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Optimization of milling parameters of ASTM a 995 grade 4A Duplex Stainless Steel using Taguchi Technique

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Abstract**:** ***This work explains the optimization of milling variables of duplex stainless steel by employing Taguchi technique. The milling tests are carried out at three levels of feeds and spindle speeds. The average of results and ANOVA are employed to investigate the machining performances. The results exposed that the feed and spindle speed are the most important variables influencing the cutting force and surface finish. It is determined that, the spindle speed is the most important variable influencing the tool wear. Confirmation tests are conducted at optimum machining conditions in order to verify the predicted results and the error is within 5%.***

Keywords**:** ***Duplex Stainless Steel, Milling Operation, Optimization, Taguchi Technique.***

I. INTRODUCTION

Stainless steels (SSs) are known for its excellent corrosion resistance, high mechanical properties and better appearance. Stainless steels are difficult to cut material due to its higher strength, lower heat conductivity and higher work hardening rate. Duplex stainless steels (DSSs) are chromium-nickel alloys that are balanced to have almost equal mixture of austenite and ferrite. Stress corrosion cracking resistance of this alloy is improved by this duplex structure. Toughness and chloride corrosion resistance of DSSs are improved by adding nitrogen. DSS alloys are used in desalination plants, marine industries, and structural applications etc. [1]

Sai *et al*. [2] conducted machining studies of DSS and carbon alloy steel in milling process. They determined that higher spindle speed (N) combined with lower feed rate (F) resulted better surface finish. The influence of depth of cut (D) has least important on the surface finish. At lower spindle speed, surface quality was poor due to the formation of BUE. Selvaraj *et al.* [3] analyzed the effect of N and F on surface roughness (R_a), cutting force (F_c) and tool wear (V_b) of 5A grade DSS in dry milling operation. Their results revealed that higher N combined with lower F decreased the R_a and F_c. They reported that abrasion and micro chipping were the main causes of the flank and rake wear of the tool inserts. Liew *et al.* [4] analyzed the wear of physical vapor deposition coated and uncoated carbide tools during milling of STAVAX SS at low cutting speeds.

Many researchers applied Taguchi technique for optimizing machining parameters due to its simple design, lower number of tests, cost and time. Ghani *et al.* [5] applied Taguchi technique to optimize the cutting variables of hardened steel in milling process. They found that lower R_a and F_c were obtained with the combination of lower D, higher N and lower F. Philip et al. [6] optimized surface finish of DSS alloy in milling process by using Box-Behnken design (BBD). They found that better R_a was achieved by employing lower D, lower F and higher N. Gouveia et al. [7] compared the cutting performance of two types of coated end mill cutters. They reported that TiAlN coated tool was more effective in milling operation of DSS grade alloys. Airao et al. [8] conducted studies on R_a analysis of super DSS in wet and dry milling operation. They developed a regression equation to determine the relation between milling variables and R_a. They exposed that the F was the most dominant variable which influences the R_a followed by cutting speed. Selvaraj [9] investigated the influences of milling parameters on F_c during the milling process of 5A grade DSS employing Taguchi method. The results exposed that F was the most dominant parameter affecting the F_c followed by N and D. Selvaraj [10] analyzed the influences of cutting variables on R_a during the milling process of 5A grade DSS employing Taguchi method. His results exposed that the effect of D is less significant compared to F and N.

From the review of literature, it is clear that the effect of N and F are more important on R_a, F_c and V_b in milling operation. It is also noticed that limited literatures are available in the milling operation of DSSs. Hence in this work, an attempt has been initiated to analyze the following in milling operation of ASTM A 995 grade 4A DSS.

To determine the optimum machining conditions using Taguchi technique which minimizes the cutting force, surface roughness and tool wear.

To investigate the influences of spindle speed and feed on cutting force, surface finish and tool wear.

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II. EXPERIMENTAL DETAILS

Taguchi method is used for designing the experiments. The test results are examined by employing the mean and ANOVA. The material chosen for the milling investigation was ASTM A 995 grade 4A DSS. Table 1 gives the chemical composition of 4A grade DSS. Rectangular work piece of size 120 X 100 X 30 mm is used as the specimen for the investigation. The experiments were conducted in a HMT make milling machine. Diameter of the milling cutter employed in the test was 20 mm. TR-100 surface roughness tester was employed for the measurement of the R_a. Kistler make dynamometer was employed for the measurement of the cutting force. Tool wear was measured by employing scanning electron microscope (model JEOL JSM-6390). Coolant was not used in the milling process (dry machining). The machining parameters selected are N and F. L9 orthogonal array was selected for designing 3 levels and 2 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 4A grade DSS

Element	C	Si	Mn	S	P	Cr	Ni	Mo	Cu	N	Fe
Wt %	0.028	0.65	0.71	0.006	0.027	22.16	5.66	3.33	0.14	0.17	Bal

Table- 2: Levels of cutting parameters

Cutting parameters	Level 1	Level 2	Level 3
N (rpm)	500	710	1000
F (mm/min)	63	100	160

Table- 3: Experimental layout using L_9 OA

Exp. No.	Cutting parameter level	
	N	F
1	1	1
2	1	2
3	1	3
4	2	1
5	2	2
6	2	3
7	3	1
8	3	2
9	3	3

III. RESULTS AND DISCUSSION

The test results for R_a, F_c and V_b of DSS during milling operation are shown in Table 4. In the present study, data analysis is carried out by using mean and ANOVA. Test results are analyzed by employing Minitab software.

Table- 4: Test results for R_a, F_c and V_b

S. No.	N (rpm)	F (mm/min)	R_a (µm)	F_c (N)	V_b (mm)
1	500	63	0.72	146	0.03
2	500	100	0.96	170	0.04
3	500	160	1.29	205	0.05
4	710	63	0.64	134	0.06
5	710	100	0.89	159	0.08
6	710	160	1.02	186	0.10
7	1000	63	0.60	115	0.09
8	1000	100	0.79	152	0.11
9	1000	160	0.91	164	0.13

A. Analysis of the Mean

The mean response tables for F_c, V_b and R_a of DSS during dry milling process are shown in Tables 5, 6 and 7, respectively. R_a, F_c and V_b

Table- 5: Mean response table for F_c

Level	N	F
1	173.7	131.7
2	159.7	160.3
3	143.7	185.0
Delta	30.0	53.3
Rank	2	1

Table- 6: Mean response table for V_b.

Level	N	F
1	0.04000	0.06000
2	0.08000	0.07667
3	0.11000	0.09333
Delta	0.07000	0.03333
Rank	1	2

Table- 7: Mean response table for R_a

Level	N	F
1	0.9900	0.6533
2	0.8500	0.8800
3	0.7667	1.0733
Delta	0.2233	0.4200
Rank	2	1

The mean response graph for F_c, V_b and R_a of DSS in milling process is shown in Figures 1, 2 and 3, respectively. From Figures 1 and 3, the lower mean response for F_c and R_a are attained at level 3 spindle speed and level 1feed rate.

Hence the optimal cutting variables for F_c and R_a during milling process of DSS are 1000 rpm spindle speed and 63 mm/min feed rate.
From Fig.2, the lower mean response for tool wear is obtained at level 1 spindle speed and level 1feed rate. Hence the optimal machining parameters for tool wear during milling process of DSS are 500 rpm spindle speed and 63 mm/rev feed rate.
The R_a and F_c values were reduced with increase of N. The tool wear values were increased with increase of N. The R_a, F_c and V_b values were increased with increase of the increase of feed.

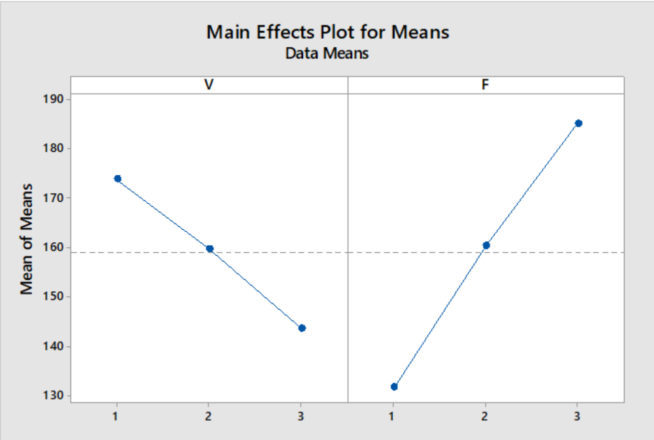

Fig. 1.Mean response table for F_c.

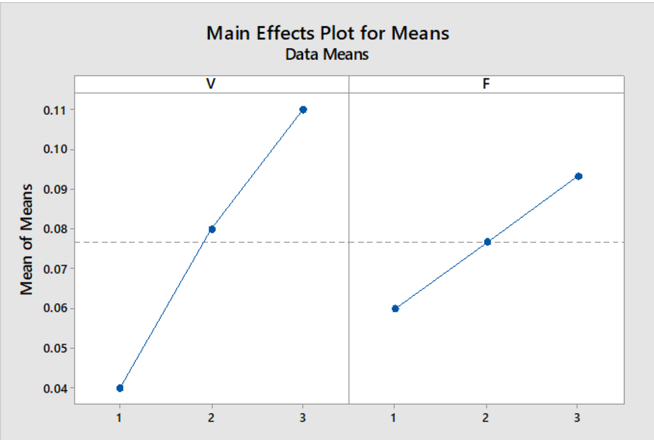

Fig. 2.Mean response table for V_b.

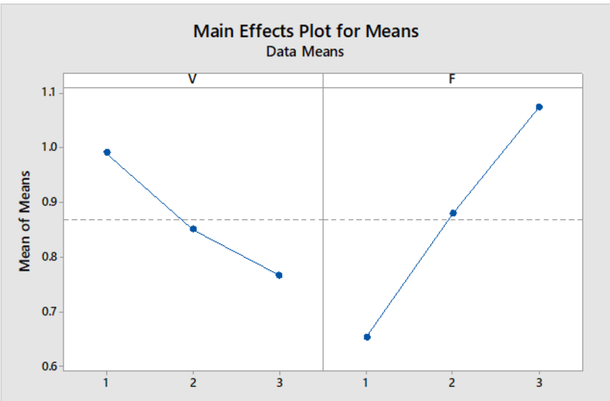

Fig. 3.Mean response table for R_a.

B. Analysis of the Variance

Tables 8, 9 and 10 show the ANOVA results of R_a, F_c and V_b of DSS during milling operation. The degree of freedom (DF), sum of squares (SS), mean sum of squares (MS), F-value and contribution % are given in the ANOVA tables. It is found that the N and F are the important machining variables influencing the R_a, F_c and V_b.

Table- 8: Results of the ANOVA for F_c

Source	DF	SS	MS	F-Value	Contribution
Regression	4	5626.7	1406.67	39.26	97.52%
N	2	1352.0	676.00	18.87	23.43%
F	2	4274.7	2137.33	59.65	74.08%
Error	4	143.3	35.83		2.48%
Total	8				100.00%

Table- 9: Results of the ANOVA for V_b

Source	DF	SS	MS	F-Value	Contribution
Regression	4	0.00906	0.00226	68.00	98.55%
N	2	0.00740	0.00370	111.00	80.43%
F	2	0.00166	0.00083	25.00	18.12%
Error	4	0.00013	0.00003		1.45%
Total	8				100.00%

Table- 10: Results of the ANOVA for R_a

Source	DF	SS	MS	F-Value	Contribution
Regression	4	0.3415	0.0853	15.45	93.92%
N	2	0.0764	0.0382	6.91	21.01%
F	2	0.2651	0.1325	23.98	72.91%
0.02211	4	0.0221	0.0055		6.08%
0.36369	8				100.00%

The contribution order of the milling variables influencing the R_a and F_c are F followed by N. The contributions order of the milling variables influencing the V_b is N followed by F.

ANOVA results indicate that, the N and F are influencing the F_c of DSS by around 23 % and 74%, respectively for end milling process. The spindle N and F are influencing the V_b of DSS by around 80% and 18%, respectively. The N and F are affecting the R_a of DSS by around 21 % and 73%, respectively.

Table- 11: Comparison result for F_c, V_b and R_a

	Optimal cutting parameters		Deviation	Error %
	Prediction	Experiment		
Cutting Force				
Level	N_3F_1	N_3F_1		
Fc (N)	119	115	4	4.39%
Tool Wear				
Level	N_1F_1	N_1F_1		
Vb (mm)	0.031	0.03	0.001	3.33%
Surface Roughness				
Level	N_3F_1	N_3F_1		
Ra (μm)	0.58	0.60	0.02	3.33%

Confirmation tests are conducted at the optimum machining condition and the results are compared with the predicted results of R_a, F_c and V_b. The comparison results are given in Table 11. The predicted values obtained are closer to the experimental result values within 5 % error.

IV. CONCLUSION

The Taguchi technique was employed to find the optimum machining variables of DSS in milling operation. The mean and the ANOVA were applied to analyze the milling characteristics. The findings of this research works are listed as follows:

(i) Minimum value of R_a and F_c are obtained with higher spindle speed (1000 rpm) and lower feed (63 mm/min). Minimization of the V_b is obtained with lower spindle speed (500 rpm) and lower feed rate (63 mm/min).

(ii) The R_a and F_c values were reduced with increase of N. The V_b values were increased with increase of N. The R_a, F_c and V_b values were increased with increase of the feed rate.

(iii) ANOVA results indicate that, the N and F are influencing the F_c by around 23 % and 74%, respectively for end milling process. The N and the F are influencing the V_b about 80% and 18%, respectively. The N and F are affecting the R_a by around 21 % and 73%, respectively.

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