INVESTIGATION OF CUTTING TIME AND TOOL WEAR RATE ON EN-24 STEEL ALLOY BY THE DRILLING PROCESS

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Abstract:

Modeling and optimization of cutting parameters are one of the most important factors in manufacturing process. The aim of present work is to establish the relation among input factors i.e. spindle speed, feed rate and depth of cut and response parameters i.e. cutting time and tool wear rate. The operation is performed on EN-24 alloy steel material. The analysis of variance (ANOVA) has been performed to find the significant and non-significant parameters. Mathematical model is developed for CT and TWR and optimized using composite desirability (CD) function technique. It was found that the best machining factor is depth of cut whereas spindle speed is the less significant machining parameter. The confirmation experiments have been also performed to validate the results. The given model could be utilized to select the level of drilling parameters.

1 Introduction

EN-24 steel alloy is useful for various industrial applications such as fabrication of gears, shafts, bolts, etc. The drilling of EN-24 alloy is due to high hardness of the material. Drilling operation has useful for the various industries like automobile, aerospace, etc. The proper selection of machining parameters provides the better material removal, product quality, surface finish production time**. Ozler et al.** performed drilling operation on AISI 1010 steel alloy to drill steel tubes. The drilling was performed by a tungsten tool. The washer geometry, length of bush and petal geometry were examined under varying parametric settings. It was found that the bushing length was distorted at higher feed rate [1]. **Bilgin et al.** performed drilling operation oneaustenitic stainless steel and calculated theetorque as well as axialeforce to develop a model. The results observed that the torque and axial force are decreased, and work piece temperature increased as the spindle speed was increased [2]. **Krishna et al.** performed study on AA 6351ealloy by usingehigh-speed steel tool. The obtained results show that, when drilling operation was performed at lower and medium spindle speed, high polished surface was obtained and at higher spindle speed, discolorewas found inethe drilledehole [3]. **Bajpai et al.** examined a drilling operation performed on 100% biodegradable composite which was based on sisal fibers and poly-lactic acid (PLA).

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Analysis of drill geometry and cutting parameters was carried out. The high value of feed induced the defects in drill geometry [4]. **Diaz et al.** executed experiments on composite material. The two different drilling geometries (HSS twist drill of 118°C point angle and HSS customized drill of 80°point angle) with 6 mm dia. were used for experiments. It was observed that with the increase in cutting speed and feed, damage extension was decreased [5]. **Miller et al.** performed experiments on AISI 1020 steel sheet. Finite element simulation was performed by using ANSYS software. Mathematical modeling was performed for torque and axial force to analyse the surface contact [6]. **Pantawane et al.** carried out experiments on AISI 1015 steel alloy by tungsten carbide tool. The impact of feed rate, work piece thickness to tool diameter ratio, and spindle speed on surface roughness, axial force, and torque was analysed [7]. **Chow et al.** analyzed the effect of sintered carbide drill bit during the drilling of AISI 304 steel. Taguchi L_{18} OA was performed to analyse the results. The drilling speed, friction contact area ratio, friction angle and feed rate were selected as the process parameters. The effect of these parameters has been analysed on surface roughness [8]. **Tyagi et al.** performed experiments on mild steel by using HSS drill tool. The L_9 orthogonal array was developed to perform the experiments. The input parameters i.e. speed (1000-2000 rpm), feed (0.5 - 1.5 mm/min) and depth of cut (3-7 mm) has been selected. It was concluded that high value of spindle speed influenced surface finish and feed rate influenced the material removal rate [9]. **Sharma et al.** carried out drilling experiments on stainless steel AISI 304 and optimized the process parameters by design of experiment methodology. The surface roughness and ovality of the drilled hole has been analyzed. The obtained results showed that with increase in feed rate and depth of cut, the surface roughness increases. **Patel et al.** performed drilling operation on EN8, EN24 & EN31 steel grades. The operation has been performed by cobalt alloy steel drill bit. The spindle speed and feed rate found the significant parameters [11]. **Bahloul et al.** conducted drilling experiments on AISI 304 stainless steel. The Taguchi's and fuzzy logic approach were used to optimize the parameters. It was concluded that these approaches were effective and capable for multi-objective optimization [12]. **Abhishek et al.** executed ANFIS-GA hybrid technique to perform the drilling operation on glass reinforced polymer composite. The feed rate, spindle speed, drill bit dia. and work piece thickness has been selected as input parameters. A mathematical model was developed to analyse the axial force and surface roughness [13]. **Kumar et al.** conducted drilling operation on mild steel by using DoE approach. The results revealed that lower cutting speed and feed rate along with medium point angle was the optimal combination to minimize the surface roughness [14]. Based on the different findings by the researchers, it was concluded that different approach has been used to optimize the process parameters of the drilling operation. In this study, an effort has been made to optimize the drilling machine process parameters by using statistical techniques i.e. design of experiment (DoE) approach and regression analysis. The obtained optimum values from the present work will be useful for industry to obtain the optimum drilling machining parameters. It has also been attempted to optimize the cutting time and tool wear rate prediction model using a desirability function approach. Figure 1 shows the drilling operation on EN-24 material.

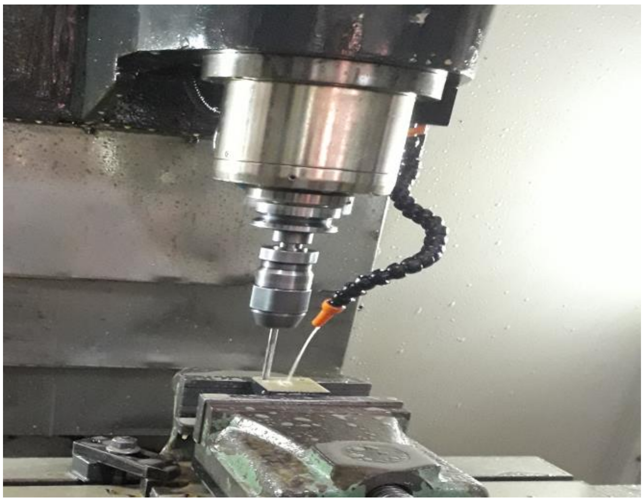

Figure 1. *Drilling operation on EN-24 material*

2 Experimental details:

The MAXMILL MTAB drilling machine (figure 2) has been used to perform experimental work. Theemachine is installed in CIPET, Jaipur, India. TheEN-24 (50 mm x 50mm x 12 mm) steel alloy is selected as a workpiece material. This industrial alloy is special hot-worked with good hardness and toughness properties. It is used for the fabrication of die and mold. The feed rate, spindle speed and depth of cut are selected the as the process parameters. The depth of cut is an important drilling machining parameter. The depth of cut in drilling is equal to one half of the drill diameter. The performance measures i.e. cutting time (CT), and tool wear rate (TWR) are selected for the present work. In present work, pilot experiments were performed to identify the effect of process parameters on machine responses. Two sections have been planned; first section is incorporated with Taguchi method analysis based on signal to noise ratio and regression modeling for S/N ratio. In second section model parameters has been optimized using desirability function. Figure 3 shown the fabricated specimen by the drilling process.

Figure 2. Pictorial view of drilling machine

2.1 Design of experiments methodology

Statistical designs of experiments (SDE) has been rigorously developed over the past several years and are being widely used in the drilling industry to optimize the machining parameters. This technique provides the relationship between process parameters and responses. A variety of statistical designs of experiments (SDE) strategies are available to obtain information within the selected test matrix. Theseeinclude Taguchi methods, evolutionaryeoperation, central compositeedesigned experimentseand full andefractional factorialeexperiments [15]. The Taguchiemethod is aepowerful design ofeexperiments (DoE) to develop the model between the drilling machining process parameters and the responses.

Figure 3. Machined specimen by drilling process

In theepresent investigation, theeraw data analysis and S/N dataeanalysis have been performed. The effects of the selected drilling process parameters on the quality characteristics have been investigated. The optimum condition for eacheof the quality characteristics has been established through S/N data analysis aided by the raw data analysis. The S/N ratioeconsolidateseseveral repetitions (at least two data points are required) into one value. Table 1 shows selected factors and level of drilling machine. The equation for calculating S/N ratios for "smaller is better" (LB), "Larger is Better" (HB) and "nominalies best" (NB) types of characteristics are as follows: -

1. Larger is Better:

$$\left(\frac{S}{N}\right)_{HB} = -10\log\,(MSD)_{HB} \qquad (1)$$

$$(MSD)_{HB} = \frac{1}{R}\sum_{j=1}^{R}\left(\frac{1}{y_j^2}\right) \qquad (2)$$

2. Smaller is Better:

$$\left(\frac{S}{N}\right)_{LB} = -10\log\,(MSD)_{LB} \qquad (3)$$

$$(MSD)_{LB} = \frac{1}{R}\sum_{j=1}^{R}(y_j^2) \qquad (4)$$

2.2 Cutting time (CT)

Cutting times is defined as the time taken by machine to complete the machining process intone cycle. Cutting time is very important parameter for every machining process. Cutting time of machining should be minimized to increase the productivity and profit of any industry. The optimum cutting time reduce the cost of production.

2.3 Tool wear rate (TWR)

Tool wear rate is defined as gradual failure of cutting tools due to regular operation. The tool wear rate is defined as the drill tool weight comparison before and after machining is taken as a measure of tool wears. The weight of drill tool is measured by using the Sartorius, model: BSA225S-CW.

Table 1. Factors and levels for drilling operation

Factor	Level			
	I	II	III	IV
Feed(mm/min)	10	11	12	13
Spindle speed (RPM)	800	900	1000	1100
DoC (mm)	1.0	1.25	1.50	1.75

3 Results

3.1 effect on TWR

The L_{16} OA has been prepared, and experiments were performed accordingly. The table 2 shows the developed orthogonal array and values of the obtained response. Figure 4 shows the main effect plots for the tool wear rate.

Table 2. OA's and value of the response

S. No	Feed	Speed	DoC	TWR	S/N Ratio	CT	S/N Ratio
1	1	1	1	0.003	48.63	145.2	43.23
2	1	2	2	0.003	49.37	138.6	42.83
3	1	3	3	0.003	50.45	135.0	42.60
4	1	4	4	0.002	51.37	130.8	42.33
5	2	1	2	0.003	49.62	132.5	42.44
6	2	2	1	0.003	50.17	127.2	42.08
7	2	3	4	0.002	50.75	123.6	41.84
8	2	4	3	0.002	51.70	114.3	41.16
9	3	1	3	0.003	49.62	125.4	41.96
10	3	2	4	0.003	50.17	121.8	41.71
11	3	3	1	0.002	51.05	93.6	39.42
12	3	4	2	0.002	52.04	97.6	39.78
13	4	1	4	0.003	49.89	120.6	41.62
14	4	2	3	0.003	50.45	92.4	39.31
15	4	3	2	0.0028	51.05	88.2	38.90
16	4	4	1	0.0025	52.04	85.2	38.60

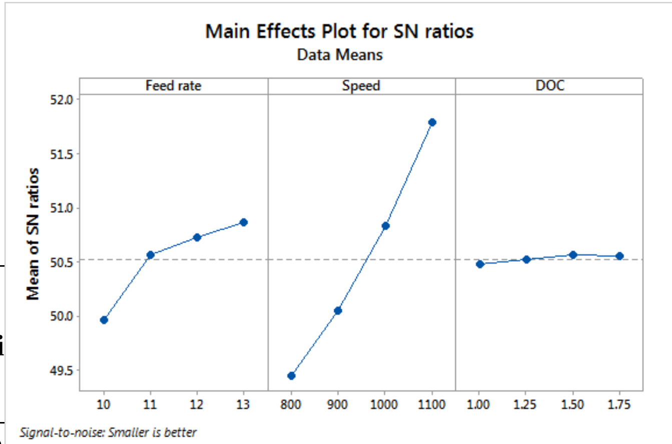

Figure 4. Main effect plots for TWR

It can be noticed that tool wear rate is mainly affected by the spindle speed. The higher value of speed leads to high TWR rate. The depth of cut shows the less effect on the tool wear rate. Interaction plots are generated to identify the effect individual parameter on the response. The figure 5 shows the obtained interaction plots fort the tool wear rate. The interaction plot shows that the input parameters have full interaction with the tool wear rate.

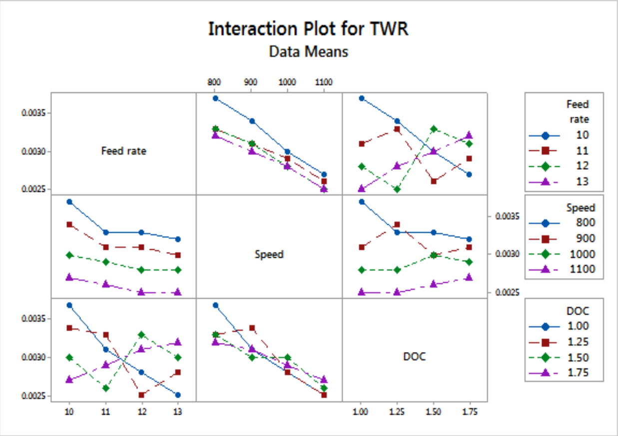

Figure 5. Full scale interaction plot for TWR

3.2 Effect on Cutting Time:

Figure 6 shows the main effect plots for the cutting time. It can be seen that the high value of feed rate provides the high cutting time. It is observed that the feed rate found the most significant parameter and depth of cut found the less significant parameter.

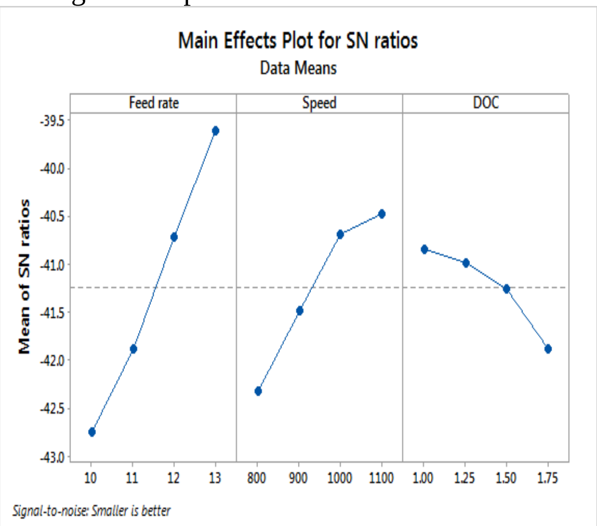

Figure 6. Main effect plots for CT

3.3 Interaction plots for CT

Fig. 7 represents the interaction plots between input factors i.e. feed, spindle speed and depth of cut with cutting time. The interaction plot shows that the input parameters have full interaction with the cutting time.

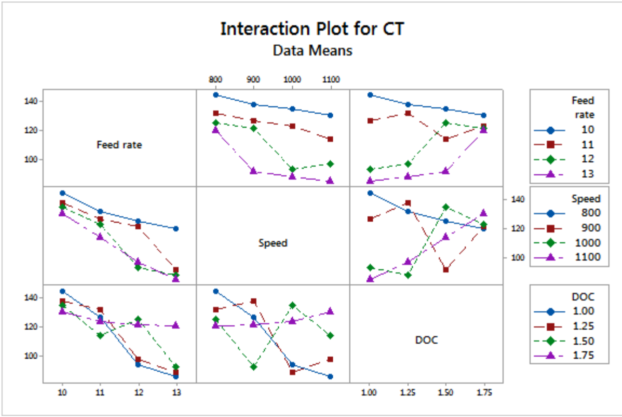

Figure 7. *Full scale interaction plot for CT response*

3.4 Optimal solution prediction

The optimal rank of levels of input factors for cutting time and tool wear rate has been identified. The results are presented in table 3 in coded value of DoE technique. The maximum values in rank identification table are considered as optimum levels of each factor for CT and TWR.

Table 3. Optimal solution for both responses

Response	A	B	C
TWR	4	4	3
CT	4	4	1

For TWR maximum values (S/N ratio analysis) for factors A(feed), B(speed) and C (DoC) are at level 4, level 4 and level 3 respectively and for CT optimum levels are at level 4, level 4 and level 1 for factors A, B and C respectively. Table 4 and 5 shows the ANOVA analysis of tool wear rate and cutting time respectively [16].

Table 4. Analyses of variance for TWR

Source	DF	Seq. SS	Contribution	Adj. SS	Adj. MS	F-value	P-value
Model	3	0.000002	95.26 %	0.000002	0.000001	80.36	0
Line	3	0.000	95.26	0.000	0.000	80.36	0

ar		002	%	002	001		
Feed rate	1	0	12.15 %	0	0	30.75	0
Speed	1	0.000001	82.75 %	0.000001	0.000001	209.43	0
DoC	1	0	0.35%	0	0.00001	0.9	0.36
Error	12	0	4.74%	0	0.00001		
Total	15	0.000002	100.00 %				

Table 5. Analysis of variance for CT

Source	DF	Seq. SS	Contribution	Adj. SS	Adj. MS	F-value	P-value
Model	3	5371.5	95.11 %	5371.5	1790.5	77.79	0
Linear	3	5371.5	95.11 %	5371.5	1790.5	77.79	0
Feed rate	1	3764.8	66.66 %	3764.8	3764.77	163.56	0
Speed	1	1336.6	23.67 %	1336.6	1336.61	58.07	0
DoC	1	270.1	4.78%	270.1	270.11	11.74	0.005
Error	12	276.2	4.89%	276.2	23.02		
Total	15	5647.7	100.00 %				

3.5 Confirmation experiment:

Table 6 shows the confirmation of experiments for the tool wear rate and cutting time. Table 6 presents the range of response TWR and CT for predicted value and experimental value of optimal solution. It can be seen that the experimental results are very well suited for the predicted results.

Table 6. Confirmation experiments for TWR and CT

Response Parameter	Optimal Set of Parameters	Predicted Optimal Value	Predicted Confidence Intervals at 95% Confidence Level	Experimental Value
TWR	$A_4B_4C_3$	0.0020	CI_{POP}: $0.0026<\mu_{TWR}<0.0033$ CI_{CE}: $0.00124<\mu_{TWR}<0.00324$	0.0023
CT	$A_4B_4C_1$	82.37	CI_{POP}: $70.68<\mu_{CT}<94.06$ CI_{CE}: $77.15<\mu_{CT}<87.59$	85.20

4 Regression Modeling

Taguchi's analysis is limited to the selection of optimal value for each response, but it could not preform regression modeling for selective responses. The regression modelling was performed by the residual plots. Quadratic model is selected as std. deviation is minimum and R square is maximum for present model. The obtain model found the 91.36% is significant.

Model Summary

S	R-sq.	R-sq.(adj.)	R-sq.(pred.)
0.0000827	95.26%	94.07%	91.36%

Figure 8 shows the residuals plot for the tool wear rate. It revealed that the residuals generally fall on a straight line implying that the errors are normally distributed. It shows that the residuals versus predicted responses

for TWR data, it is seen that no obvious pattern and unusual structure. This implies that the models proposed are adequate and there is no reason to suspect any violation of the violation of the independence or constant variance assumption [16].

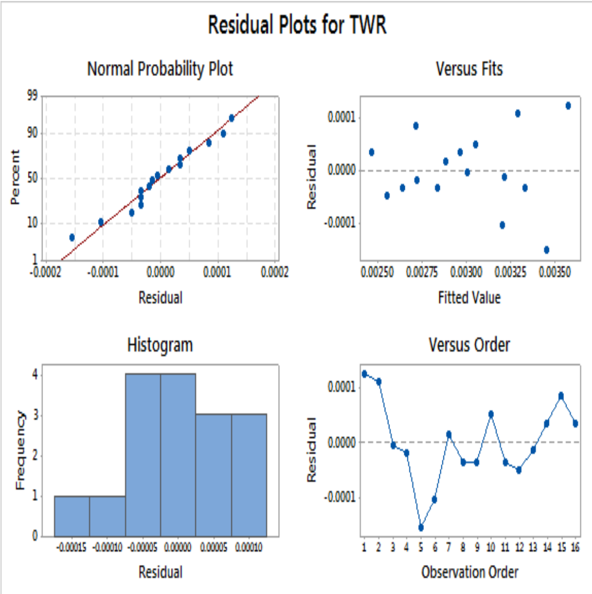

Figure 8. Residual plot for TWR

The model summary for CT is presented and it shows that the model is 90.53% is significant. The figure 9 shows that residual plots for the cutting time. It seems from the figure that the results are well lie with the selected levels of the parameters [17-18].

Model Summary

S	R-sq	R-sq(adj.)	R-sq(pred.)
4.79763	95.11%	93.89%	90.53%

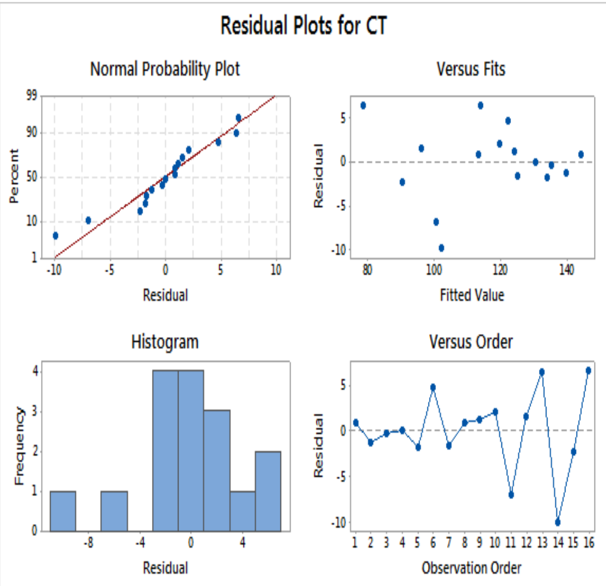

Figure 9. Residual plot for CT for linear model Model

4.1Optimizationeusing desirabilityeFunction:

The optimization of multiple response is difficult by the convention methods so in present work the multiple response optimization is performed by the desirability approach. It is an appropriate method for optimization of multiple quality characteristic problems. The method makes use of an objective function, D(X), called the desirability function and transform estimate responses into a scale free value (di) called desirability. The desirable ranges are from zero to one. The factor settings with maximum total desirability are the optimal parameter conditions. Desirability is an objective function that ranges from zero outside of the limits to one ate the goal. The numerical optimization finds point that maximizes the desirability function.

Optimal Solution as per DF

The optimum values of factor A, B and C are 13, 1100 and 1.75 respectively obtained. The desirability function obtained is 0.0024 for tool wear rate. Desirability test for cutting time is performed to optimize the input parameters to get best results for drilling operations for better production rate. The optimum values of factors A, B and C for minimized value of CT is 82.71 after optimization at feed13 mm/min, spindle speed 1075 rpm and depth of cut 1.18 mm.

Table 7. Desirability values for the TWR and CT

S.no.	Feed rate	Speed	Depth of cut	Obtained result	Desirability
TWR	13	1100	1.75	0.0024	1
Cutting time	13	1075	1.18	82.71	1

5 Conclusions:

In present study the effecteof process parameters of drilling machine process has investigated. Three process parameters have selected with four level each. The tool wear rate and cutting time were investigated in present study. Optimal solution for factors were discussed and following conclusions have been drawn.

1. The main contribution of the study is to the minimum tool wear rate and cutting time for the drilling process. The optimum drilling condition using design of experiment

methodology has been obtained. The design of experiment and regression analysis approach provide a systematic and effective methodology for modelling and optimization.

2. The optimum values i.e. feed rate 13 mm/min, spindle speed 1100 rpm and depth of cut 1.50 mm are obtained for tool wear rate and feed rate 13 mm/min, spindle speed 1100 rpm and depth of cut 1.00 mm are obtained for the cutting time.

3. The residual plots have been obtained and the generated model has found adequate. The 90.53% and 91.36% model are significant for the tool wear rate and cutting time respectively.

4. Optimization of factors for optimal solution using desirability function ‘was performed for cutting time and tool wear rate.

5. The present work is focused based on the DoE approach. Further research work can be carried out by using other approaches such as fuzzy logic, ANN, MOGA etc. for machining of advanced materials i.e. Inconel, shape memory alloy etc.

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