Optimization of Cutting Force of AISI 304 Austenitic Stainless Steel in a Wet Turning Process

D. Philip Selvaraj, P. Richard Philip

Abstract*: The objective of this research work is to optimize the machining variables of AISI 304 austenitic stainless steel during wet turning operation. The input parameters considered are depth, feed and cutting speed. The output response considered is cutting force. Taguchi technique is used to find the optimum machining conditions for cutting force. ANOVA is used to determine the effect of input variables on the cutting force. ANOVA results indicated that the most significant variable affecting the cutting force during the wet turning process is depth of cut.

***Keywords* : Austenitic Stainless Steel, Cutting Force, Optimization, Taguchi Technique, Wet Turning.**

I. INTRODUCTION

The usage of stainless steel alloys have been increased in various sectors. They have good corrosion resistance, higher strength, good formability, and good weldability. They are non magnetic. They are more difficult to machine than other steel alloys due to low thermal conductivity and high built up edge formation tendency. Austenitic stainless steel (ASS) contains about 18% Cr and 8% Ni. AISI 304 grade SS is most commonly used grade in SS alloy family. They are used to make kitchen sinks, equipments for food processing and chemical plants, machine elements, architectural applications etc. Turning is most common machining operation and is widely used in various industrial sectors [1]. There are three forces, namely axial force (Fx), radial force (Fy) and cutting force (Fz) are acting in the turning process. Power consumption of machining operation depends on cutting force and cutting speed [2].

Variations of cutting forces were observed at lower cutting speeds, while machining AISI 304 SS. This was resulted the poor surface finish of work surface [3]**.** Machinability of SS303 ASS were investigated by D.O'Sullivan et al. Work hardening of the material during turning operation attributed machining problems. Acoustic emission (AE) analysis technique was used for the on- line detection of machining problems [4].

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Effects of free cutting additives on the machinability of ASS were studied by T.Akasawa et al. Resulfurization and Cu addition decreased the cutting forces. Calcium treated steels exhibited lower cutting force than plain ASSs [5]. Tool wear analysis of ASS using coated carbide tools was carried out by Jukka Paro et al. Addition of N in the work material increases the strength of ASS. Higher N content and presence of BUE decreased the machinability of ASS. Tangential cutting force was decreased with decrease of N content in the material [6]. The effect of work piece grade, tool coatings and cutting speed on cutting forces were investigated by Ciftci. The higher values of cutting forces observed while machining AISI 316 than AISI 304 SS. The reason for the higher cutting forces was due to the presence of 2% Mo in AISI 316 [7]. Selvaraj et al. examined the machining performance of duplex stainless steel in end milling process. They found that higher spindle speed and lower feed gave minimum cutting force [8]. Selvaraj et al. investigated milling process of 5A grade DSS alloy. They reported that lower depth, lower feed and higher spindle speed gave minimum cutting force [9]. Selvaraj et al. conducted milling tests to examine the effect feed and cutting velocity on cutting force of two grades of DSS alloy. The cutting force values were in decreasing trend up to 1000 rpm. Cutting force values were increased with further increase of spindle speed due to higher wear rate of tool.

Cutting force is an important index used to determine the performance of the machining process. Hence in the current work, optimization of machining variables on cutting force during wet turning operation is carried out by employing Taguchi technique.

II. EXPERIMENTAL DETAILS

Taguchi technique is employed for the designing of experimental work. The experimental results of cutting force are investigated by employing the average and ANOVA. The work piece material selected for the wet turning investigation was AISI 304 grade ASS. Table 1 gives the chemical composition of 304 grade ASS. Cylindrical rod of diameter 90 mm and length 300 mm is used as the work piece for the investigation. The experiments were conducted in a Kirloskar make lathe. Lathe tool dynamometer was employed for the measurement of the cutting force. Coolant was used in the turning process (wet machining). The machining parameters selected are V, F and D. L9 orthogonal array was selected for designing 3 levels and 3 factors experiments. The levels of cutting variables are given in Table 2. The experimental layout is shown in Table 3**.**

Table- 1: Chemical composition of AISI 304 ASS

Element	Cr	Ni	C	Mn	Si	P	S	Fe
Weight %	19	9	0.08	2.0	1.0	0.05	0.03	Rest

Table- 2: Cutting variables and their levels

Cutting variable	Level 1	Level 2	Level 3
V, m/min	80	100	120
F, mm/rev	0.08	0.10	0.12
D, mm	0.4	0.6	0.8

Table- 3: L_9 OA for Experimental Design

S. No.	Levels of cutting variables		
	V	F	D
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

III. RESULTS AND DISCUSSION

The test result for Fc of 304 ASS in wet turning process is shown in Table 4. In the current investigation, data analysis is done by employing mean and ANOVA. Minitab software is employed for the analysis.

Table- 4: Results of F_c during wet turning

S. No.	V, m/min	F, mm/rev	D, mm	F_C, N
1	80	0.08	0.4	98
2	80	0.10	0.6	157
3	80	0.12	0.8	216
4	100	0.08	0.6	137
5	100	0.10	0.8	196
6	100	0.12	0.4	127
7	120	0.08	0.8	157
8	120	0.10	0.4	98
9	120	0.12	0.6	152

The mean response table for Fc of AISI 304 SS during wet turning process is presented in Table 5. The mean response plot for F_c of 304 SS in turning operation is illustrated in Figure 1. From table 5 and Figure 1, the lower value of mean response for F_c is obtained at level 3 cutting velocity, level 1 feed and level 1depth. Therefore, the optimal machining parameter for F_c during wet turning process of 304 SS are 120 m/min cutting velocity, 0.08 feed and 0.8 mm depth. The increase of cutting speed results reduction of the F_c values. The increase of feed and depth results increase of F_c.

Table- 5: Response Table for F_c – Wet turning

Level	V	F	D
1	157	130.7	107.7
2	153.3	150.3	148.7
3	135.7	165	189.7
Delta	21.3	34.3	82
Rank	3	2	1

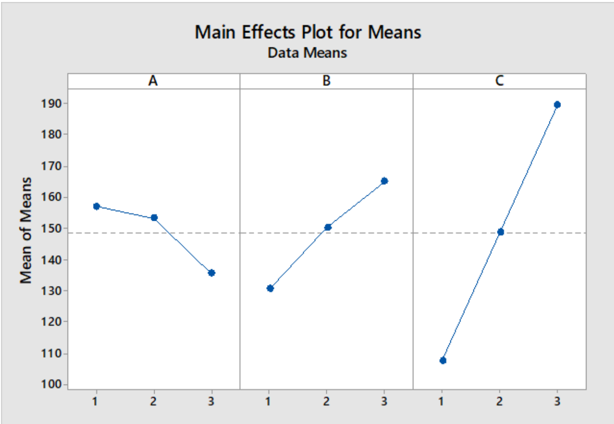

Fig. 1. Mean response graph for F_c – Wet turning

Table 6 presents the ANOVA results of F_c for 304 SS during wet turning process. The percentage contribution, P-value, F-value, mean sum of squares (MS), sum of squares (SS) and degree of freedom (DF) are presented in the ANOVA table. It is determined that the D, F and V are the significant turning parameters affecting the F_c. The contribution order of the turning parameters affecting the F_c are D followed by F and V. ANOVA results revealed that, the D, F and V are influencing the F_c of 304 SS by around 80 % , 14 % and 6 %, respectively for wet turning process.

Table- 6: Analysis of variance for F_c

Source	DF	SS	MS	F-Value	P-Value	Contribution
V	2	780.7	390.33	46.84	0.021	6.16%

F	2	1780.7	890.33	106.84	0.009	14.06%
D	2	10086	5043	605.16	0.002	79.64%
Error	2	16.7	8.33			0.13%
Total	8					100.00%

Table 7 presents the comparison of experimental and predicted cutting force values at optimum cutting conditions. For optimal cutting force, the cutting velocity should be at level 3, the feed and depth should be at level 1. The overall mean of cutting force of all tests is 149 N. The predicted value of cutting force at optimum condition is 77 N. Confirmation test is conducted at optimum cutting condition. The confirmation test result of cutting force at optimum condition is 84 N. The experimental and predicted cutting force values are compared and the variation is around 8 %.

Table- 7: Comparison of experimental and predicted F_c

Optimum cutting conditions	Experimental cutting force, N	Predicted cutting force, N	Error
V_3 = 120 m/min, F_1 = 0.08 mm/rev, D_1 = 0.8 mm	84	77	8 %

IV. CONCLUSION

The Taguchi technique was applied to determine the optimum cutting variables of 304 SS in wet turning process. The mean and the ANOVA were employed to investigate the machining performance. The findings of the experimental work are given as below:

(i) Minimum value of F_c is obtained with higher cutting velocity (120 m/min), lower feed (0.08 mm/rev) and lower depth (0.4 mm).

(ii) The F_c values were reduced with increase of V. The F_c values were increased with increase of the feed and depth.

(iii) ANOVA results indicate that, the D, F and V are affecting the F_c by around 80 %, 14 % and 6 %, respectively for wet turning operation.

(iv) The experimental and predicted cutting force values at optimum condition are compared and the variation is around 8 %.

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