EFFECT OF CUTTING PARAMETERS ON DRY TURNING OF AUSTENITIC STAINLESS STEEL (316L)

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ABSTRACT

Austenitic Stainless steel is one of the widely used stainless steel, SS 316 and SS316L are two different grades of which SS 316L has more corrosion resistant property and is weldable. Austenitic stainless steel (316L) is difficult to machine because it gets work hardened easily, its low thermal conductivity, high ductility, high strength also makes its machinability difficult. In this study theoretical analysis is done to find which cutting parameter has more effect on machining, it is done by using Taguchi and Fuzzy Inference System (FIS) from MATLAB. Data for theoretical analysis was collected from a combination of experiments which has a central composite design. The second order models were established for chip reduction coefficient and MRR. Subsequently second order models are used for converting those data to the data which is compatible for Taguchi analysis. The effect of various machining parameters on machining responses can be studied from the established model. The output from the simulation was generated as Multi Performance Characteristic Index (MPCI). Finding the position of various machining parameters was the next step of analysis. The rank with respect to various machining parameters cutting speed, feed, and depth of cut was established.

KEYWORDS: Metal Cutting, Machining, Chip Thickness, Work Hardening, Machinability.

Received: Jun 08, 2020; **Accepted:** Jun 28, 2020; **Published:** Aug 29, 2020; **Paper Id.:** IJMPERDJUN2020942

INTRODUCTION

Most parts of the world like Europe and Ushas instituted laws and regulations that appreciably affect the formulation of metal cutting fluids [1]. Industries using these fluids are relentlessly searching for better performing cutting fluids formulated from environmentally friendly materials. Also, most Governments, Industries and Employee Unions implement movements for a healthy and safe work environment, as well as disposal aspects influencing the global environment. These movements have already affected the formulation of cutting fluids in Europe and the US as follows: the removal of nitrite from cutting fluid composition and the replacement of di-ethanolamine short chained chlorinated paraffin [1, 2].

Austenitic stainless steel is one of the most widely used stainless steel because of its high corrosion resistance and high strength. Austenite phase is metastable, because of the presence of alloying element nickel, magnesium and nitrogen helps to maintain austenitic structure at all temperature from cryogenic to melting point. Austenitic stainless steel cannot be heat treated because it must maintain the same microstructure. It can be hardened by cold working only. Austenitic stainless steel is paramagnetic. Austenitic stainless steel (316L) has low carbon percentage when compared to grade SS 316, this helps to avoid corrosion of welding due to high temperature involvement and prevent sensitization.

Austenitic stainless steel is difficult to machine because of its work hardening tendency, low thermal conductivity and high built up edge formation. In this study the effect of different cutting parameters i.e. cutting velocity, feed and depth of cut on dry turning of austenitic stainless steel (316L) is analysed by using Taguchi and Fuzzy Inference system, based on Chip reduction coefficient and Material Removal Rate (MRR). From the MPCI value rank of each cutting parameters affecting the machining can be obtained

PROPOSED METHODOLOGY

Fig 1. Methodology of MPCI

Since austenitic stainless steel can be considered as difficult to machine materials, therefore the present task is undertaken to study on the machining aspects of the material. Tungalloy made tool is used. Tool holder ASBNR 25*25 M12 A and carbide insert SNMG 120404 TM T9125 were collected. After machining in predetermined parameters, the calculated values of chip reduction coefficient and MRR was taken and a second order equation was formed by using analysis of variance (ANOVA). Based on the machining parameters orthogonal array was selected for chip reduction coefficients and MRR. S/N ratios were calculated by using Taguchi analysis by considering lower the chip reduction coefficient (best) and higher the MRR (best). From the S/N ratios, normalized values were found and with the normalized values MPCI values were obtained through MATLAB software, using FIS.

EXPERIMENTATION

The workpiece is of dimension 300mm length and 60mm diameter. Machining is performed and experimental data were collected. Central composite design of input parameters was followed for machining of workpiece. 24 different combination of the machining parameters (Table II) were used for turning of workpiece. The formed data were arranged in such a way to form a central composite design consisting of 2^3 factorials with centre point replicated 4 times plus a twice replicated star design. The chip obtained for the 24 experiments were collected and the thickness of chip was calculated using relation between chip length and weight of the chip. Calculation of chip reduction coefficient and MRR will be done using

corresponding equations. Turning operation is carried out in central lathe having maximum speed 1000 rpm and minimum speed 45 rpm and feed ranges between 0.06mm/rev to 1.72mm/rev.

Table 1: Chemical Composition of Austenitic Stainless Steel (316L)

C%	Mn%	Si%	P%	Cr%	Ni%	Mo%	S%	Fe
0.010	1.623	0.321	0.010	16.122	10.147	2.123	0.005	Balanced

Table 2: Parameters used for Machining

Coding	-√2	-1	0	1	√2
Speed (m/min)	10.23	14.24	31.65	70.34	97.9
Feed (mm/rev)	0.01	0.11	0.14	0.18	0.20
DOC(mm)	0.56	0.67	1	1.5	1.77

$$\text{Chip thickness } t_2 = \frac{W}{\rho w l}$$

Where, t_2 = Chip thickness

W = Weight of chip in grams

ρ = Density of chip in g/cm³

w = Width of chip in cm

l = Average length of the chip in cm

$$\text{Width of chip } w = \frac{d}{\cos(90-\phi)}$$

Where, d = Depth of cut in mm

ϕ = Principle Cutting-edge angle (in degree)

ρ = Density of austenitic stainless steel, 8g/cm³

Uncut chip thickness t_1 ,

$$t_1 = f \sin \phi$$

Where, f = Feed in mm

ϕ = Principal Cutting-edge angle (in degree)

Chip reduction coefficient ζ ,

$$\zeta = \frac{t_2}{t_1}$$

Table III Calculated output values from experiment

Sr No.	Assigned Codes v f d			Weight of chip(W) (gms)	Length of chip(L) (mm)	Width of chip(w) (mm)	Chip thickness(t_2) (mm)	MRR (mm ³ /s)	Chip reduction coefficient(ζ)
1	1	1	1	0.340	8.3	1.552	0.330	316.51	1.898
2	1	1	-1	0.033	1.4	0.689	0.422	140.53	2.428
3	1	-1	1	0.539	21.3	1.552	0.203	189.90	1.952
4	1	-1	-1	0.139	11.2	0.689	0.225	84.31	2.166
5	-1	1	1	1.031	21.3	1.555	0.389	64.06	2.240
6	-1	1	-1	0.083	7.1	0.689	0.212	28.44	1.220
7	-1	-1	1	0.210	8.9	1.552	0.190	38.44	1.821
8	-1	-1	-1	0.181	13.3	0.689	0.246	17.06	2.359
9	$\sqrt{2}$	0	0	0.394	20	1.035	0.237	228.43	1.759
10	$-\sqrt{2}$	0	0	0.411	14	1.035	0.354	23.87	2.620
11	0	$\sqrt{2}$	0	0.709	16.2	1.035	0.528	104.97	2.750
12	0	$-\sqrt{2}$	0	0.269	13.9	1.035	0.234	51.69	2.475
13	0	0	$\sqrt{2}$	0.599	21.4	1.836	0.190	131.01	1.410
14	0	0	$-\sqrt{2}$	0.227	16.5	0.583	0.295	41.62	2.187
15	0	0	0	0.315	13.7	1.035	0.277	73.85	2.054
16	0	0	0	0.206	10.4	1.035	0.239	73.85	1.769
17	0	0	0	0.337	14.2	1.035	0.287	73.85	2.124
18	0	0	0	0.294	13.1	1.035	0.271	73.85	2.005
19	$\sqrt{2}$	0	0	0.447	15.4	1.035	0.350	228.43	2.592
20	$-\sqrt{2}$	0	0	0.355	11.3	1.035	0.379	23.87	2.805
21	0	$\sqrt{2}$	0	0.553	13.9	1.035	0.480	104.97	2.502
22	0	$-\sqrt{2}$	0	0.339	17.4	1.035	0.235	51.69	2.490
23	0	0	$\sqrt{2}$	0.525	13.9	1.836	0.257	131.01	1.901
24	0	0	$-\sqrt{2}$	0.239	17.5	0.583	0.293	41.62	2.167

For determining S/N ratios there are three characteristics lower the better, higher the better, nominal the better. For increasing the production rate higher the better is good for the case of MRR and lower the better is good for the case of chip reduction coefficient.

THEORETICAL ANALYSIS

The second order equation for chip reduction coefficient and MRR was found by using design of experiments.

$$Y(\text{Chip reduction coefficient}) = 2.1396 - 0.0447X_1 - 0.0068X_2 - 0.1085X_3 + 0.0771X_1^2 + 0.1322X_2^2 - 0.1870X_3^2 - 0.1160X_1X_2 - 0.1531X_1X_3 + 0.1553X_2X_3$$

$$Y(\text{MRR}) = 73.2725 + 72.6155X_1 + 23.1588X_2 + 36.9623X_3 + 26.6275X_1^2 + 2.7175X_2^2 + 6.7100X_3^2 + 18.2275X_1X_2 + 28.0725X_1X_3 + 10.5800X_2X_3$$

The above two equations show the DOE models for chip reduction coefficient and MRR. DOE models were interpreted in the form of plots. These plots show the variation of chip reduction coefficient and MRR with respect to cutting velocity, feed and depth of cut. In fig. 2 at constant speed code 0, it is observed that with increase in feed MRR increases similarly with increase in doc MRR increases. In fig. 2 when the speed code is increased to 1 similar kind of observation is noted hence with increase in feed, speed, doc MRR increases.

Figure 2: Variation of MRR with Feed Code and Depth of Cut at Different Speed Code. Speed Code 0 (Left) and Speed Code 1 (Right).

The variation of chip reduction coefficient with feed and depth of cut at different speed codes are shown in Fig. 3. It is observed that at constant speed code 0 with increase in feed chip reduction coefficient also increases. This is mainly because of predominating austenitic retention effect at higher feed. However, variation with respect to doc is different. It is observed that with increase in doc, chip reduction coefficient reduces. This is because of work hardening effect.

Similar case is seen for higher speed code 1, but the increase in chip reduction coefficient with respect to feed has higher value at low speed because of austenitic retention effect. The value of chip reduction coefficient is more with respect to doc at lower speed, this is also because of the austenitic retention effect is at lower cutting speed.

Figure 3: Variation of Chip Reduction Coefficient with Doc and Feed Code at Different Speed Code. Speed Code 0 (Left) and Speed Code 1 (Right).

Table 4: Parameters used for Theoretical Analysis Purpose

Coding	$-\sqrt{2}$	0	$\sqrt{2}$
Speed (mm/min)	10.23	31.65	97.9
Feed (mm/rev)	0.01	0.14	0.20
DOC (mm)	0.56	1	1.77

Orthogonal array for chip reduction coefficient and MRR was made by using parameters from table and the S/N ratios for chip reduction coefficient and MRR was made by using Taguchi analysis. The normalized values of S/N ratio were used to obtain Multi performance Characteristic Index through MATLAB software using FIS.

Table 5: Taguchi Analysis Results

Sr No	v	f	d	MRR mm ³ /s	Chip reduction coefficient (ζ)	S/N ratio of MRR (dB)	S/N ratio of Chip reduction coefficient (dB)	Normalized S/N ratio of MRR	Normalized S/N ratio of Chip reduction coefficient
1	1	1	1	71.424	2.178	37.076	-6.764	0.431	0.253
2	1	2	2	23.833	2.357	27.543	-7.447	0	0.058
3	1	3	3	56.272	2.316	35.005	-7.297	0.337	0.101
4	2	1	2	45.956	2.413	33.246	-7.653	0.257	0
5	2	2	3	138.965	1.612	42.858	-4.148	0.692	1
6	2	3	1	51.446	2.173	34.227	-6.742	0.302	0.259
7	3	1	3	266.127	2.208	48.501	-6.882	0.947	0.219
8	3	2	1	134.223	2.010	42.556	-6.064	0.679	0.453
9	3	3	2	303.862	2.253	49.653	-7.056	1	0.170

FUZZY INFERENCE SYSTEM RESULT

Multi Performance Characteristic Index (MPCI) was obtained by using fuzzy logic. Fuzzy inference system using MATLAB software was used to obtain MPCI. The inputs given were chip reduction coefficient and MRR and MPCI obtained as output. The input and output functions were plotted in terms of triangular member function, rules were framed in fuzzy and with the help of these rules the inputs were simulated to get the surface which shows the variation of MPCI values with respect to chip reduction coefficient and MRR.

Figure 4: Rules Framed in Fuzzy Inference System.

Figure 5: Surface Showing Variation of MPCI with MRR and Chip Reduction Coefficient.

Further analysis was done with MPCl values to get mean response table as shown in table VII

Table 6: MPCl Values from Fuzzy Inference System

Sr No	MPCl	SN ratio of MPCl (dB)
1	0.378	-8.450
2	0.0819	-21.734
3	0.247	-12.146
4	0.228	-12.841
5	0.759	-2.395
6	0.37	-8.635
7	0.601	-4.422
8	0.569	-4.897
9	0.562	-5.005

Table 7: Mean Response Table

Levels	v	f	d
1	-14.110	-8.571	-7.327
2	-7.957	-9.675	-13.193
3	-4.775	-8.595	-6.321
Delta (max-min) Rank	1	3	2

From the mean response table, the effect of speed is more followed by depth of cut and feed.

Rank assigned as

Speed = 1

Doc = 2

Feed = 3

The optimality condition is finally attained at (2 2 3).

CONCLUSIONS

- MRR increases with speed, feed and doc
- Chip reduction coefficient increases with increase in feed.
- Chip reduction coefficient decreases with increase in doc.
- With respect to MPCl consideration, speed effect is more influential in comparison to doc and feed.
- Machining on austenitic stainless steel (316L) is found to be influenced by austenitic retention effect and transformational effect during the machining work.

ACKNOWLEDGEMENT

Authors are grateful to National Institute of Technology Silchar for providing financial assistance to carry out this research work.

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