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INVESTIGATING OPTIMUM PARAMETER REQUIRED FOR DRILLING MILD STEEL USING RESPONSE SURFACE METHODOLOGY

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ABSTRACT: *The study investigated on optimum parameters required for drilling mild steel using Response Surface Methodology (RSM) based on L_9-A 3^{4-2} fractional factorial design. The mild steel workpiece is of dimension of 200 mm by 80 mm with a thickness of 1.5 mm. The study employed the following process parameters namely, cutting speed, feed, depth of cut and tool for minimizing surface roughness of mild steel. Vertical pillar drilling machine of METALIK PK203 model was used for the drilling operation and coupling ultrasonic thickness meter of TM-8810 model was also used to measure the surface roughness of the workpiece after drilling. Analysis of Variance (ANOVA) was carried out to test for the significant level of the process parameters for optimizing surface roughness. The findings revealed that the process parameters has a high significant effect in influencing the response variable at 5% significant level and that optimum process parameters can be achieved at an intermediate level during drilling operation. The findings also revealed that there exist a good agreement between the estimated and experimental results based on the mathematical model formulated.*

KEYWORDS: Mild Steel, Response Surface Methodology (RSM), Surface roughness, ANOVA, Process parameters

INTRODUCTION

Mild steel is the most commonly used steel in the manufacturing industries for different application such as electrical device, constructing pipelines and other construction materials, domestic cook wares, body and parts of vehicle etc. The study of mild steel became important in mechanical or metallurgical engineering because the usage is huge which requires manufacturers to know a lot about it important characteristics.

Drilling as a machining operation which is selected in the study became necessary because most manufacturing product been manufactured usually requires fasten which allows the passage of bolt and nut. Most of the fasten on the manufacturers design are so rough due to poor surface finish during machining which in turns leads to wear due to inaccurate process parameters been employed by manufacturers. Therefore the study seeks to investigate on optimum process parameters for drilling mild steel so as to minimize surface roughness.

LITERATURE REVIEW

Yogendra *et al.*, (2012) reported the drilling of mild steel with the help of CNC drilling machining operation with high speed steel by applying Taguchi methodology. They applied signal-to-noise ratio to find optimum process parameter for CNC drilling machining. They applied L9 orthogonal array and analysis of variance (ANOVA) to study the performance characteristic of machining parameter with consideration for good surface finish as well as high material removal rate (MRR). Their findings revealed that the Taguchi method and signal-to-noise ratio match closely with (ANOVA) and the feed is most effective factors for MRR. It is also revealed from their findings that spindle speed is the most effective factor for surface roughness.

Gangadhar *et al.*, (2014) investigated on an experimental approach of CNC drilling operation for mild steel using Taguchi design. They applied Taguchi method to formulate the experimental layout to ascertain the element of impact each optimum process parameters for drilling of mild steel. They conducted 27 experimental runs using orthogonal array and the ideal combination of the controllable factor levels was also determined for the material removal rate, time of machining and circularity which is measured. They also carried out design optimization for quality and signal-to-noise ratio and analysis of variance (ANOVA) using the experimental results to confirm the effectiveness of this approach. Their findings revealed that MRR decreases when spindle speed, feed and tool diameter decrease and that increased spindle speed, feed rate and tool diameter increases the quality of hole.

Vishwajeet *et al.*, (2015) focused on the optimization of drilling parameters using the Taguchi technique to obtain minimum surface roughness and maximum tool life which was experimentally performed on hardened boron steel using HSS twist drills. Analysis of Variance (ANOVA) was employed to determine the most significant control factors affecting the surface roughness and tool life. Their findings revealed that the point angle was the most significant factor for the tool life and that the feed rate was the most significant factor on the surface roughness. Their findings also revealed that the results of the confirmation experiments showed that the Taguchi method was notably successful in the optimization of drilling parameters for better surface roughness and tool life.

Rasid *et al.*, (2016) employed L9 orthogonal array to study the performance characteristics in drilling operations of mild steel (AS3679) as workpiece by using 1mm copper pipe electrode. They considered three drilling parameters namely, pulse off time, peak current and servo standard voltage to optimize drilling hole diameter. Their findings revealed that use of greater pulse off time, greater peak current and medium servo standard voltage give the better hole diameter for the specific test range.

Sudesh *et al.*, (2015) optimized cutting conditions [cutting speed, feed, wet and dry cutting, depth of hole] parameters for minimum material removal rate [MRR] in drilling of AISI H11 using face centred design. They conducted their experiments based on the design of experiment and followed by optimization of the results using analysis of variance [ANOVA] to find the maximum MRR. Their findings revealed that MRR increases with increase in feed, increase in spindle speed while depth of hole has no effect on MRR.

Pokar and Patel (2013) presented an optimization of micro-drilling parameter for EN8 [harden mild steel] workpiece using grey based Taguchi method. The design of experiment they employed is based on Taguchi L9 orthogonal array having feed rate and cutting speed as the micro drilling parameters and the responses are torque, thrust force, machining time and local circularity error. Their findings revealed that the purposed grey based relational Taguchi method is beneficial for optimization of multi-responded control parameters in micro-drilling process.

Rupesh (2013) investigated the effect of CNC drilling process variables such as spindle speed, drill diameter, material thickness and feed rate on thrust force and torque generated during the

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drilling of mild steel plate using HSS drill. The findings revealed that thrust force, torque generated and drilling process variables are statistically significant in the experimentation.

Experimental Details

In this experimental investigation, which includes selection of drilling parameters, selection range of drilling parameters, formation of the design matrix using Response Surface Methodology (RSM) based on L_9-A 3^{4-2} fractional factorial design, selection of workpiece material, experimental set-up, measurement of surface roughness.

A. Section of Drilling Parameters and the Range of Drilling Parameters

The process parameters that were chosen for experimentation are given as below:

i. Cutting speed (rpm);

ii. Feed rate (mm/rev);

iii. Depth of cut (mm); and

iv. Tool (mm).

These are the main drilling parameters that affect the surface roughness. However, machining expert can change these process parameters at any time of machining. The levels of each input parameter were decided by studying literature in detailed and according to machine limitations. Table 1 shows the levels of drilling parameters according to RSM based on L_9-A 3^{4-2} fractional factorial design.

Table 1: Drilling Parameters and their Levels

Factor	Process Parameter	Units	Type	Minimum (+1)	Maximum (-1)
X1	Cutting speed	(rpm)	Numeric	1400	1700
X2	Feed rate	(mm/rev)	Numeric	0.11	0.75
X3	Depth of cut	(mm)	Numeric	0.25	0.75
X4	Tool	(mm)	Numeric	6	10

B. Trial Machining Experiment

Experiments were conducted using the design of experiments (DOE) technique RSM based on L_9-A 3^{4-2} fractional factorial design and optimization of the results using Analysis of Variance (ANOVA) to find minimum surface roughness. The range of machining conditions was based on the industry practice for mild steel. A total of 9 numbers of experiments with triplicate has been finalized according to RSM based on L_9-A 3^{4-2} fractional factorial design. The Table 2 shows the design layout for the experimentation.

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Table 2: Design Layout for the Machining Experiment

Test No.	XI: Speed (rpm)	X2: Feed(mm/rev)	X3: Depth of cut(mm)	X4: Tool(mm)
1	1400	0.11	0.25	6
2	1400	0.18	0.5	8
3	1400	0.75	0.75	10
4	1500	0.11	0.5	6
5	1500	0.18	0.75	8
6	1500	0.75	0.25	10
7	1700	0.11	0.75	6
8	1700	0.18	0.25	8
9	1700	0.75	0.5	10

C. Experimental Set Up:

i. ***Vertical Pillar Drilling Machine***:

The drilling operation was carried out on a vertical pillar drilling machine, METALIK PK203 model, with a speed range of 75rpm to 3200rpm and driven by a motor of 1.5KW which was used for the experimentation.

ii. ***Cutting Tools***:

High speed steel (HSS) drills of 6mm, 8mm and 10mm was used for the experimentation.

iii. ***Coolant***:

Coolant was also used in all the experiments. Cutting oil of proportion ratio of water and machining oil serves as the coolant.

D. Surface Roughness Measurement

A coupling ultrasonic thickness meter, TM-8810 model, was used to measure the surface roughness of the drilled holes in the mild steel workpiece. Table 3 shows the values of the surface roughness in triplicate along with the average surface roughness and the experimental run order.

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Table 3: Results Measurements

	Process Parameters				Surface roughness of mild steel(µm)				
Test No.	XI: Speed(rpm)	X2: Feed(mm/rev)	X3: Depth of cut(mm)	X4: Tool (mm)	1st	2nd	3rd	Mean surface roughness(µm)	Standard Error surface roughness
1	1400	0.11	0.25	6	9.39	5.03	5.92	6.78	1.33
2	1400	0.18	0.5	8	5.98	6.46	9.71	7.38	1.17
3	1400	0.75	0.75	10	8.67	6.85	10.26	8.59	0.98
4	1500	0.11	0.5	6	6.01	8.80	5.65	6.82	1.00
5	1500	0.18	0.75	8	5.33	10.44	7.85	7.87	1.48
6	1500	0.75	0.25	10	4.01	3.86	4.00	3.96	0.05
7	1700	0.11	0.75	6	10.58	7.48	9.01	9.02	0.90
8	1700	0.18	0.25	8	9.51	6.79	5.61	7.30	1.16
9	1700	0.75	0.5	10	7.82	3.84	7.53	6.40	1.28

DEVELOPMENT OF SURFACE ROUGHNESS PREDICTION MODEL

To develop the surface roughness prediction model in terms of cutting speed, feed rate, depth of cut and tool, the measured value of surface roughness along with the experimental run order must have been fed into the design data. For the development of prediction model, the first step is ANOVA analysis.

A. **ANOVA for Surface Roughness Prediction Model**:

The analysis of variance (ANOVA) is based on two assumptions:

i. The variables are internally distributed; and

ii. Homogeneity of variance. Significant violation of either assumption can increase the chances of error.

To check the assumption of normal distribution, the normal probability plot of the residuals for surface roughness is shown in Figure 1. The Figure 1 displays that the residuals generally fall on a straight line, which implies that the errors are distributed normally. The Figure 2 represents residuals versus the fitted surface roughness plot. The figure shows that there is no obvious pattern and unusual structure in the points. This implies that there is no reason to suspect any violation of the independence or constant variance assumption.

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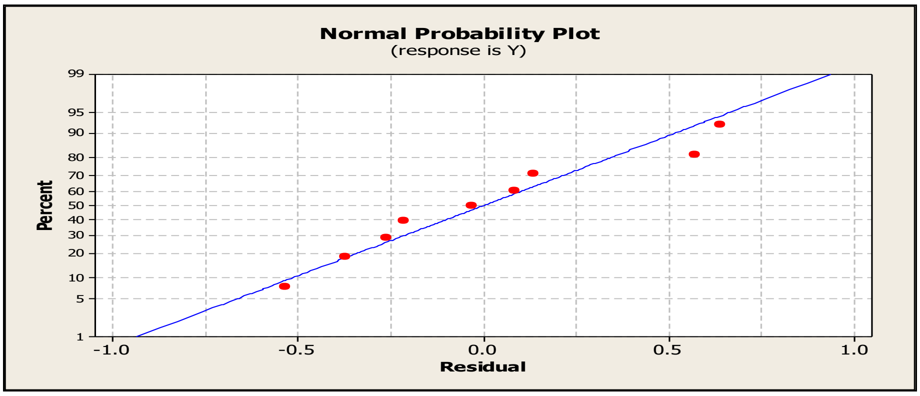

Figure 1: Normal Probability Plot of Residuals for Surface Roughness

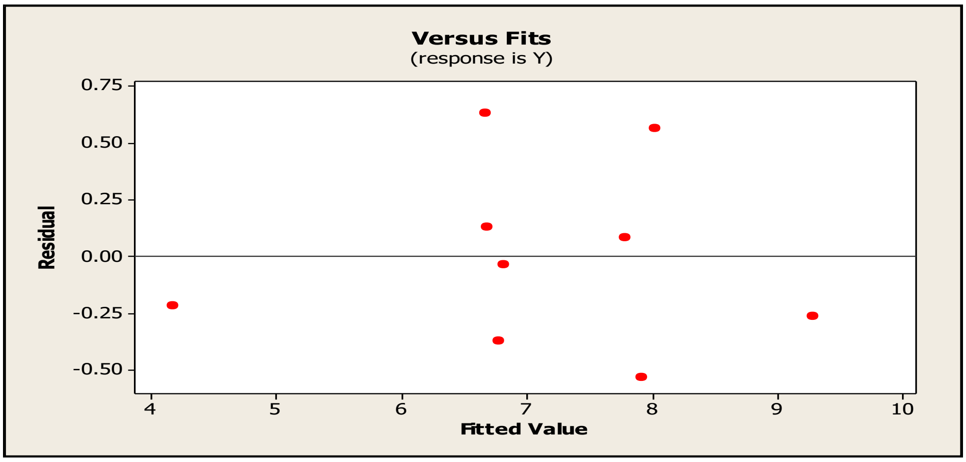

Figure 2: Plot of Residuals vs. Fitted Value of Surface Roughness

B. ANOVA Analysis for Surface Roughness

The ANOVA was carried out for a significance level of $\alpha = 0.05$, i.e. for a confidence level of 95%. The ANOVA for surface roughness is summarized in Table 4.

Table 4: ANOVA for Surface Roughness of Mild Steel

Factor	Linear Regression Effect					
	DOF	Sum of Square (SS)	Mean of Sum of Square (MSS)	F-Statistic	Predicted Value (P-value)	Remarks
X1: Cutting Speed	1	0.1238	3.7083	11.48	0.028	Significant
X2: Feed Rate	1	2.9168	2.9167	9.03	0.040	Significant
X3: Depth of Cut	1	9.2256	9.2256	28.56	0.006	Significant
X4: Tool	1	3.5846	3.58446	11.10	0.029	Significant
Error	4	1.2920	0.3230			
Total	8	17.1428				

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$R^2 = 92.46\%$; Adj. $R^2 = 84.93\%$	*P-value < 0.05 or 5% is Significant					
Factor	**Linear Square Regression Effect**					
	DOF	Sum of Square (SS)	Mean of Sum of Square (MSS)	F-Statistic	Predicted Value (P-value)	Remarks
X1	1	0.1238	3.7083	7.62	0.110	Not Significant
X2	1	2.9168	0.0007	0.00	0.972	Not Significant
X3	1	9.2256	0.0115	0.02	0.892	Not Significant
X4	1	3.5846	3.5846	7.37	0.113	Not Significant
X2*X2	1	0.0203	0.0203	0.04	0.857	Not Significant
X3*X3	1	0.2990	0.2990	0.61	0.515	Not Significant
Error	2	0.9727	0.4863			
Total	8	17.1428				
$R^2 = 94.33\%$; Adj. $R^2 = 77.30\%$	*P-value < 0.05 or 5% is Significant					
Factor	**Linear Interaction Regression Effect**					
	DOF	Sum of Square (SS)	Mean of Sum of Square (MSS)	F-Statistic	Predicted Value (P-value)	Remarks
X1	1	0.1238	0.2808	**	**	Not Significant
X2	1	2.9168	0.0524	**	**	Not Significant
X3	1	9.2256	0.0311	**	**	Not Significant
X4	1	3.5846	0.2276	**	**	Not Significant
X1*X2	1	0.4853	0.0564	**	**	Not Significant
X1*X3	1	0.4171	0.0203	**	**	Not Significant
X2*X3	1	0.3415	0.1411	**	**	Not Significant
X2*X4	1	0.0480	0.0480	**	**	Not Significant
Error	0	**	**			
Total	8	17.1428				
R^2 = **; Adj. R^2 = **	*P-value < 0.05 or 5% is Significant					
Factor	**Quadratic Regression Effect**					
	DOF	Sum of Square (SS)	Mean of Sum of Square (MSS)	F-Statistic	Predicted Value (P-value)	Remarks
X1	1	0.1238	4.6250	**	**	Not Significant
X2	1	2.9168	0.2024	**	**	Not Significant
X3	1	9.2256	0.7587	**	**	Not Significant
X4	1	3.5846	3.5846	**	**	Not Significant
X2*X2	1	0.0203	0.3002	**	**	Not Significant
X3*X3	1	0.2990	0.1972	**	**	Not Significant
X1*X2	1	0.1976	0.0096	**	**	Not Significant
X1*X3	1	0.7751	0.7751	**	**	Not Significant
Error	0	**	**			
Total	8	17.1428				
R^2 = **; Adj. R^2 = **	*P-value < 0.05 or 5% is Significant					

Source: Author computation from MINITAB 16

The characterization of machined surface quality was limited only to surface roughness. Table 4 shows the ANOVA for surface roughness for mild steel based on the linear regression effect, linear square regression effect, linear interaction regression effect and quadratic regression effect respectively. It is observed that the linear regression effect shows a very high significant with the process parameters which in turn displays a best fit in terms of the model performance for the experimental study.

Based on the linear regression effect, the coefficient of determination (R^2) is reasonably high with a value of 92.46% which explains the effect of the surface roughness on the considered factors (speed, feed, depth of cut & tool). The Adjusted R^2 of 84.93% explained the true behaviour of the R^2. The remaining 7.54% is been explained by the disturbance error which is unobservable during the experiment. Also, the P-values of the F-statistic calculated at 5% significance level, revealed that the whole process parameters contributes significantly in explaining the surface roughness of mild steel after drilling operation. This result shows a similar agreement with the work done by The-Vinh and Quang-Cherng (2016) which also use linear regression model for prediction of surface roughness of AISI H13 under MQL condition.

C. Surface Roughness Prediction Model

The regression model for surface roughness in terms of linear effect is shown as below:

$$\text{Surface Roughness} = -28.2448 + 0.0272 * X1 - 1.9862 * X2 + 4.9600 * X3 - 4.0900 * X4 \quad (1)$$

The above model is as well validated graphically to reveal the good agreement between the experimented and estimated value of the surface roughness as shown below:

Figure 3: Comparison between measured and predicted value for surface roughness of Mild Steel

Figure 3 shows validation of the surface roughness values. The experimental and estimated results were similar and not a large difference in surface roughness values

RESULTS AND ANALYSIS

The result of the machining experiment for surface roughness as in Table 3 were inputted into a MINITAB 16 software based on the experimental plan for further analysis. The surface

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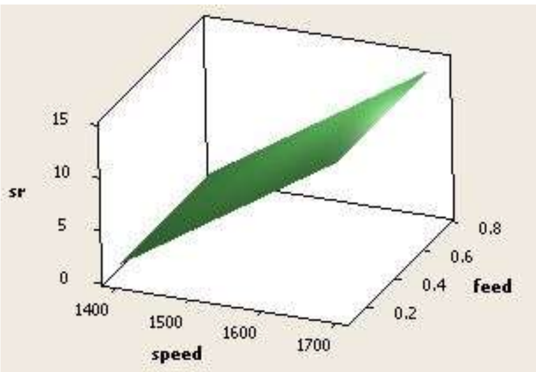
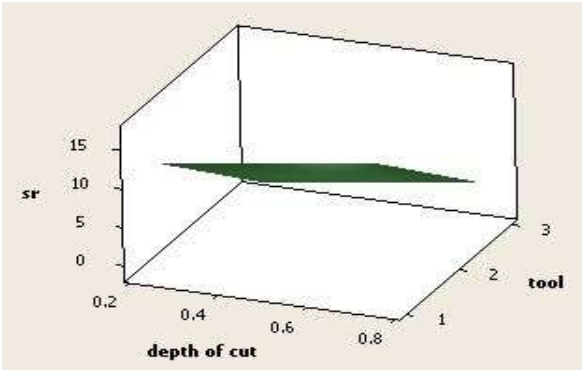
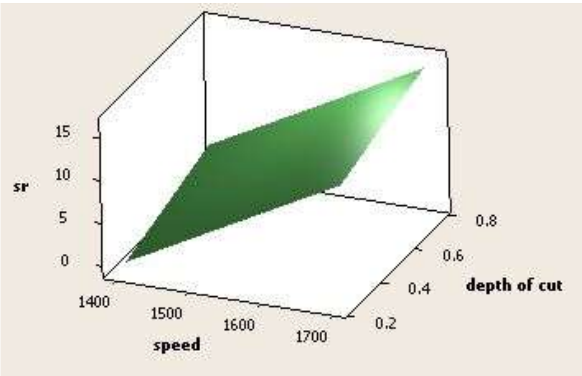
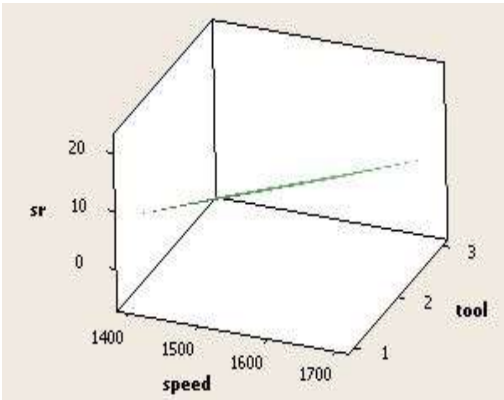
roughness was plotted against the process parameters based on the experiment measurements through surface plot graph.

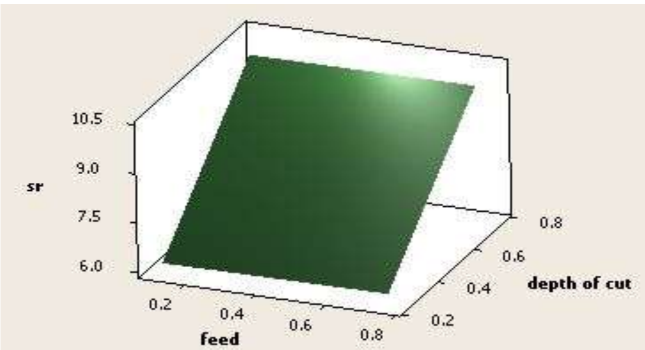
A. **Effect of Drilling Parameters on Surface Roughness**

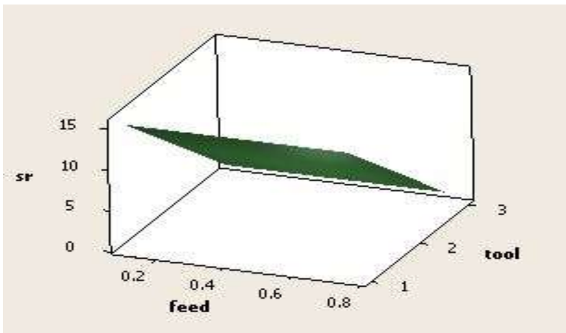












From Figure 4, it is observed at a speed of 1700rpm, with a feed rate of 0.75mm/rev, tool diameter of 10mm, depth cut of 0.75mm, surface roughness is maximum (7.58µm). We can therefore deduce that the drilling bit size of 6mm at an intermediate level should be considered for drilling mild steel based on the measure of thickness of the plate considered.

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B. Optimization of Drilling Parameters for Minimum Surface Roughness

In this research investigation, the aim is to obtain the optimal values of drilling parameters for minimizing surface roughness. The constraints used during the optimization process are summarized in Table 5 and the optimal solution is reported in Table 6.

Table 5: Constraints for Optimization of Drilling Parameters for Mild Steel

Name	Goal	Lower limit	Upper limit
X1: Cutting Speed (rpm)	is in range	1400	1500
X2: Feed Rate (mm/rev)	is in range	0.11	0.75
X3: Depth of Cut (mm)	is in range	0.25	0.75
X4: Tool (mm)	is in range	6	8
Y: Surface Roughness (µm)	minimize	3.96	9.02

Table 7: Optimization Results for Surface Roughness

S/No.	Cutting Speed (rpm)	Feed Rate (mm/rev)	Depth of Cut (mm)	Tool (mm)	Surface Roughness (µm)	Desirability	Remarks
1	1500	0.35	0.50	6	7.13	0.7869	Selected

CONCLUSION

The experimental investigation revealed that the optimal solution of the response variable cannot be actualized easily with a particular combination of process parameters settings because the optimum condition of the drilling process is concerned with minimizing surface roughness which requires in varying process parameters during experimentation. It is observed that optimum surface roughness is obtained at an intermediate level of cutting speed, feed, depth of cut and tool respectively. To acquire a minimal surface finish of workpiece based on the thickness of the mild steel, cutting speed, feed, depth of cut and tool should be set as intermediate level as possible. The important conclusions drawn from the present work are summarized as follows:

i. Surface roughness increases with cutting speed, feed rate, depth of cut and tool;

ii. The maximum surface roughness 7.58µm was obtained at a speed of 1700rpm, feed rate of 0.75mm/rev and depth cut of 0.75mm;

iii. The process parameters were highly significant in explaining the response variable of mild steel workpiece;

iv. The mathematical prediction model between surface roughness and the process parameters shows a good agreement with the experimental result. These relationships are applicable within the ranges of tested parameters; and

v. The linear square effect, linear interaction effect and quadratic effect does not contribute significantly to the experimental investigation due to lesser or no contributory effect of the process parameters in the analysis.

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REFERENCES

Gangadhar, G., Venkateswarlu, S., and Rajesh, C., (2014): Experimental Approach of CNC Drilling Operation for Mild Steel using Taguchi Design. *Journal of Modern Engineering Research (IJMER)*, 4(10): 75-81, October

Pokar, T.G., and Patel, V.D., (2013): Optimization and Modeling of Micro Drilling Process Parameters. International *Journal of Research in Modern Engineering and Emerging Technology*, 1(2), 25-30, March

Rashid, M.A., Harun, W.W., and Ghani, S.C., (2016): Optimization of EDM Small Hole Drilling Process using Taguchi Approach. *ARPN Journal of Engineering and Applied Sciences*, 11(4): 2501-2504, February

Rupesh, K.T., (2013): Multi Objective Optimization of Drilling Process Variables using Genetic Algorithm for Precision Drilling Operation. *International Journal of Engineering Research and Development*, 6(12): 43-59, May

Sudesh, G., Ravi, K.G., and Ankit, C., (2015): Effect of Material Removal Rate [MRR] on AISI H11 Die Steel in Drilling using Face Centered Design. *International Journal of Science Technology & Engineering*, 1(11): 400-410, May

The-Vinch, D., and Quang-Cherng, H., (2016): Optimization of Minimum Quantity Lubricant Conditions and Cutting Parameters in Hard Milling of AISI H13 Steel. *Journal of Applied Sciences*, 6(83): 1-11, March

Vishwajeet, N.R., Ajinkya, P.E., Prashant, D.K., and Sharad, S.C., (2015): Optimization of Process Parameters for Re-sharpened HSS Drill using Taguchi Methods. *International Journal on Engineering Technology and Sciences*, 2(3): 55-58, March

Yogendra, T., Vedansh, C., & Jyoti, V., (2012): Parametric Optimization of CNC Drilling Machine for Mild Steel using Taguchi Design and Signal to Noise Ratio Analysis. *International Journal of Engineering Science and Technology (IJEST)*, 4(8), 3758-3766, August

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