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PERFORMANCE STUDY ON AISI316 AND AISI410 USING DIFFERENT LAYERED COATED CUTTING TOOLS IN CNC TURNING

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Abstract

Stainless steel (SS) is used for many commercial and industrial applications owing to its high resistance to corrosion. It is too hard to machine due to its high strength and high work hardening property. A surface property such as surface roughness (SR) is critical to the function-ability of machined components. SS is generally regarded as more difficult to machine material and poor SR is obtained during machining. In this paper an attempt has been made to investigate the SR produced by CNC turning on austenitic stainless steel (AISI316) and martensitic stainless steel (AISI410) by different cases of coated cutting tool used at dry conditions. Multilayered coated with TiCN/Al_2O_3, multilayered coated with Ti(C, N, B) and single layered coated with TiAlN coated cutting tools are used. Experiments were carried out by using Taguchi's L_{27} orthogonal array. The effect of cutting parameters on SR is evaluated and optimum cutting conditions for minimizing the SR are determined. Analysis of variance (ANOVA) is used for identifying the significant parameters affecting the responses. Confirmation experiments are conducted to validate the results obtained from optimization.

Keywords: CNC turning, AISI316, AISI410, Surface roughness, Taguchi's Techniques, ANOVA.

1. Introduction

Turning is very important machining process in which a single point cutting tool removes unwanted material from the surface of a rotating cylindrical work piece.

Nomenclatures

CI	*Confidence interval*
Coef.	Second order coefficient
Cont	Constant
D	Depth of cut, mm
F	Feed rate, mm/rev
$F_{\alpha}\ (1, f_e)$	*Ratio at a significance level*
f_e	The error degrees of freedom
n_{eff}	The effective total number of tests
P	*P* test value
R	The number of confirmation tests
Ra	Arithmetic mean value
S/N	Signal to Noise ratio
T	*T* test value
TiAlN	Titanium aluminum nitride
$TiCN/Al_2O_3$	Titanium carbo-nitride / aluminum oxide
Ti(C,N,B)	Titanium carbo-nitride-boron
V	Cutting speed, m/min
V_e	The error mean square
α	The risk

SR is an important factor to evaluate cutting performance. Proper selection of cutting parameters and tool can produce longer tool life and lower SR [1]. Machining industries are mainly focused on high quality, surface finish, high production rate, less wear on the cutting tools, economy of machining in terms of cost saving and increase of the performance of the product [2]. SR plays an important role in many areas and is a factor of great importance in the evaluation of machining accuracy [3, 4].

SS is generally a difficult to machine due to its high strength, ductility and high work hardening tendency [5]. SS is having different grades and different properties under variation of chemical compositions. Therefore, these variations in their properties have an influence on their machinabilities [6]. Tool wear is widely considered one of the most challenging aspects of causing poor surface quality in machining. Coated carbides are basically a cemented carbide insert coated with one or more layers of wear resistant materials [7, 8]. It is well known that coating can reduce tool wear and improve the SR [9, 10]. Therefore, most of the carbide tools are used in the metal cutting industries is coated; however, coating brings about an extra cost [11, 12].

Khan and Hajjaj [13] were investigated the capabilities of cermets tools for high speed machining of AISI 316. Kaladhar et al. [14] was conducted performance evaluation of coating materials and process parameters optimization for surface quality during turning of AISI 316. Galanis et al. [15] developed SR model for turning of AISI 316 with TiN/Al2O3/TiC coated carbide tool. Thamizhmani and Hasan [16] were investigated the AISI410 by PCBN cutting tool. They found that the SR value was low at high cutting speed with low feed rate. Gutakovskis et al. [17] were performed turning test on AISI410 using nano coated cutting tool. Noordin et al. [18] were conducted a dry turning test on AISI410 using coated cermets and coated carbide tool. Only limited number of research papers is available for turning of SS. various compositions of cutting tools were used by the past researchers for turning. But comparisons of single and multi-layered cutting tools for turning AISI316 and AISI410 were not carried out by them.

Taguchi method is a powerful tool for the design of high quality systems. It provides an efficient and systematic approach to optimize designs for performance. Taguchi method is an efficient method for designing process that operates consistently and optimally over a variety of conditions. To determine the best design, it requires the use of a strategically designed experiment. Taguchi approach to design of experiments is easy to adopt and apply to users with limited knowledge of statistics, hence gained wide popularity in the engineering and scientific community [19]. The desired cutting parameters are determined based on experience or by handbook. Cutting parameters are reflected on surface roughness, surface texture and dimensional deviation turned product [20]. In a manufacturing process it is very important to achieve a consistent tolerance and surface finish [21]. Taguchi method is especially suitable for industrial use, but can also be used for scientific research [22]. In this investigation Taguchi technique is used to determine the optimum cutting parameters for different cases of cutting tool.

2. Description of Experiment

The main objective of the work is to establish a relation between cutting speed, feed and depth of cut on SR. AISI316 and AISI410 materials are taken as the work piece materials for all trials with diameter of 32 mm and machined length of 60 mm. The chemical composition of the work materials are given in Table 1. The work piece material's qualities are confirmed to grade AISI316 and AISI410. The experiments are conducted in Fanuc CNC lathe. A work piece positioning accuracy is ± 0.010 and run out is tested by dial gauge heavy duty magnetic base.

The range of cutting parameters is selected based on tool manufactures handbook (Tungaloy Cutting Tool Co., Ltd). In this investigation, three types of cutting inserts are taken for turning process. Multi-layered CNMG 120408 coated with $TiCN/Al_2O_3$ of 14 µm, multi-layered CNMG 120408 coated with Ti(C,N,B) of 6µm and single-layered CNMG 120408 coated with TiAlN of 3 µm. Tool holder of PC LNR 25 × 25 M12.1 was selected for all trials. SR is measured in all trials by the SURF TEST 211 and it is denoted by Ra. Measurements are taken by the proper setting of work pieces and the instrument. In the present work, three parameters each set at three levels are chosen for experimentation.

Table 1. Chemical composition of work piece materials.

	C	Si	Mn	P	S	Ni	Cr	Mo
AISI316	0.040	0.498	1.560	0.036	0.017	10.45	16.71	2.112
AISI410	0.095	0.341	0.680	0.040	0.0063	-	12.170	-

The turning parameters and their levels chosen for all cases are presented in Table 2. In order to have a complete study of turning process, the ranges of parameters are selected, and an appropriate planning of experimentation is essential to reduce the cost and time consuming. Hence, an experimental plan based on Taguchi's L_{27} orthogonal array has been selected. There are three categories of quality characteristic in the analysis of signal to noise(S/N) ratio such as lower the better, higher the better and nominal the better. Since the quality characteristic is to be minimized, lower the better category is used to calculate the S/N ratio for SR.

Table 2. Cutting parameters and levels.

Parameter	Designation	Level 1	Level 2	Level 3
Cutting speed (m/min)	V	110	160	210
Feed (mm/rev)	F	0.1	0.2	0.3
Depth of cut (mm)	D	0.7	1.4	2.1

Minitab 14 statistical software has been used for the analysis of the experimental work. The software studies the experimental data and then provides the calculated results of S/N ratio. The response tables for AISI316 and AISI410 with different cases of coated inserts are given in Tables 3 and 4 respectively. The experimental results are analysed with ANOVA which is used for identifying the factors which significantly affecting the performance measures. The results of the ANOVA for AISI316 and AISI410 with different cutting tools are given in Tables 5 and 6. This analysis is carried out for significance level of α = 0.05, i.e., for a confidence level of 95%.

Table 3. Taguchi analysis for SR on AISI316.

Level	$TiCN/Al_2O_3$			TiAlN			Ti(C,N,B)		
	V	F	D	V	F	D	V	F	D
1	0.06	1.64	-2.6	1.11	3.9	-1.0	-3.2	1.7	-4.5
2	-1.5	-2.4	-0.7	0.25	-1.3	0.45	-3.7	-3.6	-3.3
3	-2.0	-2.6	-0.0	-0.5	-1.7	0.45	-3.9	-9.0	-3.1
Delta	2.06	4.33	2.65	1.62	5.6	2.45	0.7	10.7	1.3
Rank	3	1	2	3	1	2	3	1	2

Table 4. Taguchi analysis for SR on AISI410.

Level	$TiCN/Al_2O_3$			TiAlN			Ti(C,N,B)		
	V	F	D	V	F	D	V	F	D
1	-5.0	-2.7	-3.9	-2.6	2.2	-3.7	-5.7	0.2	-3.6
2	-4.5	-4.0	-5.9	-3.9	-4.8	-4.0	-3.8	-5.0	-4.7
3	-6.0	-8.8	-5.6	-5.6	-9.7	-4.5	-3.9	-8.7	-5.1
Delta	1.5	6.1	2.0	2.9	11.9	0.8	1.9	9.0	1.5
Rank	3	1	2	2	1	3	2	1	3

3. Results and discussions

3.1. Performance of AISI316 using different cutting tool

Taguchi method is applied for solving single response optimization problem with objective of minimization of SR. experiments were conducted for turning AISI316 using different types coated inserts. The results are shown in Table 3.

From Table 3 delta value for feed rate is 4.33 and depth of cut is 2.65 for $TiCN/Al_2O_3$. Delta value for feed rate is 5.62 and depth of cut is 5.62 for TiAlN. Delta value for feed rate is 10.78 and depth of cut is 1.37 for Ti(C,N,B). It shows that feed rate is strongest effect followed by cutting speed.

Minimum SR is obtained with the optimal setting parameters of cutting speed set as 110 m/min, feet rate set to as 0.1 mm/rev, depth of cut set as 2.1 mm using $TiCN/Al_2O_3$, TiAlN and Ti(C,N,B) coated insert. From ANOVA table, Table 5, the major effect on SR using $TiCN/Al_2O_3$ is the linear effect of feed rate and followed by quadratic feed rate having a P-value of 0.023 and 0.066. The major effect on SR using TiAlN is the linear effect of feed rate and followed by linear depth of cut having a P-value of 0.035 and 0.045. The major effect on SR using Ti(C,N,B) is the linear effect of feed rate and followed by quadratic feed rate having a P-value of 0.000 and 0.001.

Table 5. ANOVA for AISI316.

Term	$TiCN/Al_2O_3$			TiAlN			Ti(C,N,B)		
	Coef	T	P	Coef	T	P	Coef	T	P
Cont	1.43	11.48	0.00	1.09	9.6	0.00	1.57	36.8	0.00
V	0.03	0.49	0.64	0.09	1.4	0.21	0.03	1.19	0.28
F	0.24	3.23	0.02	0.20	2.8	0.03	1.03	39.7	0.00
D	0.14	-1.95	0.10	-0.1	-2.6	0.04	0.04	-1.7	0.13
V*V	0.12	-1.12	0.31	0.00	0.01	0.99	0.09	-2.3	0.06
F*F	0.26	-2.35	0.06	0.13	-1.3	0.24	0.27	7.10	0.00
D*D	0.00	-.05	0.95	0.10	1.03	0.34	0.01	0.26	0.80
V*F	0.00	0.00	1.00	0.13	-1.3	0.23	0.05	-1.4	0.21
V*D	0.00	0.00	1.00	0.01	0.12	0.90	0.04	1.08	0.32
F*D	0.23	2.20	0.07	0.09	0.99	0.36	0.09	-2.5	0.05

3.2. Performance of AISI410 using different cutting tool

Taguchi method is applied for solving single response optimization problem with objective of minimization of SR. Experiments were conducted for turning AISI410 using different types coated inserts. The results are shown in Table 6.

From Table 6 delta value for feed rate is 6.10 and depth of cut is 2.01 for $TiCN/Al_2O_3$. It shows that feed rate is strongest effect followed by depth of cut. Delta value for feed rate is 11.94 and cutting speed is 2.99 for TiAlN. Delta value for feed rate is 9.03 and cutting speed is 1.93 for Ti(C,N,B). It shows that feed rate is strongest effect followed by cutting speed. Minimum SR is obtained with the optimal setting parameters of cutting speed set as 160 m/min, feed rate set to as 0.1 mm/rev, depth of cut set as 0.7 mm using $TiCN/Al_2O_3$ and Ti(C,N,B) coated insert. The optimal setting parameters of cutting speed set as 110 m/min, feed rate set to as 0.1 mm/rev, depth of cut set as 0.7 mm using TiAlN coated insert.

The major effect on SR using $TiCN/Al_2O_3$ is the linear effect of feed rate and followed by depth of cut having a P-value of 0.000 and 0.021 is shown in Table 6. The major effect on SR using TiAlN is the linear effect of feed rate and followed by cutting speed having a P-value of 0.000 and 0.069. The major effect on SR using Ti(C,N,B) is the linear effect of feed rate and followed by interaction effect of feed rate and depth of cut having a P-value of 0.000 and 0.006.

Table 6. ANOVA for AISI410.

Term	$TiCN/Al_2O_3$			TiAlN			Ti(C,N,B)		
	Coef	T	P	Coef	T	P	Coef	T	P
Cont	1.52	11	0.00	1.79	11	0.00	1.57	18	0.00
V	0.02	-0.31	0.76	0.21	2.31	0.069	0.09	-1.8	0.121
F	0.81	9.82	0.00	1.09	11.7	0.00	0.82	15.5	0.000
D	0.27	3.32	0.021	0.07	-0.80	0.45	0.01	0.28	0.788
V*V	0.19	1.57	0.17	0.08	0.64	0.55	0.13	1.66	0.156
F*F	0.51	4.17	0.009	0.23	1.70	0.15	0.17	2.18	0.081
D*D	0.11	-0.92	0.39	0.23	-1.7	0.14	0.17	2.27	0.072
V*F	0.01	-0.10	0.91	0.07	-0.5	0.61	0.14	1.93	0.110
V*D	0.11	-0.98	0.37	0.22	1.71	0.14	0.17	2.37	0.064
F*D	0.02	0.23	0.82	0.02	-0.15	0.88	-0.3	-4.5	0.006

3.3. Confirmation experiments for all cases

The objective of the confirmation test is to determine the selected machining parameters will produce better results than produced in the first part of the experiment. The confirmation experiments are used to evaluate the parameters and levels chosen from an experiment. The optimal SR is predicted at the selected optimal setting of parameters. Confidence interval for the expected results from the confirmation experiment is calculated using the Eq. (1)

$$CI = \sqrt{F_{\alpha}(1, f_e)V_e \frac{1}{n_{eff}} + \frac{1}{R}} \quad (1)$$

where, $F_{\alpha}(1, f_e)$ is the F ratio at a significance level of α %, α is the risk, fe is the error degrees of freedom, V_e is the error mean square, neff is the effective total number of tests and R is the number of confirmation tests. The confirmation experiment is conducted at the optimum settings to verify the SR for turning of AISI316 and AISI410. The SR value for AISI316 of case I at the optimal settings of V1, F1, and D3 was found to be 0.56 µm, Corresponding S/N ratio is 5.03 dB, the confidence interval range is 2.55 dB≤ η_{Ra} ≤5.41 dB. The SR value for case II at the optimal settings of V1, F1, and D3 was found to be 0.39 µm, Corresponding S/N ratio is 8.17 dB the confidence interval range is 3.26 dB≤ η_{Ra} ≤8.5 dB. The SR value for case III at the optimal settings of V1, F1, and D3 was found to be 0.70 µm, Corresponding S/N ratio is 3.09 dB the confidence interval range is 1.56 dB≤ η_{Ra} ≤3.21 dB. The SR value for AISI410 of case I at the optimal settings of V2, F1, and D1 was found to be 0.79 µm, Corresponding S/N ratio is 2.04 dB, the confidence interval range is -0.59 dB≤ η_{Ra} ≤2.95 dB. The SR value for case II at the optimal settings of V1, F1, and D1 was found to be 0.47 µm, Corresponding S/N ratio is 6.55 dB the confidence interval range is 3.32 dB≤ η_{Ra} ≤6.74 dB. The SR value for case III at the optimal settings of V2, F1, and D1 was found to be 0.59 µm, Corresponding S/N ratio is 4.5 dB the confidence interval range is -1.15 dB≤ η_{Ra} ≤4.77 dB.

3.4. Performances of different cutting tools

The average SR used in industries is selected for measurement in this SR [23]. Optimal settings for minimization of SR are obtained mostly at low level of parameters from the above results. Figures 1-4 show that SR is varying with different cutting tools turning on AISI316 and AISI410 at various cutting speed range.

Figures 1 and 2 show that feed rate 0.1 mm/rev, depth of cut 0.7 and 2.1mm for AISI316. It clearly shows the best results obtained from the TiAlN than TiCN/Al_2O_3 and Ti(C,N,B).

From Fig. 2, SR decreased for Ti(C,N,B) at high cutting speed. Figures 3 and 4 shows feed rate 0.1 mm/rev, depth of cut 0.7 and 2.1mm for AISI410. From Fig. 3 and particularly from Fig. 4 one can observe that minimal SR can be obtained using TiAlN. Figures 5 and 6 show the comparison charts for turning of AISI316 and AISI410 by different cutting tools. Figure 5 show feed rate of 0.1 mm/rev, cutting speed 110 m/min and depth of cut 0.7 mm. Figure 6 shows feed rate of 0.1 mm/rev, cutting speed 210 m/min and depth of cut 2.1 mm. It clearly shows the best SR obtained from AISI316 than AISI410 for all cutting tools.

As reported by S. Thamizhmanii and B. Bin Omar to turn the martensitic stainless steel at medium level cutting speed, high feed rate and high depth of cut [24]. The Cutting speed found to have a significant effect on the austenitic stainless steels machined surface roughness values Suggested by Ciftci [25]. From this study the feed rate is strongest effect on surface finish and lower feed rate is recommended to obtain the best surface finish.

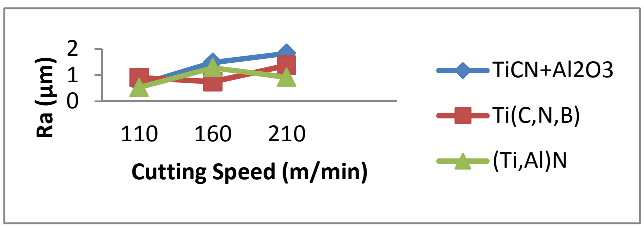

Fig. 1. Cutting speed vs. SR for AISI316 – feed rate of 0.1 and D 0.7 mm.

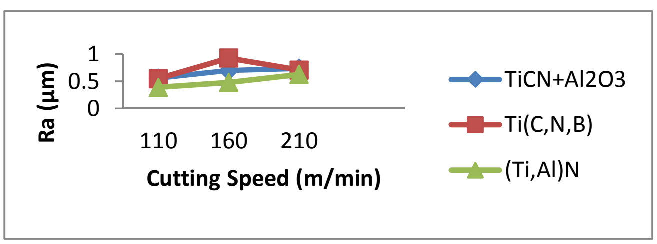

Fig. 2. Cutting speed vs. SR for AISI316– feed rate of 0.1 and D 2.1 mm.

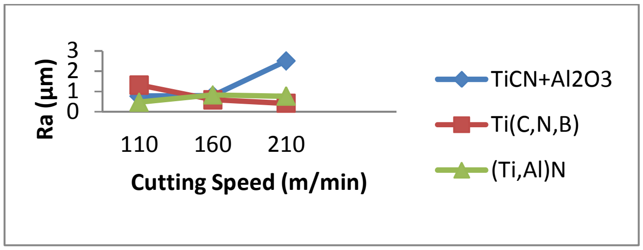

Fig. 3. Cutting speed vs. SR AISI410 – feed rate of 0.1 and D 0.7 mm.

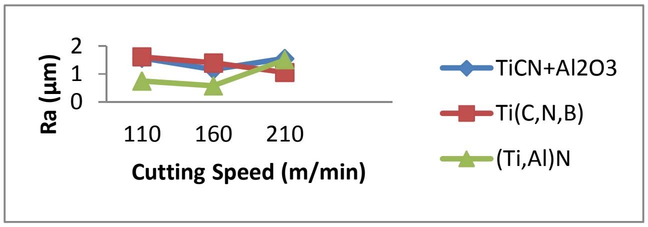

Fig. 4. Cutting speed vs. SR for AISI410 – feed rate of 0.1 and D 2.1 mm.

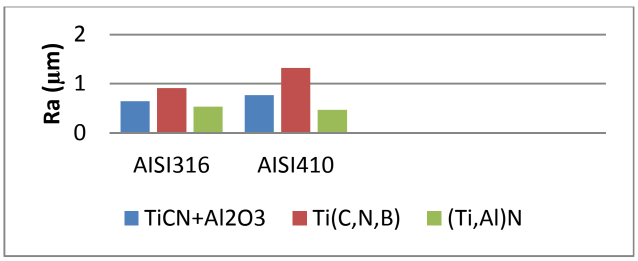

Fig. 5. Comparisons chart for AISI316 and AISI410.

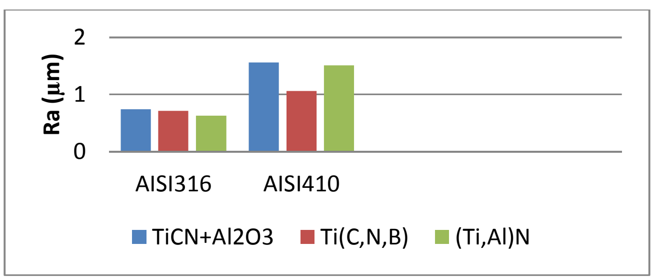

Fig. 6. Comparisons chart for AISI316 and AISI410.

4. Conclusion

The current investigation is focused on optimization of parameters in CNC turning on AISI316 and AISI410 during change of cutting parameters with different cases. Analysing the results obtained using Taguchi's techniques. These following conclusions can be arrived.

- Optimum setting for minimization of SR on AISI316 is cutting speed 110 m/min, feed rate 0.1 mm/rev, depth of cut 2.1 mm/rev [V1F1D3] using TiCN/Al_2O_3, TiAlN and Ti(C,N,B).
- Optimum setting for minimization of SR on AISI410 is cutting speed 160 m/min, feed rate 0.1 mm/rev, depth of cut 0.7 mm/rev [V2F1D1] using TiCN/Al_2O_3 and Ti(C,N,B).
- Optimum setting for minimization of SR on AISI410 is cutting speed 110 m/min, feed rate 0.1 mm/rev, depth of cut 0.7 mm/rev [V1F1D1] using TiAlN.
- Linear feed rate and followed by quadratic feed rate are the most significant factor for the SR. The TiAlN composition coated insets is better performance than the other composition coated inserts.
- Confirmation test results proved that the determined optimum combination of machining parameters satisfy the real requirements of CNC turning on AISI316 and AISI410.

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