Optimization of End Milling Machining Parameters of AISI 321Stainless Steel using Taguchi Method

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Abstract - In this work, the end milling parameters of AISI 321 grade of stainless steel are optimized by using Taguchi method. The end milling tests were carried out with PVD multilayer coated cemented carbide end mill tools. The multilayer coating consists of TiN/TiAlN/TiN coating. The experiments were conducted at three different cutting speeds (80 m/min, 100 m/min, and 120 m/min) with three different feed rates (0.1 mm/rev, 0.2 mm/rev, and 0.3 mm/rev) and a constant depth of cut of 0.5 mm. The cutting parameters are optimized using S/N ratio and analysis of variance. The effects of end milling parameters on surface roughness, flank wear and Material Removal Rate (MRR) were analyzed. The feed rate was found as the more significant parameter for surface roughness, whereas the cutting speed was identified as the more significant parameter influencing flank wear and MRR. The confirmation tests are carried out at optimum cutting conditions. The results at optimum cutting condition are predicted using estimated signal to noise ratio equation. The predicted results are found to be closer to experimental results by confirmation test.

Keywords - *Taguchi, AISI 321, PVD, ANOVA, MRR.*

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I. INTRODUCTION

Stainless steel is a material having very wide applications. It is having three main types (austenitic, ferritic, and martensitic), out of these austenitic stainless steel is highly consumed worldwide. These steels contains chromium, nickel and manganese or just chromium or nickel as the principle alloying elements. Austenitic stainless steels are having some grate properties such as chemical and corrosion resistance, resistance to oxidation at high temperature, improved formability, resistance to localized corrosion etc. based on their alloying elements [1-2].The austenitic stainless steels can be hardened only by cold working; heat treatment serves onlyto soften them. It is categorized under “difficult to cut” material due to its rapid work hardening tendency and low thermal conductivity property. The austenitic stainless steels are having strong affinity with the cutting tools during machining, especially when machining with cemented carbide tools [3-4].

Many researchers have been carried out their research work in optimization of cutting parameters for austenitic stainless steel mainly for AISI 304 and AISI 316. K. A. Abou-El-Hossein and Z. Yahya [5] optimized end milling of AISI 304 with carbide insert. The feed rate values were mainly responsible for rate of flank wear progression. They found that cutting speed is having significant effect on surface roughness due to its BUE formation tendency. Ahmad Hamdan et al. [6] studied optimization method of machining parameters for AISI 304 to obtain best surface finish. They found that feed rate is most influencing parameter for surface roughness followed by cutting speed and depth of cut. They observed highest value of surface roughness (2.74 μm) for highest values of cutting parameters. Julie Z. Zhang [7] used Taguchi method for surface finish optimization in end milling operation. The results indicated effect of cutting speed and feed rate on surface roughness is more than that of depth of cut. Bala Murgan Gopalsamy et al. [8] applied Taguchi method to find optimum parameter. Further, it was coupled with ANOVA and Regression model. Yu-Hsuan Tsai et al. [9] developed surface recognition system based on neural network to assure product quality and increase production rate by predicting the surface roughness finish in real time.

II. EXPERIMENTAL DETAILS

A. *Work piece Material*

The work piece material selected for investigation is AISI 321 austenitic stainless steel with the chemical composition as shown in Table I. The AISI 321 is stabilized austenitic stainless steel with a titanium addition of at least five times the carbon content. This titanium addition reduces or prevents carbide precipitating during welding and in 427-816˚C service. It also improves the elevated temperature properties of alloy such as it maintains its corrosion resistance at about 900˚C elevated temperature also. Work material is taken in the form plates having dimensions of length= 150 mm, width= 100 mm, thickness= 15 mm. The Plate of material is held with the help of fixture on the work table of CNC milling machine.

TABLE I
CHEMICAL COMPOSITION OF AISI 321 STAINLESS STEEL

	C	Mn	Si	P	S	Cr	Ni	N	Other
Min	-					17	9		Ti=
									5(C+N)
		2	0.75	0.045	0.03			0.1	
Max	0.08					19	12		0.7

B. Experimental Procedure

The end milling tests are conducted on CNC HAAS milling machine with maximum speed of 4000 rpm and power rating of 7.5 hp.

Fig. 1 Photograph of CNC HAAS TM2 milling machine tool

The solid carbide end mill tools with its fine grains are coated with PVD coating technique. The coating consists of layers of TiN/TiAlN/TiN respectively. The end mill tool is having diameter of 10 mm with its coating thickness of 3µm (Fig. 2). The tool wear mechanism (flank wear) is studied using Toolmakers microscope and Nikon microscope.After every 10 passes surface roughness and flank wear is measured. One pass is having cutting length of 150 mm and the experiments are carried out for 40 passes. The close up view of experimental set is depicted in Fig. 1.The experiments were carried out under dry condition (without using cutting fluid).

The influence of cutting speed and feed rate are more significant as compared to depth of cut [10-11]. Hence, cutting speed and feed rate are selected as the main cutting parameters in this study with constant depth of cut. The experiments are planned using the Taguchi's orthogonal array. The machining tests were conducted according to a 3-level and 2-factor L9 orthogonal array. The cutting parameters and their levels are indicated in Table II. The experimental layout for the L9 orthogonal array is shown in Table III.

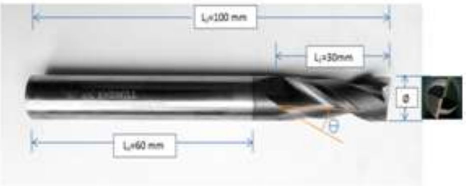

Fig. 2Geometry of solidcarbide square end mill tool

TABLE II
CUTTING PARAMETERS AND THEIR LEVELS

Symbol	Factor	Level 1	Level 2	Level 3
A	Cutting speed (m/min)	80	100	120
B	Feed rate (mm/rev)	0.1	0.2	0.3
C	Depth of cut (mm)	0.5	0.5	0.5

TABLE III
EXPERIMENTAL LAYOUT USING L9 ORTHOGONAL ARRAY

Expt. no	Cutting Speed (m/min)	Feed (mm/rev)	DOC (mm)
1	80	0.1	0.5
2	80	0.2	0.5
3	80	0.3	0.5
4	100	0.1	0.5
5	100	0.2	0.5
6	100	0.3	0.5
7	120	0.1	0.5
8	120	0.2	0.5
9	120	0.3	0.5

III. RESULT AND DISCUSSION

To satisfy the objective of given experiment, cutting parameters need to be optimize to get lower values of surface roughness and flank wear along with larger value of MRR during end milling of AISI 321 austenitic stainless steel. Table IV shows standard L9 array and experimental results for surface roughness, flank wear and MRR.

TABLE IV
EXPERIMENTAL RESULTS OF RESPONSE VARIABLES

Expt. no.	Surface roughness, Ra (µm)	Flank wear, Vb (mm)	MRR (cm^3/min)
1	0.4875	0.281	1.2735
2	1.09	0.245	2.547
3	1.6375	0.234	3.8205
4	0.4125	0.167	1.592
5	0.98	0.155	3.184
6	1.595	0.142	4.776
7	0.67	0.175	1.9095
8	1.145	0.187	3.819
9	2.6347	0.2	5.7285

A. *Analysis of the Signal-to-Noise (S/N) ratio*

In this study, lower the better performance characteristic is chosen for minimum surface roughness and minimum flank wear, whereas larger the better characteristic is chosen to obtain maximum MRR. The mean S/N ratios for the nine experiments are calculated for surface roughness, flank wear and MRR in Table V. In addition, the mean S/N for each level of the cutting parameters is summarized and called the mean S/N response table (Table VI).

TABLE V
S/N RATIOS FOR RESPONSE VARIABLES

Expt. No.	Surface roughness, Ra (µm)	Flank wear, Vb (mm)	MRR (cm^3/min)
1	6.2405	11.0258	2.0999
2	-0.7485	12.2166	8.1205
3	-4.2836	12.6156	11.6424
4	**7.6915**	15.5456	4.0388
5	0.1754	16.1933	10.0594
6	-4.0552	**16.9542**	13.5812
7	3.4785	15.1392	5.6183
8	-1.1761	14.5631	11.6389
9	-8.4146	13.9794	**15.1608**

TABLE VI
MEAN S/N RESPONSE TABLE FOR RESPONSE VARIABLES

Response variables	Cutting Parameters	Mean S/N ratios			
		Level 1	Level 2	Level 3	Max-Min
Surface roughness	Cutting speed	0.4028	**1.2706**	-2.0374	4.28
	Feed rate	**5.8035**	-0.5831	-5.5845	0.61
Flank wear	Cutting speed	11.95	**16.23**	14.56	4.28
	Feed rate	13.90	14.32	**14.52**	0.61
MRR	Cutting speed	7.288	9.227	**10.806**	3.518
	Feed rate	3.919	9.940	**13.462**	9.542

S/N ratio gives optimum cutting parameters for given response output variable. To get optimum cutting parameters, parameter with higher S/N ratio value is selected and selected cutting parameters can be verified from mean S/N response table.

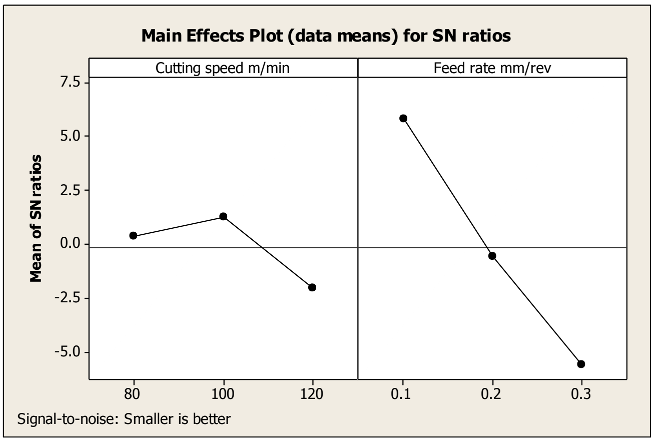

Fig. 3 Main effect plot for S/N ratio of surface roughness

The higher S/N ratio value found with cutting speed of 100 m/min and feed rate of 0.1 mm/rev as given in Fig.3, Therefor the optimum cutting parameters for minimum surface roughness are (cutting speed= 100 m/min and feed rate= 0.1 mm/rev).

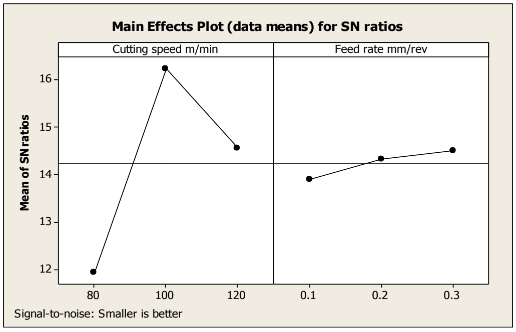

Fig. 4 Main effect plot for S/N ratio of flank wear

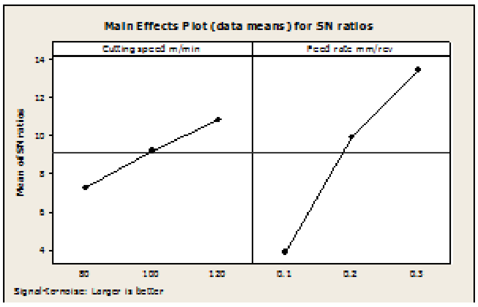

Fig. 5 Main effect plot for S/N ratio of MRR

It is found that cutting speed of 100 m/min and feed rate of 0.3 mm/rev are the optimum cutting parameters for flank wear (Fig. 4), which produces lower value of flank wear. The main effect plot for S/N ratio (Fig. 5) gave cutting speed of 100 m/min and feed rate of 0.3 mm/rev as optimum cutting parameters for maximum MRR.

B. *ANALYSIS OF VARIANCE (ANOVA)*

The purpose of ANOVA to investigate which end milling parameters significantly affected the performance characteristics. ANOVA is performed with a confidence level of 95% in order to evaluate the significant factor that tends to affect the desired output parameter.P-value of parameters indicates significance of cutting parameter towards machining performance. Statistically, there is tool called F-test to see which parameters have significant effect on the quality characteristic. Usually, when F>4, it means that the change of process parameters has significant effect on quality characteristics.

Table VII shows the results of ANOVA for the given response variables.

TABLE VII
RESULTS OF THE ANOVA FOR RESPONSE VARIABLES

Response variables	Cutting Parameters	F-value	Contribution (%)	P-value
Surface roughness	Cutting speed	2.51	10.64	0.197
	Feed rate	19.06	80.78	0.009
Flank wear	Cutting speed	21.1	89.2	0.011

	Feed rate	0.56	2.37	0.609
MRR	Cutting speed	12	13.45	0.02
	Feed rate	75.16	84.3	0.001

From Table VII it is clear that, for given study feed rate is showing more significance for surface roughness than cutting speed, whereas it is exactly reverse for tool flank wear having more significance of cutting speed on it. MRR is significantly affected by feed rate with percentage contribution of 84.30%.

Therefor based on Table VI and Table VII, the optimum cutting parameters for surface roughness are A2B1, for flank wear are A2B3 and for MRR are A3B3.

C. CONFIRMATION TEST

After obtaining the best level of process parameters, optimum parameters found for minimum surface roughness (cutting speed= 100 m/min, feed rate= 0.1 mm/rev) and flank wear (cutting speed= 100 m/min, feed rate= 0.3 mm/rev) with maximization of MRR (cutting speed= 120m/min, feed rate= 0.3 mm/rev). Results of confirmation test and ANOVA are verified which shows same significance of process parameters toward response variables.

TABLE VIII
RESULTS OF CONFIRMATION TEST

Response variables		Optimal cutting parameters	
		Predicted	Experimental
Surface roughness	Level	A2B1	A2B1
	Surface roughness (μm)	0.4118	0.4120
	S/N ratio	7.7062	7.7020
Flank wear	Level	A2B3	A2B3
	Flank wear (mm)	0.143	0.140
	S/N ratio	16.8932	17.0774
MRR	Level	A3B3	A3B3
	MRR (cm^3/min)	5.7285	5.7285
	S/N ratio	15.1608	15.1608

IV. CONCLUSIONS

Analysis and optimization of the dry end milling process has been performed in this research work with help of Taguchi method and ANOVA. The optimization has been done to reduce surface roughness and flank wear with maximization of MRR.From this experimental study it can be concluded that:

- From the Taguchi and ANOVA analysis it can be seen that feed rate contributes the most for surface roughness and cutting speed contributes the most for flank wear, whereas MRR is significantly affected by feed rate.
- Higher surface roughness values obtained at lower cutting speed attributes to the higher ductility of material resulted into higher BUE formation tendency.Increase in surface roughness at higher cutting speed is mainly caused due to the increases in cutting zone temperature.
- Low feed rate values causes work hardening during machining process leads to higher flank wear.
- The optimal parameters for end milling of AISI 321 austenitic stainless steel to reduce surface roughness (A2B1) and flank wear (A2B3) with maximization of MRR (A3B3) were obtained through this experimental study, which produced a low Ra and Vb with maximum MRR during confirmation experiments.

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