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# Study on End Brush Deburring and Sintered Diamond Ball Deburring of Micro-features Milled

**T K Sai, K Saptaji* and N Fatchurrohman**

Faculty of Manufacturing Engineering, University Malaysia Pahang, 26600 Pekan, Pahang Darul Makmur, Malaysia

Corresponding author *: kushendarsyah@ump.edu.my

**Abstract.** The presence of top burr in the micro-features produced by milling process can deteriorate and affect the surface quality of the products. Though there are some deburring methods can be used and reported successfully remove the burr in the micro scale features, however simpler and alternative method is still needed. Two of the deburring methods that can be used are end brushing and sintered diamond ball methods. Therefore the aim of this paper is to study the application of the end brush and sintered diamond ball for deburring top burrs exist on micro features produced by milling process. Slot milling experiments were conducted and subsequently deburring process using the two methods was conducted. Micro scale features were also produced using milling process followed by deburring. The deburred results were observed visually using optical microscope and Scanning Electron Microscope (SEM) and surface roughness was measured. Experimental results show that the end brush and sintered diamond ball deburring have successfully remove the top burrs. The end brush deburring method produced better surface quality compared to the sintered diamond ball.

## 1. Introduction

Burr is defined as the material plastic deformation produced at workpiece edges as a result of machining or shearing process [1]. The presence of burrs affects the quality and the appearance of the machined parts such as the dimension accuracy, surface quality, fit and ease of assembly [2]. The real profile of the burr such as height, width and length; is sometimes difficult to quantify due to the complex shape of the burrs and the limitation of measurement methods such as using stylus method or optical method. In the machining of micro scale features, the size of the burrs is more significant and comparable with the size of the features being produced. Burrs normally occur when mechanical material removal process such as micro-milling used in the production of micro scale features.

The formation of burrs in the micro-milling process can be reduced or even eliminated by two methods; by using the optimum cutting parameters or by deburring process. Changes in process parameters can be adopted to reduce burr formation. Several researchers have reported the effect of cutting parameters and optimization of cutting parameters for various metallic alloys. In micro milling aluminum alloys, the burrs can be minimized by using high spindle speed of about 60,000 rpm and low feed per tooth between 1.0 µm and 2.0 µm [3]. In micro-milling of aluminum alloys Al2124 and stainless steel SS-304, the burr height can be decreased by increasing feed, tool diameter and number of flutes [4]. Lekkala *et al.* [4] argued that the speed has less significant effect on the burr thickness and height whereas tool diameter, depth of cut, number of flutes and the interaction between feed rate and number of flutes have significant effect on the burr height in the micro-milling process.

Deburring is defined as the removal of minute amounts of material from edges after major part features have been produced [5]. Deburring process is difficult to apply on micro-features produced by micro-milling; the process must be carefully conducted to avoid damage to the small features. Incorrect selection of deburring techniques or parameters may also introduce dimensional errors, damage, poor surface finish and residual stresses. The deburring method is normally dependent on the burr locations and has to be based on burr characteristics together with part properties [5].
There are various deburring methods used in the micro-features production especially micro slot using micro-milling reported previously such as using electrochemical polishing [6], diamond milling [6], micro-EDM [7], powder blasting [8], micro-peening [9], supporting material [10] and tapered tool [11]. Alternatively, the end brush [5] and diamond sintered ball can also be used for deburring of micro-features. There are not much literature have reported on the applications of end brush and diamond sintered ball for deburring. Hence, this paper aims to study the effectiveness of two deburring methods namely, stainless steel end brush and diamond sintered ball. These two methods are simple deburring methods that can be applied easily especially on the CNC milling machine.

## 2. Experimental Setup

In this experiment, two carbide end mill with diameter of 4 mm and 2 mm were used as cutting tool and Aluminum Al6061-T6 was used as workpiece. Experiments were conducted using Makino Ke55 CNC milling machine. At first, the preliminary slotting test was performed in order to have optimum cutting parameters. There are about 16 slot produced using different parameters. Deburring process was performed using 2 different deburring methods namely stainless steel end brush, and diamond sintered ball (Figure 1). The deburring experiments were conducted on the slots without removing the workpiece from the workpiece holder vise. Hence the proposed deburring methods are convenient and efficient to be applied especially for the milling process in producing slots where the deburring can be applied without removing the workpiece. Subsequently, some micro-fluidic device cavities were produced based on the optimal parameters. The micro-fluidic cavity design consists of straight protruded wall cross section and conical protrusion. Visual observation of burr formation and surface roughness measurements were conducted using optical microscope, Scanning Electron Microscope (SEM).

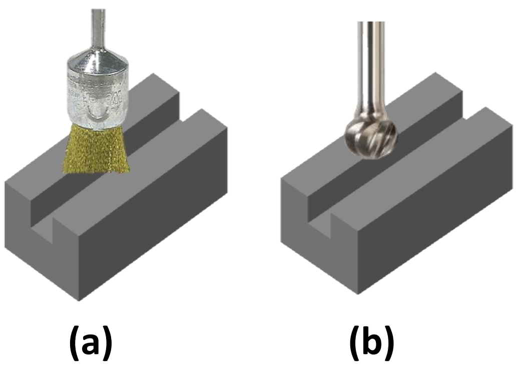


**Figure 1.** Two deburring methods tested in this experiment, (a) end brush, and (b) diamond sintered ball

### *2.1. Machining Parameter for slotting*

There are four factor used in slotting experiment, tool diameter, depth of cut, spindle speed and feed rate. The slotting parameters with their level were shown in Table 1.

**Table 1.** Machining parameters and factor levels

| Factors | Unit | Factor Levels | |
|---|---|---|---|
| | | 1 | 2 |
| A. Tool diameter | mm | 4 | 2 |

| | | | |
|---|---|---|---|
| B. Depth of cut | μm | 100 | 200 |
| C. Spindle speed | rpm | 3,000 | 4,000 |
| D. Feed rate | mm/min | 10 | 100 |

### 2.2. *Deburring Parameters*
There are 3 factors that used in deburring which were deburring tool, depth of cut, and spindle speed. The deburring parameters with their level were shown in Table 2.

**Table 2.** Deburring parameters and factor levels

| **Factors** | **Factor levels** | | |
|---|---|---|---|
| | **1** | **2** | **3** |
| A. Deburring Tools | End brush | Diamond sintered ball | Diamond sintered cylinder |
| B. Depth of Cut (mm) | 0.100 | 0.200 | - |
| C. Spindle Speed (rpm) | 2000 | 4000 | - |

### 2.3. *Design of experiment*
Taguchi orthogonal array (OA) $L_{16}$ was used as the design of experiment for slotting experiment. The experiment layout of L16 was generated by using Minitab software and shown in Table 3. In addition, 1 factor with four level and 2 factor with two level were used in deburring experiment resulted in a total of 12 experiments layout as shown in Table 4.

**Table 3.** Experiment layour of $L_{16}$ OA for slotting

| **Slot Number** | **Tool Diameter (mm)** | **Depth of Cut (mm)** | **Spindle Speed (rpm)** | **Feed rate (mm/min)** |
|---|---|---|---|---|
| 1 | 4 | 0.1 | 3000 | 10 |
| 2 | 4 | 0.1 | 3000 | 100 |
| 3 | 4 | 0.1 | 4000 | 10 |
| 4 | 4 | 0.1 | 4000 | 100 |
| 5 | 4 | 0.2 | 3000 | 10 |
| 6 | 4 | 0.2 | 3000 | 100 |
| 7 | 4 | 0.2 | 4000 | 10 |
| 8 | 4 | 0.2 | 4000 | 100 |
| 9 | 2 | 0.1 | 3000 | 10 |
| 10 | 2 | 0.1 | 3000 | 100 |
| 11 | 2 | 0.1 | 4000 | 10 |
| 12 | 2 | 0.1 | 4000 | 100 |
| 13 | 2 | 0.2 | 3000 | 10 |
| 14 | 2 | 0.2 | 3000 | 100 |
| 15 | 2 | 0.2 | 4000 | 10 |
| 16 | 2 | 0.2 | 4000 | 100 |

**Table 4.** Experiment layout for deburring

| **Deburring Number** | **Deburring Tools** | **Spindle Speed (rpm)** | **Depth of cut (mm)** |
|---|---|---|---|
| 1 | End brush | 4000 | 0.00 |
| 2 | End brush | 4000 | 0.10 |
| 3 | End brush | 2000 | 0.00 |
| 4 | End brush | 2000 | 0.10 |

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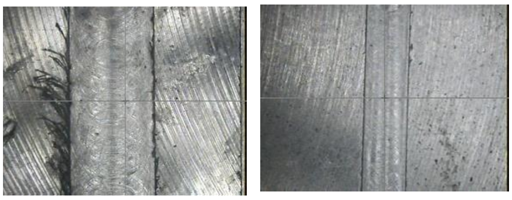
| | | | |
|---|---|---|---|
| 5 | Diamond sintered ball | 4000 | 0.00 |
| 6 | Diamond sintered ball | 4000 | 0.10 |
| 7 | Diamond sintered ball | 2000 | 0.00 |
| 8 | Diamond sintered ball | 2000 | 0.10 |
| 9 | Diamond sintered cylinder | 4000 | 0.00 |
| 10 | Diamond sintered cylinder | 4000 | 0.10 |
| 11 | Diamond sintered cylinder | 2000 | 0.00 |
| 12 | Diamond sintered cylinder | 2000 | 0.10 |

## 3. Results and Discussion

### *3.1. Burr formation for slotting*
The result of the slots having the most and least burrs are shown in Figure 2. The most burrs was occurred for the slot #5 with the cutting parameters for this slot were tool diameter 4 mm, cutting depth of 200 µm, spindle speed 3,000 rpm and feed rate 10 mm/min. The slot #12 has the least burr formation as shown in Figure 2 (b). The machining parameters for this slot are tool diameter of 2 mm, cutting depth 100 µm, spindle speed 4,000 rpm and feed rate 100 mm/min.



(a) (b)

**Figure 2.** Slot results having (a) the most burrs and (b) the least burrs

It can be seen that the least burrs formed when the smaller diameter of tool was used and the lower depth of cut was applied. Moreover, the highest the spindle speed with the combination of the highest feed rate will also contribute to the lowest formation of burrs. According to the Wang and Zhang [12], the burr height increased with the depth of cut and feed rate. Besides, the burr height decrease when the spindle speed was increased [13].

### *3.2. Surface roughness for each slot*
The surface roughness measurements result of the slot is shown in Figure 3. It can be seen from Figure 3 that the slot number 12 with the tool diameter 2 mm, cutting depth 100 µm, spindle speed 4,000 rpm and the feed rate 100 mm/min has the lowest surface roughness value which is 0.133 µm. In contrast, the slot number 7 has the highest surface roughness value which is 0.590 µm. The machining parameters for the slot number 7 were tool diameter of 4 mm, depth of cut of 200 µm, spindle speed of 4,000 rpm and feed rate of 10 mm/min. By comparing these two results, it can clearly be observed that with the criteria of bigger tool diameter, higher depth of cut, higher spindle speed and lower feed rate will cause a poor surface finish. This result was in line with the observation of Boswell et. al. [14], stated that the better surface finish can obtain with the combination of high spindle speed and the high feed rate.

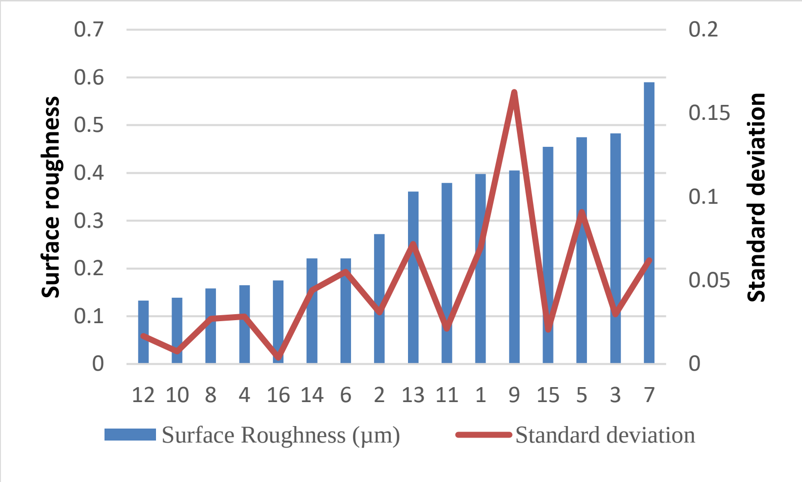
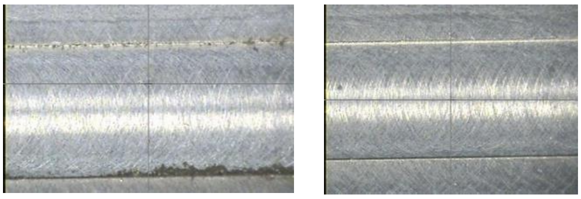



**Figure 3.** Surface roughness values for all slots

### *3.3. Deburring slot*
Deburring experiments were conducted for the slot produced by 2 mm tool diameter, 4,000 rpm spindle speed, 200 μm depth of cut and 100 mm/min feed rate. 16 slots were produced for the deburring experiments.

#### *a. End Brush*
The result of the most and the least burrs remained on the slot after deburring by end brush is shown in Figure 4. The most burrs remain on the wall of slot after deburring using end brush is resulted on deburring number 3 (Table 4). The parameters used for this deburring are spindle speed 2,000 rpm and depth of cut 0.00 mm (the end of brush is levelled with the top surface). In contrast, the least burrs remain on the slot was deburring number 2. The parameters for this slot are the spindle speed of 4,000 rpm and the depth of cut of 100 μm. This can be occurred because when deburring with certain depth of cut, the end brush will cover the top and the wall of the slot this can make sure the top burr and side burr was fully remove.



(a) (b)

**Figure 4.** Comparison of deburring slot using end brush (a) the most burr remain b) the least burr remain

Figure 5 shows the average surface roughness of the slot after deburring by end brush. It can be seen that the deburring slot number 2 has the lowest surface roughness with the parameters of 4,000 rpm for spindle speed and 100 μm depth of cut. This was due to the end brush have contact with the slot with a high speed. In contrast, deburring slot number 1 slot has the highest surface roughness with the parameters of 4,000 rpm spindle speed and 0.00 mm depth of cut. It can be seen that the depth of cut has an important role in the removing of burr and the surface finish.

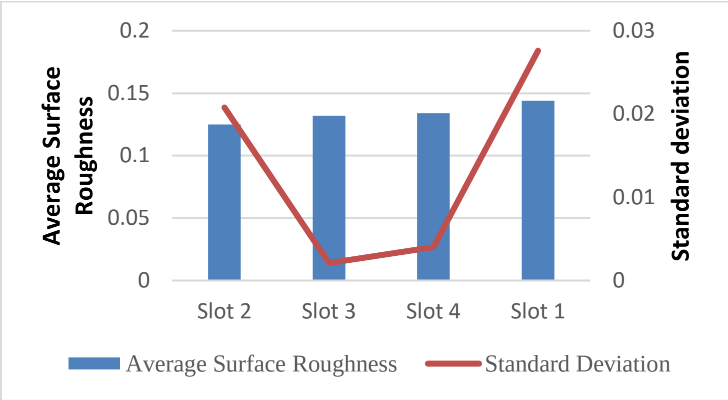
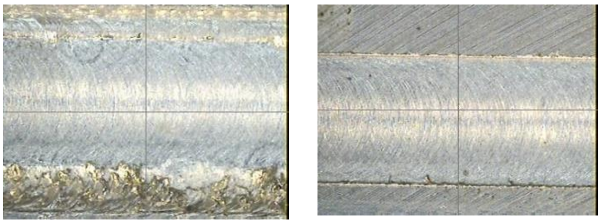



**Figure 5.** Average surface roughness for slots deburred by end brush.

b. *Diamond Sintered Ball*



(a) (b)

**Figure 6.** Comparison of deburring slot using diamond sintered ball (a) the most burrs remain b) the least burrs remain

Figure 6 shows the most and the least burrs remain on the slot after deburring using diamond sintered ball. The most burrs remain on the slot was produced on deburring slot number 6 which produced using 4,000 rpm spindle speed and 100 µm depth of cut. In contrast, the least burrs produced using 4,000 rpm spindle speed and 0.00 mm depth of cut. It can be seen that using minimum depth of cut, the second burrs was formed on the slot and causes more burrs. The result is the same for diamond sintered cylinder used as deburring tools.

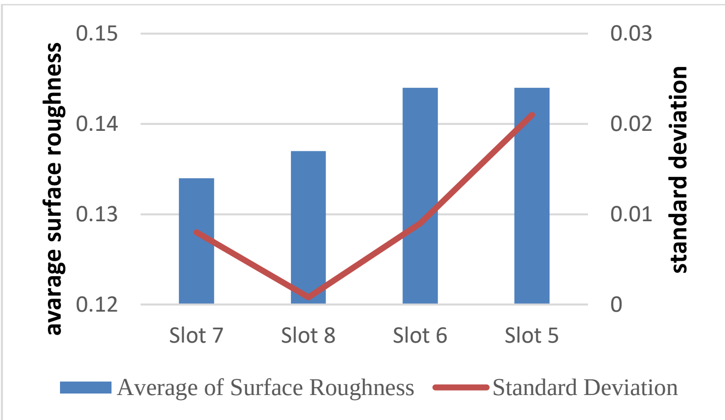



**Figure 7.** Average surface roughness for slots deburred by diamond sintered ball

Figure 7 shows the average surface roughness of the deburring slots using diamond sintered ball. It can be seen that deburring slot number 7 has the lowest surface roughness. The spindle speed and the depth of cut for this slot are 2,000 rpm and 0.00 mm. On the other hand, the deburring slot number 5 has the highest surface finish with the spindle speed of 4,000 rpm and 0.00 mm for depth of cut. From this result the higher the spindle speed of the higher the surface roughness of the slot.

### *3.4. Micro-fluidic devices cavity*

Based on previous results, the micro-fluidic devices cavities were produced and deburring process by various methods with their optimum deburring parameter was applied. The result of micro-fluidic cavities and the deburred micro-fluidic device cavity are shown in Figure 8. It can be seen that the proposed deburring methods using end brush and diamond sintered ball have successfully removed the burr at the edge of wall. However, the used of diamond sintered ball resulted in the traces of diamond sintered ball mark. Hence, the end brush deburring method shows better results in term of surface quality compared to deburring using diamond sintered ball.

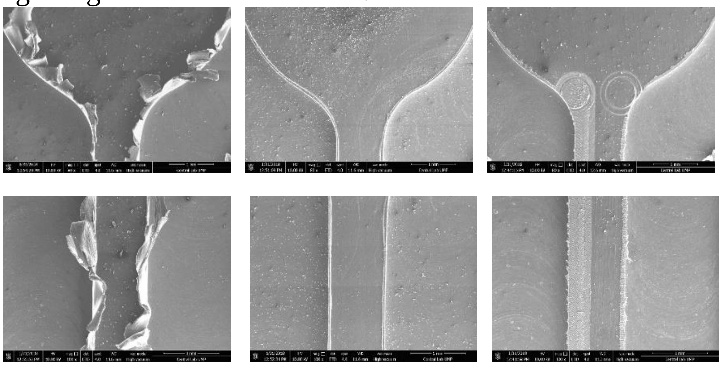



**Figure 8.** SEM images of the micro-fluidic device cavities produced without deburring and various deburring methods

## 4. Conclusion

The main conclusions of this paper are:

1. Slotting and deburring experiments have been carried out on aluminium alloys with various parameters. In this paper the optimum slotting and deburring parameters have been figured out.
2. The optimum machining parameters for the least burr formation in this experiment were 2 mm tool diameter, 100 µm depth of cut, 4,000 rpm spindle speed and 100 mm/min feed rate.
3. The optimum deburring parameters by using end brush when using 4,000 rpm spindle speed and 100 µm depth of cut.
4. The optimum deburring parameters by using diamond sintered burr ball are found when using 4,000 rpm spindle speed and 0.00 mm depth of cut.
5. The deburring method using end brush visually shows better result compared to diamond sintered ball method.

## Acknowledgements

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