Journal of Engineering Science and Technology
Vol. 5, No. 3 (2010) 293 - 301

OPTIMIZATION OF SURFACE ROUGHNESS OF AISI 304 AUSTENITIC STAINLESS STEEL IN DRY TURNING OPERATION USING TAGUCHI DESIGN METHOD

PHILIP SELVARAJ[1], P. CHANDRAMOHAN[2,*]

[1]Faculty of School of Mechanical Sciences, Karunya University, Coimbatore, India
[2]Faculty of Mechanical Engineering, Coimbatore institute of Engineering and Information Technology, Coimbatore, India
*Corresponding Author: pcmohu@yahoo.co.in

Abstract

The present work is concentrated with the dry turning of AISI 304 Austenitic Stainless Steel (ASS). This paper presents the influence of cutting parameters like cutting speed, feed rate and depth of cut on the surface roughness of austenitic stainless steel during dry turning. A plan of experiments based on Taguchi's technique has been used to acquire the data. An orthogonal array, the signal to noise (S/N) ratio and the analysis of variance (ANOVA) are employed to investigate the cutting characteristics of AISI 304 austenitic stainless steel bars using TiC and TiCN coated tungsten carbide cutting tool. Finally the confirmation tests that have been carried out to compare the predicted values with the experimental values confirm its effectiveness in the analysis of surface roughness.

Keywords: Austenitic stainless steel, Optimization, Taguchi method, S/N ratio, ANOVA.

1. Introduction

In the past two decades, the applications of stainless steel materials have increased enormously in various fields. The attractive combination of excellent corrosion resistance, a wide range of strength levels including strength retention at cryogenic and elevated temperatures, good formability, and an aesthetically pleasing appearance have made stainless steel materials of choice for a diverse range of applications, from critical piping components in boiling water nuclear reactors to the ubiquitous kitchen sink [1-6]. Stainless steels are known for their corrosion resistance along with better mechanical properties. At the same time, machinability is one cumbersome issue which is being discussed by the fabricators for a quite long

Nomenclatures

F	A statistical parameter
M.S.D	Mean square deviation
S	Surface roughness, μm
SS	Squared deviation
S/N	Signal to noise, db

Greek symbols

η	Signal to noise ratio

period. This argument is placed in relative terms to that of other alloy steels which is due to some reasons such as low heat conductivity, high built up edge tendency and high deformation hardening of most of the stainless steel varieties. Austenitic stainless steels, characterized by a high work hardened rate and low thermal conductivity [7], are used to fabricate chemical and food processing equipment, as well as machinery parts requiring high corrosion resistance [8]. ICiftci [9] investigated the Machining characteristics of austenitic stainless steels (AISI 304 and AISI 316) using CVD multi layer coated carbide tools. The turning tests were conducted at four different cutting speeds with a constant feed rate and depth of cut. The influence of work piece grade, cutting tool coating top layer and cutting speed were investigated on cutting forces and machined surface roughness. With increasing cutting speed surface finish values decreased until a minimum value was reached, beyond which they increased.

Ihsan Korkut et al. [10] carried turning tests to determine optimum machining parameters for machining of austenitic stainless steel. In the machining of AISI 304 austenitic Stainless steels, optimum cutting speed lead to lowest tool flank wear. Tool flank wear decreased with increasing the cutting speed up to 180 m/min. The poor performance of the tool was by the thermal softening of the tool due to the higher influence of the heat on the cutting tool and less efficient heat dissipation at the lower cutting speeds. Surface roughness values were found to decrease with increasing cutting speeds. This was attributed to the presence of built up edge at the lower cutting speeds. Inhomogeneous distribution of chip thickness at the lower cutting speed indicated the variation of cutting forces. Due to the force fluctuations results the poor surface finish.

Effects of free cutting additives such as S, Ca, Cu and Bi on the machinability of work materials SUS303, SUS303Cu, SUS304 and SUS316 were studied by Akasawa et al. [11]. The resulfurization deteriorated the surface texture at lower cutting speeds in dry cutting. Resulfurization and copper addition decreased the cutting force. Bismuth addition resulted in the surface finish being undeteriorated and the chip thickness being decreased. Calcium treated steels with inclusions of an anorthite composition exhibited a better surface finish and lower cutting force than those of plain austenitic stainless steels. Since there exists a necessity for an optimization in the machinability parameters of stainless steels a familiar design technique can be attempted.

Taguchi primarily recommends experimental design as a tool to make products more robust – to make them less sensitive to noise factors. He views experimental design as a tool for reducing the effects of variation on product and process quality characteristics [12]. The complete procedure in Taguchi design method can be divided into three stages: system design, parameter design, and tolerance design. Of the three design stages, the second stage – the parameter design – is considered to be the most important stage [13]. It has been widely applied in the developed countries like US and Japan with great success for optimizing industrial/production processes. This stage of Taguchi parameter design requires that the factors affecting quality characteristics in the manufacturing process have to be determined. The major goal of this stage is to identify the optimal cutting conditions that yield the lowest surface roughness value. Few steps to be followed in the Taguchi parameter design are: selecting the proper orthogonal array (OA) according to the numbers of controllable factors (parameters); running experiments based on the OA; analyzing data; identifying the optimum condition; and conducting confirmation runs with the optimal levels of all the parameters. Several researchers have carried out their studies using Taguchi method on the various machining operations like turning, end milling etc in various alloys using various cutting tools. Few such closely related literatures and their findings are as follows.

Yang et al. [14] have used Taguchi method to optimize the turning operation of S45C steel bars using tungsten carbide cutting tools and reported that cutting speed, feed rate, and depth of cut are the significant cutting parameters for affecting surface roughness. However, the contribution order of the cutting parameters for surface roughness is feed rate, then depth of cut, and then cutting speed. Zhang et al. [15] have used Taguchi method for surface finish optimization in end milling of Aluminum blocks. The experimental results indicate that in this study the effects of spindle speed and feed rate on surface finish were larger than depth of cut for milling operation. Nalbant et al. [16] used Taguchi method to find optimum cutting parameters for surface roughness in turning of AISI 1030 carbon steel bars using TiN coated tools. Three cutting parameters namely, insert radius, feed rate, and depth of cut are optimized with considerations of surface roughness. In turning, use of greater insert radius, low feed rate and low depth of cut are recommended to obtain better surface roughness for the specific test range. Ghani et al. [17] applied Taguchi method to find optimum cutting parameters for surface roughness and cutting force in end milling when machining hardened steel AISI H13 with TiN coated P10 carbide insert tool under semi-finishing and finishing conditions of high speed cutting. The milling parameters evaluated are cutting speed, feed rate, and depth of cut. In end milling, use of high cutting speed, low feed rate and low depth of cut are recommended to obtain better surface roughness and low cutting force.

From the literature stated above, it becomes clear that machinability studies have been carried out by various researchers in the mechanically formed (Rolled or Forged) stainless steels in the form of rod, tube etc. Still there remains some difficulty in the daily machining of stainless steels which reveals the fact that still more research work has to be carried out to find a reasonable solution. Therefore in this work, studies on machinability are carried out by making use of the proven experimental design procedure.

2. Experimental Procedure

2.1. Workpiece material

The workpiece material selected for investigation is the AISI 304 Austenitic Stainless Steel rod with the composition given in Table 1. The size of the workpiece used for experimentation is a round rod with the dimension 80 mm diameter and 300 mm length/height.

Table 1. Chemical Composition of the Workpiece Material.

Element	C	Mn	Si	P	S	Cr	Ni	Fe
Weight (%)	0.08	2.0	1.0	0.05	0.03	19	9	68.84

2.2. Machining processes

The cutting tests were made on medium duty Kirloskar Turn master-35 Lathe. A tool holder with a general specification PSBNR 2525M12 was used in this experiment. Carbide insert (Tagutec make) with a general specification of SNMG 120408 MT TT5100 coated with TiC and TiCN was used as the cutting tool insert. The experiments were conducted as per the orthogonal array and the surface roughness for various combinations of parameters was measured using TR-100 surface roughness tester. The measurement accuracy meets the ISO and DIN standards. The Piezoelectric stylus and cut-off (2.5 mm) was used for taking the surface roughness measurements. The experimentations were conducted with out the application of cutting fluid (dry turning).

2.3. Plan of experiments

The experiments were planned using Taguchi's orthogonal array in the design of experiments, which helps in reducing the number of experiments. The experiments were conducted according to a 3-level L_9 orthogonal array. The cutting parameters identified were cutting speed, feed and depth of cut. The control parameters and their levels are indicated in Table 2.

Table 2. Cutting Parameters and their Levels.

Symbol	Cutting parameters	Unit	Level 1	Level 2	Level 3
A	Cutting speed	m/min	80	100	120
B	Feed rate	mm/rev	0.08	0.10	0.12
C	Depth of cut	mm	0.4	0.6	0.8

3. Design and Analysis of Cutting Parameters

The results of the cutting experiments were studied using the S/N and ANOVA analyses. Based on the results of the S/N and ANOVA analyses, optimal cutting parameters for surface roughness were obtained and verified.

3.1. Analysis of the S/N ratio

In the Taguchi method, the term 'signal' represents the desirable value (mean) for the output characteristic and the term 'noise' represents the undesirable value (S.D) for the output characteristic. Therefore, the S/N ratio is the ratio of the mean to the S.D. S/N ratio is used to measure the quality characteristic deviating from the desired value. The S/N ratio η is defined as

$$\eta = -10\log(M.S.D) \tag{1}$$

where *M.S.D* is the mean square deviation for the output characteristic.

To obtain optimal cutting performance, the–lower–the–better quality characteristic for surface roughness must be taken. The *M.S.D*. for the–lower–the– better quality characteristic can be expressed as:

$$M.S.D = \frac{1}{M}\sum_{i-1}^{m} S_i^2 \tag{2}$$

where, S_i is the value of the surface roughness for the *i*-th test.

Table 3 shows the experimental results for surface roughness and the corresponding S/N ratio. The S/N response table and S/N response chart for surface roughness are shown in Table 4 and in Figs. 1-3.

Table 3. Experimental Results for Surface Roughness and S/N Ratio.

Experiment No.	Cutting speed (m/min)	Feed rate (mm/rev)	Depth of cut (mm)	Surface roughness (µm)	S/N ratio (dB)
1	80	0.08	0.4	0.66	3.61
2	80	0.10	0.6	0.81	1.83
3	80	0.12	0.8	0.90	0.92
4	100	0.08	0.4	0.67	3.48
5	100	0.10	0.6	0.77	2.27
6	100	0.12	0.8	0.83	1.62
7	120	0.08	0.4	0.85	1.41
8	120	0.10	0.6	0.91	0.82
9	120	0.12	0.8	0.98	0.18

Table 4. S/N Response Table for Surface Roughness.

Symbol	Cutting parameters	Mean S/N ratio (dB)			
		Level 1	Level 2	Level 3	Max-min
A	Cutting speed	2.12	2.46	0.80	1.66
B	Feed rate	2.83	1.64	0.91	1.92
C	Depth of cut	2.02	1.83	1.53	0.49

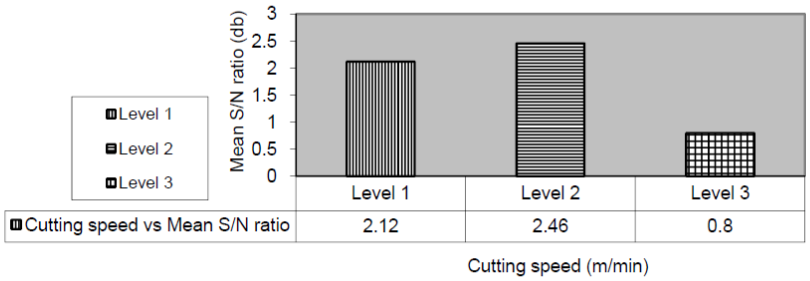

Fig. 1. S/N Response (Cutting Speed) for Surface Roughness.

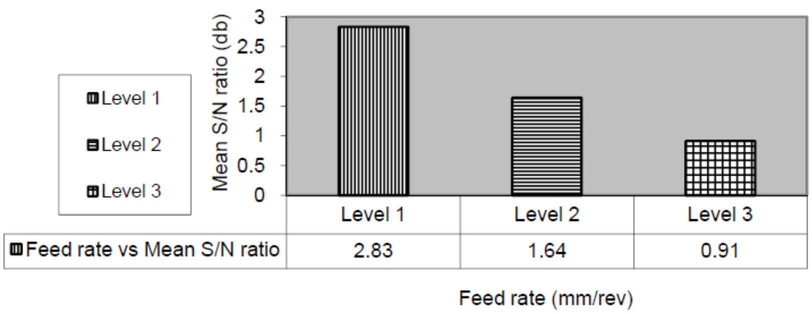

Fig. 2. S/N Response (Feed Rate) for Surface Roughness.

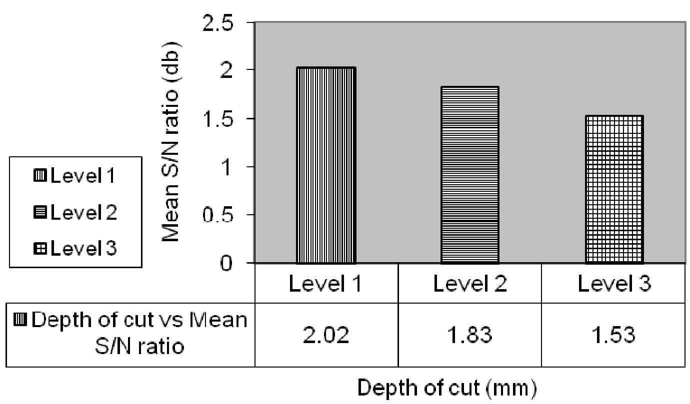

Fig. 3. S/N Response (Depth of Cut) for Surface Roughness.

3.2. Analysis of the variance

The purpose of the analysis of the variance (ANOVA) is to investigate which design parameters significantly affect the quality characteristic. This is accomplished by separating the total variability of the S/N ratios, which is measured by the sum of the squared deviations from the total mean S/N ratio, into contributions by each of the design parameters and the error. First, the total sum of the squared deviations SS_T from the total mean S/N ratio η_m can be calculated as

$$SS_T = \sum_{i=1}^{n} (\eta_i - \eta_m)^2 \qquad (3)$$

where n is the number of experiments in the orthogonal array and η_i is the mean S/N ratio for the i-th experiment.

The total sum of squared deviations SS_T is decomposed into two sources: the sum of squared deviations SS_d due to each design parameter and the sum of squared error SS_e.

The percentage contribution by each of the design parameters in the total sum of squared deviations SS_T is a ratio of the sum of squared deviations SS_d due to each design parameter to total sum of squared deviations SS_T.

Statistically, there is a tool called an F- test named after Fisher to identify the parameter that has significant effect on the quality characteristic. In performing the F-test, the mean of squared deviations SS_m due to each design parameter needs to be calculated. The mean of squared deviations SS_m is equal to the sum of squared deviations SS_d divided by the number of degrees of freedom associated with the design parameter. Then, the F-value for each design parameter is simply the ratio of the mean squared deviations SS_m to the mean squared error. In general if $F > 4$, then it means that the change of the design parameter has significant effect on the quality characteristic.

Table 5 shows the results of ANOVA for surface roughness. Cutting speed, feed rate and depth of cut are the significant cutting parameters for affecting the surface roughness. However, the contributions are in the following order: feed rate, cutting speed and then depth of cut. The optimal cutting parameters for surface roughness are the cutting speed at level 2, the feed rate at level 1 and depth of cut at level 1.

Table 5. Results of the Analysis of Variance for Surface Roughness.

Symbol	**Cutting Parameter**	**Degrees of freedom**	**Sum of squares**	**Mean square**	***F***	**Contribution (%)**
A	Cutting speed	2	4.56	2.28	9.12	41.99
B	Feed rate	2	5.63	2.82	11.28	51.84
C	Depth of cut	2	0.18	0.09	0.36	1.66
Error		2	0.50	0.25		4.61
Total		8	10.86			

3.3. Confirmation tests

Once the optimal level of the design parameters has been selected, the final step is to predict and verify the improvement of the quality characteristic using the optimal level of design parameters. The estimated S/N ratio $\hat{\eta}$ using the optimal level of the design parameters can be calculated as

$$\hat{\eta} = \eta_m + \sum_{i=1}^{o} \left(\eta_{im} - \eta_m \right) \tag{4}$$

where, η_m is the total mean S/N ratio, η_{im} is the mean S/N ratio at the optimal level, and o is the number of the main design parameters that affect the quality characteristic.

Table 6 shows the comparison of the predicted surface roughness with the actual surface roughness using the optimal cutting parameters, good agreement between the predicted and actual surface roughness being observed.

Table 6. Results of the Confirmation Experiment for Surface Roughness.

	Optimal Cutting Parameters	
	Prediction	**Experiment**
Level	A2B1C1	A2B1C1
Surface roughness (μm)	0.65	0.61
S/N ratio (dB)	3.73	4.29

4. Conclusions

In this study, the Taguchi optimization method was applied to find the optimal process parameters, which minimizes the surface roughness during the dry turning of AISI 304 Austenitic Stainless Steel. A Taguchi orthogonal array, the signal to noise (S/N) ratio and the analysis of variance (ANOVA) were used for the optimization of cutting parameters. ANOVA results shows that feed rate, cutting speed and depth of cut affects the surface roughness by 51.84%, 41.99% and 1.66% respectively. A confirmation experiment was also conducted and verified the effectiveness of the Taguchi optimization method.

Acknowledgement

The authors sincerely thank the management of Karunya University, Coimbatore, India for the financial support for doing this research work. The authors thank Dr.S.Darius Gnanaraj, Director and Dr.A.S.Varadarajan, Professor, Karunya School of Mechanical Sciences (KSMS) for providing the facilities of the Centre for Research in Design and Manufacturing (CRDM) for carrying out this work. Mr. Jones Robin, Engineering Technician, Lathe shop is also acknowledged for his help during this experimental work.

References

1. Davis, J.R (1996). *ASM specialty handbook stainless steels*. ASM International.
2. Bouchaïr, A.; Averseng, J.; and Abidelah, A. (2008). Analysis of the behaviour of stainless steel bolted connections. *Journal of Constructional Steel Research*, 64(11), 1264-1274.
3. Cigada, A.; Amici, F.; Cavallini, M.; De Santis, G.; Gatti, A.M.; Giacomazzi, M.; Rondelli, G.; Roos, A.; Vicentini, B.; and Zaffe, D. (1990). Characterization of a high performance duplex stainless steel for orthopedic applications. Engineering in Medicine and Biology Society, *Proceedings of the Twelfth Annual International Conference of the IEEE,* 2082 – 2084.
4. Cunat, Pierre-Jean (2000). Stainless steel properties for structural automotive applications. Metal Bulletin, International Materials conference Cologne.
5. HeNian, Q. (2001). Research of cold rolling oil for stainless sheet steel. *Science in China (Series A)*, 44, 142-148.
6. Machado, J.P.S.E.; Silva, C.C.; Sobral-Santiago, A.V.C., de Sant'Ana, H.B.; and and Farias, J.P. (2006). Effect of temperature on the level of corrosion caused by heavy petroleum on AISI 304 and AISI 444 stainless steel. *Materials Research*, 9(2), 137-142.
7. Sandvik Coromant (1997). *Modern metal cutting - practical handbook.* Sandvik Coromant Co. Inc, Sweden.
8. Groover M.P. (1996), *Fundamentals of modern manufacturing –materials, process and systems.* (2^{nd} Ed.)*,* Wiley.
9. Ciftci, I. (2006). Machining of austenitic stainless steels using CVD multi-layer coated cemented carbide tools. *Tribology International*, 39(6), 565-569.
10. Korkut, I.; Kasap, M.; Ciftci, I., and Seker, U. (2004). Determination of optimum cutting parameters during machining of AISI 304 austenitic stainless stee. *Materials & Design*, 25(4), 303-305.
11. Akasawa, T; Sakurai, H.; Nakamura, M.; Tanaka, T.; and Takano, K. (2003). Effects of free-cutting additives on the machinabilty of austenitic stainless steel. *Journal of Materials Processing Technology*, 143-144, 66-71.
12. Locner, R.H.; and Matar, J.E. (1990). *Designing for quality*. Productivity Press.
13. Taguchi, G.; Sayed, M.El; and Hsaing, C. 1(1989). *Quality engineering and quality systems*. McGraw-Hill, NY.
14. Yang, W.H.; and Tarng, Y.S. (1998), Design optimization of cutting parameters for turning operations based on the Taguchi method. *Journal of Material Processing Technology*, 84(1-3), 122-129.
15. Zhang, J.Z.; Chen, J.C.; and Kirby, E.D. (2007). Surface roughness optimization in an end-milling operation using the Taguchi design method. *Journal of Material Processing Technology*, 184(1-3), 233-239.
16. Nalbant, M.; Gokkaya, H.; and Sur, G. (2007). Application of Taguchi method in the optimization of cutting parameters for surface roughness in turning. *Materials & Design*, 28(4), 1379-1385.
17. Ghani, J.A.; Chodhury, I.A.; and Hassan, H.H. (2004). Application of Taguchi method in the optimization of end milling parameters. *Journal of Material Processing Technology*, 145(1), 84-92.