OPTIMIZATION OF PROCESS PARAMETERS FOR MACHINING OF MILD STEEL EN18 BY RESPONSE SURFACE METHODOLOGY

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ABSTRACT

Present work considers the parametric optimization of CNC MAX MILL machining for Mild Steel (EN18) with Cemented Carbide as cutting tool under constant flow of coolant. The machining cutting parameters (cutting speed, feed rate and depth of cut) optimized to evaluate high material removal rate and minimum surface roughness. Response surface method interpreted the experiment data with the help of Design of experiment. Analysis of variance (ANOVA) shows the different parameters which provide the significant impact on the values of surface roughness and material removal rate. The optimum solution of Material Removal Rate (MRR) and Roughness (SR) can be found at the cutting speed of 4186 rpm, feed rate of 1831 mm/min. and depth of cut of 0.60 mm.

KEYWORD

CNC MAX MILL Machine, Response Surface Method (RSM), Material Removal Rate (MRR), Cutting Parameter, Output Parameter

1. INTRODUCTION

In present competitive world, the demand for high quality and fully automated production keeps attention on the surface roughness of the products. Surface roughness is contributed by the shape and average size of grains for the material. The material consists grains are of microscopic dimensions and having size of 10^{-6}µm. During machining process, small scratch and grooves is formed into the work piece by the cutting tool. Surface roughness decided the fatigue life of the final product. The fatigue life is determined by introducing residual stress into the outer surface of the work piece. This is caused to the failure of the product. Higher surface roughness can be obtained by optimizing the cutting parameters like cutting parameters like cutting speed, feed rate, depth of cut, cutting environment, cutting force etc. of machine. The shape, size and dimensional accuracy of the product are most important factor during the manufacturing. These characteristics can be approached through the material removal by the cutting operation which may be physical and chemical operation.

The objectives are to minimize the surface roughness and maximum the material removal rate for the machining of Mild Steel. Mild Steel EN 18 is the common form of Steel because it is economic and provides strength, hardness, wear resistance, toughness and low ductile properties that are acceptable for different applications. Different Application of Mild Steel can seen in various industries such as automobile industry for making axles, bearings, gears etc, construction of space frames for any vehicle, ship building and repair, sheet metal and Nut bolt etc. Several researchers had optimized different parameters for various materials under dry condition.

2. LITERATURE REVIEW

Machining parameters problem have been dealt by several researchers. Alauddin et al.[1] formulated mathematical model to optimize the cutting parameters (cutting speed, feed and axial depth of cut) with help of response surface method. Pintasee[7], Kadirgama et al.[9],[10] revised the experiment and considered the parameter like cutting speed, feed rate, radial depth and axial depth of cut. Tsai Y H et al.[3] used Neural Network method to predict the surface roughness by accounting cutting parameters i.e. spindle speed, feed rate and depth of cut and vibration. Jae-Seop Kwak et al.[6] investigated the effect on surface roughness and grinding force by using Genetic Algorithm and RSM for grinding. Kopac and Krajnik[8] applied Taguchi method with Grey relational analysis to investigate effect of Cutting speed, feed rate and depth of cut parameters of CNC milling machine on surface roughness. Ghani et al.[2] and J.S. Pang et al.[13] determined lowest surface roughness and lowest cutting force corresponds to depth of cut, cutting speed and feed rate with Taguchi method. Franci Cus and Joze Balic[5] proposed a new method to compare Genetic Algorithm and Neural Network method and determined the best among them for milling operation. Milon D. Selvam et al.[12] used Taguchi and Genetic Algorithm to minimize surface roughness by optimizing the machine parameters (Number of passes, Depth of cut, Spindle speed and Feed rate). Bharat Chandra Routara et al.[11] applied Taguchi method to predict surface quality by optimizing the cutting parameters such as spindle speed, depth of cut and feed of CNC end milling. S.Karthikheyen et al.[18] optimized the cutting speed, feed rate and depth of cut for MRR of milling machine by using Taguchi method. P. Palanisamy et al.[17] analyzed the optimum cutting parameters i.e. cutting force, tool life, feed rate, depth of cut, cutting speed, surface roughness, cutting force and amplitude of vibrations during constant material removal rate in a Universal milling machine by Genetic Algorithm. Reviewed by Afrim Gjelaj et al.[14] to optimize the cutting speed, feed rate and depth of cut of end milling for analysis the cutting force and reduced machining time. Mohammed T. Hayajneh et al.[19] used Analysis of variance (ANOVA) to predict the surface roughness with accuracy of 12% by considering the spindle speed, cutting feed rate and depth of cut. R. Ramanujam et al.[4] revised the experiment to study the interaction of the material removal rate and surface roughness with corresponding parameters such as feed rate, depth of cut and spindle speed of milling machine by using ANOVA. E. Rivière-Lorphèvre et al.[15] predicted the fitness of model by using simulation and Genetic Algorithm for milling. Shunmugam et al.[20] optimized the parameters(number of passes, depth of cut in each pass, speed and feed) to obtain the minimum production considering parameters such as dimensional accuracy, surface finish, tool wear for face milling by using genetic algorithm. R. Noorani et al.[16] predicted the effect of parameters (spindle speed, depth of cut, feed rate and tool size) on surface roughness of milling machine by using design of experiment.

Above researcher did not mention the effect of temperature on surface roughness. During machining, the heat is generated by shearing, deformation and friction between the tool and surface. Heat generation caused to reduce tool life, edge formation and micro cracks on surface. These effects are minimized by maintaining constant flow of coolant.

Table 1. Authors and their research area

Year	Authors	Independent parameters	Methodology	Response parameters	Material
1995	Alauddin et al.	Cutting speed, feed and axial depth of cut	Response surface method	Surface roughness	BHN 190 steel
1999	Tsai et al.	spindle speed, feed rate and depth of cut and vibration "intensity" per revolution	Neural Network method	Surface roughness	Anisotropic material
2000	Shunmugam et al.	number of passes, depth of cut in each pass, speed and feed	Genetic algorithm	Dimensional accuracy, surface finish, tool wear and machine tool	Silver clay composite
2010	Franci Cus and Joze Balic	cutting speed, feed rate and depth of cut	Genetic Algorithm and Neural Network method	Cutting force	16MnCrSi5 XM Steel
2004	Ghani et al.	Cutting speed, feed rate and depth of cut	Taguchi method	Cutting force and surface finish	Hardened steel
2006	Jae-Seop Kwak et al.	Cutting speed, feed rate and depth of cut	Genetic Algorithm and RSM	Surface roughness and grinding force	
2006	Pintasee	spindle speed and feed rate	Response surface method	Surface finish	Aluminum, Brass and cast iron
2007	Mohammed T. Hayajneh et al.	spindle speed, cutting feed rate and depth of cut	Analysis of variance	Surface roughness	Aluminum
2007	Kopac and Krajnik	coolant employment, number of end mill flutes, cutting speed, feed per tooth, axial depth of cut and radial	Grey-Taguchi method with Grey-relational analysis	Cutting forces, surface roughness and MRR	Al-alloy

		depth of cut			
2007	P. Palanisamy et al.	feed rate, depth of cut and cutting speed,	Genetic Algorithm,	Tool life, surface roughness, cutting force and amplitude of vibrations	AISI 316
2010, 2008	Kadirgama et al.	Cutting speed, axial depth, and radial depth.	Response Surface Method	Surface roughness	Aluminum Alloys(AA6 061-T6)
2010	Bharat Chandra Routara et al.	Spindle speed, depth of cut and feed.	Taguchi method	Surface quality	UNS C34000 medium Leaded Brass
2012	Milon D. Selvam et al.	Number of passes, Depth of cut, Spindle speed and Feed rate	Taguchi method and Genetic Algorithm	Surface roughness	Mild Steel
2013	J.S. Pang et al.	Depth of cut, cutting speed and feed rate	Taguchi method	Surface roughness and cutting force	Halloysite Nanotube
2014	R. Ramanujam et al.	Cutting velocity, feed rate and depth of cut	Analysis of Variance (ANOVA)	Surface roughness and MRR	Inconel 718 Alloy
2009	R. Noorani et al.	spindle speed, depth of cut, feed rate and tool size	Design of Experiments	Surface roughness	Aluminum Alloy 6061
2007	E. Rivière-Lorphèvre et al.	depth of cut, feed rate	simulation and Genetic Algorithm	Cutting force	
2013	Afrim Gjelaj et al.	cutting speed, depth of cut and feed rate	Artificial Intelligence method.	Cutting force	Steel EN 19
2014	S.Karthikheyen et al.	Cutting speed, feed rate and depth of cut	Taguchi method	MRR	

3. RESPONSE SURFACE METHODOLOGY (RSM)

Response surface methodology (RSM) is very useful and modern technique for the optimization of machining performances. G.E.P. Box and K.B. Wilson developed RSM in 1951. A series of designed experiments are performed to obtain the best set of parameters from the available range of parameters to optimize response variables. Box and Wilson have introduced a 2nd order polynomial to understand the significant of surface roughness and material removal rate. RSM is studied to understand the structure of the response surface i.e. to understand where the maximum, minimum and ridge lines occur and to find the region of occurrence of optimal response value. RSM is a mathematical tool used to analyze the relationship between response parameters and cutting parameters for optimizing and improving processes. The 2nd order polynomial model analyses the parametric effect on the various dependent parameter.

3.1 Experimental Setup

Work Piece Material and tool

The experiments had been performed with constant flow of coolant on CNC MAX MILL of MTAB Engineers Pvt. Ltd. The cutting tool used was cemented carbide and its specification shown in table 4. The detailed information of chemical composition and mechanical properties and specification of mild steel EN18 is provided in table 2, tables 3 and table 4 respectively.

Table 2. Compositions of work piece

Name of specimen	%C	%Mn	%S	%P	%Si	%Cr
Mild Steel EN18	0.35-0.45	0.60-0.95	0.050	0.050	0.10-0.35	0.85-1.15

Table 3. Mechanical properties of work piece

Tensile strength	570 MPa
Yield strength	295 MPa
Elastic modulus	210 GPa
Bulk modulus	140 GPa
Shear modulus	80 GPa
Poisson's ratio	0.29

Table 4. Specification of work piece

Dimension (mm)	150×146×48 (L×W×D)
Weight (kg)	8.21
Density (gm/cm^3)	7.85

Table 5. Specification of cutting tool

Diameter	10mm
Overall length	100mm
Fluted length	40mm
Hardness	56 HRC
Transverse rupture strength	2400 MPa
Coolant used solvable oil	soluble oil
Helix Angle (^{0})	30
Rake Angle (^{0})	7

3.2. Experiment plan

The experiment is performed to investigate the affect of input parameters on response. Design of experiment (DOE) has a large effect on approximate accuracy and cost of response surface. The experiment of 20 runs randomized by using Design of Experiment. DOE is evaluated the response on model fitted. The design data is evaluated by the running the twenty sample through milling operation and calculate the MRR and measuring the surface roughness using stylus type profilometer. The range of cutting parameter of CNC MAXMILL plus machine is given in table 6. The procedure to build the model consist the following steps:

1. Choose the parameter to be studied and range of independent parameters.
2. Collecting the experimental data of these parameters with interaction response parameter.
3. Analysis the data by using response surface method.
4. Build up the response model.

Table 6. Independent Parameter Range

Parameter	Range
Speed(rpm)	1000-5000
Feed rate(mm/rev)	200-2500
Depth of cut(mm)	0.2-1.0

$$MRR\ (gm/\ min) = d \times D \times f \times \rho$$

Where d is depth of cut (mm), D is diameter of tool (mm), f is the feed rate (mm/min) and ρ is the density of work piece.

Table 7. Experimental values obtained from CNC MAX MILL plus Machine

Std.	Run	A: Cutting Speed (RPM)	B: Feed Rate (f) mm/min	C: Depth of Cut (d) mm	Material Removal Rate (MRR) gms/min	Surface Roughness (Ra)
3	1	3250	120	0.50	20	3.3
12	2	3250	2980	0.50	48.2	7.1
2	3	5000	700	0.30	35.2	3.3
20	4	1500	700	0.70	37.12	6.5
4	5	3800	1550	0.50	55.2	5.4
6	6	3250	1550	0.50	57.3	10.64
7	7	5000	2400	0.70	65	9.18
15	8	1500	2400	0.30	46.8	17.2
5	9	5000	2400	0.30	51.34	2.96
19	10	3250	1550	0.84	76.2	3.74
10	11	3250	1550	0.16	48.3	8
9	12	3250	1550	0.50	57.3	9.72
11	13	1500	2400	0.70	78.3	14.2
14	14	3250	1550	0.50	49	12.60
8	15	1500	700	0.30	15.85	6.76
18	16	5000	700	0.70	46.83	3.28
13	17	3250	1550	0.50	57.3	6.36
17	18	2200	1250	0.60	53.5	7.5
16	19	3250	1550	0.50	57.3	5.06
1	20	3250	1550	0.50	61	8.00

4. RESULTS AND DISCUSSION

4.1. ANOVA Analysis

The analysis of variance (ANOVA) of response surface method was applied to study the effect of the independent parameters on the response parameters. CCD has build up mathematical quadratic model which is the best appropriate model.

From table 8 shows that the Model F-value of 3.05 implies the model is significant for surface roughness. There is only a 4.87% chance that a "Model F-Value" this large could occur due to noise.

Always, $F < 0.05$

Values of "Prob > F"

This means model design is desirable and best fitted as shown in table 8. The independent parameters such as cutting speed and feed rate had significant effect on surface roughness while the depth of cut has no impact on model.

Table 8. ANOVA for Response Surface Quadratic Model for Surface Roughness

Analysis of variance table [Partial sum of squares]						
Source	**Sum of Squares**	**DF**	**Square**	**Mean Value**	**Prob > F**	**Response**
Model	208.33	9	23.15	3.05	0.0487	**significant**
A	83.41	1	83.41	10.98	0.0078	
B	79.75	1	79.75	10.5	0.0089	
C	0.56	1	0.56	0.073	0.7919	
A^2	8	1	8	1.05	0.3288	
B^2	14.34	1	14.34	1.89	0.1994	
C^2	8.74	1	8.74	1.15	0.3085	
AB	20.64	1	20.64	2.72	0.1302	
AC	12.12	1	12.12	1.6	0.2351	
BC	1.72	1	1.72	0.23	0.6446	
Residual	75.94	10	7.59			
Lack of Fit	36.72	5	7.34	0.94	0.528	**not significant**
Pure Error	39.22	5	7.84			
Cor Total	284.28	19				

Central composite design has applied to formulate 2nd order model for response parameters surface roughness and MRR.

The following response equation for surface roughness (R_a) and material removal rate (MRR) in coded form is given below:

$$\text{Surface Finish} = +8.23 - 2.43\times A + 2.29\times B - 0.17\times C + 0.67\times A^2 - 0.68\times B^2 - 0.45\times C^2 - 0.88\times A\times B + 0.62\times A\times C + 0.28\times B\times C$$

$$\text{MRR (Material Removal Rate)} = + 50.45 + 3.71\times A + 12.25\times B + 6.09\times C - 1.61\times A^2 - 5.07\times B^2 + 1.14\times C^2 - 2.59\times A\times B - 1.74\times A\times C + 0.92\times B\times C$$

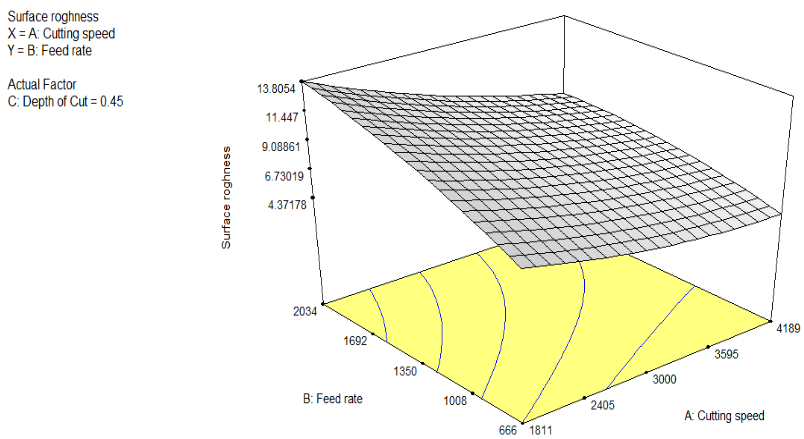

Figure 1: 3D Graph plots surface roughness Vs feed rate vs cutting speed.

From table 9 shows that the Model F-value of 27.30 implies the model is significant for MRR. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise. Similarly

F < 0.05

Values of "Prob > F"

This means model design is desirable and significant effect on MRR. The independent paramaeters such as the cutting speed,feed rate and depth of cut had significant effect on MRR. The curvilinear shape of 3D graph represents the quadratic model is fitted and broad range of interaction between model and data for surface roughness and MRR as shown in fig. 1 and fig. 2 resp.

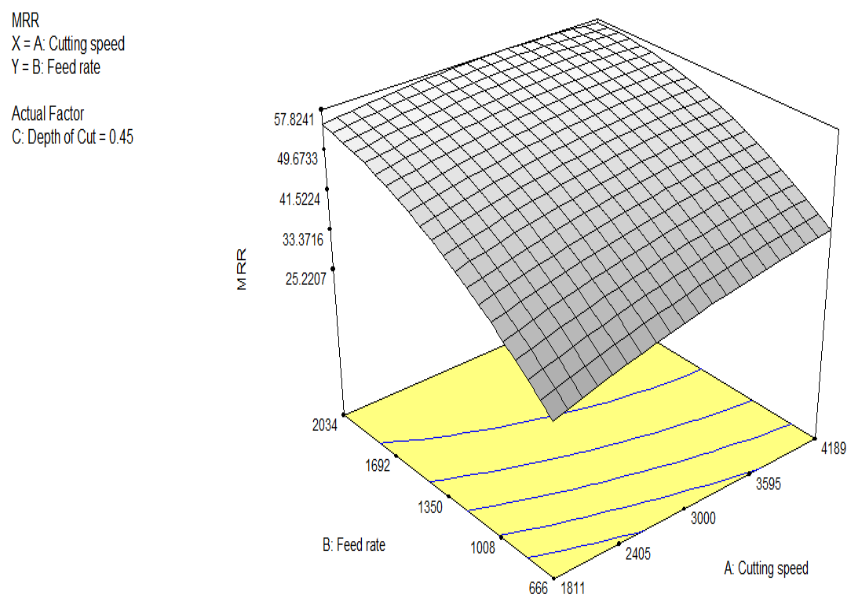

Figure 2: 3D Graph plots MRR v/s feed rate v/s cutting speed.

Table 9. ANOVA for Response Surface Quadratic Model for Material Removal Rate

Analysis of variance table [Partial sum of squares]						
Source	**Sum of Squares**	**DF**	**Square**	**Mean Value**	**Prob > F**	**Observation**
Model	4370.61	9	485.62	27.3	< 0.0001	**significant**
A	194	1	194	10.91	0.008	
B	2292.01	1	2292.01	128.84	< 0.0001	
C	691.39	1	691.39	38.86	< 0.0001	
A^2	46.35	1	46.35	2.61	0.1376	
B^2	792.85	1	792.85	44.57	< 0.0001	
C^2	57.19	1	57.19	3.21	0.1032	
AB	180.44	1	180.44	10.14	0.0097	
AC	96.13	1	96.13	5.4	0.0424	
BC	19.12	1	19.12	1.07	0.3243	
Residual	177.9	10	17.79			
Lack of Fit	98.85	5	19.77	1.25	0.4061	**not significant**
Pure Error	79.05	5	15.81			
Cor Total	4548.51	19				

The design summary of model for optimum response parameter corresponding to the process parameter is given in table10 below:

Table 10. Design Summary

Study Type	Response Surface				**Experiments**	20	
Initial Design	Central Composite				**Blocks**	No Blocks	
Design Model	Quadratic						
Response	**Response parameters**	**Units**	**Observation**	**Minimum**	**Maximum**	**Trans**	**Model**
Y1	Surface roughness	microns	20	2.96	17.2	None	Quadratic
Y2	MRR	gm /min.	20	15.85	78.3	None	Quadratic
Factor	**Process parameters**	**Units**	**Type**	**Low Actual**	**High Actual**	**Low Coded**	**High Coded**
A	Cutting speed	RPM	Numeric	1810.79	4189.21	-1.000	1.000
B	Feed rate	mm/min	Numeric	666.21	2033.79	-1.000	1.000
C	Depth of Cut	mm	Numeric	0.3	0.6	-1.000	1.000

The minimum surface roghness and maximum MRR is obtained at the approximate optimum value of cutting speed, feed rate and depth of cut as shown in table 11.

Table 11. Optimal Solution

No.	**Cutting Speed**	**Feed Rate**	**Depth of Cut**	**Surface Roughness**	**MRR**
1	4189	1831	0.60	7.31072	62.980

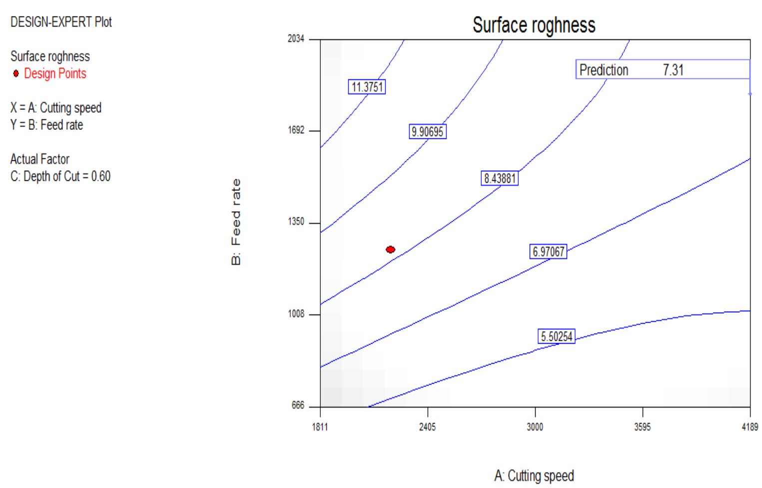

Figure 3: Optimum solution surface roughness v/s feed rate v/s cutting speed

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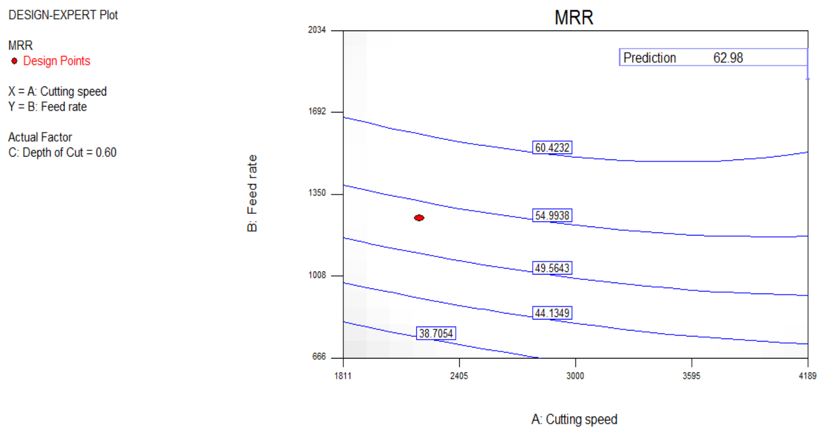

Figure 4: optimum solution MRR v/s feed rate v/s cutting speed.

Figure 3 and figure 4 represents contour plots to explore better design response for the surface roughness and MRR resp. interaction with the feed rate and cutting speed.

5. CONCLUSIONS

Experimental work is performed to investigate the effect of independent parameters on response parameters of EN18 under constant flow of coolant. Response surface method is used to examine the most significant parameters of the model. The polynomial model is formulated and evaluates the interaction of parameters by central composite design. The 2^{nd} order model is predicted approx. MRR and surface roughness value for machining process and checked 95% confidence level for the adequacy. The optimum surface roughness and MRR during cutting process occurs at cutting speed of 4186rpm, feed rate of 1831mm/min and depth of cut 0.60mm is 7.31072µm and 62.980gm/min respectively.

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