

Effects on Vibration and Surface Roughness in High Speed Micro End-Milling of Inconel 718 with Minimum Quantity Lubrication

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Abstract. This paper presents the study on vibration and surface roughness of Inconel 718 workpiece produced by micro end-milling using Mikrottools Integrated Multi-Process machine tool DT-110 with control parameters; spindle speed (15000 rpm and 30000 rpm), feed rate (2 mm/min and 4 mm/min) and depth of cut (0.10 mm and 0.15mm). The vibration was measured using DYTRAN accelerometer instrument and the average surface roughness Ra was measured using Wyko NT1100. The analysis of variance (ANOVA) by using Design Expert software revealed that feed rate and depth of cut are the most significant factors on vibration meanwhile for average surface roughness, Ra, spindle speed is the most significant factor.

1. Introduction

Recently, micro-milling process offers many benefits to manufacturing industries through numerous products which can be produced using this method. In order to meet the demand of miniature parts and components with increasing number of functions, micro-machining has an important role in today's manufacturing technology especially in Micro Electro-Mechanical systems (MEMS) [1]. In machining operation, the aim is to have a good surface finish. Most machining processes do not produce good surface finish due to vibration that occurs during these processes resulting in low dimensional accuracy, poor surface finish and bad stability to the system as well as tool damage and machine tool damage [2].

Machining parameters especially feed rate, depth of cut and spindle speed if not properly controlled can increase the vibration in the machining process. Too high vibration is very dangerous and may lead to serious injury. Therefore, vibration must be minimized to stabilize the cutting process, improve surface roughness and prevent tool from breaking. Machining parameters and properties of the workpiece need to be fully considered before machining process [3]. Forced and self-excited vibration limits the stability of cutting and lead to tool and machine damage. It also limits the productivity of machining operation.

Cutting fluids are used in machining process to reduce temperature and contact between tool-work piece, to reduce thermal deformation of work piece and to wash away chips formation between tool and work piece zone. As a result, dimensional accuracy is achieved and surface finish and tool life are improved [4]. However there are many bad effects of using cutting fluids which include danger to health of user and environment due to the airborne mist [5]. Not only that, it contributed to major expenses in machining operation [6].



Dry cutting is very useful to minimize costs of using cutting fluids in addition to being safer and eco-friendly. However, dry cutting causes faster tool wear because of higher temperature due to greater friction and adhesion between chip and tool [7]. Therefore, minimum quantity lubrication (MQL) was introduced. Instead of using large amount of cutting fluids in flood cooling, only small amount of cutting fluids is used in MQL system at the cutting zone. By minimizing the use of cutting fluids in MQL, costs related to cutting fluids in machining process can be reduced [8].

Since less amount of fluids is used in MQL, some economical advantage results. MQL is also efficient in improving surface roughness of machined part. However, due to vibration, most of machining operations do not often produce good surface finish. Many studies on surface finish for micro-milling with dry cutting and flood cooling have been done. There are however few studies done on the impact of MQL in alleviating the effects of vibration and improving surface roughness of machined surface in high speed micro-milling. Therefore, in this study the effects of cutting tool vibration as well as the surface roughness in micro end-milling of Inconel 718 with MQL were investigated.

2. Experiment

The experiments were conducted using Mikrottools Integrated Multi-Purpose Machine Tool DT 110 suitable for high, middle and low spindle speeds for various processes such as micro-milling. MQL Bluebe FK type with Accu-Lube LB-200 (LB-1) was used for lubrication and cooling. DYTRAN Instrument accelerometer was used to detect the vibration on the machine. Figure 1a shows the accelerometer attached to the outer spindle during the machining process. The Multi-Channel Orchestra System was used to analyze the vibration detected by the accelerometer. For a good operating of the Orchestra system, the 01dB-Metravib software displayed the result of vibration data (see Figure 1b). Wyko NT1100 was used to measure the surface roughness of the micro-channels machined.

The workpiece used was Inconel 718 with dimensions of 50 mm x 40 mm x 7 mm. For cutting tool, tungsten carbide end mill with two flutes with \varnothing 0.5 mm diameter was used. Two-level factorial design was used as the experimental design to conduct 8 experiments. The experimental parameters and the results are shown in Table 1 and Table 2 respectively.

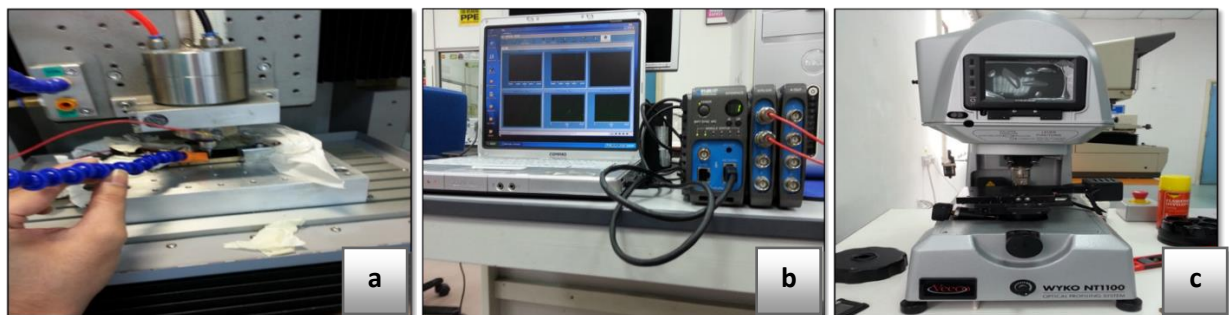


Figure 1. (a) position of accelerometer, (b) vibration monitor using Metravib software, and (c) Wyko NT1100 Optical Profiler

Table 1. Experimental Parameters

Control Parameters	Factor	Level	
		I	II
Depth of Cut, DOC (mm)	A	0.10	0.15
Feed Rate, v (mm/min)	B	2	4
Spindle Speed, N (rpm)	C	15000	30000

Table 2. Experimental results

No	DOC (mm)	v (mm/min)	N (rpm)	Avg. Tool Vibration (Hz)	Ra (μm)
1	0.10	2	15000	98.3	0.12
2	0.15	2	15000	98.5	0.17
3	0.10	4	15000	98.7	0.15
4	0.15	4	15000	99.7	0.18
5	0.10	2	30000	98.1	0.22
6	0.15	2	30000	99.6	0.20
7	0.10	4	30000	99.3	0.21
8	0.15	4	30000	99.8	0.24

3. Results and Discussion

The results of vibration generated during micro end-milling with different spindle speed, feed rate and depth of cut were analyzed. Analysis of variance results showed the main and interaction effects of the process variables on the responses (see Table 3). The model was developed with 95% confidence interval. The Model F-value of 7.34 implies the model is significant. There is only a 4.20% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A and B are significant model terms.

Table 3. ANOVA for response surface 2FI Model of average vibration

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F
Model	2.72	3	0.91	7.34	0.0420 (significant)
A	1.28	1	1.28	10.34	0.0324
B	1.12	1	1.12	9.09	0.0394
C	0.32	1	0.32	2.59	0.1831
Residual	0.50	4	0.12		
Corr. Total	3.22	7			

Figure 2a shows the model graph of contour for spindle speed versus feed rate with constant depth of cut of 0.13 mm. From the graph, the average vibration is at maximum when it is at highest spindle speed and at highest feed rate. The average vibration starts decreasing slowly for further decrease in spindle speed and feed rate. However, Figure 2b shows the model graph of contour for spindle speed versus depth of cut with constant feed rate 3 mm/min. From the graph, average vibration gradually increases when the spindle speed and depth of cut increases. The tool vibration starts decreasing for further decrease in depth of cut and spindle speed. Meanwhile, Figure 2c shows the model graph of contour for feed rate versus depth of cut with constant spindle speed of 22500 rpm. From the graph, average vibration is at maximum value when the depth of cut increases with highest feed rate. The average vibration decreases when both feed rate and depth of cut decreases.

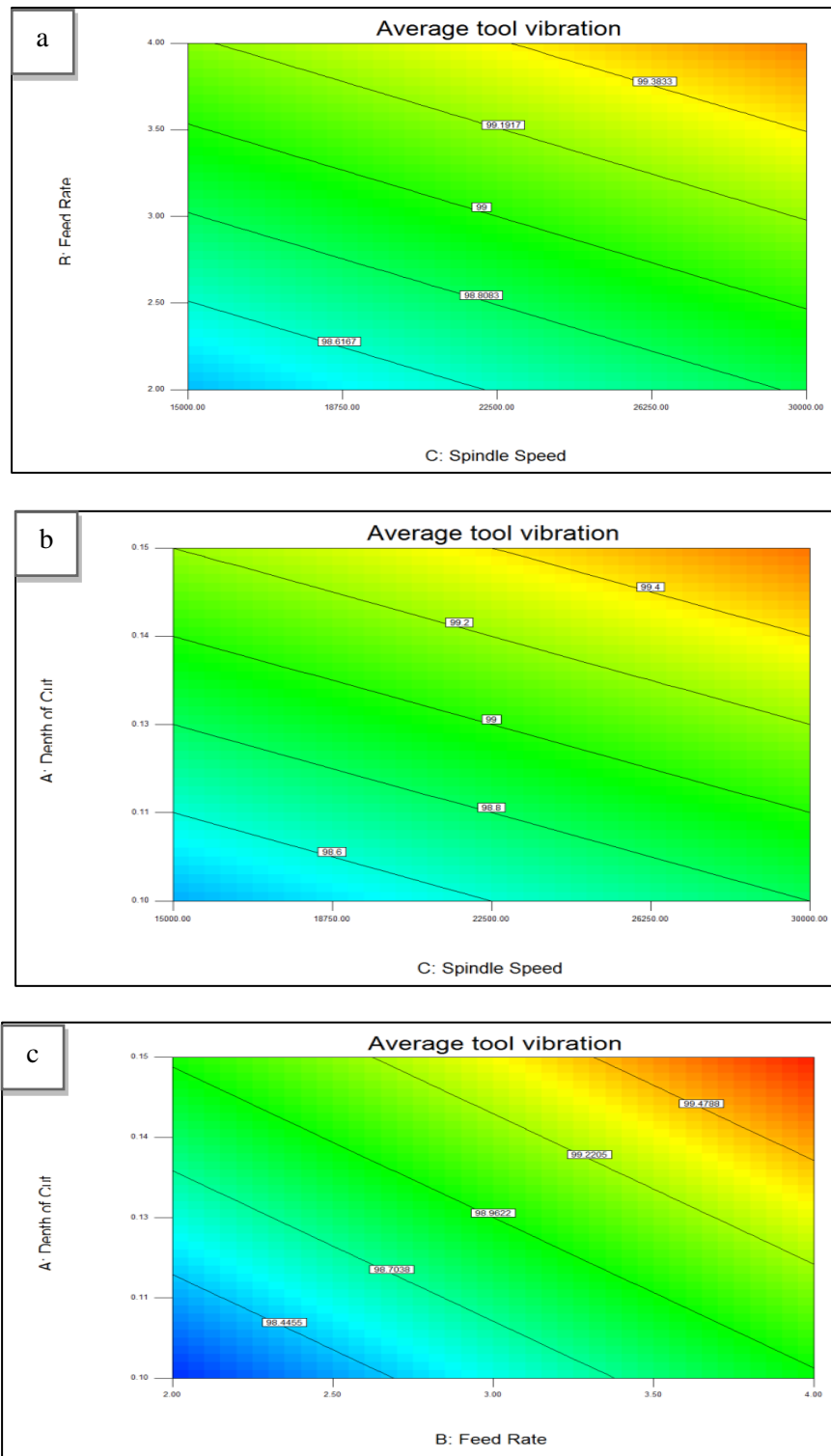


Figure 2. Contour plot for average vibration (a) spindle speed vs. feed rate with depth of cut 0.13 μm , (b) spindle speed vs. depth of cut with feed rate 3 mm/min, and (c) feed rate vs. depth of cut with spindle speed 22500rpm

Analysis of variance (ANOVA) approach was used to check the adequacy of the model for average surface roughness Ra. ANOVA results for response surface 2FI Model is shown in Table 4. The model was developed with 95% confidence interval. The Model F-value of 9.32 implies the model is significant. There is only a 2.81% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case C are significant model term.

Table 4. ANOVA for response surface 2FI Model of average surface roughness

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F
Model	9.437E-003	3	3.146E-003	9.32	0.0281(significant)
A	1.013E-003	1	1.013E-003	3.00	0.1583
B	6.125E-004	1	6.125E-004	1.81	0.2492
C	7.813E-003	1	7.813E-003	23.15	0.0086
Residual	1.350E-003	4	3.375E-004		
Corr. Total	0.011	7			

Figure 3a shows the model graph of contour for spindle speed versus feed rate with constant depth of cut of 0.15 mm. From the graph, average surface roughness is at maximum when feed rate and spindle speed are at highest value. The average surface roughness starts decreasing for further decrease in feed rate and spindle speed. However, Figure 3b shows the model graph of contour for spindle speed vs. depth of cut with constant feed rate of 3 mm/min. The graph indicates that average surface roughness decreases when the spindle speed and depth of cut decrease. Meanwhile, Figure 3c shows the model graph of contour for feed rate vs. depth of cut with constant spindle speed of 22500 rpm. From the graph, average surface roughness is at maximum value when the depth of cut increases with highest feed rate. The average surface roughness decreases when both feed rate and depth of cut decrease.

4. Conclusions

The purpose of this paper is to investigate vibration and average surface roughness, Ra of Inconel 718 in micro end-milling and the results were analyzed using ANOVA. So, from this investigation, it can be concluded that:

1. The highest value for average tool vibration is 99.8 Hz and the lowest value for average tool vibration is 98.1 Hz.
2. The highest value for average surface roughness is 0.24 μm and the lowest value for average surface roughness is 0.12 μm .
3. For average tool vibration, depth of cut and feed rate are significant factors while for average surface roughness, spindle speed is the significant factor in this experiment.

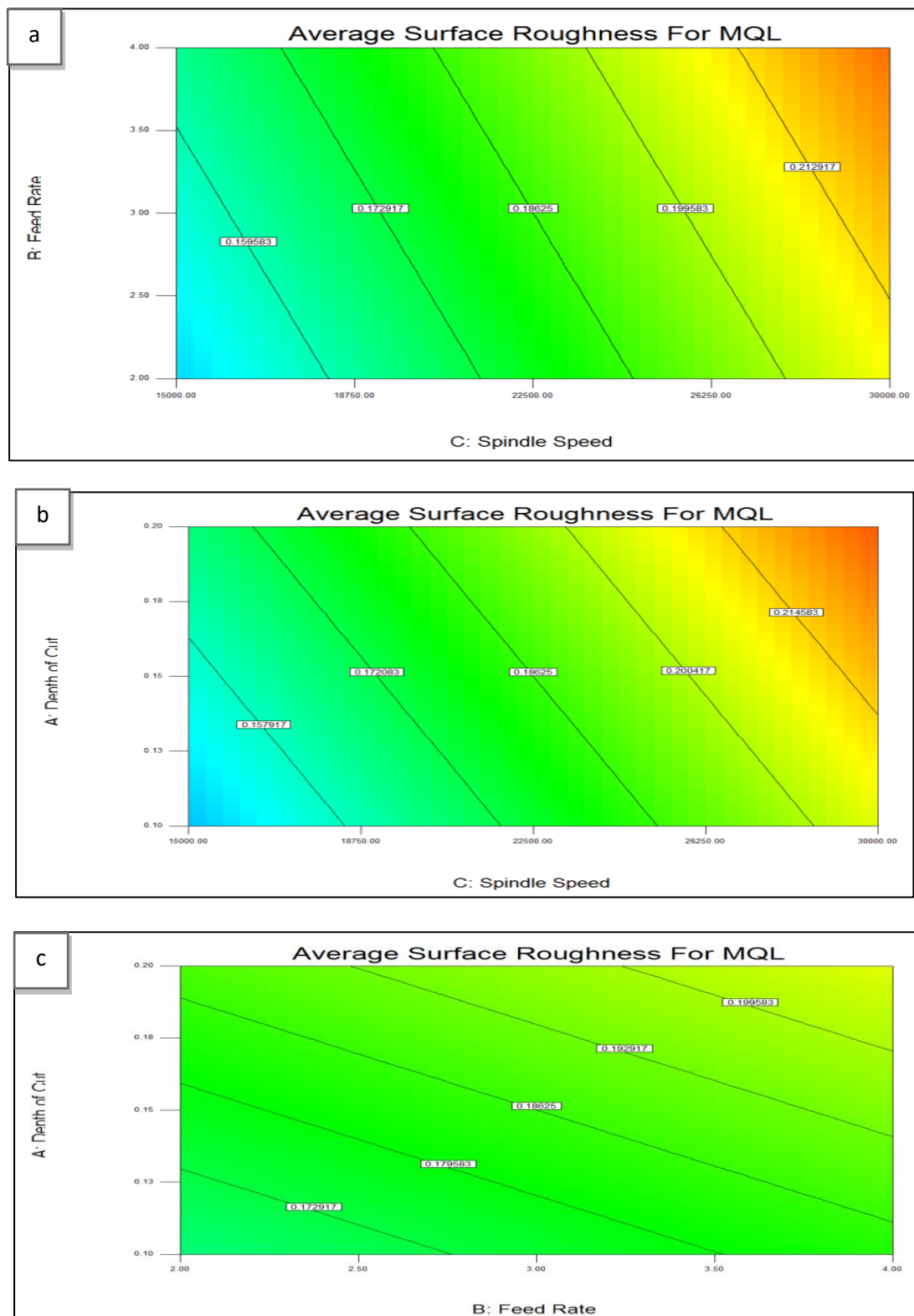


Figure 3. Contour plots for average surface roughness (a) spindle speed vs. feed rate with depth of cut 0.15 μm , (b) spindle speed vs. depth of cut with feed rate 3 mm/min, and (c) feed rate vs. depth of cut with spindle speed 22500 rpm

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