A Study on Surface Roughness and Burr Formation of Al6061 with Different Spindle Speed and Federate for Small End Milling Cutter

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Abstract

This paper reports the results of experiments to investigate surface roughness and burr formation during the slot milling of Aluminum 6061. The experiment was carried out with small cutting tool diameter and several of spindles speed and federate. Generally, cutting parameters will influence on surface roughness and the formation of burrs in small slot milling operations. Although it is not possible to avoid burr formation by modifying the cutting parameters, the burr size can be reduced by selecting the appropriate values. The results showed that slot milling with cutting tool with diameter 2.0mm and 3.0mm have a similar behavior for surface roughness with respect to federate and spindle speed. The larger cutting tool diameter results in a larger burr formed. Burr height increased due to larger chip load as the spindle speed increased. It also shown that Burr-breakage type of burr more significant in cutting AL6061

Keywords: Al6061, Burr Type, High Speed Milling, Surface Roughness.

1. INTRODUCTION

Milling is a well established material removal process for fabricating three dimensional components. With recent advancement in micro and nano devices, mechanical machining can, in principle, be used in the fabrication of micro-scale components. Milling at the micro-scale is able to produce intricate three dimensional features while at the same time satisfy stringent dimensional tolerance and surface finish requirements needed in micro-scale components. However, there are still numerous challenges in micro-cutting to be overcome before it can emerge as a technically sound, economically viable and reliable process to fabricate micro components. In milling, spindle speed, depth of cut, feed rate and cutting speed are the main controlling parameters. There is close relation between the cutting tool workpiece interaction and surface quality [1].

Shi Hyoung Ryua et al. [2] study the plane surface generation mechanism in flat end milling. From this study, surface texture in end milling process is determined by the combinations of tool geometry and cutting conditions including feedrate and spindle speed. Tool run-out and setting error play an important role in surface profile generation and tool deflection induced by cutting forces affects the surface form error.

Ming-Yung Wang et al. [3], done an experimental study on surface roughness in slot end milling of AL2014-T6. The aim of this work is to analyze the influence of cutting condition and tool geometry on surface roughness when machining a slot end milling AL2014-T6. The parameters considered were the cutting speed, feed, depth of cut, concavity and axial relief angles of the end cutting edge of the end mill. Surface roughness models for both dry cutting and coolant conditions were built using the response surface methodology (RSM) and the experimental results.

P.G. Benardos et al. [4], done a work on prediction of surface roughness (Ra) in CNC face milling by using a neural network modeling approach. The data used for the training and checking of the network performance derived from experiments conducted on a CNC milling machine according to the principles of Taguchi design of experiments (DoE) method. The factors considered in the experiment were the depth of cut, the feed rate per tooth, the cutting speed, the engagement and wear of the cutting tool, the use of cutting fluid and the three components of the cutting force.

Lee and Dornfeld [5], done an experimental study on a micro burr formation in milling of aluminum 6061-T6 and copper 110. Different burr formation types in micro
milling and conventional milling were discussed. Flag-type, rollover-type, wavy-type, and ragged-type burrs were observed in micro milling aluminum and copper. The rollover-type burr on tool entrance and flag-type burr on tool exit were found to be proportionally bigger than in conventional milling processes
considering the ratio of burr size to chip load. The up-milling produced smaller top burrs than down-milling. As the depth of cut and feed rate increased within the studied range, the burr size was also increase. The effect of the crystallographic orientation on the mechanism of chip formation, surface generation and the variation of the cutting forces were studied [6-11].

Liu et al. [12] developed a dynamic cutting force and vibration model of the micro-end milling process that accounts for the dynamics of the micro-end mill, influences of the stable built-up edge, and the effects of minimum chip. thickness, elastic recovery, and the elastic-plastic nature in ploughing/ rubbing. Using the model, the effects of the minimum chip thickness on the cutting forces and vibrations as well as the stability of the micro-end milling process been studied. A salient feature of stability in micro milling, that differentiates it from the stability of conventional milling, is that stability becomes sensitive to the feed rate, resulting in a low feed rate instability phenomenon.

In recent times, there have been extensive studies of tool life, edge radius effect, surface generation, minimum chip thickness, micro structural effects as well as finite element modeling and molecular
dynamics simulation of micro and nano scale cutting. However, fundamental understanding and general consensus on the mechanism that dominates mechanical machining at the transition stage between macro and micro scale is still lacking. Specifically, basic understanding of burr

formation mechanism and machined surface integrity in those scale machining. The objective of this study is to develop a better understanding of milling at the transition gap between macro and micro scale for AL6061. This study will focus on effect of cutting parameter on surface roughness and burr formation.

2. EXPERIMENTAL DESIGN

The factors contributing to the surface roughness are cutting conditions, tool geometries and mechanical stiffness while using the conventional end milling machine tools. Feed rate and spindle speed, which are the parameters of cutting condition, is the most influential on surface roughness [13]. However, situations of small cutting tool diameters are more complex than conventional case because of the small structure and the slim end milling cutters. Tool chatter is easy to generate because the periodical cutting force and high spindle speed will vibrate the machine tool. The cutting speed, which had been found to have insignificant influence on burr formation [14, 15], was fixed for this series of tests. With constant spindle speed, increases of tool diameter will increase cutting speed. Meanwhile, with constant tool size, cutting speed increase as spindle speed increase.

Mechanical stiffness mainly cause by types of material being cut, in this work Aluminum 6061 were used. Chemical composition and mechanical properties of Aluminum 6061 is shown in table 1 and 2. Aluminum is the least expensive metal that has a strong resistance to corrosion. It is a relatively light metal compared to other metals such as steel, nickel, brass, and copper. It offers a range of good mechanical properties easily machinable and has a wide variety of surface finishes. It also has good electrical and thermal conductivities and highly reflective to heat and light. It can be fabricated by most of the commonly used techniques. Aluminum 6061 is widely used of products and applications from aircraft structures to screw machine parts and structural components.

Element	Al	Si	Cu	Mg	Cr
Weight %	97.9	0.60	0.28	1.0	0.20

Table 1: Chemical composition of Aluminum 6061

Properties	
Density (×1000 kg/m^3)	2.7
Poisson's Ratio	0.33
Elastic Modulus (GPa)	70 – 80
Tensile Strength (MPa)	115
Yield Strength (MPa)	48
Elongation (%)	25
Hardness (HB500)	30
Shear Strength (MPa)	83
Fatigue Strength (MPa)	62

Table 2: Mechanical Properties of Aluminum 6061

3. EXPERIMENTAL PROCEDURE

A Proxxon MF70 modified to CNC milling was used for the experiments. The main purpose of this study is to determine the effect of spindle speed, federate and cutting tool diameter to surface roughness and burr formation, therefore the other cutting parameter were remain constant such as depth of cut, number of flute and workpiece material. The slot milling experiments were conducted using two flute carbide cutting tool, while the depth of the cut was chosen as 0.2 mm. The cutting conditions used in the study are listed in Table 3. Each experiment was repeated 5 times to verify the result. The range of feed rates and spindle speed was selected to double up from original value. This was done to identify the relation between selected cutting parameter, roughness and burr types. During the experiments, both workpiece speed and tool rotating speed, taking into the consideration of cutting speed as;

$$V = \frac{\pi DN}{1000} \text{ (m/min)} \quad (1)$$

where V is the cutting speed of workpiece,
D the diameter of workpiece/cutter
N is the workpiece/cutter speed.

Exp. No.	Tool Diameter (mm)	Feedrate (mm/min)	Spindle Speed (RPM)	Cutting Speed (m/min)
1	2.0	100	5000	31.420
2	2.0	200	10000	62.840
3	2.0	400	20000	125.680
4	2.5	100	5000	39.275
5	2.5	200	10000	78.550
6	2.5	400	20000	157.10
7	3.0	100	5000	47.130
8	3.0	200	10000	94.260
9	3.0	400	20000	188.52

Table 3: Cutting conditions

Surface Roughness (Ra) of the slot milled surface was measured using Mahr Perthometer Model M4Pi. Three measurements were made on each surface and the arithmetical means of them were calculated. The burr formation of the slot were observed using Optical Microscope.

4. RESULT AND DISCUSSION

In order to verify the effect of feed rate, spindle speed and cutting tool diameter on surface roughness and burr formation on Aluminum 6061, 27 experiments were conducted. The experiment was design in such way to identify the relation between surface roughness and double increment of federate and spindle speed. Because of the high variability of burrs, there is no standardized method of burr measurement available. In this study, the burrs are observed optically using an optical microscope.

The slot milling experiments were carried out on Aluminum 6061 workpiece materials under different cutting conditions are given graphically in Figure 1 and the corresponding experimental values of surface roughness (Ra) are shown in Table 4.

Figure 1: Workpiece material machined with different cutting condition

Exp. No.	Spindle Speed (rpm)	Feedrate (mm/min)	Ra_{min}		
			TD = 3.0mm	TD = 2.5mm	TD = 2.0mm
1	5000	100	1.903	1.367	0.975
2	5000	200	2.145	1.921	1.354
3	5000	400	2.305	2.961	2.779
4	10000	100	1.240	2.476	0.706
5	10000	200	1.568	2.221	1.544
6	10000	400	2.009	2.143	1.878
7	20000	100	1.339	0.606	1.229
8	20000	200	1.106	0.765	0.725
9	20000	400	0.937	0.975	0.662

Table 4: Experimental values of surface roughness (Ramin) on machined surface.

5. EFFECT ON SURFACE ROUGHNESS

5.1 Effect of feed rate and cutting tool diameter on surface roughness

The influence of feed rate on the surface roughness although deviates from the traditional relationship between feed rate and surface roughness, it could be due to the relatively closer levels of feed rate employed during the experiments undertaken. When the feed rate increased, surface roughness also increased. Surface roughness occurred during the experiment is due to tool vibration. Because tool vibration, milled surface has been affected due to the dynamic forces occurred on the tool with increases of feed rate. Figure 2 shows the variation of surface roughness, Ra, between feed rate and tool diameter.

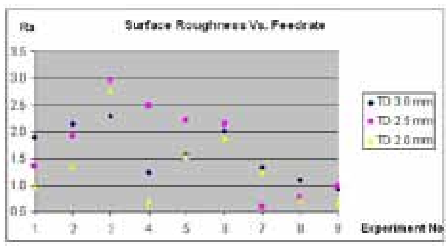


Figure 2: The variation of surface roughness, Ra, between feed rate and tool diameter

By referring to table 4, and figure 2, surface roughness are increases as federate for all cutting tool diameter for spindle speed with 5000 rpm. Cutting tool diameter 3.0mm and 2.0mm shows a similar behavior for experiment 4 to 6 and 7 to 9. But for cutting tool with diameter 2.5mm, it had shown a reversed behavior for those ranges. It can be conclude that, cutting tool with diameter 2.0mm and 3.0mm have a similar behavior for surface roughness with respect to feedrate.

The figure of percentage difference of increment feedrate and tool diameter is shown in figure 3. It show that, a similar behavior occur for those cutting parameter. The figure shows a sinusoidal shape of graph. But there is no specific conclusion can be made such as, when increase the feedrate by double, the Ra will either increase or decrease double or half.

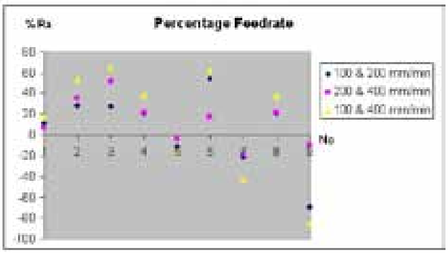


Figure 3: The percentage difference of increment feedrate and tool diameter.

5.2 Effect of spindle speed and cutting tool diameter on surface roughness

The Ra value and figure of surface roughness effect on spindle speed are shown in figure 4. As the federate are constant in experiment 1, 4 and 7, cutting tool with diameter 3.0mm and 2.0mm shows a similar behavior and it reverse with cutting tool diameter 2.5. For experiment 2, 5 and 8, TD 2.5 and 2.0 having similar behavior, but TD 3.0mm has decreased it Ra value. All tool diameter have similar behavior for exp 3, 6 and 9, as spindle speed increase, the Ra also increase. It can be conclude that, cutting tool with diameter 2.0mm and 3.0mm have a similar behavior for surface roughness with respect to spindle speed.

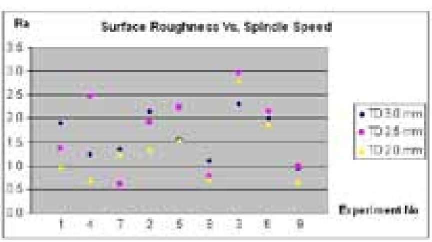


Figure 4: The Ra value and figure of surface roughness effect on spindle speed

6. EFFECT ON BURR FORMATION

6.1Effects of feed rate, spindle speed and cutting tool diameter on burr formation

According to R.L Tsann [12], burr formation in micro milling can be classified into 5 types, the knife-type burr (K) is created by the pushing out of the uncut part when cutting was not occurred. The saw-type burr (S) is similar to the knife-type burr, but a small amount of cutting has occurred. The burr-breakage (B) is formed when a fracture causing separation of the burr occurs near the middle of the burr. The curl-type burr (C) is due to tool chipping which is so severe that the chip is pushed and bent over the edge. The wave-type burr (W) is due to stretching where the material undergoes when the burr is formed, which results in the length of the burr at the top being longer than the actual length of the edge machined, and therefore the burr is forced to take a wavy shape to be able to accommodate itself on a shorter edge length.

The influence of in-plane exit angle on burr formation of Al 6061 is shown in Table 5. Under the chosen depth of cut 0.2 mm, only Saw-type burr (SB), Curl-type burr (CB), and Burr-breakage (BB), burrs were found according to different in-plane exit angles. Table 6 shows the types of the burrs occur for feedrate, cutting tool diameter and spindle speed at over the whole cutting process. There are no changes for type of burr for tool diameter 2.0mm, while facing different feedrate and spindle speed, the burr-breakage (BB) occurs. For cutting tool size with diameter 2.5mm, burr-breakage (BB) occurs for experiment 1 to 6 and saw-type burr (SB) occur for experiment 7 to 9. It show increment of spindle speed will change the type of burr. Similar behavior also happen when tool diameter 3.0mm is used, it show that the Curl-type burr (CB) occur in experiment 1 to 6 and Burr-breakage (BB)occur in experiment 7,8 and 9.

Exp. No.	Tool Diameter (mm)		
	2.0	2.5	3.0
1	BB	BB	CB
2	BB	BB	CB
3	BB	BB	CB
4	BB	BB	CB
5	BB	BB	CB
6	BB	BB	CB
7	BB	SB	BB
8	BB	SB	BB
9	BB	SB	BB

Table 5: Type of burr formation occur with respect to experiment

Note: Chip clog inside slot (CC), Saw-type burr (SB), Curl-type burr (CB), Wave-type burr (WB), Knife-type burr (KB), Burr-breakage (BB), Tool break (TB)

6.2 Effect of burr formation on tool size and feedrate

It clears that the burr sizes have significant effect on cutting tool size with the progress of cutting and less significant effect on feedrate. This is formed because as the cutting progresses, the chipping of the tool edge promotes burr formation.

Generally, at larger tool size, large chips are produced, might give rise to larger burr height. The small tool diameter, have the least volume of metal removal. Therefore small burr produced. The large cutting tool diameter has the largest volume of metal removal and the higher burr height. Furthermore, it can be seen in table 3 that the width of the cut has a strong influence. In other words, changes in cutting tool diameter will highly affect the burr size. This is due to the cutting edge entering with a high chip load. As the cutting edge proceeds through the material, a chip is formed which in the end hinges at the top edge. The burr produced in the end is the final top burr, meaning that as the chip formation time increases, the burr size increases as well. Therefore, a larger cutting tool diameter results in a larger burr. As shown in table 6 for depth of cut 0.1mm, the burr size is increase as the cutting tool diameter increase. With respect to the depth of cut, the burrs in the large cutting tool diameter are much larger than the burrs occur in small cutting tool diameter.

6.3 Effect of burr formation on spindle speed

Experiment 7, 8 and 9 was conducted with spindle speed of 20000 rpm, by comparing with spindle speed 10000, type of burr occur are different. It shows that increment of spindle speed will change the type of burr and sizes. As the spindle speed increased, the friction between the chip and tool also increased. When the tool faces friction increases, there is a corresponding increase in the shear angle and accompanying increases in the chip thickness. Thus the plastic strain associated with chip formation is reduced. This reduction affects the size of the burrs produced. Therefore the burr height increased due to larger chip load as the spindle speed increased.

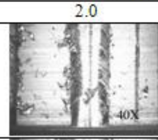
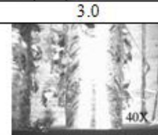
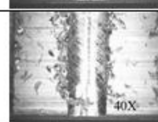
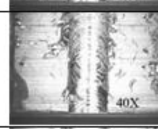
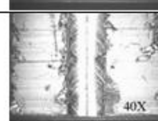
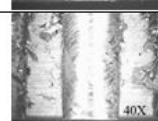
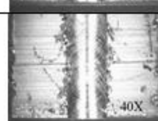
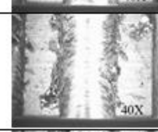
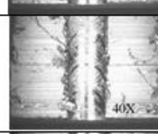
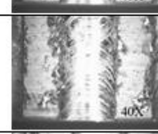
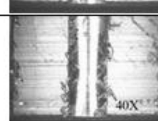
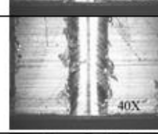
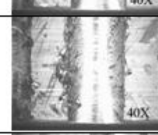
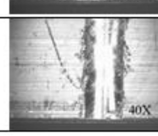
Exp. No.	Tool Diameter (mm)	
	2.0	3.0
1		
2		
3		
4		
5		
6		
7		
8		
9		

Table 6: Burr formation of tool diameter 2.0 and 3.0 with respect to experiment

7. CONCLUSION

In general, cutting parameters very much influences on surface roughness and the formation of burrs in small slot milling operations. Although it is not possible to avoid burr formation by modifying the cutting parameters, the burr size can be reduced by selecting the appropriate values. Several important experimental results of small slot milling were observed:

- Cutting tool with diameter 2.0mm and 3.0mm have a similar behavior for surface roughness with respect to feedrate.
- Cutting tool with diameter 2.0mm and 3.0mm have a similar behavior for surface roughness with respect to spindle speed.
- Larger cutting tool diameter results in a larger burr sizes.
- Burr sizes increased due to larger chip load as the spindle speed increased.
- Burr-breakage type of burr more significant in small slot milling of AL6061 Hence, a more detailed study and analysis of cutting forces, chip geometry, harder engineering materials and surface morphology over a wider range of undeformed chip thicknesses using more precise machines can be conducted.

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