Investigation on Effect of Machining Process Parameter on Surface Roughness and Material Removal Rate in Plano Miller for Alloy Steel SA-387

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Abstract:In the present experimental investigation, the parametric optimization method using Taguchi's robust design is proposed for Plano milling machining of alloy steel SA387 & mild steel IS2062 with coated cemented tungsten carbide tip tool. In this paper, the effects of process parameters like cutting speed, feed rate and depth of cut have been investigated to reveal their impact on material removal rate and surface roughness. The Plano Milling Machine is used to conduct experiments based on the Taguchi design of experiments (DOE) with orthogonal L9 array. The orthogonal array, signal-to-noise ratio (S/N) and analysis of variance (ANOVA) were employed to find the maximum material removal rate and minimum surface roughness. The experimental results showed that that the optimal combination of parameters for surface roughness are at cutting speed of 250 rpm, feed rate of 1.42 mm/rev, depth of cut of 1.5 mm while for material removal rate are at cutting speed of 400 rpm, feed rate of 1.42 mm/rev, depth of cut of 1.5 mm for material SA-387. The Optimum value of the surface roughness (Ra) comes out to be 2.31 µm. While the optimum value of the material removal rate (MRR) comes out to be 18.8x10^{-6} mm^3/min for alloy steel A387.

***IndexTerms* -** Plano Miller Machine; Process parameter; Taguchi's method; SA-387 alloy steel

I. INTRODUCTION

Machining is a major manufacturing process in engineering industry. Performance of the product to a large extent is dependent on the accuracy and consistency of the machining processes used to produce the parts. Cutting parameters in machining- speed, feed and depth of cut (DOC) are to be the maximum to reduce the cycle time. Cutting parameters are dependent on machine tools, work-holding, cutting tool materials and their capability to withstand the heat generation and shock loading during the cutting, tool rigidity, and coolant. Plano Milling Machine is type of metalworking machine tools that uses linear as well as rotational relative motion between the work piece and a milling cutter to cut the work piece. A Plano Miller is similar to a Planer & Milling Machine but in this machine cutting tool has rotary motion and it is fixed at its fix position and table with work piece moving towards it. The various literature reviewed here indicated that different researchers were tried to optimize various machining processes for improving the quality of the product. Among different quality attributes surface finish of the component obtained after various machining processes is considered to be most important.

In order to produce parts of desired quality, proper machining parameters like spindle speed, feed rate, depth of cut, cutter diameter, number of cutting flutes, and tool geometry must be selected. Design of experiments (DOE) is a systematic, approach to engineering problem-solving that applies principles and techniques at the data collection stage to ensure the generation of valid and supportable engineering conclusions. Also all of this is carried out under the constraint of a minimal expenditure of engineering runs, time, and money. Taguchi method which is a technique of Design of experiments can be used for attaining high quality at minimum cost. The quality obtained by means of the optimization of the product or process is found to be cost effective [1]. Response surface methodology (RSM) which is another analysis technique is a collection of mathematical and statistical techniques for empirical model building where the objective is to optimize a response (output variable) which is influenced by several independent variables (input variables) [2]. Mustafa et al. investigated the effect of feed rate, cutting speed and depth of cut on surface roughness, cutting temperature and cutting force in turning of aluminium 7075 alloy using diamond like carbon coated cutting tools [3]. Al-Refaie et al. used Taguchi method coupled grey analysis to determine the optimal combination of control parameters in milling, the measures of machining performance being the MRR and SR [4]. Surface roughness has been significantly influenced by feed rate, speed and depth of cut [5]. RSM can be utilized to create an efficient analytical model for surface roughness in terms of cutting parameters: feed, cutting speed, axial depth of cut, radial depth of cut and machining tolerance [6]. Surface roughness of machined work piece depends on technological parameters (cutting peed; feed; cutting depth) and concluded that technological parameter range also plays a very important role on surface roughness [7]. Feed rate was the most significant machining parameter used to predict the surface roughness in the multiple regression models [8]. A systematic approach for identifying optimum surface roughness performance in end milling operations has been presented by Taguchi parameter design at the minimum cost [9].Suresh et al. developed a mathematical model for predicting value of surface roughness while machining mild steel using response surface methodology and optimized the developed model using genetic algorithm, in order to attain the required surface quality [10]. Aruna et al. developed a model for predicting the surface roughness based on cutting speed, feed and depth of cut using response surface methodology. Surface roughness contour for cutting speed-depth of cut is developed to describe the values resulting from the cutting parameters selected [11]. Kumar et al. optimized turning parameters based on the Taguchi's method with regression analysis. They developed model for prediction of surface roughness and material removal rate in machining of unidirectional glass fiber reinforced plastics composites with a polycrystalline diamond tool [12].

II. MATERIAL AND EXPERIMENTAL METHODS

Experiments were carried out on converted plano miller machine from old planer machine as in Fig.1. In a converted plano miller mechanical table drive units (MTDU) is the most economical solution for the table feed system. In a converted Plano miller the MTDU consists of a reconditioned 5-speed Gear Box of Fiat Car and 1 HP DC motor is used to run the drive. AC Motor of 7 HP was installed in tool head for spindle rotation. The tool holder has rotational motion and it is fitted with bearing housing. Four tools can be fitted in tool holder at a time for machining operation. These tools can be adjusted with the different heights.

Fig.1 Converted plano miller machine with gear box

Alloy steel SA-387 Gr-12 was used as work piece material of size 150mm x 100 mmx15mm. The chemical composition of workpiece material is shown in table1.

Table 1. Chemical Properties of alloy steel SA387

Elements	**Composition (Wt %)**
Carbon	0.04-0.17
Manganese	0.35-0.73
Phosphorous	0.035
Sulphur	0.035
Silicon	0.13-0.45
Chromium	0.74-1.21
Molybdenum	0.4-0.65

The single point cutting tool made of carbide tip is used for matching at various parameters. The size of the tool is 20cmx5cmx5cm. Cutting tool holder and single point carbide tip tool are shown in Fig.-2

Fig. 2 Cutting tool holder and single point carbide tip tool

In this study detailed experimental analysis has been carried out based on standardized DOE of L9 Taguchi orthogonal array of experiments to study and optimize the processing parameters. Surface roughness and material removal rate in Plano milling process analysed properly based on the preliminary trials on selected independent process parameters as shown in table 2 that affects the surface finish and material removal rate. In this study, spindle speed, feed rate and depth of cut were considered as machining parameters.

Table 2. Machining Parameters and their Levels

Factors	Level 1	Level 2	Level 3
Cutting Speed	250	300	400
Feed Rate	0.63	0.71	1.42
Depth of cut	0.5	1	1.5

In order to eliminate any surface defects and wobbling, Work pieces were cleaned prior to the experiments by removing 0.3 mm thickness of the top surface. Material removal rate was calculated by using equation. The average surface roughness (Ra) was measured after machining, in the feed direction using a hand held roughness tester TR200. The optimal results were verified with the help of analysis of variance (ANOVA).

Independent process parameters that affect the surface finish and material removal rate were identified as spindle speed, feed rate, depth of cut. Alloy Steel material is machined with DOE set of trials using its ranges of operation as per the recommendations of our local small scale industry EM Tech Fabrication, Navsari.

III. MATERIAL AND EXPERIMENTAL METHODS

3.1 Effect of process parameters on the Surface Roughness

Experiments were conducted using L9 orthogonal array in order to understand the effect of process parameters on the surface roughness and material removal rate and the obtained results are shown in table 3 and 4. The average experimental values of surface roughness for each parameter at levels 1, 2 and 3 for calculated signal-to-noise ratios are plotted in table 3.

Table 3.Experimental results of surface roughness (Ra) and S/N ratios

Ex. No.	Spindle speed (rpm),	Feed Rate (mm/rev)	Depth of Cut (mm)	Surface Roughness (µm)	S/N Ratio of SR
1.	250	0.63	0.5	4.95	13.89
2.	250	0.71	1	3.5	10.88
3.	250	1.42	1.5	2.31	7.27
4.	300	0.63	0.5	9.87	19.88
5.	300	0.71	1	7.71	17.74
6.	300	1.42	1.5	7.15	17.08
7.	400	0.63	0.5	10.2	20.17
8.	400	0.71	1	7.5	17.50
9.	400	1.42	1.5	4.76	13.55

The main effect plots of S/N ratios on surface roughness (Ra) are plotted graphically using MINITAB software as shown in Fig.3. The figures specify the influence of various factors on the surface roughness and it has been observed that surface roughness increases with increase in cutting speed and decreases as the feed rate and depth of cut increases. The same influence was observed on surface roughness experimentally as per Fig 4. The experimental results showed that the optimal combination of parameters for surface roughness are at cutting speed of 250 rpm, feed rate of 1.42 mm/rev, depth of cut of 1.5 mm with optimum value of the surface roughness (Ra) comes out to be 2.31 µm lower than other combinations.

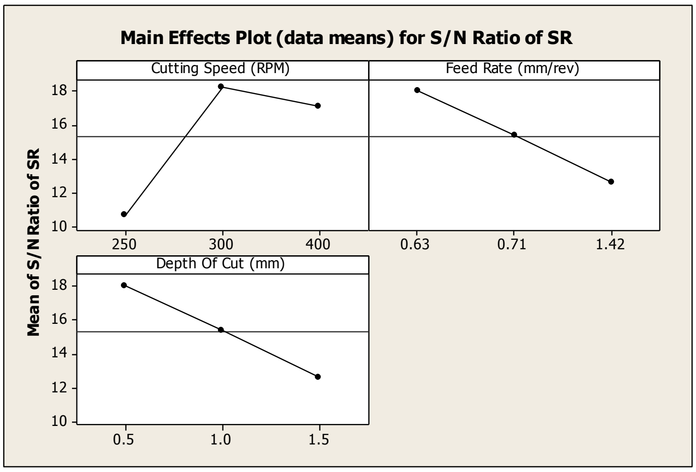

Fig. 3 Main effects plot for S/N ratios for surface roughness

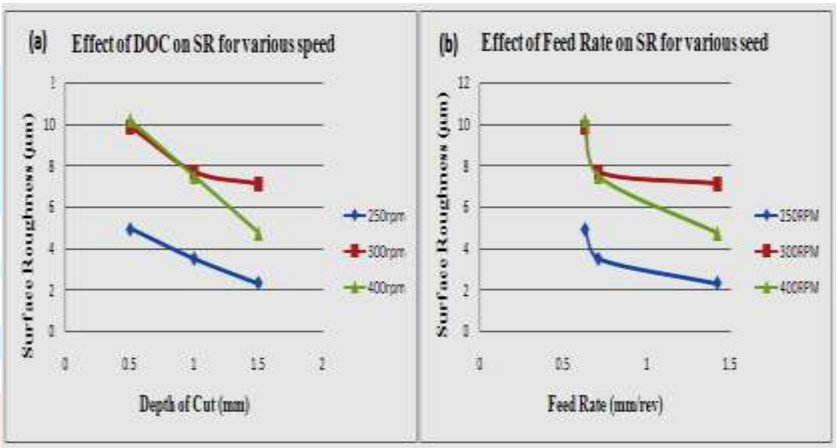

Fig. 4 Effect of depth of cut and feed rate on surface roughness for various cutting speeds

3.2 Effect of process parameters on the Material Removal Rate (MRR)

The average experimental values of material removal rate for each parameter at levels 1, 2 and 3 for calculated signal-to-noise ratios are plotted in table 4.

Table 4. Experimental results of material removal rate and S/N ratio of MRR

Ex. No.	Spindle speed (rpm)	Feed Rate (mm/ rev)	Depth of Cut (mm)	MRR (mm^3/min)	S/N Ratio of MRR
1.	250	0.63	0.5	$11.19*10^{-6}$	-99.23
2.	250	0.71	1	$9.6*10^{-6}$	-100.35
3.	250	1.42	1.5	$5.7*10^{-6}$	-104.88
4.	300	0.63	0.5	$4.18*10^{-6}$	-107.57
5.	300	0.71	1	$3.95*10^{-6}$	-108.06
6.	300	1.42	1.5	$8.15*10^{-6}$	-101.77
7.	400	0.63	0.5	$18.8*10^{-6}$	-94.51

8.	400	0.71	1	$17.9*10^{-6}$	-94.94
9.	400	1.42	1.5	$12.2*10^{-6}$	-98.27

The main effect plots of S/N ratios on material removal rate MRR are plotted graphically using MINITAB software as shown in Fig. 5. It has been observed that MRR increases with increase in cutting speed, feed rate and depth of cut. Cutting theory state that material removal rate is directly proportional to the spindle speed, feed rate and depth of cut. The spindle speed refers the speed at which the work piece material is moving past the cutting tool. Feed always refers to the cutting tool, and is the rate at which the tool advances along its cutting path. The feed rate is directly related to the spindle speed. Thus, as spindle speed increases the feed rate too increases, thereby resulting in increase in material removal rate. Depth of cut is the thickness of the layer being removed (in a single pass) from the work piece or the distance from the uncut surface of the work to the cut surface. Thus, the volume of material removed increases with increase in depth of cut. The equivalent influence was observed on MRR experimentally as per Fig 6.

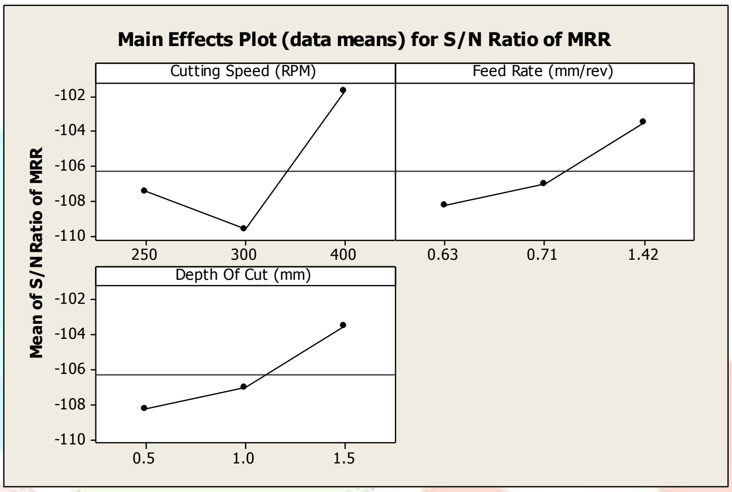

Fig. 5 Main effects plot for S/N ratios for Material removal rate (MRR)

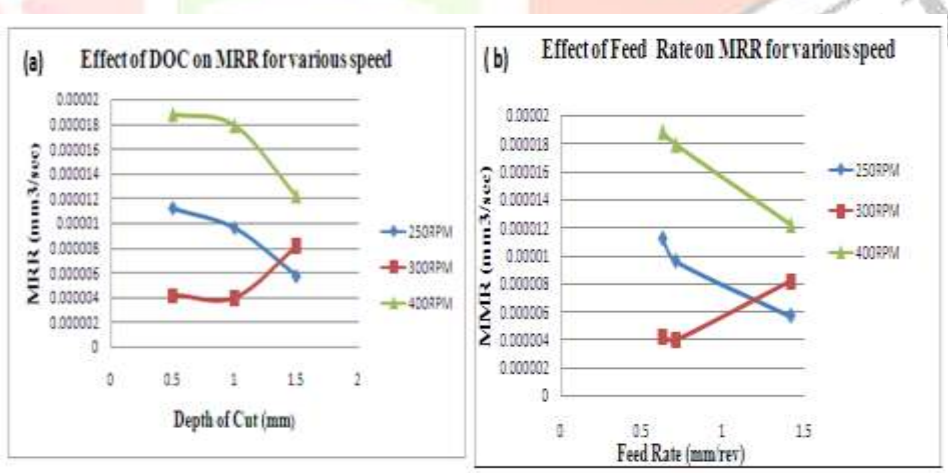

Fig. 6 Effect of depth of cut and feed Rate on MRR for various spindle speed

3.3 Analysis of Variance (ANOVA) for Surface Roughness and Material Removal Rate

ANOVA is a standard statistical technique to interpret experimental outcomes and used to detect differences in average performance of groups of items under investigation. It breaks down the variation in the experimental result into liable sources and thus finds the parameters whose contribution to total variation is significant. Thus ANOVA is used to study the relative influences of multiple variables, and their significance. The purpose of ANOVA is to investigate which process parameters significantly affect the quality characteristic. The analysis of the experimental data is carried out using the software MINITAB 14 specially used for DOE applications. In order to find out statistical Significance of various factors like speed, feed, and depth of cut, and their interactions on surface roughness (Ra) and material removal rate, analysis of variance is performed on experimental data. Table 5 and 6 shows the result of the ANOVA with the roughness and MRR.

Table 5. Analysis of variance for means of surface roughness (Ra)

Source	DOF	S_{eq} SS	A_{dj}MS	F	P
Cutting Speed	2	37.46	18.6	-2.16	0.6255
Feed rate	2	19.81	9.91	-1.15	0.3308
Depth of Cut	2	19.81	9.91	-1.15	0.3308
Error	2	-17.2	-8.6		-0.2872
Total	8				
S = 59.88					

Table 6. Analysis of variance for means of material removal rate (MRR)

Source	DOF	S_{eq} SS	A_{dj} MS	F	P
Cutting Speed	2	$1.82*10^{-10}$	$9.1*10^{-11}$	8.667	0.7811
Feed Rate	2	$1.5*10^{-11}$	$7.5*10^{-12}$	0.714	0.0643
Depth of Cut	2	$1.5*10^{-11}$	$7.5*10^{-12}$	0.714	0.0643
Error	2	$2.1*10^{-11}$	$1.05*10^{-11}$		0.0901
Total	8				
S = 2.33*10^{-11}					

It can be seen from this table that for the surface finish (Ra), the contribution of cutting speed (62.55%) is more significant than feed rate and depth of cut. Similarly for the MRR, the contribution of cutting speed (78.11%) is more significant than feed rate and depth of cut. It is clear that the effect of noise factor (9.01%) on MRR is very low as compared to the control factors.

IV. CONCLUSIONS

The experimental results showed that the optimal combination of parameters for surface roughness are at cutting speed of 250 rpm, feed rate of 1.42 mm/rev, depth of cut of 1.5 mm while for material removal rate are at cutting speed of 400 rpm, feed rate of 1.42 mm/rev, depth of cut of 1.5 mm for material SA-387.

The surface roughness is mainly affected by cutting speed, feed rate & depth of cut. With the increase in feed rate & depth of cut the surface roughness decreases, as the cutting speed increases the surface roughness first increase and decrease.

From ANOVA analysis, it has been observed that cutting speed has significant effect on surface roughness and MRR & its contribution to surface roughness and MRR is 62.55 % and 78.11% respectively. The Optimum value of the surface roughness (Ra) comes out to be 2.31 µm and the material removal rate (MRR) comes out to be 18.8x10^{-6} mm3/min for material SA-387.

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REFERENCES

[1] Taguchi G, Konishi S (1987). ‘’Taguchi Methods, orthogonal arrays and linear graphs, tools for quality’’ American supplier institute, American Supplier Institute; 1987 [p. 8-35]

[2] George E. P. Box and Norman R. Draper (2006). ‘’Response Surfaces, Mixtures, and Ridge Analyses’’, Published Online Wiley Series in Probability and Statistics 10 APR 2006

[3] A. Mustafa, K. Tanju (2011). ‘’Investigation of the machinability of the Al 7075 alloy using DLC coated cutting tools’’, Science Research and Essay, Vol. 6(1), 2011, pp. 44-51.

[4] A. Al-Refaie, L. Al-Durgham, N. Bata, (2010). ‘’Optimal parameter design by regression technique and grey relational analysis’’, The World Congress of Engineering, pp. 35-42,.2010.

[5] Benardos.,Vosniakos., (2002). “Prediction of Surface Roughness in CNC Face Milling Using Neural Networks and Taguchi’s Design of Experiments”, Robotics And Computer-Integrated Manufacturing, 18(5-6), 343-354.

[6] Oktem.H.,Kurtaran.H., (2005). “Application of response surface methodology in the optimization of cutting conditions for surface roughness”, Journal of Material Processing Technology 170, Pp. 11–16.

[7] Kromanis.A.,Krizbergs., (2008). “Surface Roughness Prediction Technique In End Milling Using Regression Analysis”, Tallinn, Estonia Industrial Engineering, pp. 42-51.2008

[8] Lou.M.S.,Chen.J.C. , Caleb.M., (1999). "Surface Roughness Prediction Technique for CNC End-Milling", Journal of Industrial Technology, Volume 15, Number 1-6.

[9] Yang.J.L.,Chen.J.C., (2001). "A Systematic Approach For Identifying Optimum Surface Roughness Performance In End-Milling Operations" Journal Of Industrial Technology, Volume 17, Number 2-5.

[10] P.V.S. Suresh, P. V. Rao, S.G. Deshmukh (2002)., ''A genetic algorithmic approach for optimization of surface roughness prediction model'', International Journal of Machine Tool and Manufacture, Vol. 42, 2002, pp. 675-680.

[11] M. Aruna, V. Dhanalaksmi,(2012). ''Design optimization of cutting parameters when turning Inconel 718 with cermet inserts'', World Academy of Science, Engineering & Technology, Vol. 61, 2012 pp.952-955

[12] S. Kumar, M. Gupta, P.S. Satsangi, H.K. Sardana (2010). ''Modeling and analysis for surface roughness and material removal rate in machining of UD-GFRP using PCD tool'', International Journal of Engineering, Science and Technology, Vol. 2(8), 2010, pp. 248-270.