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EFFECT OF CUTTING SPEED AND FEED RATE ON SURFACE ROUGHNESS OF AISI 316L SS USING END-MILLING

Muhammmad Yasir[1], Turnad Lenggo Ginta[2], Bambang Ariwahjoedi[3], Adam Umar Alkali[1], and Mohd Danish[1]
[1]Mechanical Engineering Department, Universiti Teknologi Petronas, Perak Malaysia
[2]The Rehabilitation and Bio-Medical-Mechanic Research, Bio-Medical Technology MOR Universiti Teknologi Petronas, Perak Malaysia
[3]Fundamental & Applied Science Department Universiti Teknologi Petronas, Bandar Seri Iskandar Tronoh, Perak Malaysia
E-Mail: unique470.utp@gmail.com

ABSTRACT

This paper investigates the effect of cutting parameters on the surface topography of AISI 316L stainless steel with tungsten carbide tool by using response surface methodology (RSM). Feed rates ranges from 0.10 mm/rev to 0.14 mm/rev while the cutting speeds ranges from 80 m/min to 120 m/min were used. Scanning electron microscope (SEM) and Mitutoyo surface tester were used to study in detail the surface topography of AISI 316L stainless steel. A mathematical relationship was built between cutting parameters and surface roughness. From the results it was found that feed rate was the main factor affecting the surface roughness while cutting speed have negligible effect on the surface roughness of the end-milled AISI 316L stainless steel samples. From analysis of variance it was found that the percentage contribution of feed rate was 10.38 % and cutting speed as 2.1 %.

Keywords: End-milling, surface roughness, RSM, ANOVA, 316L stainless steel.

INTRODUCTION

Austenitic stainless steels are well-known in various fields of aeronautical, biomedical and marine technology due to their high mechanical strength and corrosion resistance [1]. Among various types of austenitic stainless steels like 304, 304L, 308L and 316L stainless steel which has low carbon content finds its application in the fabrication of implants. This selection is based on the excellent mechanical properties, corrosion resistance, ease of availability and low cost [2]. But in some cases where AISI 316L stainless steel is used as an implant causes failure of the implants before completion of medication which results in the re-surgery, long healing time and high remedy cost [3, 4]. There are many reasons which lead to the catastrophic failure. Surface roughness is one of the major issue and has a serious concern in the fabrication of the AISI 316L stainless steel implant [5-7]. Researchers have used many surface modification techniques for minimizing the surface roughness and made a better quality of the implants. Ti/TiN multilayer coating was used on AISI 316L stainless steel in order to improve its surface finish and make it corrosion resistant in vivo. Their results showed that Ti/TiN multilayer coated samples had lower trend towards the susceptibility of corrosion in simulated body fluid as compared to the bared samples [8]. Ranganath *et al*. [9] used Response Surface Methodology (RSM) was used to study the turning parameters on the surface roughness and finding an optimal design which can give a good surface finish. They found that increase in cutting speed and decrease in feed rate minimizes surface roughness. Different machining techniques have great effect on the surface roughness and surface integrity improvement of AISI stainless steel. Amin *et al*. [10] used permanent magnet in end milling in order to optimize the surface roughness of AISI 304L stainless steel. The results showed that the roughness was decreased by 67% in the presence of magnetic field. As machining parameters such cutting speed, feed rate has effect on the surface roughness and surface integrity of the sample [11]. But Computerized Numeric Control (CNC) end-milling which is a high speed machining technique has a great importance in the field of biomedical devices manufacturing. As high speed machining is a good way to produce prototype as well as mass production of the biomedical devices, which is need in the field of orthopedic surgery. In high speed end-milling, cutting speed and feed rate which are the input variables have an effect on the surface topography and surface integrity of workpiece material. The versatility of the automation in the CNC end-milling is the not the final achievement in the field of manufacturing. There is a need of improvement in the end-milling process by optimizing the machining parameters such as cutting speed (V_c) and feed rate (f), which influence the output parameters namely surface topography and surface integrity.

Surface roughness is an important indicator for the evaluation of manufactured biomedical device. Yang *et al*. [12] used Taguchi system design for controlling the milling machines. They also used the control design in order to produce optimum surface roughness by using some specific combination of cutting parameters in end-milling process. Ghani *et al*. [13] adopted the Taguchi approach of process optimization to cut hardened steel by using TiN coated carbide tool. They used two finishing conditions for the process parameters: cutting speed, feed rate and depth of cut. They found optimized cutting parameters for the surface roughness.

The literature available about the improvement of surface roughness of AISI 316L stainless steel by end-milling operations is still incomplete as for biomedical devices are concerned [3, 8]. The aim of this paper is to develop a relationship between surface roughness in terms of varying machining parameters by using response surface methodology (RSM).

MATERIALS & METHODS

The milling procedure was carried out on MAZAK Variaxis 630-5x whose maximum spindle speed ranges between 20-12000 r/min and power of 3.7 kW made by MAC Co Ltd JAPAN. Tungsten carbide (WC) end-mill having 5 mm of dia having four flutes was used in investigation. Rectangular plate of AISI 316L stainless steel was used as workpiece. The chemical composition of 316L SS was: 0.03C, 1.1Mn, 0.5Si, 16.5Cr, 10.02Ni, 2.01Mo, 0.02P, 0.013S and balance Fe (all in wt %).

Optical microscopic test were under taken for the surface analysis after milling has been done in order to analyze the surfaces. The surface profilometer which was used for the surface roughness measurement after the milling process was Mitutoyo Model SV-3000. For each sample the cut off length was kept as 3 mm and sampling length as 10 mm, to find the accurate surface roughness of the specimen.The samples after measuring their surface roughness (R_a) were proceeded to the scanning electron microscopy (SEM) for studying the surface morphologies of the milled surfaces and also for the chips dimensions. As end milling is a 3D cutting process.

Experimental Design

In the present study the main focus was cutting speed (V_c) and feed rate (f) whose effects were investigated in terms of surface roughness. In design of experiments (DOE) response surface methodology (RSM) was selected in order to perform the experiments and validate the experimental results with the design model [14].

In the present study, RSM technique is used for defining the effects of the input cutting parameters of milling process on the surface roughness. A second order polynomial mathematical model has been developed in order to understand in detail the influence of cutting parameters; cutting speed (V_c) and feed rate (f) on the surface roughness. The second order model is generally of the following type as given below in equation 1.

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i=1}^{k} \sum_{j=2}^{k} \beta_{ij} x_i x_j + \varepsilon \quad (1)$$

Where y is the dependent variable which depends on the input parameters of milling process and x_i (1,2,…..) are the levels of the process input variables. Whereas $\beta_0, \beta_i, \beta_{ij}$ are the coefficients of second order regression model. In order to study the effect of cutting parameters on the surfaces roughness in case of milling technique the second order polynomial can be written as:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_1 x_1^2 + \beta_2 x_2^2 + \beta_{12} x_1 x_2 \quad (2)$$

where β_0, β_1 and β_2 are the regression coefficients of the model, whereas x_1 and x_2 are cutting speed (V_c) and feed rate (f) respectively.

RESULTS AND DISCUSSION

The milling process was studied using central composite design (CCD) approach with the values of the three levels and two input parameters respectively as shown in the Table-1.

Table-1. Paramters and levels selected for miling.

	Parameter	
Level	V_c(m/min)	f (mm/rev)
1	80	0.10
2	100	0.12
3	120	0.14

Using the combination of the above input parameters in design expert 9.0 a total of 13 experiments were conducted in this study as shown in Table-2. By establishing the mathematical process model using 'Design Expert 9.0' software with input process parameters to achieve the desired response i-e. surface roughness during milling process.

Table-2. Experimental results for surface roughness.

Test no.	V_c	f	R_a
1	100	0.12	0.293
2	80	0.1	0.701
3	120	0.12	0.56
4	80	0.12	0.64
5	100	0.12	0.348
6	100	0.1	0.609
7	100	0.12	0.263
8	120	0.14	0.725
9	100	0.14	0.879
10	100	0.12	0.28
11	100	0.12	0.33
12	120	0.1	0.609
13	80	0.14	0.78

The value of P for the model is lower than 0.05 (i.e. α = 0.05 or 95% confidence which means that the model is statistically significant. In our model the value of R-square is 0.827. It is a measure of the amount of reduction in the variability of y obtained by using the regression variables x_1, x_2,… x_k in the model. The value of R^2 is between 0 and 1. If the value of R^2 approaches to 1 it means that the model values fit the experimental data. As mentioned above the value of R^2 is 88.4% of the variability in surface roughness.

There are some values of F and p which represents the interactions of parameters with the surface roughness (R_a). If the value of p is less than 0.05 then that model term is significant and vice versa. According to the table cutting speed (V^2_c) and feed rate (f^2) have significant effects on R_a. The last column represents the percentage of contribution of each parameter on the R_a. The regression equation which shows the effect of the input parameters on the surface roughness is in the following form:

$$R_a = 0.349345 - 0.37833 V_c + 0.07755 f + 0.134293 V_c^2 + 0.278293 f^2 + 0.009250 V_c \cdot f \quad (3)$$

From the Table-3 it is clear that feed rate (f) effect the surface roughness (R_a) as their percentage of contribution is 10.38%. The percentage of error is 1.4 % it means that all the parameters in the design and experimentation are considered.

Table-3. Analysis of variance (ANOVA) for surface roughness (R_a)

Source	DF	Sum of Squares	Mean Square	F Value	p-value Prob > F	Contr. (%)
V_c- Cutting Speed	1	0.0073	0.0073	0.43	0.5394	2.1104
f-feed rate	1	0.036	0.036	2.16	0.2018	10.378
$V_c f$	1	0.0007	0.0007	0.04	0.8465	0.2025
V^2_c	1	0.069	0.069	4.07	0.0996	19.89
f^2	1	0.21	0.21	12.6	0.0165	60.536
$V^2_c f$	1	0.016	0.016	0.93	0.3783	4.6123
$V_c f^2$	1	0.0029	0.0029	0.17	0.6981	0.8221
Pure Error	4	0.005	0.0012			1.4365
Cor Total	12	0.57				

Figure-1 shows the main effect plots and interaction effect plots for the surface roughness R_a. It is clear from the graph in Figure-1 that increase in cutting speed (V_c), the surface roughness (R_a) value first decreases to a considerable amount and then increases. As cutting speed increases it minimizes the built-up-edge (BUE) formation. Moreover in this high speed machining more heat is produced which raises the temperature in the shear zone and makes the material removal easier for the cutting tool and ultimately decreases surface roughness. From 100 m/min of cutting speed the surface roughness start increasing up to 120 m/min, it might be due to some chatters or material flow on side of 316L stainless steel sample [15]. Huang *et al*. [16] and Sudhansu Ranjan Das *et al*. [17] found that the surface roughness increases as the feed rate increases it produces the thrust forces which act on the surface and also produces vibrations which ultimately increase surface roughness.

Figure-2 shows the scanning electron microscope (SEM) micrographs of end-milled AISI 316L stainless steel using tungsten carbide end mills (WC). Micrographs consist of smooth surface and rough surface which were obtained at different cutting parameters. As shown in test number 7 (V_c = 100 m/min, f = 0.12) and test number 9 (V_c = 100 m/min, f = 0.14) which were selected as best and worst conditions for observations. It shows the surface topography of the machined AISI 316L stainless steel for both test numbers which includes feed marks, chip particles, voids and material flow rough surface and smooth surface. Figure-2a) shows the finished surface in which the feed marks are not noticeable, uninterrupted and smooth at low feed rate (f = 0.12 mm/rev). Secondly there is no such waviness and ridges on the surface. This is because of the less cutting force which produces low plastic deformation and consequently a smooth surface [17, 18]. On the other hand in Figure-2 b) at high feed rate (f = 0.14 mm/rev) interrupted feed marks which were clearly seen on the surface and some crests and troughs which were produced due to high temperature which was produced in the shear zone and high plastic deformation of the surface which led to the formation of rough surface. The formation of the waves on the surface is might be due to the vibrations produced and also due to the tool wear which made the material to move from one surface machined by one flute of the tool and the second flute respectively. Similarly some micro-cracks were observed on the surface. The micro-cracks were due to the incomplete material removal from the surface [18, 19].

CONCLUSIONS

End-milling process was used on AISI 316L stainless steel in order to achieve maximum surface finish in dry conditions. According to the results of analysis of variance (ANOVA), feed rate (f) is the most significant parameter on the surface roughness while cutting speed (V_c) is less significant. The main effect plot shows that the surface roughness increases at the feed rate increases. Cutting speed as per main plot shows that constant cutting speed have no effect on the surface roughness but when feed rate was varied the roughness get altered.

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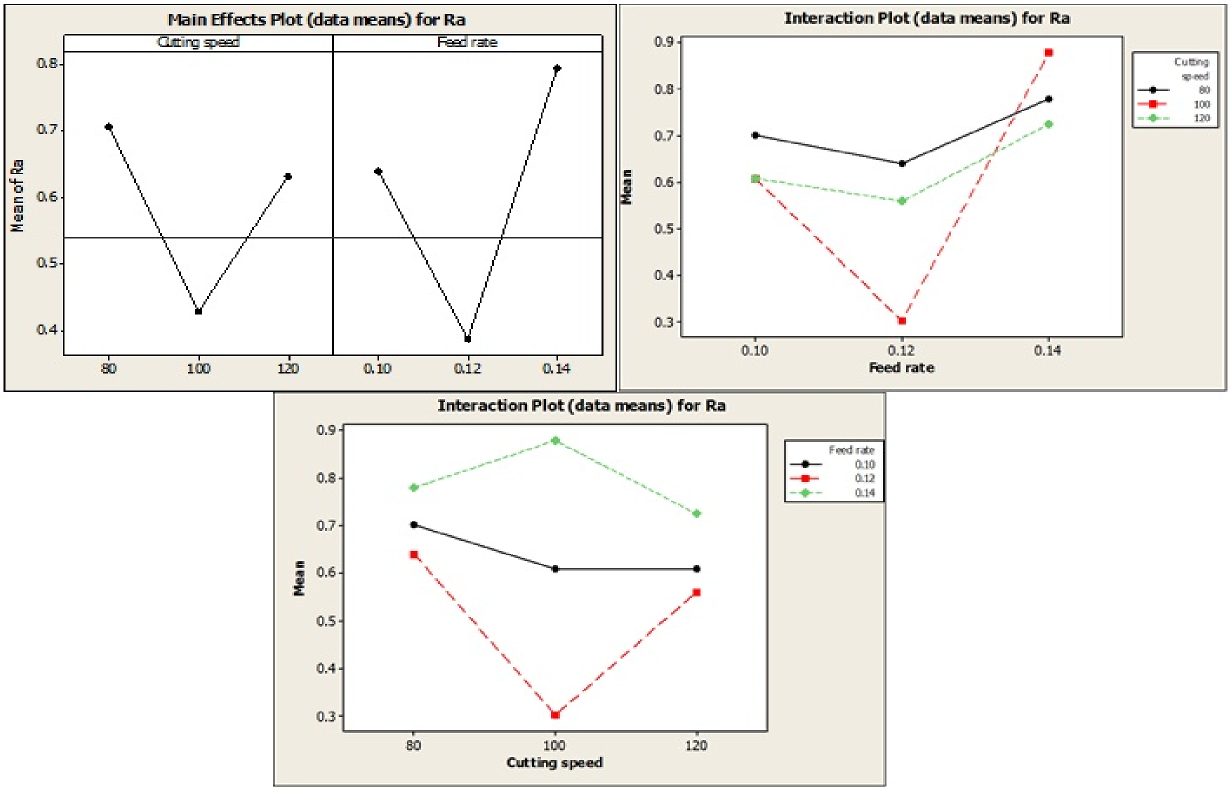

Figure-1. Main effects and interaction effects graphs for surface roughness parameters.

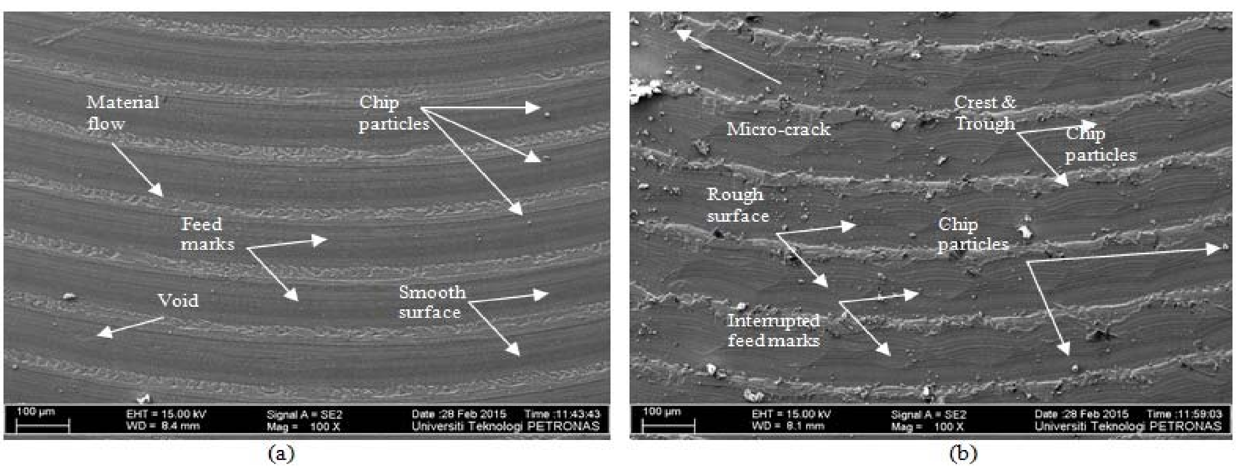

Figure-2. SEM micrographs of end-milled surface of AISI 316L stainless steel a) Vc = 100 m/min, f = 0.12mm/rev and b) Vc = 100 m/min, f = 0.14 mm/rev.

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