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Optimization of dry turning parameters on surface roughness and hardness of Austenitic Stainless steel (AISI316) by Taguchi Technique.

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Austenitic stainless steel, because of its excellent resistance to oxidation and corrosion, is found in variety of industrial applications. Producing machined surfaces with good finish and wear resistance in those applications is a prime requirement, especially when it is used in food and medical equipment. The present investigation is concerned with the determination of optimal turning parameters for reduced roughness and increased hardness of the machined surfaces while turning austenitic stainless steel 316 using carbide insert coated with TiN under dry condition. Experimental trails were performed as per Taguchi's full factorial design. To determine the optimum levels of control factors, the statistical analysis for means (ANOM) based on S/N ratio was used. Along with this, analysis of Variance (ANOVA) was carried out to note those process parameters and their interactions that were strongly contribute to the objective function. It is found that feed rate plays a significant role in Ra and Rz values of surface roughness, where as cut depth and interaction of speed and cut depth have moderate effects. Speed and cut depth influence more on Rz value compared to its Ra value. On the other hand, for maximizing the hardness of the turned surface, joint effect of turning speed and feed rate, and cut depth showed significant effects.

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Introduction

Austenitic stainless steel, because of its excellent resistance to oxidation and corrosion, is found in variety of industries such as marine, chemical, dairy, power and biomedical etc. [1, 4, 5, 9, and 10]. Therefore, Austenitic grade of stainless steel is among largest consumed steel which makes up to 70% of total stainless steel consumed worldwide [1, 8, 10, and 11]. However, machining of this hard to cut material is not that easy due to its high strength, poor surface finish, lower thermal conductivity, higher work hardening, high ductility, more micro structural and mechanical sensitivity to strain and strain rate, etc. [1-9]. As a result of it, this material induces rapid wear in cutting tools and tool wear related problems while machining. It is also found that addition of free cutting additives like lead, sulfur, selenium and tellurium increase the machinability of austenitic stainless steels, [2, 3].

Producing machined surfaces with good finish and resistance to wear are the prime requirements especially when Austenitic steel is used in medical equipment and food processing containers. Fine surface is also entailed for the improvement of tribological properties, corrosion resistance, fatigue strength, creep life and aesthetic appeal in the manufactured parts etc.[4, 8, and 12]. Surface finish in particular is found to be affected by parameters like nose radius along with cutting speed, cutting depth and feed rate [13]. Machining at lower speeds has a tendency to form built up edge causing increased surface roughness. But the formation of built up edge can be avoided by choosing higher cutting speeds [4]. Ibrahim Ciftci [7] while machining austenitic stainless steel with cemented carbide inserts having multiple coatings of TiN observed that, increase in cutting velocity initially reduces the surface roughness till it reaches a lower value and then it increases. A general consensus prevails amongst the

investigators regarding predominance of cutting speed and feed rate amongst all those factors influencing roughness of machined surface [10, 15 and 16]. However, in contrast to it few investigators such as Kaladhar et al. [8] and Dilbag Singh and VenkateswaraRao [13] identified that, after the feed rate next most predominant factors are nose radius, rake angle and cutting velocity. From the literature it can be revealed that substantial work has been carried out in analyzing the cause of machining parameters on roughness of the turned surface but, little focus on wear resistance and the micro-hardness of machined subsurface. Therefore, the main intention of this investigation is to find the optimal turning parameters(speed, feed and cut depth) for the combined effect of surface roughness and micro hardness of the turned surfaces while machining austenitic stainless steel 316 with TiN-coated carbide insert.

Taguchi's full factorial design (L_{27}) orthogonal array has been used to achieve the above objective. And also, a numerical analysis (ANOVA) has been performed to know which process variables and their interactions are statistically important. Finally, ANOM is done to find the optimum level of each variable for both surface roughness (R_a and R_z) and microhardness, and results are compared with the experimental values. Statistical package MINITAB was used to perform the statistical analysis.

Methodology

The present study is carried out using Taguchi's full factorial design. This method makes use of orthogonal arrays for optimizing the responses. The orthogonal arrays consider simultaneously the effect of many controlling factors on the response quantity. The orthogonal experiments were conducted to obtain the optimum level for every controlling factor. Further these experiments provide

information about effect of individual parameters and interactive effect of the on response[18, 19].

In this optimization technique objective function is formed on the basis of “signal to noise (S/N) ratio” which is subjected to the constraints formed by the noise factors using orthogonal matrix.[18, 19]. Thus Taguchi method gives the expected optimal performance under the noise factors. Based on the nature of variable i.e. S/N values ratios, the objective function can be selected as to “smaller the better”, “larger the better” and “nominal the best” type. ANOM of S/N ratio helps in determining the admirable combination of controlling parameters and their levels. The ANOVA helps in understanding the individual and interactive effect of control factors on the responses [18, 19].

Experimentation:

In the present investigation, cylindrical turning trails were carried out as per the full

factorial (3^3) design matrix, a whole of 27 trials, all having a unique combination of every levels of factors were carried out. Three control factors namely cutting speed, cut depth and feed rate are chosen as control factors for the present study. The different levels of cutting parameters are decided in accordance with the tool manufacturer’s recommendation for the given material used in the experiments. Each controlling factors is considered at three levels and are illustrated in Table 1. According to Taguchi’s full factorial design method, L_{27} orthogonal array was used in the design of experiment. Table 2 gives the detailed outline of experimentation. The CNC lathe machine with Fanuc control (11 kW with spindle speed up to 4000 rpm) was used to conduct the turning trails in dry condition. The work material used in the experiment is round bar of 32 mm diameter Austenitic Stainless Steel AISI316 and Table 3 gives detail composition of it.

Table1. Control factors with chosen 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	Cut depth, mm	0.5	1.0	1.5

Table 2. Full Factorial Array (L_{27}), measured response and corresponding S/N ratios.

Trail No	Speed, A	Feed, B	Cut depth, C	R_a (μm)	R_z (μm)	Hardness, H (Hv)	S/N Ration For R_a η_1 (dB)	S/N Ration for R_z η_2 (dB)	S/N Ration for Micro Hardness η_3 (dB)
01	120	0.20	0.5	2.332	10.884	248	-7.3546	-20.7358	47.8890
02	120	0.20	1.0	2.538	12.112	272	-8.0898	-21.6643	48.6914
03	120	0.20	1.5	3.026	14.566	288	-9.6174	-23.2668	49.1878
04	120	0.25	0.5	3.584	14.922	291	-11.0874	-23.4765	49.2779
05	120	0.25	1.0	3.736	17.152	315	-11.4481	-24.6863	49.9662
06	120	0.25	1.5	3.832	18.208	341	-11.6685	-25.2052	50.6551
07	120	0.30	0.5	4.582	18.838	335	-13.2211	-25.5007	50.5009
08	120	0.30	1.0	4.272	18.876	297	-12.6126	-25.5182	49.4551
09	120	0.30	1.5	3.832	20.258	331	-11.6685	-26.1319	50.3966

10	150	0.20	0.5	2.378	10.726	322	-7.5242	-20.6088	50.1571
11	150	0.20	1.0	2.632	13.278	315	-8.4057	-22.4627	49.9662
12	150	0.20	1.5	2.068	12.228	328	-6.3110	-21.7471	50.3175
13	150	0.25	0.5	3.510	15.236	297	-10.9061	-23.6574	49.4551
14	150	0.25	1.0	3.324	16.262	330	-10.4332	-24.2235	50.3703
15	150	0.25	1.5	2.610	12.124	375	-8.3328	-21.6729	51.4806
16	150	0.30	0.5	4.418	17.742	305	-12.9045	-24.9801	49.6860
17	150	0.30	1.0	3.978	18.000	312	-11.9933	-25.1055	49.8831
18	150	0.30	1.5	3.020	14.622	335	-9.6001	-23.3001	50.5009
19	180	0.20	0.5	3.284	14.872	288	-10.3281	-23.4474	49.1878
20	180	0.20	1.0	2.592	13.688	292	-8.2727	-22.7268	49.3077
21	180	0.20	1.5	1.664	10.300	378	-4.4231	-20.2567	51.5498
22	180	0.25	0.5	3.460	14.342	273	-10.7815	-23.1322	48.7233
23	180	0.25	1.0	3.630	19.068	257	-11.1981	-25.6061	48.1987
24	180	0.25	1.5	1.420	07.734	272	-3.0458	-17.7681	48.6914
25	180	0.30	0.5	4.380	17.766	292	-12.8295	-24.9918	49.3077
26	180	0.30	1.0	4.886	21.332	339	-13.7791	-26.5806	50.6040
27	180	0.30	1.5	3.328	15.374	359	-10.4437	-23.7357	51.1019

Table 3. 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

The carbide inserts with CVD coating of TiN (*CNMG 120416*) having integrated chip breaker were used during the experiment. The tool having combination of tungsten carbide as base matrix and TiN as a coating material, exhibit the properties of high thermal resistance and low frictional coefficient. This makes the tool to become ideal for dry turning of hard to

cut materials. A square shank tool holder with ISO specification of GCLNR2020 K12 was used during machining. Straight turning trails were done on specimen for the length of 30 mm each for every combination of three parameters with three levels which is shown in Fig1. Fig.2 depicts the experimental setup.

Fig.1 Work material labeled with experiment numbers.

Fig.2 Experimental setup for CNC turning.

The measured surface roughness and microhardness were considered to assess the surface quality and wear resistance of turned surface respectively. The Mitutoyo Surf Test model 'SJ-201' was employed to determine the values of surface roughness at five various locations around the turned surface to reduce the error. A cut-off length of 0.8 mm for the 5

samples was chosen during the measurement. The mean values of R_a and R_z were used for the analysis of surface roughness. The microhardness of every specimen was determined by using low load Vickers hardness tester (Technosys, 0.2-5Kg with 40X magnification) and is illustrated in fig.3.

Fig.3 Vickers hardness tester.

Results and Discussion

ANOM and ANOVA

The present investigation on dry turning, roughness of the machined surface is to be smaller and the hardness is to be larger. To attain this S/N ratio for all runs of the orthogonal array is given by:

$$\begin{aligned}\eta_1 &= -10\log_{10}(R_a^2) \\ \eta_2 &= -10\log_{10}(R_z^2) \\ \eta_3 &= -10\log_{10}(H^{-2})\end{aligned}\quad (3)$$

The successive S/N ratios for all the runs of L_{27} are depicted in Table 2. To arrive at control factors with the optimum levels, ANOM based on S/N ratio was used and summery of which is illustrated in Table 4, 5 and 6. The level of control factor having greatest S/N ratio is the optimum level. For minimum surface roughness the set of optimum control factors for R_a value is A3, B1 and C3 and for R_z value is A2, B1 and C3. Similarly for maximum hardness of turned surface, control factors with best levels are found to be A2, B3 and C3.

Table 4. Optimum level of R_a Value using ANOM

Parameter Code	Levels			Optimum Level
	1	2	3	
A	-10.752	-9.601	-9.456	3
B	-7.814	-9.878	-12.117	1
C	-10.771	-10.693	-8.346	3

Table 5. Optimum level of R_z Value using ANOM.

Parameter code	Levels			Optimum Level
	1	2	3	
A	-24.02	-23.08	-23.14	2
B	-21.88	-23.27	-25.09	1
C	-23.39	-24.29	-22.56	3

Table 6. S/N ratio based ANOM for Micro hardness

Parameter code	Levels			Optimum Level
	1	2	3	
A	49.56	50.20	49.63	2
B	49.58	49.65	50.16	3
C	49.35	49.60	50.43	3

To know the relative contribution of every control factors, ANOVA based on S/N ratio has been used [18, 19] and Tables 7, 8 and 9 represent these results. It can be observed from ANOVA Table that, for R_a value of surface roughness feed rate (45.69%) plays an important role where as cut depth (18.74%) and combined effect of speed and cut depth (17.14%) have slight effect. Similarly for R_z value of surface roughness again feed rate

(41.87%) has its highest contribution and interactive effect of speed and cut depth (23.38%) has its noticeable effect. On the other hand, for maximizing the hardness of the turned surface, interaction of speed and feed (36.42%) and cut depth (25.23%) play significant effect, whereas cutting speed and feed rate do not affect significantly in increasing microhardness.

Table 7. S/N ratio based ANOVA for R_a value.

Parameter Code	Degree of Freedom	Sum of squares	Mean square	% Contribution
A	2	9.077	4.5387	4.97
B	2	83.362	41.6810	45.69
C	2	34.186	17.0928	18.74
A*B	4	8.128	2.0321	4.45
A*C	4	31.265	7.8162	17.14
B*C	4	3.143	0.7858	1.72
Error	8	13.294	1.6617	7.29
Total	26	182.455	75.6083	100

Table 8. S/N ratio based ANOVA for R_z value.

Parameter Code	Degree of Freedom	Sum of squares	Mean square	% Contribution
A	2	4.975	2.487	4.45
B	2	46.774	23.387	41.87

C	2	13.335	6.668	11.94
A*B	4	5.702	1.426	5.11
A*C	4	26.115	6.529	23.38
B*C	4	6.514	1.629	5.83
Error	8	8.290	1.036	7.42
Total	26	111.705	43.162	100

Table 9. S/N ratio based ANOVA for Micro Hardness.

Parameter Code	Degree of Freedom	Sum of squares	Mean square	% Contribution
A	2	2.2406	1.12029	9.88
B	2	1.7960	0.89798	7.92
C	2	5.7209	2.86045	25.23
A*B	4	8.2533	2.06332	36.42
A*C	4	0.2533	0.06334	1.12
B*C	4	0.1868	0.04670	0.82
Error	8	4.2201	0.52752	18.61
Total	26	22.6710	7.57960	100

For predicting and confirming the projected output based on the greatest combined effect of control factors, the predicted Taguchi's signal to noise ratio (η_{opt}) is obtained from [18, 19]:

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

Where, $(m_{i,j})_{\max}$ is the S/N ratio of the best combination i^{th} level with j^{th} factor for p^{th} main design factor. The quality characteristic of the experiments conducted for the conformation of methodology is expressed by the confidence interval (CI). It is determined by using the following relation [19]:

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

where $F_{(1,\gamma_e)}$ is the F value for 95% CI, γ_e is the degree of freedom for error, V_e is the variance

for error, $\eta_{eff} = \frac{N}{1+\gamma}$; N=Total number of trials in orthogonal array and γ = degree of freedom of main control factor and η_{ver} is number of validation test trials taken. This confidence interval is determined to witness the proximity of the observed value (η_{obs}) to that of predicted value (η_{opt}).

Table 10 shows the results of validation tests and it reveals that the predicted error i.e., $(\eta_{opt} - \eta_{obs})$ is within confidence interval value. Thus, Taguchi technique was used to optimize the surface roughness and micro hardness with a 0.05 significance level. The optimum level of control factors that reduce the surface roughness and increase the surface hardness are presented in Table 11.

Table 10. Test report of confirmation experiments.

Performance measures	R_a	R_z	Hardness
Levels (A, B, C)	3, 1, 3	2, 1, 3	2, 3, 3
S/N predicted (η_{opt}),dB	-5.74311	-20.6933	51.19889
Observed value	1.664 μm	12.228 μm	335 Hv

S/N observed(η_{obs}),dB	-4.4231	-21.7471	50.5009
Prediction error, dB	-1.32001	1.0538	0.69799
Confidence interval value (CI), dB	± 1.876208	± 1.807246	± 1.289606

Table 11.Optimal combination of control factors with optimal values of out puts.

Response	Optimal combination of input variable			
	Speed (m/min)	Feed (mm/rev)	Cut depth (mm)	Optimal value
Surface roughness (R_a)	180	0.20	1.5	1.664 μm
Surface roughness (R_z)	150	0.20	1.5	12.228 μm
Hardness	150	0.30	1.5	335

Effects of cutting parameters

To determine the effect of cutting parameters on surface roughness (R_a and R_z) and surface hardness during dry turning direct main effect plots are drawn using MINITAB 16 software [20].

Analysis of surface profile

The main effect of cutting parameters on surface profile when they change from the minimum to maximum levels

can be observed in fig.4 for R_a and Fig.5 for R_z . From the S/N ratio analysis in fig.4 (a), the optimum cutting variables for minimum R_a value are found to be 180 m/min of speed, 0.20 mm/rev of feed rate and 1.5 mm or cut depth. Whereas, in fig 5(a) for minimum R_z value of surface roughness, 150m/min of speed, 0.20mm/rev of feed rate and 1.5mm of cut depth are the optimum values.

Fig.4. Main effect plots (a) Means of S/N ratio for R_a value (b) Effect of control factors on R_a Value.

Fig.5. Main effect plots (a) Means of S/N ratio for R_z value (b) Effect of control factors on R_z Value.

From the effect of control factor plots of surface roughness for R_a value in Fig.4(a), it can be seen that, as the cutting speed increase from 120 m/min to 150 m/min there is decrease in R_a value, but further increase to 180 m/min increases the R_a value which may be, due to the presence of chatter at higher speed, formation of builtup edges during low cutting speeds and fluctuation in cutting force [5,7]. The surface roughness increases with increase in feed rate due to heat generation thereby tool wear hence, the higher surface roughness. Formation of chatter at higher feed rate may also be the cause for higher surface roughness. And also, as the cut depth increases the R_a value decreases and same was also observed by Kaladhar et al.,[8] and this may be attributed by interactive effect of speed and cut depth.

From the figure 5(b), same effect is observed for R_z value as far as speed and feed are concerned for R_a value but, for the cut depth, initially the R_z value increased with increase in cut depth and for further increase in cut depth suddenly there is a decrease in R_z value.

Analysis of surface Hardness.

Fig. 6 (a) shows the optimum values of cutting parameters for maximum surface hardness in consideration with S/N ratio. According to this, 150m/min of speed, 0.3mm/rev of feed rate and 1.5mm of cut depth are observed as optimum parameters. It can be observed from the fig.6 (b) that, increase in cutting speed from 120 m/min to 150 m/min increases the surface hardness. It is attributed by more time of penetration of cutting tool in to the work material during low speed which leads to more plastic deformation hence more work hardening. But further increase from 150 m/min to 180 m/min of speed reduced the surface hardness, may be due to increased surface deformation because of increased work hardening recovery due to rise in temperature. It can be seen from the fg.5(b) that, Increase in feed rate increases the surface hardness which is, because of increased heat generation and hence more work hardening. With increase in cut depth there is an increase in micro hardness of the turned surface. This is due to more strain hardening because of thermal softening of the material at high cut depth [21].

Fig.6. Main effect plots (a) Means of S/N ratio Hardness (b) Effect of control factors hardness.

Residual plots for cutting parameters normal probability plot of residuals for quality loss, plots of residual vs. fitted value, histogram and residual vs. the order of the data for R_a , R_z and micro hardness, are shown in Fig. (7) (a), (b) and (c) respectively. According to residual

plots it can be concluded that data are fairly normal and small deviations are observed for all the response parameters. It is also observed that, no significant unusual patterns for vs. fits, histograms and vs. orders present in the data.

Fig.7. Residual Plots for (a) R_a (b) R_z and (c) Hardness (Hv)

Conclusion

In the present experiment, Taguchi methodology was used for optimizing the cutting parameters during turning of Austenitic Stainless Steel 316 grade under dry cutting condition involving CVD coated TiN insert on CNC lathe. Optimum levels of speed, feed and cut depth were found so that minimized surface roughness and maximized surface hardness could be attained.

From the investigation it is evident that, feed rate is the principal parameter that contributes more on minimizing the surface roughness values of R_a with 45.69% and R_z with 41.87% of contribution. Cut depth and its interaction with speed have become next dominating factors after the feed rate for R_a value with contribution of 18.74% and 17.14% respectively. The most optimal results for R_a value were found for maximum cutting speed which was set at 180 m/min, feed rate of 0.2 mm/rev and cut depth of 1.5 mm. For minimum R_z value of surface roughness optimum levels of cutting parameters were found to be 120 m/min of speed, 0.20 mm/rev of feed rate and 1.5 mm of cut depth.

The optimal levels for maximizing the surface hardness of the work specimen after dry turning were measured and it revealed that, joint effect of feed and speed has become the significant factor with 36.42% of contribution and is followed by cut depth with 25.23%. Maximum hardness was noticed at greater feed

rate and cut depth with moderate cutting speed. From the present study, with 150 m/min of cutting speed, 0.3 mm/rev of feed rate and 1.5 mm of cut depth have resulted with maximum surface hardness of 335 Hv.

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