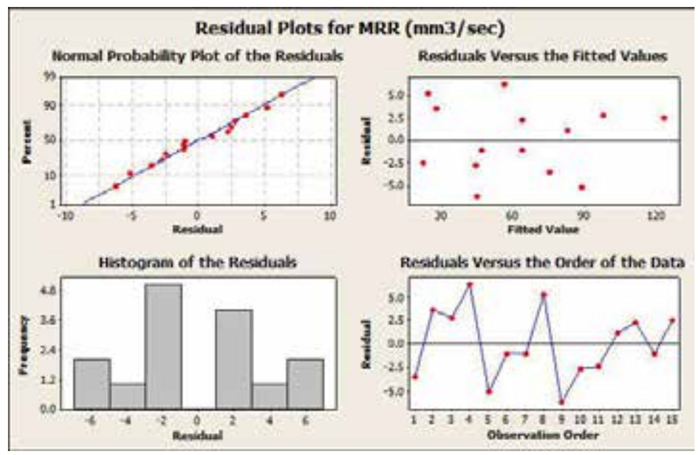
(a) Main Effect Plot for MRR



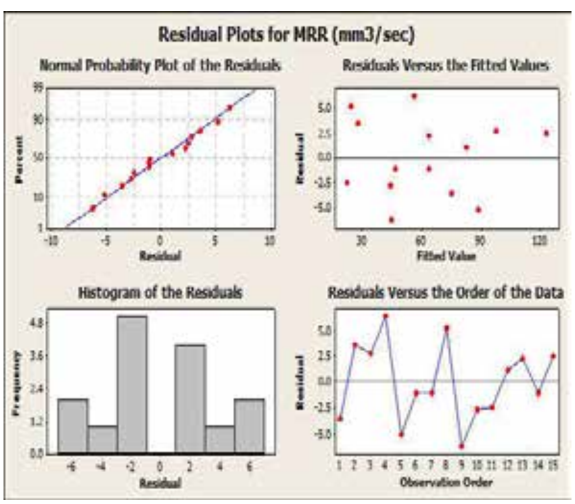
(b) Main Effect Plot for SF



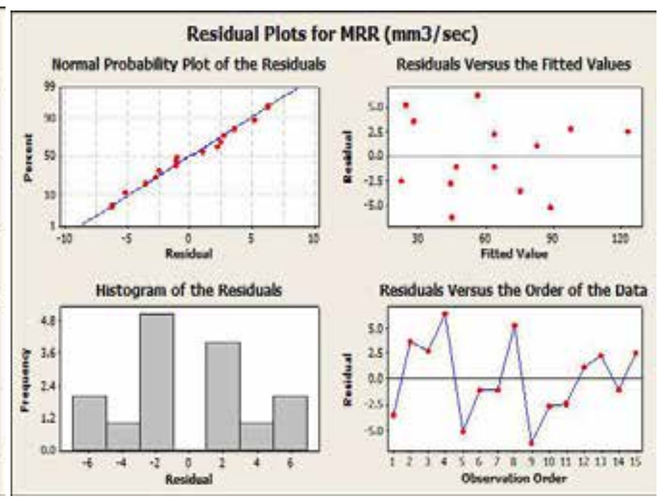
(c) Residual Plot for MRR



(d) Residual Plot for MRR



(e) Residual Plot for MRR



(f) Residual Plot for MRR

Fig. 7

Average material removal rate is obtained around 60 mm^3/sec, main effects for MRR are plotted based on this value. From this graph, medium level of speed, feed rate and point angle follows mean material removal rate value. When the spindle speed is in maximum level around 1000 rpm, material removal rate goes above mean value. Material removal rate almost follows mean value at 750 rpm and it goes down at 500 rpm. The lowest feed rate 0.075 mm/rev, material removal rate plotted below mean value, it is far from mean value. Medium level feed rate 0.1625 mm/rev is just above mean value and it can be said almost follows mean value. If the feed rate is maximum, material removal rate increased above average value. Minimum tool angle 110º is plotted just above the mean value, at 118º point angle MRR value touches mean value, at 126º tool angle MRR just below mean value.

VI. Conclusion

Stainless steel AISI 429 plate is selected for this study and HSS 8 mm drill bit is used to put hole on stainless steel plate under dry condition. This investigation is carried out at various speed, feed rate and point angle and MRR, surface roughness are calculated. From this study it is concluded that speed and feed rate is the most significant factor on material removal rate and surface roughness, but point angle does not shown any significant effect. Coefficient of determination (R^2) for material removal rate is obtained 98.3%, for surface roughness coefficient of determination (R^2) is obtained 84.5%. Maximum speed, feed rate and minimum point angle increase material removal rate. To increase MRR, the recommended combination of speed, feed and point angle is1000 rpm, 0.25 mm/ rev and 110º respectively. Maximum speed, minimum feed rate and minimum point angle improves surface roughness of the hole. To reduce surface roughness speed 1000 rpm, feed 0.1625 mm/ rev and point angle 110º is recommended. Minimum surface roughness 1.181 µm is obtained speed 1000 rpm, feed rate 0.1625 mm/rev and angle 110º, surface finish 4.13 µm is obtained at speed 500 rpm, feed 0.1625 mm/rev, angle 126º. Maximum MRR 125.6 mm^3/sec are measured at speed 1000 rpm, feed 0.25 mm/rev and point angle 118º. Minimum MRR 20.096 mm^3/sec are measured at speed 500 rpm, feed 0.075 mm/ rev and point angle 118º. Due to material ductility burr is formed as a cap at exit of the hole and roughness value is high.

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