Effect of Machining Parameters on Tool Wear and Surface Roughness In Dry and Wet Machining of Aisi 316 Austenitic Stainless Steel by Taguchi Method

Sunil G Dambhare, Sandeep S Kore, Firoz Z Pathan, Sandesh Kurne

Abstract: Stainless steels are widely used to manufacture mechanical components due to excellent mechanical properties. Machining is considered as one of the most critical manufacturing processes in mechanical industry to produce desired shapes and dimensional accuracy of the components. It also affects the performance of the components in its functional requirement. This paper deals with the optimization of cutting parameters in machining operation for AISI 316 austenitic steel with dry and wet environment conditions. The chosen machining parameters in this research are cutting speed, feed rate, and depth of cut as input variables, whereas the response factors are surface roughness and wear rate. Taguchi method with the L9 orthogonal array was used to analyze the process parameters based in dry and wet machining conditions. The Taguchi approach provides the best setting with lower values of surface roughness and wear rate. The regression analysis is performed to obtain a mathematical model of responses in terms of the process parameter. The composite regression optimization gives best setting for dry condition (cutting speed 173 rpm, feed 0.25 mm/rev, and 0.87 mm of the depth of cut) and for wet condition (cutting speed 173 rpm, feed 0.3 mm/rev, and 0.57 mm of the depth of cut). The results show that surface roughness and wear rate are lower in the wet environment than the dry environment.

Index Terms : Taguchi method, Regression analysis, composite optimization, surface roughness , tool wear

I. INTRODUCTION

Stainless steels are widely used to manufacture mechanical components because of its outstanding mechanical properties, corrosion resistance and good weldability[1]. It contains chromium which prevents corrosion of the steel. One of the essential characteristics of stainless steels is its ability to be fabricated by standard manufacturing processes. On the other hand, because of higher yield strength and work hardening properties more power and the hence, more heavy machinery is required to manufacture the components [2][3]. The stainless steel is classified into five major groups, namely austenitic stainless steel, ferritic stainless steel, martensitic stainless steel, duplex steel, and precipitation-hardening. The percentage of chromium in Austenitic steels varies from 16% to 26% and percentage of Nickel is up to 35% and possesses very high corrosion resistance. It is not hardenable by any heat treatment process, or thermal cycle caused due to the welding process and is nonmagnetic. Austenitic stainless steel is characterized by its high ductility, low yield stress, and high ultimate tensile strength. Applications of stainless steel include food-processing industries, aircraft, the dairy and chemical industry, ocean technology, etc. [4]. On the cooling of carbon steel, austenite is transformed into a mixture of ferrite and cementite. Presence of chromium in the austenitic stainless steel suppresses this transformation and maintains the austenite phase during cooling. Hardness and yield strength of austenitic stainless steel can be enriched using cold working technique but at the cost of its ductility.[5][6][7] One of the most critical manufacturing processes in mechanical industry to produce desired shapes and accuracy of the components is machining process. The machining process has a substantial effect on the functionability, manufacturing cost, and quality of the components. Researchers carried out investigations in the machining processes by studying the cutting conditions, environment, cutting tool materials and measuring the machining responses such as tool life, the surface quality, and the power consumption, etc. [8]. Tool wear and surface quality (roughness) are significant responses from the economic aspect of a machining process. Achieving the desired surface finish during machining and improving tool life can bring down the machining cost and make it more profitable. cutting tools are at most importance in turning, hence, numerous tool materials and geometry have been selected by the researchers previously. Hoier et al. studied the post machining effect on the microstructure of 316L austenitic stainless steels. The authors concluded that the tool wear by dissolution/diffusion was the key mechanisms for cutting work pieces, which is due to the varying micro-constituents present in the work pieces [9]. Ferreria et al. analyzed effect of tool geometry on surface finish and tool wear during the hard turning of AISI H13 steel using ceramic tools. It was noted that the cutting speed contributes significantly in flank wear while the surface roughness during the machining phase does not have a clear connection [10]. Kamenik et al. investigated tool wear intensity during machining of austenitic stainless steel. The study revealed that during initial phase the toolwear occurs rapidly, increases gradually at the second stage and remarkably increased at the final stage.

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Due to the small contact area between the cutting tool and the workpiece the wear at the initial stage was rapid. It increases the temperature at cutting edge, and hence, the tool material easily comes out from the cutting tool [11]. An overview of the economic machining of hard turning steels and related process parameters described by Anand et al. indicates that heat generation and friction at the work piece tool interface are primarily accountable for the tool life and the surface finish. [12].

Surface finish is another essential output variable of machining process discussed in previous studies.de Oliveira Junior et al. performed tests with input variables such as cutting speed and machining environment with low and high fluid pressure. The study reported that better surface finish can be obtained while turning with PVD-coated inserts under high-pressure cooling [13]. Selvaraj et al. discussed the effect of dry turning process using Taguchi method and optimization of surface roughness, cutting force, and tool wear of nitrogen alloyed duplex stainless steel. The study concluded that t the feed rate is the more critical parameter influencing the surface roughness and cutting force while cutting speed was responsible for more tool wear [14]. A methodology to predict surface roughness in low-speed while turning of AISI316 steel is developed by Acayaba and de Escalona. They used Artificial Neural Network (ANN) model integrated with Simulated Annealing (SA) to predict the surface finish. The model obtained predicted the surface roughness variation of 15% under the same cutting conditions [15]. Coolants play a significant role in achieving lower tool wear rate and better surface finish in a machining process. Sivaiah and Chakradhar compared machining performance during turning of 17-4 PH stainless steel under wet machining and cryogenic conditions. Cutting temperatures, cutting force, chip morphology, tool wear and surface finish under cryogenic machining environment were observed. Cryogenic environment resulted in better values of output compared to wet conditions [16]. Therefore we can conclude that the surface roughness and tool wear depends on cutting speed and feed. As cutting speed increases with low feed rate better surface finish is obtained. Also, to reduce tool wear, cutting speed must be increased. Depth of cut and cutting speed affects material removal rate and cutting force.

Literature reviewed suggests that studies were made on the relative performance of machining environment, parameters, and tools on tool wear and surface roughness. However, in the machining of austenitic stainless steel AI 316 studies found to be rarely given attention. Tool wear that adversely impacts the quality of the product and in general machining performance has been overlooked. A number of studies are presented by researchers where cutting parameters were optimized for surface roughness or cutting force(s) or both. However, tool life, which is an essential factor for the economic viability of the machining process, was not considered in most of the studies. Thus, there is a need for the development of a robust model which can predict the machining performance during turning of austenitic stainless steel.

In this study, Taguchi' technique is used to optimize machining parameters. Analysis of variance (ANOVA) is performed to optimize results and to reduce the effect of the parameter. This study deals with a comparison of the wet and dry environment on the machining of AISI 316 austenitic steel using a Taguchi design of the experiment. The objective of the study is to compare the effect of wet and dry machining environment on tool wear and surface roughness. Taguchi analysis is applied to optimize settings for machining environment and response variable.

II. MATERIAL AND METHODS

This study deals with the optimization of process parameter for machining of AISI 316 austenite steel. The process parameters selected through detailed literature survey and industry professionals. The Taguchi method is implemented to design of experiment and performance parameters like surface finish, and tool wear are measured to analyze the effect of the process parameter. Moreover, this article presents the comparison of machining of AISI 316 austenitic steel in the wet and dry cutting environment.

A. *Material Selection*

The AISI 316 austenitic stainless steel is used for analysis due to its wide industrial applications as chemical, cellulose, and medical are few among them. It has good corrosion resistant and heat resistant property. The chemical composition of AISI 316 austenitic steel is shown in Table 1. Also, the physical properties of the material is shown in Table 2.

Table 1: Chemical Composition of AISI 316 Austenitic Stainless Steel.

C	Mn	P	S	Si	Cr	Ni	Mo	N
0.08 max	2.00 max	0.045 max	0.030 max	0.75 max	16.00 -18.0	10.0 - 14	2.00- 3.00	0.1 max

B. *Work piece Specifications:*

Round rolled bars of 35 mm diameter and 130 mm length were used for machining according to ASTM standards. Figure No.2 shows the work piece material used for the experimentation.

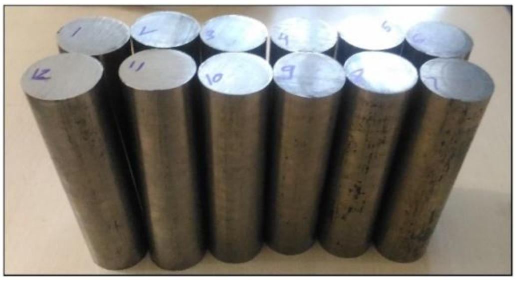

Figure No. 2 - Work piece Material AISI 316

C. *Machine Specification*

Machining experiments were carried out using a CNC lathe machine in dry and wet machining conditions. Figure No. 3 shows the actual machine used for experimentation.

D. *Machine Specification*

The Process parameter is selected based on the literature survey. Performance of machining operation can be affected by several parameters. Some of the critical parameter studied by researchers is cutting speed, feed rate, and depth of cut is selected for this study. The range of each parameter is varied according to the working environment, machine capability, literature, and past experiences of the industry professionals. The process parameters with the range of each are shown in table 3. The range is converted into 3 levels to check the effect on the response variable.

Figure No. 3 – CNC Machine used for experimentation

E. Taguchi Design of Experiment

The Taguchi method has been widely used in engineering analysis by various researchers. It is a powerful tool to design a high-quality system of experimentation. Taguchi method uses an orthogonal array to design the experiments and measure the effects on the response variable using a small number of experiments [17]. In this study, the design of the experiment is done based on Taguchi's Design technique. As there are 3 processing parameters and 3 levels each, the 3-Level design is selected. The L9 array is selected, and optimal combinations are obtained. Table-4 shows orthogonal design.

F. Machining Environment

As mentioned earlier dry and wet environment during machining on a CNC Lathe was used during the experimentation. The turning operation performed on the random order of process parameter settings selected from table 4. The turning was carried out for 300 mm length.

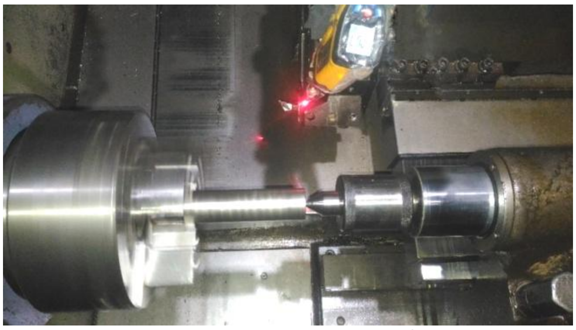

Figure No. 4 –Experimental Setup used for machining

The experiments were performed on the CNC machine, and the program was generated according to the requirement. For dry machining, the machine was run without coolant. For wet machining, the eco-friendly coolant was used. During experimentation, the cutting condition was set as per the table 4, and machining was carried out. After completion of the machining for the desired length, the insert was changed and examined for the wear, and the chips sample was collated for examination. The machine was then cleaned, and the machine was set for the next experiment.

Similarly, all experiments were carried out in the dry and wet cutting environment, respectively. Each experiment was repeated thrice to capture uncertainty that could arise during measurements due to manual intervention. For analysis purpose, the average values were considered.

G. Machining Environment

All the measurements were carried out using standard and calibrated instruments in a controlled environment. The surface roughness was measured using the Mitutoyo SJ 210 Surface roughness measuring tester. The readings were taken at three positions on them, and the average value is taken for further analysis. The tool wear was measured using toolmakers microscope of Mitutoyo make, shown in Figure 5.

Figure 5 – Toolmaker's Microscope

III. RESULTS AND DISCUSSION

The measurements are tabulated in table 3 for wet and dry conditions. The surface roughness (Ra) and tool wear should be lower to improve the productivity of machining process. Therefore, Taguchi analysis is carried using lower the better criteria for signal noise (SN) ratio. The SN ratio (Smaller is Better criteria) is calculated using equation 1.

$$\frac{S}{N} Ratio = 10 * log10 \left(\frac{\sum Y^2}{n}\right) \dots \dots \quad (1)$$

A. Taguchi analysis

Taguchi analysis performed on the results obtained using the SN ratio of the dry and wet environment is as follows

1. Surface roughness values in the dry environment give optimum settings as - cutting velocity 180mm/sec, feed 0.3 mm/min and depth of cut 1.5 mm. The SN Ratio variation with respective parameters is shown in figure7 (a)
2. Figure 7(b) represents SN ratio variation of tool wear in a dry environment. It is observed that cutting velocity 160 mm/sec, feed 0.2 mm/min and depth of cut 1.5 mm gives optimum settings.
3. Surface roughness values of the wet environment are optimum with cutting velocity 200 mm/sec, feed 0.3 mm/min and depth of cut 0.5 mm. The SN Ratio variation with respective parameters is shown in figure 7 (c)
4. Wear of wet environment gives optimum settings as cutting velocity 160 mm/sec, feed 0.2 mm/min and depth of cut 1 mm. The SN Ratio variation with several parameters is shown in figure7 (d).

Variation of process parameters concerning performance parameters can be calculated with the help of regression analysis of the dry and wet condition and is shown in figure 8 and figure 9, respectively.

The behavior of the process parameters with performance parameters is discussed below.

i. Increase in the cutting speed increases surface roughness obtained in machining. However, the tool wear is reduced as cutting speed increases for both wet and dry environment for machining operation.
ii. The feed rate is affecting the surface roughness and tool wear in a different manner, with an increase in feed rate the surface roughness increases at the beginning, hit peak value and then reaches to the lowest point. However, the wear rate initially found to be decreased, reached to lowest point then increased. The behavior is similar for dry and wet environments.
iii. The depth of cut behavior is precisely opposite to that of the behavior of feed rate for surface roughness and wear rate, respectively.
iv. The machining operations are optimized to reduce surface roughness and tool wear. The composite regression graph shows the optimization of both parameters.
v. For the dry environment, optimized settings found to be - cutting speed 173 rpm, feed 0.25 mm/rev, and 0.87 mm of the depth of cut.
vi. For wet environment, optimized settings found to be - cutting speed 173 rpm, feed 0.3 mm/rev, and 0.57 mm of the depth of cut.

Figure 10 shows the surface roughness with respect to feed rate at depth of cut 0.5 mm , the surface roughness for the dry and wet environment can be clearly distinguished. The surface roughness for wet environment is lower than in case of dry environment.

The figure 11 shows the tool wear with respect to feed rate at the depth of cut of 1 mm. The tool wear for dry environment observed to be higher compared to wet environment.

Moreover, as the cutting speed increases the wear rate is also increasing.

IV. CONCLUSION

In this study Taguchi' technique is used to optimize cutting parameters. Analysis of variance (ANOVA) is performed to obtain optimized results. The study shows comparison of wet and dry environment in machining of AISI 316 austenitic steel using Taguchi design of experiment. The Taguchi analysis gives the optimized setting for machining environment and response variable. From the above experimentation and results following points can be concluded.

i. Surface roughness and tool wear depends on the machining parameter discussed in the study. With increase in the cutting speed Surface roughness is increased but tool wear is reduced. Reduction in tool wear is due to reduced friction between workpiece and the tool.
ii. Machining environment plays important role on the performance parameters . Wet machining gives better performance when compared with dry machining.
iii. Feed rate also has a effect on surface roughness and tool wear. Increase in feed rate increases surface roughness. The behavior is found to be similar in dry and wet environment.
iv. The depth of cut behavior is exactly opposite to that of the behavior of feed rate for surface roughness and wear rate respectively in both machining environment.
v. Taguchi method can be used effectively to obtain optimized parameters in dry and wet machining.

Future study can be based on effect of cryogenic machining on the response variables. The coolants used in the wet machining can be reduced using minimum quantity lubrication method. The coolants used have effect on environment and hence future work can be performed on environmental sustainability of machining process.

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APPENDIX

Table 2: Physical Properties of AISI 316 Austenitic Stainless Steel.

Size mm	Tensile Strength Mpa Min		Yield Stress Mpa Min		Elongation in 50mm % Min.		Impact Charpy V J		Hardness HB	
	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold
3.18 to 325	515	620	205	310	40%	30%	180	190	15	195

Table No. 3: Variation of process parameters and levels

Levels	Cutting Speed (m/min) (A)	Feed Rate (mm/rev) (B)	Depth of Cut (mm) (C)
1	160	0.1	0.5
2	180	0.2	1
3	200	0.3	1.5

Table No. 4: L9 Orthogonal Design Matrix

Sr. No.	A	B	C
1	160	0.2	1.5
2	160	0.1	1
3	160	0.3	0.5
4	180	0.3	1.5
5	180	0.2	1
6	180	0.1	0.5
7	200	0.1	1.5
8	200	0.3	1
9	200	0.2	0.5

Table No 5 Summary of cutting conditions used for machining AISI 316.

Sr. No.	Cutting Condition	Description
1	Work piece	AISI 316
2	Cutting Insert	PVD (coated carbide)
3	Diameter of Work piece	36mm
4	Length of Work piece	130mm
5	Cutting Speed (Vc)	160 – 180 – 200 (m/min)
6	Feed rate (fd)	0.1 - 0.2 - 0.3 (mm/rev)
7	Depth of Cut (d.o.c)	0.5 - 1 - 1.5 (mm)
8	Cutting Environment	Dry – Wet

Table No. 6 Results obtained for dry and wet machining.

A	B	C	Wet		Dry	
			Ra(Dry) µm	Wear(Dry) Mm	Ra(Wet) µm	Wear(Wet) Mm
160	0.2	1.5	3.0510	0.010	1.6525	0.005
160	0.1	1.0	1.5785	0.030	3.4105	0.005
160	0.3	0.5	1.1810	0.025	1.2565	0.045
180	0.3	1.5	1.5175	0.020	1.6345	0.015
180	0.2	1.0	1.3895	0.015	3.2200	0.005
180	0.1	0.5	2.0510	0.035	1.1515	0.035
200	0.1	1.5	1.6365	0.085	3.0640	0.025
200	0.3	1.0	0.9515	0.045	1.6805	0.010
200	0.2	0.5	3.3090	0.025	0.9685	0.02

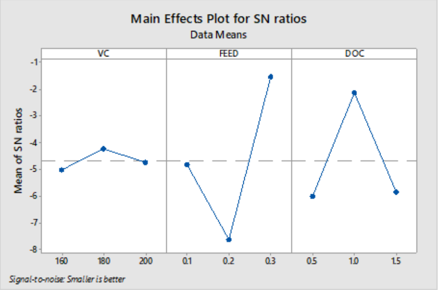

Figure 7 (a) Variation of SN ratio of surface roughness (Dry)

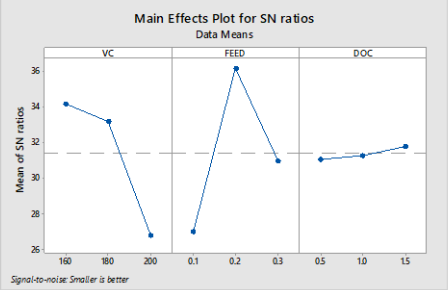

Figure 7 (b) Variation of SN ratio of tool wear (Dry)

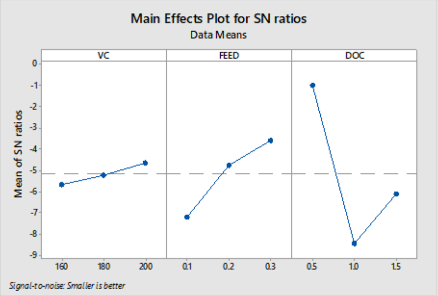

Figure 7 (c) Variation of SN ratio of surface roughness (Wet)

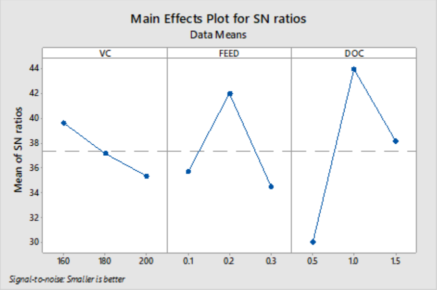

Figure 7 (d) Variation of SN ratio of tool wear (Wet)

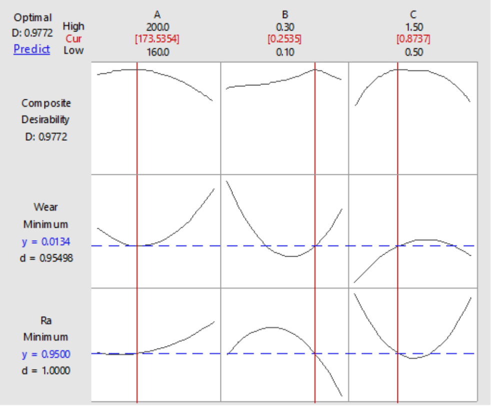

Figure 8 Variation of process parameter with performance parameter of dry condition machining

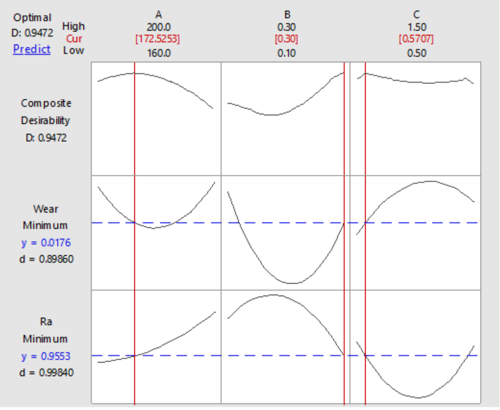

Figure 9 Variation of process parameter with performance parameter of Wet condition machining

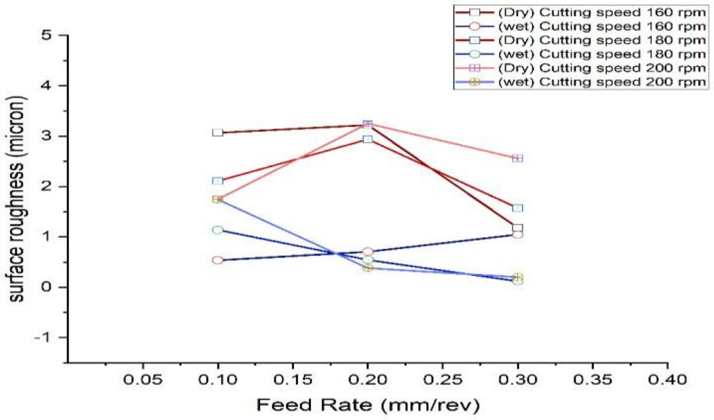

Figure 10 Variation of surface roughness with respect to feed rate at depth of cut at 0.5 mm

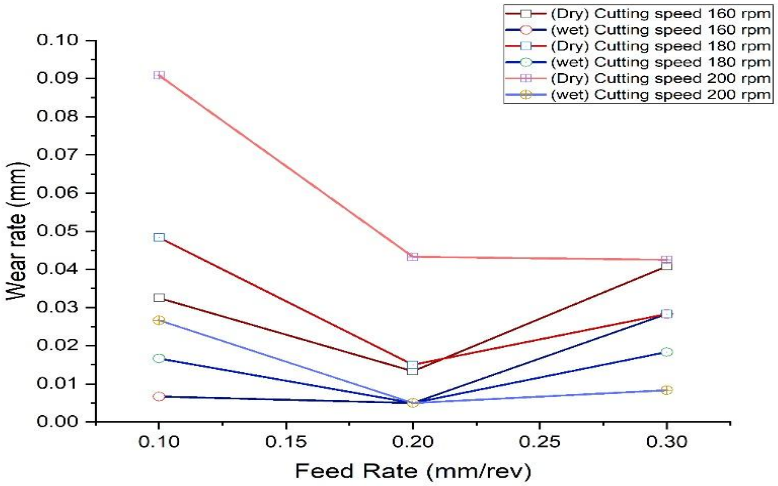

Figure 11 Variation of tool wear with respect to feed rate at depth of cut at 1 mm