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EXPLORING MILLING BURR FORMATION UNDER DIFFERENT TOOL EXIT ANGLES

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Abstract: A burr creates problem while aligning components in assembly stage and may be harmful to an operator. So, any machining operation needs control of this type of unwanted projection. As an additional deburring process is often required to remove burr, it is likely to increase production time and cost. The aim of this work is to investigate influence of different parameters on burr formation on aluminium block during slot milling. A condition would be recommended at which quite less, or no burr, occurs. Two sets of experiments are done in this work. Experiment set I is carried out at varying tool exit angles, while experiment set II is performed under varying feed. It is observed from experiment set I that at 60° and 90° tool exit angle, burr height is a bit small. When feed is 0.12 mm/tooth at experiment set II, no burr is observed.

Key words: Milling burr; tool exit angle; burr height; machining; milling; burr reduction.

1. INTRODUCTION

Burr is formed at the edge of a workpiece during any material removal process. It may be eliminated by an additional deburring process incurring additional cost of manufacture [1, 2]. Presence of burr creates problem during assembly, and often results in product malfunctioning during operation. It is hazardous for workers at the time of handling components. Burr formation can be controlled at design, process planning, and tool path planning stage. Burr can be reduced or eliminated by improving material properties, tool engagement condition, tool geometry and cutting parameters such as feed, cutting velocity, depth of cut and machining environment [3-7]. According to Narayanswami *et al*. [8], the required additional deburring to alleviate burr can damage the object. Hanshimura *et al.* [9] observed that burr formation affect the performance, reliability and durability of an engine.

Gillespie and others stated [10] that burr may not be fully avoidable, but it can be minimized by suitable selection of tool geometry and cutting parameters which such as feed rate, cutting velocity, etc. Aurich *et al.* [11] also discovered that burr formation could not be prevented fully, and it could be at the most substantially reduced. So an additional cleaning or deburring operation should be required thereby increasing the manufacturing cost of product. To avoid this problem and to minimize the burr size, they suggested some strategies such as selection of appropriate process parameters, work material, work geometry, process sequencing and tool path planning. Pratim and Das [12] investigated the effect of bevel angle provided at the edge of an object on burr formation of an aluminium alloy specimen. It was found that beveling at exit edge reduces burr formation, and at 15° exit edge bevel angle, burr formed was quite small in height. It was also found that feed rate had more effect on burr formation than cutting velocity. Silva *et al.* [13] studied the effect of cutting conditions such as cutting speed, feed per tooth and depth of cut on burr minimization in face milling of mould steel.

They reported that at a cutting speed of 100m/min, feed per tooth of 0.0859 mm/tooth and 0.3 mm depth of cut, burr height was minimum. Machado *et al.* [14] explored burr formation in carbon steel for semi-orthogonal cutting operation. They observed entrance burr length to depend on entry angle and depth of cut, but its thickness to be greatly affected by all the cutting parameters, such as cutting speed, feed rate and entering angle.

Saha and Das [15] did some research works on exit burr formation in medium carbon steel during face milling by providing exit edge beveling. They reported that at 15° exit edge bevel angle along with high cutting speed and feed rate, very small burr of less than 15 μm height had been formed. Das *et al*. [16] tried to minimize burr by selecting the optimum in-plane exit angle. They observed that at 60°, 120° and 150° in-plane exit angle with different feed, no burr is formed. This might be due to effectively low tool exit angle facilitating some support from around the exit edge. Saha and Das [17] provided 15° edge beveling on the job producing less burr due to decreasing need of back up support material. Wyen *et al.* [18] performed an experiment on burr formation of titanium alloy (Ti-6Al-4V) in milling by varying cutting edge radius. It was seen that in up milling, formation of burr increased with the increase of cutting edge radius, but it had little influence in down milling because some burr is removed with chip. Besides different cutting parameters, Heisel *et al*. [19] discovered the influence of cutting fluid on burr formation. They found that at constant feed rate, there was no effect on burr formation when cutting speed was varied. But when feed per tooth was varied, exit burr size at lateral face increased in dry machining in comparison with low quantity lubrication. Wang *et al.* [20] investigated the formation and control of burr in precision machining. They identified the factors which could affect formation of burr such as material of workpiece, cutting parameters, tool geometrical parameters. They observed that when the tool exit angle was more than 90°, small sized burr was produced. Similarly the effect of tool conditions and cutting conditions on burr formation was investigated by Deng et al. [21]. They found that by increasing tool exit angle from 60° to 120°, the location of pivoting points was much below the machined surface producing thick and long burr. Similarly at a lower rake angle, the pivoting point was far below the machined surface generating thick and long burr. It was also observed that with increasing feed rate, burr thickness also increased. Lin [22] found that larger feed rate produced larger burr height in face milling of stainless steel whereas high cutting speed produced smaller burr. The burr formation in orthogonal metal cutting was studied by Park and Dornfeld [23]. According to them, thin burr was formed when the development of high negative shear near the tool edge extended to the edge of the workpiece. For a carbon-nanotube reinforced polymer composite, the increased carbon nanotube produced ductile to brittle transition during machining and resulted in minimum chip thickness and burr dimension, as observed by Samuel *et al*. [24]. Chern [25] studied burr formation in aluminum alloys during face milling. It was seen that at low in plane exit angle (30°-60°) curl type burr was produced of low height. With increasing exit edge angle, wavy and knife type burr of large height was reportedly formed.

The aim of this work is to explore the extent of burr formation in aluminum block, and to reduce burr at some machining conditions. Tool exit angle and feed rate are varied in two experiment sets to find out the appropriate machining conditions giving subsequently reduced burr size.

2. EXPERIMENTAL INVESTIGATION

Slot milling is done in the present work on an aluminium block by a coated carbide insert end milling cutter on a vertical axis CNC milling machine. Only one insert is fitted in the cutter for machining. Experiments are performed in dry environment at a constant velocity of 100m/min and depth of cut of 2 mm. Details of experimental set up are tabulated in Table1.

Experiments are divided into two sets. Burr height is observed in experiment set I at 0.1 mm/tooth feed, and by varying tool exit angle (ø) from 60° to 115°. ø is the angle between velocity vector and feed direction at the point of tool exit from workpiece as defined in Fig.1. Tool exit angle is varied by placing the cutter axis in such a way that during slot milling, locus of the cutter axis makes a pre-determined distance from the exit edge and thus, the angle ø is produced. Tool exit angles chosen are 60°, 70°, 90°, 105° and 115°. At each tool exit angle, five successive measurements of burr height are made along the machined exit edge of the specimen.

Table 1 Experimental set up

Machine Tool	Vertical Axis CNC Milling Machine, Make: Bharat Fritz Werner, Bangalore, India Model: AksharaVF30CNC Accuracy: Positioning ± 10 microns, Repeatability : ± 5 microns		
Cutting Tool	End milling cutter, Diameter: f16 mm (Sandvik India make), Insert: TiN coated Carbide insert		
Job Material	Aluminum block, Size: 160 mm × 108 mm × 72 mm		
Cutting Conditions	Cutting velocity:100 m/min, Depth of cut: 2 mm, Environment: Dry		
		Feed (mm/rev)	Tool exit angle (°)
	Experiment Set I	0.1	60°, 70°, 90°, 105°, 115°
	Experiment Set II	0.04, 0.05, 0.06, 0.07, 0.08, 0.1, 0.12, 0.14	90°

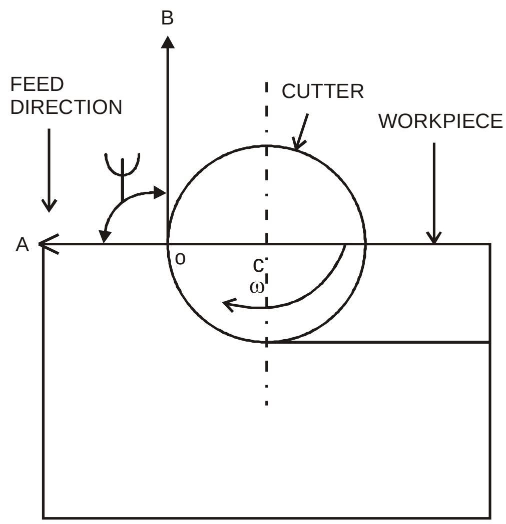

Fig. 1 Schematic diagram of workpiece and cutter showing tool exit angle (ψ)
[OA indicates feed direction, and OB is the direction of cutting velocity at the point of tool exit].

In the experiment set II, slot milling operation is done by varying feed at a constant tool exit angle of 90° and depth of cut of 2 mm. The feed values set are 0.04, 0.05, 0.06, 0.07, 0.08, 0.1, 0.12 and 0.14 mm/rev. Five measurements are done along the exit edge at each feed. Burr is observed and measured by a tool makers microscope made by Mitutoyo, Japan.

3. RESULTS AND DISCUSSION

Results of Experiment Set I are tabulated in Table 2. Bar chart of maximum burr height at varying tool exit angle is shown in Fig. 2. When tool exit angle is increased from 60° to 115°, maximum height of burr does not show any clear trend. Largest burr height is found to be of 0.60 mm. Average burr height values are found to be within

ψ

0.13 to 0.263 mm. Micrographs of burr formed are shown in Fig. 3. At a higher tool exit angle, there is a tendency to have higher average burr height. Similar observation was also noticed by Deng *et al.* [21] and Saha *et al.* [26].

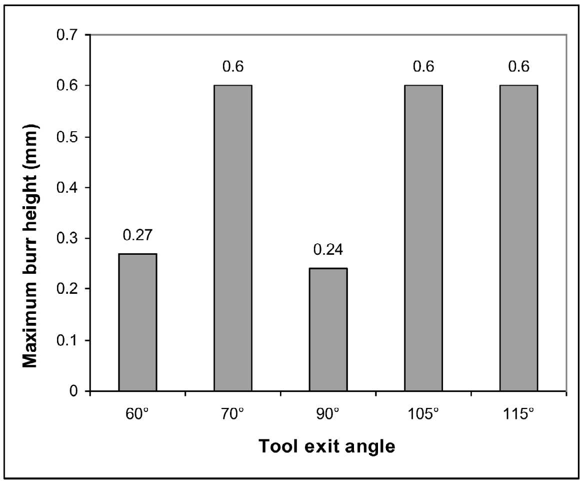

Fig. 2 Variation of maximum height of burr with different tool exit angles under a constant feed of 0.1mm/rev in Experiment Set I

At low tool exit angle, low burr height is possible as exit velocity of cutter is much inclined towards the cutting edge and is likely to get some support from inside the edge of the specimen [25]. Experiment set II is done at a constant tool exit angle of 90°. Feed is varied from 0.04 to 0.14 mm/rev. It is observed from Table 3 that at 0.12 mm/rev feed, no burr is generated and a maximum height of burr of 0.34 mm is generated at 0.14 mm/rev feed. At lower feed, less burr height is expected following reference [25]. However, obtaining no detectable burr at a relatively high feed of 0.12 mm/rev feed needs further investigation to undertake.

Graphical representation of variation of burr height with feed is shown in Fig. 4. Microscopic views of burr at different feed are shown in Fig 5.

Table 2 Height of burr at different tool exit angles under constant feed of 0.1mm/rev in Experiment Set I

Sl. No.	Tool exit angle (ø)	Burr height at different portions of exit edge of workpiece (mm)	Maximum burr height (mm)	Average height of burr (mm)
1	60°	0.17, 0.15, 0.15, 0.25, 0.27, 0.07, 0.21, 0.10, 0.11, 0.10	0.27	0.158
2	70°	0.15, 0.6, 0.17, 0.10, 0.20, 0.10, 0.25, 0.10, 0.24, 0.10	0.60	0.201
3	90°	0.24, 0.05, 0.23, 0.10, 0.10, 0.05, 0.18, 0.06, 0.15, 0.15	0.24	0.131
4	105°	0.15, 0.20, 0.17, 0.05, 0.13, 0.05, 0.38, 0.05, 0.33, 0.6	0.60	0.211
5	115°	0.12, 0.60, 0.23, 0.20, 0.25, 0.22, 0.36, 0.25, 0.18, 0.22	0.60	0.263

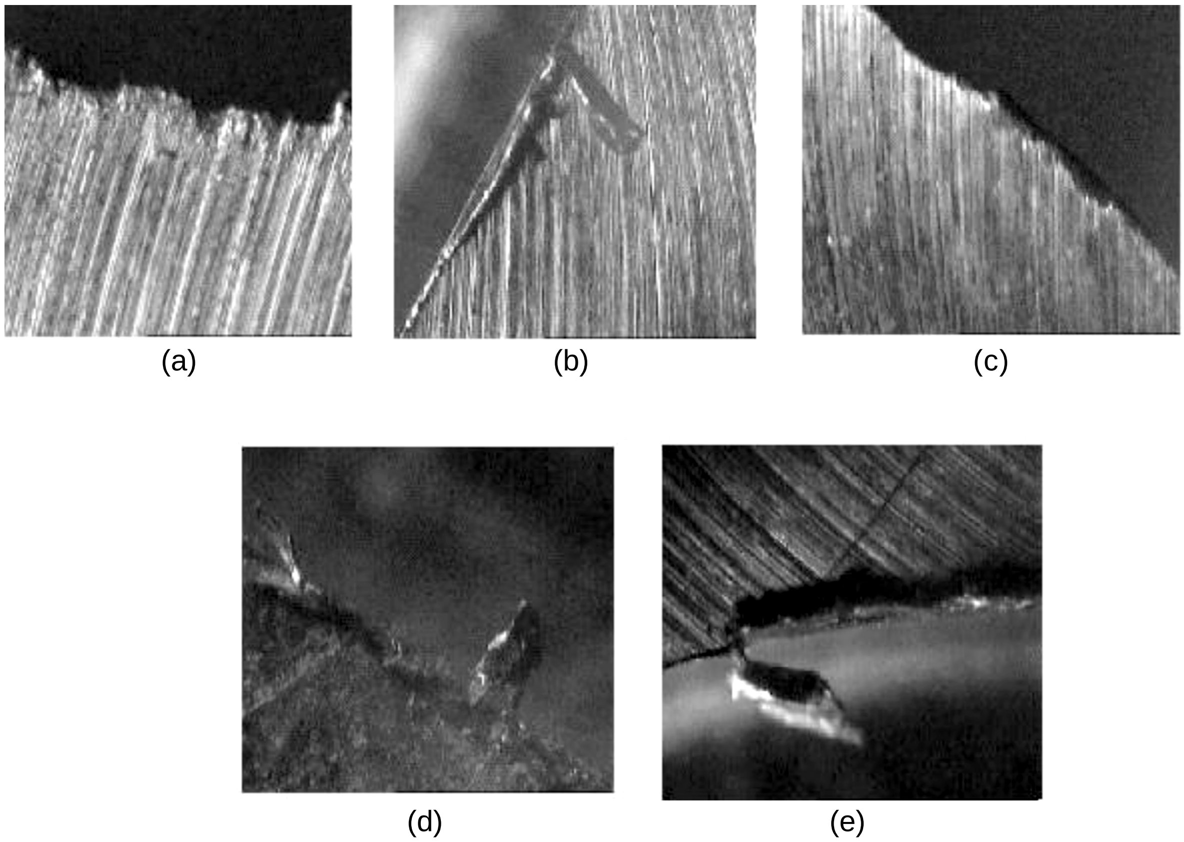

Fig. 3 Typical microscopic view(X20) of burr at Experiment Set I at a feed of 0.1 mm/tooth with tool exit angle of a) 60° b) 70° c) 90° d) 105° and e) 115°

Table 3 Height of burr with different feed with a tool exit angle of 90° in Experiment Set II

Sl. No.	Feed rate (mm/rev)	Burr height (mm) at different positions of exit edge of workpiece	Maximum height of burr (mm)	Average height of burr (mm)
1	0.04	0.05, 0.03, 0.04, 0.06, 0.04	0.06	0.044
2	0.05	0.12, 0.05, 0.09, 0.01, 0.02	0.12	0.058
3	0.06	0.15, 0.25, 0.12, 0.08, 0.27	0.27	0.174
4	0.07	0.23, 0.09, 0.15, 0.18, 0.23	0.23	0.176
5	0.08	0.23, 0.13, 0.04, 0.03, 0.05	0.23	0.096
6	0.1	0.02, 0.04, 0.01, 0.08, 0.02	0.08	0.034
7	0.12	0	0	0
8	0.14	0.34, 0.18, 0.01, 0.01, 0.01	0.34	0.11

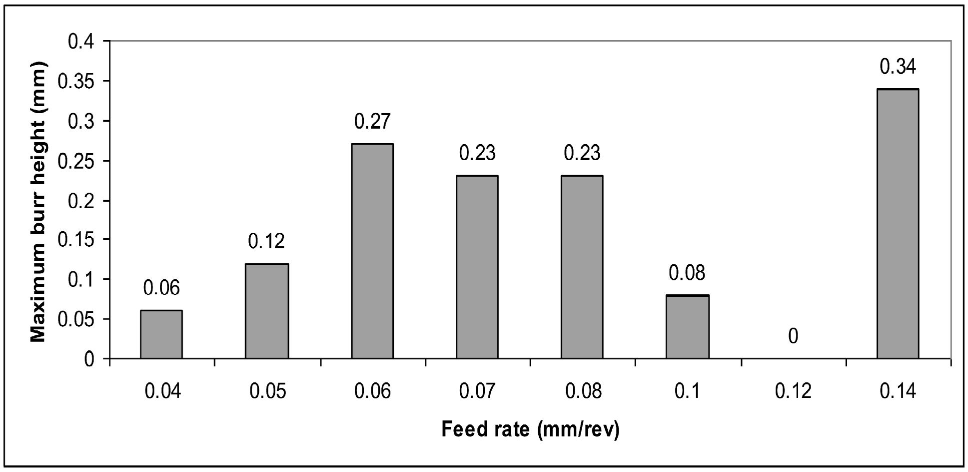

Fig. 4 Variation of maximum height of burr with different feed at a tool exit angle of 90°

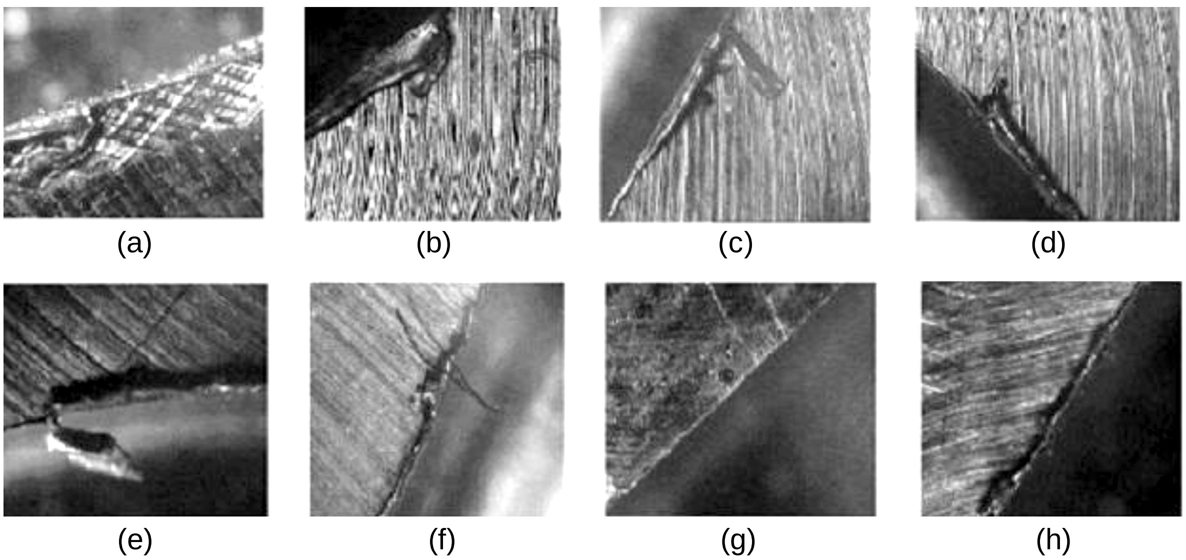

Fig. 5 Microscopic view (X20) of burr with tool exit angle of 90° and depth of cut of 2mm at a feed of [a) 0.04, b) 0.05, c) 0.06, d) 0.07, e) 0.08, f) 0.1, g) 0.12 and h) 0.14 mm/tooth]

4. CONCLUSION

From the experimental observation on slot milling operation of aluminium block using a single coated carbide tool insert at a cutting velocity of 100 m/min and depth of cut of 2 mm, no burr is found when feed is 0.12 mm/rev even when and tool exit angle is 90°.

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