Effect of Cutting Parameters on Surface Quality of AISI 316 Austenitic Stainless Steel in CNC Turning

Prajwalkumar M. Patil [1], Rajendrakumar V. Kadi [2],Dr. Suresh T. Dundur[3],Anil S. Pol [4]

[1]Research Scholar, Department of Product Design and Manufacturing, VTU, Belagavi, Karnataka, India
[2] Asst. Professor, Department of Mechanical Engineering, TCE, Gadag, Karnataka, India
[3]Professor, Department of Industrial and Production Engineering, BEC, Bagalkot, Karnataka, India
[4] Asst. Professor, Department of Product Design and Manufacturing, VTU, Belagavi, Karnataka, India

***

Abstract—*Surface quality is one of the prime requirements of customers for machined parts. The present work deals with the study of effect of cutting parameters on surface roughness and hardness of AISI 316 austenitic stainless steel in CNC turningunder conventional cooling condition. Taguchi method has been employed in the optimization of cutting parameters- such as speed, feed and depth of cut.The turning experiments under conventional cooling were planned as per* ***Taguchi's*** *L_9 orthogonal array (O.A.) which is designed with three levels of turning parameters. The Analysis of Means (ANOM) and Analysis of Variance (ANOVA) were carried out to determine the optimal parameter levels and obtain the level of importance of the cutting parameters, respectively.Validation tests with optimal levels of parameters were performed to demonstrate the effectiveness of Taguchi optimization. The optimization results revealed that feed is the significant parameter for minimizing the surface roughness, whereas depth of cut plays important role in maximizing the hardness. Also a comprehensive analysis has been made to understand the nature of deformation beneath the turned surface and thickness of machining affected zone (MAZ).*

Keywords— Austenitic Stainless Steel AISI 316, CNC Turning, Conventional cooling condition, Taguchi Method, Surface Roughness, Surface Hardness, ANOVA.

1. INTRODUCTION

Austenitic stainless steel is one of the most important engineering materials with wide variety of applications. This material is attractive because of its properties such as high hardness, toughness, yield strength, excellent ductility, superior resistance to corrosion and oxidation, compatibility in high temperature and high vacuum. But these materials are very "difficult to machine" than carbon and low alloy steels because of their high strength, poor thermal conductivity and a higher degree of ductility and work hardenability [1, 2, 4, 5]. The problems such as poor surface finish and high tool wear are common while machining these materials [1]. Therefore, attempts have been made to improve the machinability of austenitic stainless steel by adding free machining elements like lead, sulfur, tellurium and selenium [7]. In the machining process, one of the most noteworthy mechanical requirements of the customers is surface finish. To improve the fatigue strength, corrosion resistance, aesthetic appeal and tribological properties of the product; a sensibly good surface finish is required. Nowadays, fabricating commercial ventures are particularly concerned with dimensional precision and surface completion. Our main objective is to study effect of cutting parameters on AISI 316 austenitic stainless steel workpiece surface roughness and hardness by employing design of experiments via Taguchi methods and Analysis of Variance (ANOVA) using tungsten carbide tool on CNC lathe under wet environment. Austenitic grade of stainless steel is one of the vastly consumed steel (70 percentage) universally [4, 8]. The austenitic alloys used most often are those of the AISI 300 series. Grade 316 is the standard molybdenum-bearing grade. Molybdenum gives 316 preferable corrosion resistance properties over crevice corrosion in chloride environment. It has excellent forming and welding characteristics. AISI 316 austenitic stainless steel has wide range of applications such as it is used in chemical processing equipment; aerospace components; for food, dairy and beverage industries; for surgical embeds inside of the threatening environment of the body; in deck components for boats and ships in marine environment; and for heat exchangers [3, 4].

1.1 Taguchi Parameter Design

In the early 1950s, Dr. Genichi Taguchi, "the father of Quality Engineering", introduced the concept of off-line Quality control techniques known as Taguchi parameter design [9]. Off-line Quality control techniques are those activities performed during the product (or process) design and development phases. Taguchi parameter design is based on the concept of fractional factorial design [10]. Taguchi design is a powerful methodology designed for finding the optimum levels of the control process parameters to make the product or process impervious to the noise factors [11, 12]. The Taguchi method is based on matrix experiments, and these experimental matrices are special orthogonal arrays (OA's), which allow the simultaneous effects of several process parameters to be studied [11, 12]. The purpose of conducting an orthogonal experimentation is to determine the most favourable level for every single process parameter and to determine the relative significance of individual parameter on performance characteristic [11, 12]. Classical experimental design methods are too intricate, time-consuming and not simple to use. A large number of tests have to be performed when more parameters are involved. To resolve this problem, the Taguchi principle uses a special purpose design of orthogonal arrays (OA's) to study the complete parameter space with only a lesser number of experimentations. Taguchi conveys that signal-to-noise (S/N) ratio is the main objective function for orthogonal matrix trials [11, 12]. The signal-to-noise ratio is used to measure performance characteristics and shows the degree of expectable performance in the existence of noise factors. Taguchi categorizes the S/N ratio into types "smaller the better", "larger the better" and "nominal the best" based on the nature of objective function. The "Analysis of Means" (ANOM) established on the S/N ratio is used to decide the best levels of the process parameters in Taguchi's design of experiment. The optimal level for a process parameter is the level of outcomes in the maximum value of signal-to-noise ratio in the experimental region. The "Analysis of Variance" (ANOVA) in Taguchi constraint design creates the comparative significance of process parameters and was performed on the S/N ratio to find the contribution of each process parameter [11, 12].

2. EXPERIMENTAL DETAILS

2.1 Materials and Methods Used

Turning is a popular material removal process in which a cutting tool removes unwanted outer layer of material from the rotating cylindrical workpiece. The Computer Numerical Controlled (CNC) machine play a critical function in current machining industry to improve an item quality and profitability [13].

The workpiece material selected for investigation is AISI 316 austenitic stainless steel rod. In the present work, we have used a round workpiece of dimensions 360 mm length and 30 mm diameter. The chemical composition, mechanical and physical properties of AISI 316 austenitic stainless steel are shown in Table-1 and Table-2 respectively.

Turning experiments were performed using CNC 'Ace Turn Mill Fanuc', lathe type 'LT-2XLMMC'. The lathe is equipped with maximum spindle speed of 4000 rpm and 11 KW. A tool holder with a general specification 'GCLNR 2020MK12' was used in this experiment. The coated carbide insert of ISO geometry 'CNMG 120416' with chip breaker were used throughout the experiment. The inserts have CVD coating of TiN on cemented carbide substrate, which consists of thick, moderate temperature, chemical vapor deposition (MT CVD) of TiN for heat resistance and low coefficient of friction. The turning experiments were conducted under conventional cooling condition where soluble oil (1:20) was used as a coolant.

The experiments are conducted with three controllable 3-level factors and two response variables.Table-3 presents three controlled factors of the cutting speed (i.e., A (m/min)), the feed rate (i.e., B (mm/rev)), and the depth of cut (i.e., C (mm)) with three levels for each factor. As per full factorial designs, 3^3 design can be expressed as a $\{3 \times 3 \times 3 = 3^3\}$ design, where total of 27 runs are needed. Turning experiments are conducted for 27 sets of cutting parameters which are recorded as per L_{27} orthogonal array. After turning, two quality objectives of the workpieces are selected, that includes the surface roughness (R_a and R_z(μm)) and micro-hardness (H (HV)). Typically, small values of surface roughness and target values of micro-hardness are desirable for the surface integrity in turning operations. For 27 turned parts surface roughness test is carried out. Table-4 shows 27 set of cutting parameters listed as per L_{27} orthogonal array with corresponding surface roughness values. Nine trial runs based on the orthogonal array L_9 are necessary. Nine cutting experimental runs are selected according to L_9 O.A. (orthogonal array) table. Wire cutting was carried out for only 9 turned portions amongst 27 referring to L_9 O.A. This was done to reduce the cost and time of experimentation.

2.2 Measuring Apparatus

The surface roughness of the 27 turned surfaces was measured with a Mitutoyo Surf test model SJ-201P, a portable surface roughness instrument. All the measurements were carried out with a cutoff length of 0.8 mm, and in each case the average of five readings was used. The surface roughness was measured to assess the quality of the turned surface quantitatively. To measure the hardness, the first step is to wire cut the turned surface of the round bar. And then measure the hardness of the wire cut specimen using hardness tester. The surface hardness of 9 wire cut specimens was measured along the length and around the periphery by applying a load of 0.3 kg from the surface of the specimen to the depth of the specimen. The average values of six measurements for each specimen was recorded. The hardness value was used to explain the effect of surface modification caused by the turning process. Figure-1 and Figure-2 exhibit the photographs of surface roughness measuring device and Vickers hardness tester employed in the present work. The calculated values of surface roughness and hardness are tabulated in Table-5.

Fig-1:Mitutoyo Surf Test Model SJ-201P

Fig -2: Vickers Hardness Tester

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

Elements	C	Si	Mn	S	P	Cr	Ni	Mo	Cu	Co	Ti	V	Nb	Fe
Wt. (%)	0.058	0.349	1.080	0.019	0.013	16.536	10.769	2.086	0.559	0.079	0.009	0.014	0.020	68.319

Table-2: Mechanical and Physical Properties of Austenitic Stainless Steel (AISI 316)

Property	Value
Yield strength (Mpa)	290
Tensile strength (Mpa)	580
Hardness (HB)	140-160
Density(g/cm³)	8
Poisson's Ratio	0.25
Elongation at break	50%
Modulus of elasticity (Gpa)	193

Table-3:Control factors and their levels

Code	Control Factor	Level		
		1	2	3
A	Speed, (m/min)	120	150	180
B	Feed, (mm/rev)	0.20	0.25	0.30
C	Depth of Cut, (mm)	0.5	1.0	1.5

TABLE-4: O.A. L_{27} of the experimental runs with measured surface roughness

Trail No.	Speed, A (m/min)	Feed, B (mm/rev)	Depth of Cut, C (mm)	Surface Roughness	
				R_a (µm)	R_z(µm)
1	120	0.20	0.5	1.37	6.394
2	120	0.20	1.0	1.434	6.700
3	120	0.20	1.5	1.442	6.798
4	120	0.25	0.5	2.01	9.372
5	120	0.25	1.0	2.03	9.458
6	120	0.25	1.5	1.89	8.790
7	120	0.30	0.5	2.17	10.075
8	120	0.30	1.0	2.29	10.706
9	120	0.30	1.5	2.3	10.700
10	150	0.20	0.5	1.25	5.766
11	150	0.20	1.0	1.466	6.852
12	150	0.20	1.5	1.35	6.330
13	150	0.25	0.5	1.68	7.746
14	150	0.25	1.0	1.77	8.176
15	150	0.25	1.5	1.48	6.876
16	150	0.30	0.5	2.152	9.934
17	150	0.30	1.0	1.86	8.712
18	150	0.30	1.5	1.98	9.230
19	180	0.20	0.5	1.09	5.030
20	180	0.20	1.0	1.18	5.478
21	180	0.20	1.5	1.446	6.058
22	180	0.25	0.5	1.79	7.918
23	180	0.25	1.0	1.83	9.612
24	180	0.25	1.5	1.82	9.912
25	180	0.30	0.5	1.97	8.986
26	180	0.30	1.0	2.296	10.024
27	180	0.30	1.5	2.08	9.608

TABLE-5:Orthogonal array L_9 of the experimental runs withMeasured Responsesand Corresponding S/N Ratios

Sl. no.	Speed (m/min)	Feed (mm/rev)	DOC (mm)	R_a (µm)	R_z (µm)	Hardness H (Hv)	S/N Ratio for R_a η_1 (dB)	S/N Ratio for R_z η_2 (dB)	S/N Ratio for Hardness η_3 (dB)
1	120	0.2	0.5	1.37	6.394	208	-2.73441	-16.1155	46.3613
2	120	0.25	1.0	2.03	9.458	224	-6.14992	-19.5160	47.0050
3	120	0.30	1.5	1.89	8.790	266	-5.52924	-18.8798	48.4976
4	150	0.2	1.0	1.466	6.852	239	-3.32268	-16.7163	47.5680
5	150	0.25	1.5	1.48	6.876	248	-3.40523	-16.7467	47.8890
6	150	0.30	0.5	2.152	9.934	206	-6.65685	-19.9425	46.2773
7	180	0.2	1.5	1.446	6.058	267	-3.20337	-15.6466	48.5302
8	180	0.25	0.5	1.79	7.918	212	-5.05706	-17.9723	46.5267
9	180	0.30	1.0	2.296	10.02	221	-7.21944	-20.0208	46.8878

3. RESULTS AND DISCUSSIONS

3.1 ANOM and ANOVA

In the present work, the goal is to reduce the surface roughness and to increase the hardness of turning process. Hence, "smaller the better type" classification for surface roughness and "larger the better type" classification for hardness have been selected. The S/Nratio connected with the target capacities for each trial of the orthogonal array is given by:

$$\eta_1 = -10 \log_{10} ({R_a}^2) \qquad (1)$$
$$\eta_2 = -10 \log_{10} ({R_z}^2) \qquad (2)$$
$$\eta_3 = -10 \log_{10} (H^{-2}) \qquad (3)$$

The S/Nratios for each trial of L_9orthogonal array were determined using Eqs. (1), (2) and (3) and are presented in Table-5.

The "Analysis of Means" (ANOM) based on the "*S/N* ratio" was used to determine the optimal levels of process parameters [11]; the results of ANOM for surface roughness (R_a), surface roughness (R_z) and hardness (*H*) are represented in Tables 6, 7 and 8 respectively. The parameter level that corresponds to highest value of "*S/N* ratio" is the best level of combination. The ideal parameter setting is found to be A2, B1, C3 for minimum surface roughness ($R_a$and R_z); and A3, B1, C3 for maximum hardness.

TABLE-6:ANOM for $R_a$values based on S/N Ratio

Parameter Code	Levels			Optimum Level
	1	2	3	
A	-4.805	-4.462	-5.160	2
B	-3.087	-4.871	-6.469	1
C	-4.816	-5.564	-4.046	3

TABLE-7:ANOM for $R_z$values based on S/N Ratio

Parameter Code	Levels			Optimum Level
	1	2	3	
A	-18.17	-17.80	-17.88	2
B	-16.16	-18.08	-19.61	1
C	-18.01	-18.75	-17.09	3

TABLE-8:ANOM for Micro Hardness based on S/N Ratio

Parameter Code	Levels			Optimum Level
	1	2	3	
A	47.29	47.24	47.31	3
B	47.49	47.14	47.22	1
C	46.39	47.22	48.31	3

The "Analysis of Variance" (ANOVA) based on *S/N* ratio has been employed to study the effects of turning process parameters quantitatively [11, 12]. The summary of ANOVA results of surface roughness (R_a), surface roughness (R_z) and hardness are given Tables 9, 10 and 11, respectively. It can be observed from the ANOVA tables that feed (75.76%) in case of R_a and feed (77.43%) in case of R_z make major contributions in minimizing the surface roughness; whereas speed and depth of cut have least effects in minimizing the surface roughness. The depth of cut (90.93%) play major role in maximizing the hardness, whereas speed and feed do not show noticeable effects in controlling the hardness.

TABLE-9: ANOVA for R_a values based on S/N Ratio

Parameter Code	DF	Adj SS	Adj MS	% Contribution
A	2	0.7317	0.3658	3.23
B	2	17.1710	8.5855	75.76
C	2	3.4570	1.7285	15.25
Error	8	1.3050	0.6525	5.76
Total	26	22.6647	11.3323	100.00

TABLE-10: ANOVA for R_z values based on S/N Ratio

Parameter Code	DF	Adj SS	Adj MS	% Contribution
A	2	0.2263	0.1132	0.97
B	2	17.9778	8.9889	77.43
C	2	4.1494	2.0747	17.87
Error	8	0.8632	0.4316	3.73
Total	26	23.2167	11.6084	100.00

TABLE-11:ANOVA for Micro Hardness based on S/N Ratio

Parameter Code	DF	Adj SS	Adj MS	% Contribution
A	2	0.00751	0.00376	0.12
B	2	0.19691	0.09846	3.20
C	2	5.58826	2.79413	90.93
Error	2	0.35305	0.17652	5.75
Total	8	6.14573	3.07287	100.00

3.2. Main Effect Plots Analysis

The analysis is made with the assistance of software package MINITAB-16 [14]. The main effect of the plot is shown in Fig. 3, 4 and 5. It demonstrates the variation of every single response with three parameters i.e. speed, feed rate and depth of cut distinctly. In the plot, x-axis signifies the value of each process parameter and y-axis signifies the response value. The mean of the response is indicated by horizontal line. The main effect plots are utilized to determine the optimal design conditions to get the ideal surface finish and hardness. As indicated by main effect plots, the ideal conditions for least surface roughness (R_a *and* R_z) are speed at level 2 (150 m/min), feed rate at level 1 (0.20 mm/rev) and depth of cut at level 3 (1.5mm); the ideal conditions for most extreme hardness are speed at level 3 (180 m/min), feed rate at level 1 (0.20 mm/rev) and depth of cut at level 3 (1.5mm).

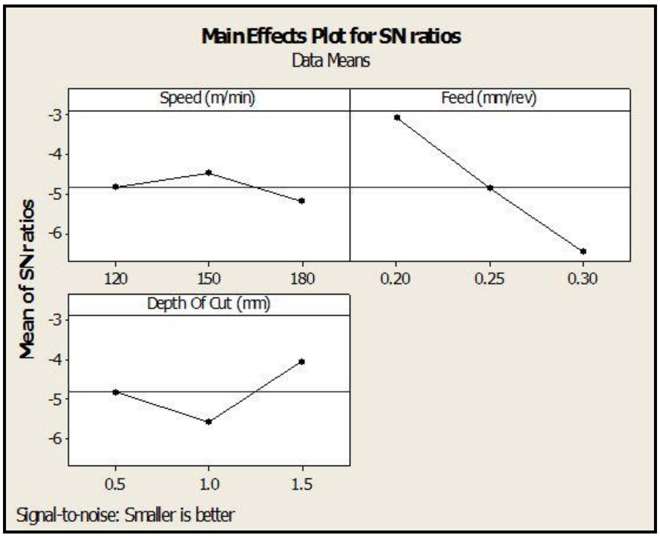

Fig-3: Effect of turning parameters on Surface Roughness (R_a)

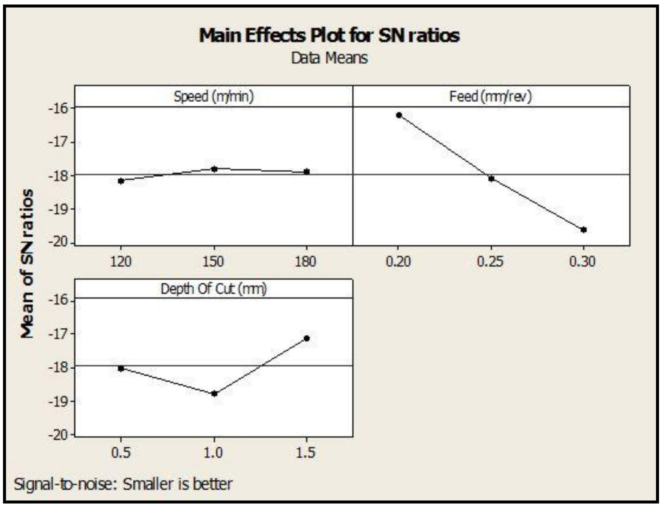

Fig-4: Effect of turning parameters on Surface Roughness (R_z)

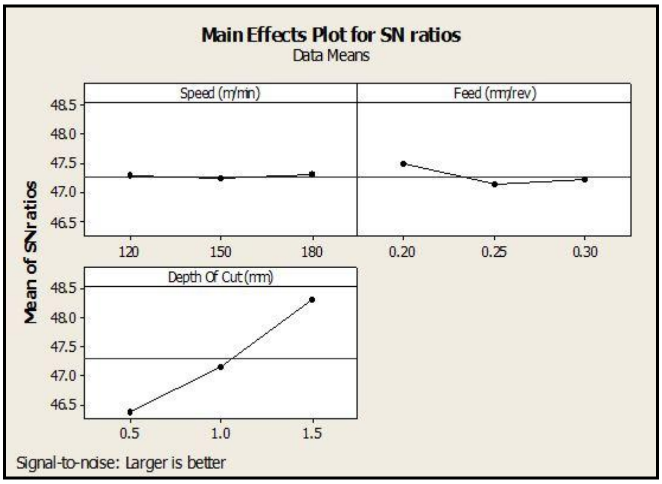

Fig-5: Effect of turning parameters on Hardness

3.3 Machining Affected Zone (MAZ)

Micro-hardness is measured by taking 6 micro-indentations diagonally along the cross section of turned surface. This distinguishes between MAZ and the bulk material and a steep micro-hardness gradient has been observed. Fig. 6 shows the typical micro-hardness profile of one of the samples used in the experiment. Micro-hardness of all the specimen varies in between 268 to 160 and depth of MAZ lies between 100 to 120 µm.

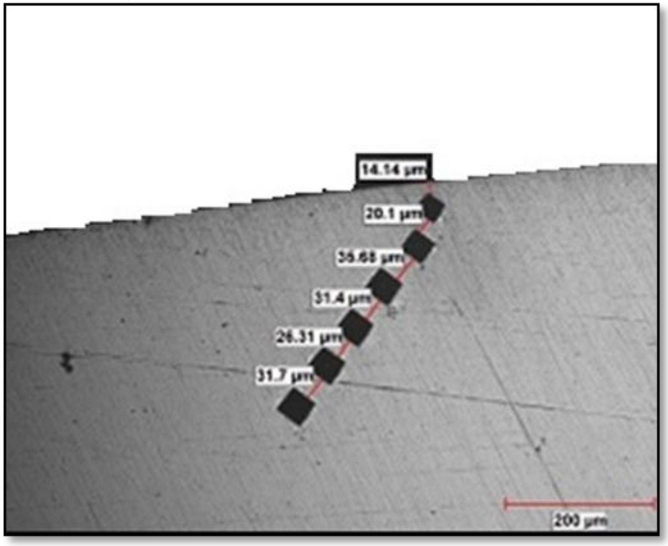

Fig-6: Micro indentation along MAZ

3.4. Verification Test of Optimal Result

After selecting the optimal level of process parameters, the last step is to predict and confirm the performance characteristics. The predicted optimum value of S/N ratio (η_{opt}) is given by [10] :

$$\eta_{opt} = m + \sum_{j=1}^{p}[(m_{i,j})_{max} - m] \qquad (4)$$

where$(m_{i,j})_{max}$ is the S/N ratio of optimum level iof parameter j, mis the overall mean of S/N ratio and p is the number of parameters that affect the machinability characteristics.

In order to judge the closeness of the experimental value of S/N ratio (η_{expt}) with that of the predicted value (η_{opt}), the confidence interval (CI) of (η_{opt}) for the optimum process parameter level combination at 95% level is determined. The CI is given by [10, 11]:

$$CI = \sqrt{F_{(1,v_e)} V_e \left(\frac{1}{\eta_{eff}} + \frac{1}{\eta_{ver}}\right)} \qquad (5)$$

where $F_{(1,v_e)}$is the F value for 95% confidence interval; $v_e$is the degrees of freedom for error; $V_e$is the mean square of error; $\eta_{eff} = N/1 + v$, N = Total trial number in orthogonal array and v = Degrees of freedom of p factors; η_{ver} is the confirmatory test trial number.

Here, the best combination values of the process parameters obtained through Taguchi optimization were set, and the workpieces of the identical lots were turned. The experimental value of *S/N* ratio (η_{expt}) and predicted value of S/N ratio (η_{opt}) were compared. Table-12 gives the confirmatory test results, and from the table we see that the prediction error, i.e., $(\eta_{opt} - \eta_{expt})$ is within the *CI* value, indicating the adequacy of the surface roughness and hardness additive models. The best combinations of process parameters for minimizing surface roughness and for maximizing hardness, along with the corresponding optimal values are given in Table-13.

TABLE-12:Results of Confirmatory Tests

Performance measures	R_a	R_z	Hardness
Levels (A, B, C)	2, 1, 3	2, 1, 3	3, 1, 3
Experimental value	1.35 µm	6.330 µm	267 Hv
S/N experimental (η_{expt}),dB	-2.60668	-16.0281	48.5465
S/N predicted (η_{opt}),dB	-1.977	-15.15	48.53
Prediction error, dB$(\eta_{opt} - \eta_{expt})$	0.62968	0.8781	-0.0165
Confidence interval value (CI), dB	±3.6629	±2.9791	±1.9052

TABLE-13:Optimal Parametersetting and the Corresponding Optimal Values

Response	Optimal process parameter setting			
	Speed (m/min)	Feed (mm/rev)	DOC (mm)	Optimal value
Surface roughness (R_a)	150	0.20	1.5	1.35 µm
Surface roughness (R_z)	150	0.20	1.5	6.330µm
Hardness	180	0.20	1.5	267 Hv

4. CONCLUSIONS

The following are the conclusions drawn based on the experimental investigation conducted on turning AISI 316austenitic stainless steel using Carbide insert under conventional cooling conditions at three levels by employing Taguchi technique to determine the optimal level of process parameters.

- Analysis of variance (ANOVA) demonstrates that the feed rate has the highest influence on surface roughness. R_a is influenced by feed rate with PCR of 75.76%. R_z is influenced by feed rate with PCR of 77.43%. Nevertheless, the depth of cut and cutting speed have negligible influence on the surface roughness at the reliability level of 95%.
- ANOVA demonstrates that the depth of cut has the highest influence on hardness. Hardness is influenced by depth of cut with PCR of 90.93%. Cutting speed and feed rate have negligible influence on the hardness.
- The optimal combination process parameters for minimum surface roughness (R_a and R_z) is obtained at 150 rpm, 0.2 mm/rev and 1.5mm.
- The optimal combination of process parameters for maximum hardness is obtained at 180 m/min cutting speed, 0.3 mm/rev feed, 1.5 mm depth of cut.
- The hardness values of the micro-hardness profile revealed that the hardness of the turned specimen goes on decreasing from the surface to the depth of the specimen.
- The verification tests have deduced that the results obtained are accurate up to 95% of confidence level.
- It is also predicted that Taguchi method is a best method for optimization of various machining parameters as it reduces the number of experiments.

ACKNOWLEDGMENT

The authors would like to express their gratitude to Mr. Adivesh. K. of Karnataka Original Equipment Manufacturers (KOEM), Gadag, Karnataka, India for extending their laboratory facilities to carry out the experiments and for their valuable suggestions during its accomplishment.

REFERENCES

[1] IhsanKorkut , Mustafa Kasap , Ibrahim Ciftci, UlviSeker, “Determination of optimum cutting parameters during machining of AISI 304 austenitic stainless steel”, Materials and Design 25, 2004; pp. 303–305.

[2] IlhanAsilturk, SuleymanNeseli, “Multi response optimization of CNC turning parameters via Taguchi method-based response surface analysis”, Measurement 45, 2012; pp. 785–794.

[3] Kaladhar, M., VenkataSubbaiah, K., Shrinivas Rao, Ch., “Determination of optimum process parameters during turning of AISI 304 Austenitic stainless steel using Taguchi method and ANOVA”, International journal of Lean Thinking, 2012; Vol. 3, Issue1.

[4] Atul P. Kulkarni, Girish G. Joshi, Vikas G. Sargade, “Dry turning of AISI 304 austenitic stainless steel using AlTiCrN coated insert produced by HPPMS technique”, International Conference on Design and Manufacturing, 2013; pp. 737-746.

[5] MalekHabak, Jean Lou Lebrun, “An experimental study of the effect of high-pressure water jet assisted turning (HPWJAT) on the surface integrity”

International Journal of Machine Tools & Manufacture 51(9), 2011; pp. 661–669.

[6] Anthony Xavior, M., Adithan, M., "Determining the influence of cutting fluids on tool wear and surface roughness during turning of AISI 304 austenitic stainless steel", Journal of materials processing technology 209, 2009; pp. 900–909.

[7] Akasawa, T., Sakurai, H., Nakamura, M., Tanaka, T., Takano, K., "Effects of free-cutting additives on the machinability of austenitic stainless steels", Journal of Materials Processing Technology, 2003; 143–144, pp. 66–71.

[8] O'Sullivan, D., Cotterell, M., "Machinability of austenitic stainless steel SS303", Journal of Materials Processing Technology, 2002; 124, pp. 153–159.

[9] Antony, J. and Kaye, M., "Experimental Quality—A Strategic Approach to Achieve and Improve Quality", Norwell, Massachusetts, Kluwer Academic Publishers, 1999.

[10] Montgomery, D.C., "Design and Analysis of Experiments", 4th edition, 1997; John Wiley & Sons, New York.

[11] Phadke, M.S., "Quality Engineering Using Robust Design", 1989; Prentice-Hall International, Englewood Cliffs, New Jersey.

[12] Ross, P.J., "Taguchi Techniques for Quality Engineering", 2nd Edition, 1996; McGraw-Hill, New York.

[13] Tian-SyungLan., "Taguchi optimization of Multi objective CNC machining using TOPSIS", Information Technology Journal, 2009; 8(6): pp. 917-922.

[14] Minitab Inc., "Minitab User Manual", Version 16, 2011; State College, Pennsylvania, USA.

[15] Gaitonde, V.N., Karnik, S.R., "Selection of optimal process parameters for minimizing burr size in drilling using Taguchi's quality loss function approach", Journal of the Brazilian Society of Mechanical Sciences and Engineering, 2012; Vol. 34, no.3, pp. 238-245.

[16]Krishankant, JatinTaneja, MohitBector, Rajesh Kumar, "Application of Taguchi Method for Optimizing Turning Process by the effects of Machining Parameters", International Journal of Engineering and Advanced Technology (IJEAT), 2012; ISSN: 2249 – 8958, Volume-2, Issue-1.

[17] Sreenivasa Murthy, T., Suresh, R.K., Krishnaiah, G., Diwakar Reddy, V., "Optimization of process parameters in dry turning operation of EN 41B alloy steels with cermet tool based on the Taguchi method", International Journal of Engineering Research and Applications (IJERA), 2013; ISSN: 2248-9622, Vol. 3, Issue 2

BIOGRAPHIES

Mr. PrajwalkumarM.Patil completed B.E.(Mechanical) degree in 2013 fromTontadarya College of Engineering, Gadag,Karnataka, Indiaand M.Tech. (Product Design and Manufacturing) degree in 2015 from Visveswaraya Technological University, Belagavi, Karnataka, India.

Mr. Rajendrakumar V. Kadicompleted B.E.(Industrial and production engineering) degree in 1996 and M.Tech. (Production Management) degree in 2003 from BEC, Bagalkot, Karnataka, India. He is currently working as an Asst. Professor in the Department of Mechanical Engineering, Tontadarya College of Engg., Gadag, Karnataka, India. He has 12 years of teaching experience. He has published many research papers in international and national journals.

Dr. Suresh T. Dundurcompleted B.E. (Mechanical) degree in 1984 from BEC, Bagalkot, Karnataka, India and M.Sc. (Engg.) in M/c Design and Analysis from REC, Rourkela in 1990. He is also awarded Ph.D. in Metal Machining, Slipline Field Theory from NIT, Rourkela in 2006. He is also a Lifetime Member in ISTAM, ISTE and a Fellow Member in IE. He is currently a Professor and Head in the Department of Industrial and Production Engineering, BEC, Bagalkot, Karnataka, India.He has published many research papers in international and national journals.

Mr. Anil S. Pol completed B.E. (Mechanical) degree in 2010 from KLE's MSSCET, Belagavi, Karnataka, India and M.Tech(Product Design and Manufacturing) in 2012 from VTU, Belagavi, Karnataka, India. He is currently working as anAsst. Professor in the Department of Product Design and Manufacturing, VTU, Belagavi, Karnataka, India.He has 2 years of teaching experience. He has published 2 research papers in national journals.