OPTIMIZATION OF CUTTING PARAMETERS ON TURNING MULTIPHASE MEDIUM CARBON MICROALLOYED STEEL

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Abstract
This paper discusses the optimization of process parameters such as speed, feed and depth of cut while machining multiphase ferrite-bainite-martensite (F-B-M) Vanadium-microalloyed steel using Taguchi orthogonal array. The effect of process parameters on cutting force and surface roughness were studied and the analysis of variance (ANOVA) was also employed to identify the most significant parameter that influence cutting conditions. A regression model was also developed for prediction of cutting force and surface roughness. Confirmation tests were also conducted to validate the model.

Keywords: Multiphase microalloyed steel, optimization, taguchi, ANOVA

1 INTRODUCTION

Medium carbon microalloyed (MA) steels are cost effective in terms of processing as compared to quenched and tempered (Q&T) steels. MA steels are widely used in automotive components such as engine, crankshaft, connecting rods, etc. (Naylor, 1998).Two step cooling (TSC) procedure after forging followed by annealing was adopted to produce multiphase (ferrite-bainite-martensite) microstructures and the mechanical properties were analogous to those of Q&T steels (Sankaran, Sangal and Padmanabhan, 2005). However the machinability of such a high strength multiphase microalloyed steel has not been reported elsewhere, which motivated to study machinability aspects and to optimize the machining parameters.

Turned components are extensively used in critical automotive and aerospace applications and hence the turning process was selected to assess the effect of machining parameters on cutting forces. (Hasçal k and Çayda 2008) optimized the machining parameters on surface roughness and tool life for Ti-6Al-4V alloy and concluded that feed rate and cutting speed are most influential factors. The investigations on S45C steel bars showed that tool life and surface roughness are improved by applying taguchi technique (Yang and Tarng, 1998).The studies on the influence of cutting conditions on turning metal matrix composites shows that cutting velocity influenced more on tool wear than cutting time and feed rate (Davim,2003; Muthukrishnan et al,2008). It is also observed that feed rate influences more on surface roughness than cutting velocity and cutting time. Applying taguchi method to find optimum parameter for end milling of AISI D2 steels shows that cutting speed is the most influencing parameter than feed, depth of cut and width of cut (Gopalsamy et al., 2009).

Shetty et al., (2009) optimized the cutting parameters in turning of age hardened Al6061-15 vol. % SiC25 µm particle size with steam as coolant and it was found that steam pressure influenced more on surface roughness than tool wear, cutting force, feed force and thrust force. Pawade et al. (2007) studied the surface damage during

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turning of Inconel 718 and observed that poor surface finish is obtained as the cutting forces increases. It is also seen that depth of cut and feed rate has significant influence on magnitude of cutting forces. The machining of SKD 11 using taguchi and grey relational analysis shows that depth of cut contributes more than cutting speed and feed rate. (Tzeng et al., 2009).

1.1 Taguchi Techniques

Genichi Taguchi developed a statistical method to improve quality of product. In classical experimental design if the number of process parameter increases, a large number of experiments are required to be conducted. In order to reduce the number of experiments taguchi orthogonal arrays are used. The orthogonal array requires a fraction of the full-factorial design. Based on the process parameters and level, one can choose the orthogonal arrays which estimates minimum number of experimental design and Signal-to-Noise ratio (S/N) is useful in data analysis and also to predict the optimum results. The steps followed in taguchi experimental design are: a) identify control factors and objective functions to be optimized b) identify the number of control factors and their levels c) select appropriate orthogonal array based on factors and levels d) conduct the experiment with randomized order e) analyze the data using S/N ratio and ANOVA and find the optimum level and performance f) conduct verification test. (Rosa et al., 2009).

2 Experimental Procedure

The machining experiments were carried out in a conventional high speed lathe. The cutting insert of SNMG 120408 was used to perform turning operation. The cutting forces were measured using 9257B Kistler dynamometer and surface roughnesses were measured using Mahr perthometer. The chemical composition of the material is given in table 1.

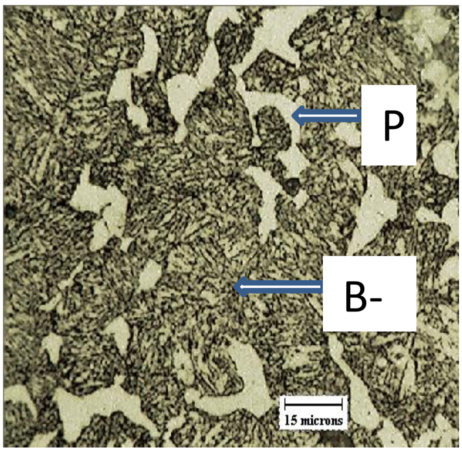
Table 1 Chemical composition (wt. %) of 38MnSiVS5

C	Si	Mn	P	S	V	N	Cr	Fe
0.38	0.68	1.5	0.022	0.06	0.11	0.066	0.18	Balance

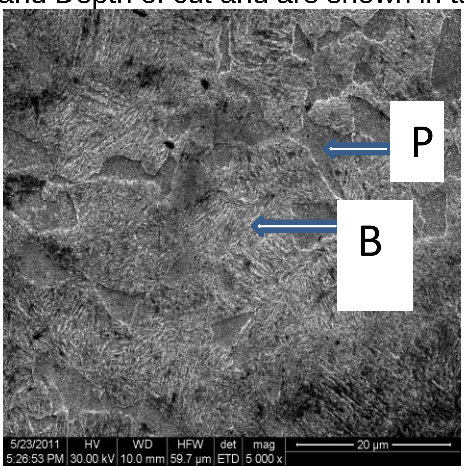
The microstructure of the multiphase microalloyed steel is shown in figure 1. The primary microstructure constituents are ferrite, bainite and martensite.

2.1 Selection of Parameter and orthogonal array

In order to perform the experiment three parameters were selected with each at three levels. They are Cutting speed, Feed rate and Depth of cut and are shown in table 2



(a) Optical image of F-B-M



(b) SE Micrograph of F-B-M

Figure 1(a) Optical and (b) Scanning electron micrograph showing polygonal ferrite and bainite-martensite colonies in the multiphase microstructure. (Sivaraman et al. 2015)

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With these three parameters the performance of microalloyed steel can be assessed easily by turning. Based on the total degree of freedom, L9 orthogonal array was selected to plan the experiment and is shown in table 3. In total 9 experiments were conducted with different combinations given by orthogonal array. The cutting force and surface roughness were measured for every set of experiment and repeated once to get the average value. The values are presented in Table 4.

Table 2 Machining Parameters and Levels

Symbol	Cutting Parameters	Level 1	Level 2	Level 3
A	Cutting speed (m/min)	40	50	60
B	Feed rate (mm/rev)	0.25	0.35	0.45
C	Depth of cut (mm)	0.2	0.4	0.6

Table 3 Taguchi L9 Orthogonal Array

Experiment Number	Cutting speed (A)	Feed rate (B)	Depth of cut (C)	Error (D)
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

3 Result and Discussion

After completion of the experiment with orthogonal array the influence of each cutting parameter was analyzed by ANOVA. Signal to Noise ratio was considered for calculation of ANOVA for both cutting force and surface roughness. Log transformation of mean -squared deviation (MSD) was named as S/N ratio (Roy Ranjit k 2001). In taguchi robust design the effect of uncontrollable factors (noise factors) must be minimized and the control factor chosen should reduce the variability in a process or product. If the S/N ratio is higher it means the product is more robust against noise. Based on the objective of the experiment three different S/N ratios are available to choose as follows

1. Smaller is the better characteristic (Minimize)

$$S/N = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right)$$

2. Larger is the better (Maximize)

$$S/N = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y^2}\right)$$

3. Nominal is the best

$$S/N = -10\log_{10}\left(\frac{\bar{y}}{s_y^2}\right)$$

Where $\bar{y}$ is the average of observed data, s_y^2 is the variance of y, n is the number of observations and y is the observed data (Hasçal k and Çayda 2008)

Here the main objective is to obtain a minimum value for both cutting force and surface roughness so that tool life will be more with less power consumption. Therefore,

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smaller the better S/N ratio was selected. The S/N ratio for both cutting force and surface roughness (Ra) are also shown in table 4.

Table 4 S/N ratio for cutting force and surface roughness

Experiment Number	Cutting Speed (m/min)	Feed rate (mm/rev)	Depth of cut (mm)	Cutting Force (N)		Surface Roughness (µm)	
				Measured	S/N ratio	Measured (µm)	S/N ratio
1	40	0.25	0.2	236	-47.458	3.1	-9.827
2	40	0.35	0.4	471	-53.460	3.7	-11.364
3	40	0.45	0.6	714	-57.073	5.0	-13.979
4	50	0.25	0.4	320	-50.102	2.5	-7.958
5	50	0.35	0.6	635	-56.055	4.0	-12.041
6	50	0.45	0.2	233	-47.347	5.6	-14.963
7	60	0.25	0.6	474	-53.515	2.4	-7.604
8	60	0.35	0.2	208	-46.361	4.5	-13.064
9	60	0.45	0.4	412	-52.297	5.9	-15.417

3.1 Analysis of Variance for Surface Roughness

The results of analysis of variance helps to find the factors that significantly affect the performance of a process. The results of ANOVA for surface roughness are shown in Table 5. The analysis was done with a 95% confidence level. Here the feed rate contributes more with 91.82% and then depth of cut with 4.860% and finally cutting speed contribute less with 0.360 %. The main effect plot shown in figure 2 shows the cutting speed 50m/min, feed rate 0.25 mm/rev, depth of cut 0.6 mm [A2B1C3] as optimum cutting parameters.

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Table 5 ANOVA for surface roughness

Symbol	Cutting Parameter	Degree of freedom	Sum of squares	Means square	F	Contribution (%)
A	Cutting Speed	2	0.2376	0.1188	0.12	0.360
B	Feed rate	2	60.5413	30.2706	30.95	91.812
C	Depth of cut	2	3.2050	1.6025	1.64	4.860
Error		2	1.9560	0.9780		2.966
Total		8	65.9398			100.000

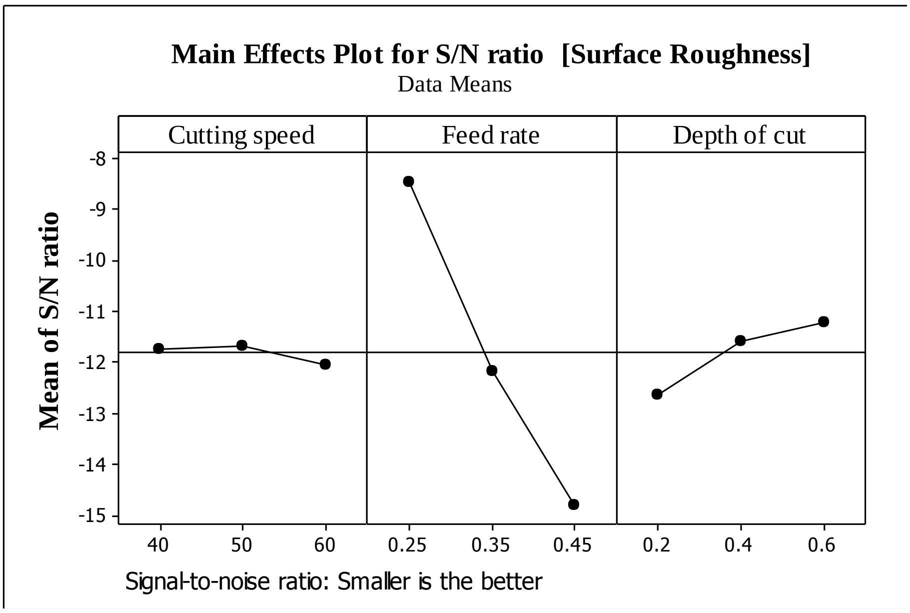

Figure 2 Main effect plot for surface roughness

3.2 Analysis of Variance for Cutting Force

The percentage contribution of cutting parameters for cutting force is entirely different compared to the surface roughness. Here the depth of cut contributes more with 89.157 % where as feed rate and cutting speed contributes more or less equal with 5.049% and 5.065%. The result of ANOVA for cutting force is shown in Table 6. The main effect plot shown in Figure 3 shows the cutting speed 60 m/rev, feed rate 0.25 mm/rev and depth of cut 0.2 mm [A3B1C1] as optimum cutting parameters.

Table 6 ANOVA for Cutting Force

Symbol	Cutting Parameter	Degree of freedom	Sum of squares	Means square	F	Contribution (%)
A	Cutting Speed	2	6.195	3.0973	6.97	5.065
B	Feed rate	2	6.176	3.0882	6.95	5.049
C	Depth of cut	2	109.041	54.5206	122.67	89.157
Error		2	0.889	0.4445		0.726
Total		8	122.301			100.000

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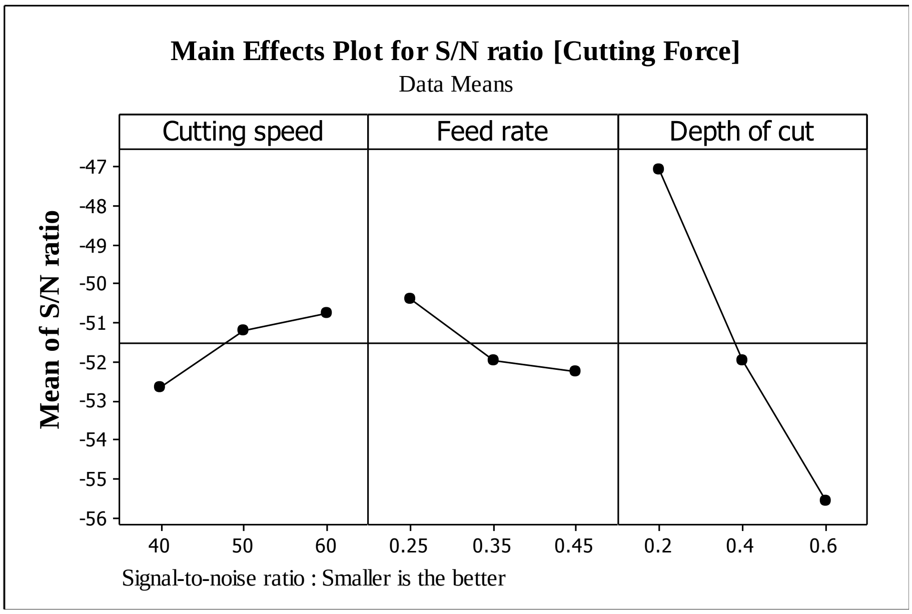

Figure 3 Main effect plot for cutting force

3.3 Regression Model

A linear regression model has been formed by considering the cutting speed, feed rate and depth of cut to predict cutting force and surface roughness.

Cutting Force = 110 – 5.45 v_c + 548 f + 955 a_p

Surface Roughness = -1.11 + 0.0167 v_c + 14.2 f -1.50 a_p

Where v_c = Cutting Velocity (m/min) , f = Feed rate (mm/rev) , a_p = Depth of cut (mm)

3.4 Confirmation test

A confirmation test was conducted to validate the regression equation formulated for cutting force and surface roughness. The cutting parameter with level 2 (Cutting speed 50m/min, Feed rate 0.35 mm/rev, Depth of cut 0.4 mm) was chosen to find the percent deviation from the experimental result. Also, the optimized value for cutting force (Cutting speed 60m/min, Feed rate 0.25 mm/rev, Depth of cut 0.2 mm) and surface roughness (Cutting speed 50m/min, Feed rate 0.25 mm/rev, Depth of cut 0.6 mm) were also considered to conduct confirmation test.

Table 7 Confirmation test result for cutting force and surface roughness

Parameters	Cutting Speed (m/min)	Feed rate (mm/rev)	Depth of cut (mm)	Cutting Force (N)			Surface Roughness (µm)		
				Experiment	Model	Deviation (%)	Experiment	Model	Deviation (%)
A2B2C2	50	0.35	0.4	437	411	5.94	3.9	4.1	4.87
A3B1C1	60	0.25	0.2	108	111	2.77	3.3	3.1	6.06
A2B1C3	50	0.25	0.6	575	547	4.86	2.3	2.4	4.34

The percentage deviation obtained for all the three different sets of parameters are shown in Table 7 and it is seen that the deviation is well within 6%.

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4 Conclusions

1. Analysis of variance for surface roughness shows the feed rate contributes more on the performance than depth of cut. The influence of cutting speed is very low on cutting force.
2. Analysis of variance for cutting force indicates the depth of cut contributes more when compared to cutting speed and feed rate. The influence of both cutting speed and feed rate are more or less equal.
3. A regression model to predict both cutting force and surface roughness has been obtained with the cutting parameters such as cutting speed, feed rate and depth of cut.
4. The confirmation test was carried out by considering the optimal value for cutting force and surface roughness. The result shows that the percentage deviation is within the acceptable level and hence the regression model is valid.

5 References

Davim, J.P. *Design of optimisation of cutting parameters for turning metal matrix composites based on the orthogonal arrays*. Journal of Materials Processing Technology. **2003,** 132, 340-344.

Gopalsamy, B.M. et.al. *Taguchi method and anova: An approach for process parameters optimization of hard machining while machining hardened steel*. Journal of Scientific & Industrial Research **2009.** 68, 686-695.

Hasçal k, A.; Çayda , U. *Optimization of turning parameters for surface roughness and tool life based on the taguchi method*. The International Journal of Advanced Manufacturing Technology, **2008.** 38, 896-903.

Muthukrishnan, N. et.al. *An investigation on the machinability of al-sic metal matrix composites using pcd inserts.* The International Journal of Advanced Manufacturing Technology. **2008,** 38, 447-454.

.Naylor, D. *Microalloyed forging steels*. Trans Tech Publ. **1998**, 83-94.

Pawade, R. et.al. *An investigation of cutting forces and surface damage in high-speed turning of inconel 718*. Journal of Materials Processing Technology, **2007,** 192, 139-146.

Rosa, J. et.al. *Electrodeposition of copper on titanium wires: Taguchi experimental design approach.* Journal of Materials Processing Technology . **2009,** 209, 1181-1188.

Sankaran, S. et.al. *Microstructural evolution and tensile behaviour of medium carbon microalloyed steel processed through two thermomechanical routes*. Materials science and technology.**2005,** 21, 1152-1160.

Sivaraman.V. et al. *A study on the influence of cutting parameters on forces during machining the multiphase V-microalloyed steel*. International Journal of Advanced Manufacturing Technology **2015**, 79:1285-1292

Shetty, R. et.al. *Taguchi's technique in machining of metal matrix composites*. Journal of the Brazilian Society of Mechanical Sciences and Engineering. **2009,**31, 12-20.

Tzeng, C.J. et.al. *Optimization of turning operations with multiple performance characteristics using the taguchi method and grey relational analysis*. Journal of Materials Processing Technology**. 2009,** 209, 2753-2759.

Yang, W., Tarng, Y. *Design optimization of cutting parameters for turning operations based on the taguchi method*. Journal of Materials Processing Technology.**1998**, 84,122-129.

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