Effect of exit edge beveling on drilling burr formation under wet environment

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ABSTRACT

Keywords:
Drilling,
Exit Edge Beveling,
Wet Environment,
Machining,
Burr,
Backup Support.

In drilling, burr formation is mostly observed at the exit edge of a workpiece. A burr can cause premature failure of cutting tools, dimensional errors in manufactured components and serious problems in assembly. Deburring operation is usually employed for removal of burr. For reduction of deburring cost and time, burr reduction is essentially needed. The present investigation on drilling burr formation demonstrates an approach for burr reduction at the exit edge of the workpiece. A number of experiments has been carried out on low carbon steel flats under water soluble oil cooled environment to explore the influence of different exit edge bevel angles on burr formation under different machining conditions. At 20^o exit edge bevel angle, negligible burr is found at 0.2 mm/rev feed at all the cutting velocities considered and this condition may be adopted. However, with 25^o exit edge bevel angle, sizeable burr is obtained making it unsuitable.

1. Introduction

In machining operations to produce circular holes with relatively tight tolerances, high productivity, low cost, and good quality hole drilling is one of the most widely used operation. It is estimated that of all the machining operations carried out, there are about 20% hole making operations. Burr is usually produced at the exit edge of the hole during drilling and deburring is needed for finished component. Presence of burr causes various difficulties in the assembly operation of the precision component, safety hazard to personnel due to sharp shape (Chern, 2006, Saha et al., 2007, Pratim & Das, 2011, Kim et al., 2001, Kim et al. 2006) and can cause jamming and misalignment. They may also cause short circuits in electrical components. So, a number of deburring operations may be employed (Gillespie & Blotter, 1976) to remove burrs resulting in additional time and cost. This cost may even be 30% of the total cost of production. A team led by Dornfeld carried out (Dornfeld et al., 1999, Dornfeld, 2003, Tripathi & Dornfeld, 2004) many experiments in the area of burr minimization and prescribed some strategies for preventing and minimization burr formation.

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Beier (1999) tried to find out the cause of burr formation and stated that the process of burr formation can be regarded as forming process. Min and others (2007) developed a series of finite element models with experimental observation that was used to evaluate the effects of other parameters on drilling and other machining burr formation including part design. Lin & shyu (2005) carried out an experiment to minimize the amount of burr and improvement of tool life choosing a different method by using variable feeds in drilling operations. Developing a model finite element analysis, another work by Guo & Dornfeld (1998) investigated on mechanisms of drilling burr minimization and predicted cutting forces with two sets of back up materials. Min (2001) had developed a number of finite element models of burr formation in 3-D oblique cutting that could be used to understand 3-D drilling burr formation process. Kim (1999) did an experiment to investigate the detailed geometry of the drilling burr produced during drilling of stainless steel. Leitz and others (2009) carried out an experiment on the drilling burr formation in the intersecting holes, on the other hand Matsumura and Leopold (2009) investigated the effect of burr formation on drilling process through cutting force model. Several other researchers (Aurich et al., 2009, Nakayama & Arai, 1987) studied various methods for suppression of burrs and its complex phenomena in different machining processes.

Continued efforts were made in analyzing and controlling drilling burr using simulation and validating its results by the observation of experimental work (Lauderbaugh, 2009). Series of works were done by the group led by Das on machining burr - its formation and exploring its reduction/ elimination (Saha et al., 2007, Pratim & Das, 2011, Roy et al., 2010, 2014, Karmakar et al., 2013, Kundu et al., 2014 (a,b), 2015 (a,b), 2016, Mondal et al., 2014, 2019, Misra et al., 2016, 2019). While chemical deburring was tried in one work by Karmakar et al. (2013), a number of other works were performed to reduce drilling burr by optimal choice of drilling process parameters, and/or providing metallic (Kundu et al., 2014b, 2015a) or adhesive (Misra et al., 2016) back-up, putting coolant (Mondal et al., 2014), or making beveled exit end (Kundu et al., 2016), etc. Some works were also carried out to model or for optimizing drilling burr formation using artificial Neural Networks (Misra et al., 2019), genetic algorithm (Mondal et al., 2019), and some other methods (Kundu et al., 2014a).

Different other research groups across the globe did extensive works on drilling burr reduction (Kaplan et al., 2011, Gaitonde & Karnik, 2012, Pilný et al., 2012, Altan & Altan, 2014, Kamboj et al., 2015, Wei et al., 2016, Azarrang & Baseri, 2017, Vats et al., 2017 and Pardo et al., 2019). Kamboj and others (2015) tried to minimize drilling burr formed in aluminium-SiC composites using step drills, when parametric optimization was attempted by Kaplan et al. (2011), Gaitonde & Karnik (2012), Altan & Altan (2014), Kamboj et al. (2015), Azarrang & Baseri (2017) and Vats et al. (2017) to control burr size in dry drilling. Effect of inter-layer gap on drilling burr of aluminium stacks was also investigated by Wei et al. (2016) and Pardo et al. (2019). While some researchers worked on reducing burr during drilling holes in aluminium sheets (Pilný et al., 2012), in plastics (Altan & Altan, 2014), etc., majority of other works were performed on various category of steels. Although many works were taken up on drilling burr and its control, still elimination of burr remains a challenge to the practicing engineers in many applications.

The aim of the present experimental investigation is to explore the effect of different machining conditions and different edge bevel angles on burr formation in drilling of low carbon steel flat using HSS twist drill. Experiments have been carried out to find out the optimum value of the exit edge bevel angle under different machining conditions so that formation of burrs can be reduced or eliminated significantly.

2. Experimental Investigations

Drilling experiments have been carried out on Kerry made vertical axis radial drilling machine with HSS twist drill of 12 mm diameter on low carbon steel flats along with three levels of cutting velocity of 15, 21 and 26 m/min and three levels of feed such as 0.1, 0.2 and 0.3 mm/rev under water soluble oil cooled condition. Three sets of experiments have been undertaken. Detailed experimental set up and machining conditions have been chosen considering the availability of the machine and usual industrial practice as detailed in Table 1. To reduce the possibility of burr at exit edge of the drilled hole, a number of test pieces has been made by providing three different exit edge bevel angles of 15^0, 20^0 and

Table 1
Experimental set up and machining conditions.

<table>
<tr><td>Machine Tool</td><td colspan="4">Vertical axis radial drilling machine, Model No.: E4, Make: KERRY
Speed range (RPM): 90-120 (9 steps)
Feed range (mm/min): 0.1-0.3 (3 steps)</td></tr>
<tr><td>Cutting Tool</td><td colspan="4">Taper shank, Uncoated HSS twist drill of diameter 12 mm</td></tr>
<tr><td>Job Material</td><td colspan="4">Low carbon steel (Mild steel)</td></tr>
<tr><td>Job Size</td><td colspan="4">100mm X 50mm X 6mm</td></tr>
<tr><td rowspan="2">Machining Conditions</td><td>Environment</td><td>Cutting velocity ,
Vc (m/min)</td><td>Feed, mm/rev</td><td>Exit edge bevel angle, degree</td></tr>
<tr><td>Wet with water soluble oil</td><td>15, 21, 26</td><td>0.1, 0.2, 0.3</td><td>15, 20, 25</td></tr>
</table>

25^0, and for each bevel angle, as depicted in Fig. 1, experiments have been done with three different feed. After every drilling operation, formation of burr is observed on the workpiece at exit edge. Burr height is measured and classified in a 7 point scale where each '*' indicates 1 point as given in Table 2.

3. Results and Discussion

Experiment set I has been carried out with a constant velocity of 15 m/min on three numbers of work pieces under water soluble oil cooled environment. Three different exit edge bevel angles, 15^0, 20^0 and 25^0 are taken, and for each bevel angle, three different feed rates have been tested to observe the burr formed. Results are presented in Table 3. Except experiment No. 5, for all other conditions, burr height of more than 0.1mm is seen and for few cases, burr height more than 0.2mm is also detected at 25^o exit edge bevel angle. It can be said that negligible burr within 0.1 mm height are formed at an exit edge bevel angle of 20^0. This may be due to requirement of no or quite less back-up support material at the exit edge. When there is no support at the exit edge, the shear plane is oriented to a negative shear plane resulting in a burr (Lauderbaugh, 2009, Roy et al., 2010, 2014, Karmakar et al., 2013, Kundu et al., 2014 (a), 2015 (a), Mondal et al., 2014).

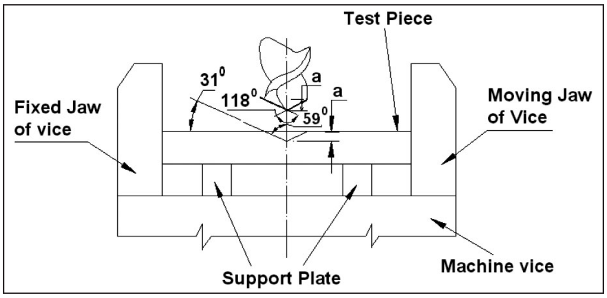

Fig. 1. Making 31^0 exit edge bevel with a twist drill having 118^0 point angle.

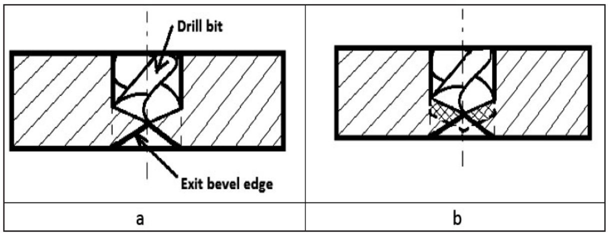

Fig. 2. Material removal with the progress of drilling with exit edge bevel (a) drill bit touches the exit edge bevel while it moves downward, b) drill bit moving in to the bevelled exit edge (changed position is shown as dotted line) and the cross hatch portion is getting removed thereby).

However, when a tool exits the workpiece with a suitable bevel, depth of cut gradually decreases when the drill passes across the bevel. Correspondingly, cutting force components also go on decreasing and reaching to zero at the tool exit point. This phenomenon entails no need of providing any external support to suppress burr formation. Fig. 2(a,b) illustrates reduction of the depth of cut while the drill bit moves downwards within the portion of exit edge bevel. A photographic view of typical drilled workpiece of experiment set no. I is shown in Fig. 3 (a-e).

Experiment set II has been performed in wet condition with a constant velocity of 21 m/min on three numbers of work pieces. Three different exit edge bevel angles (15^0, 20^0 and 25^0) are chosen and for each angle three different feed rates have been tested to observe the nature of burr formed. Results of these experiments

Table 2
Qualitative assessment of amount of burr in 7-point scale.

Burr height	Range of burr height observed
*	Negligible burr up to 0.1 mm height
**	Considerable not visible burr above 0.1 mm and up to 0.2mm height
***	Small burr above 0.2 mm and up to 0.5 mm height
****	Considerable large burr above 0.5 mm and up to 2 mm height
*****	Large burr above 2 mm and up to 4 mm height
******	Substantially large burr above 4 mm and up to 5 mm height
*******	Quite burr above 5 mm in height

Table 3
Results of experiment set I, II & III with edge bevel in wet condition.

Number of workpieces	Experiment set No.	Experiment Sl. No.	Feed (mm/rev)	Cutting Velocity (m/min)	Exit Edge Bevel Angle (degree)	Burr Size
1	I	1	0.1	15	25	**
		2			20	**
		3			15	**
2		4	0.2		25	***
		5			20	*
		6			15	**
3		7	0.3		25	***
		8			20	**
		9			15	**
4	II	10	0.1	21	25	**
		11			20	*
		12			15	**
5		13	0.2		25	**
		14			20	*
		15			15	*
6		16	0.3		25	***
		17			20	**
		18			15	**
7	III	19	0.1	26	25	***
		20			20	*
		21			15	**
8		22	0.2		25	***
		23			20	*
		24			15	**
9		25	0.3		25	***
		26			20	**
		27			15	**

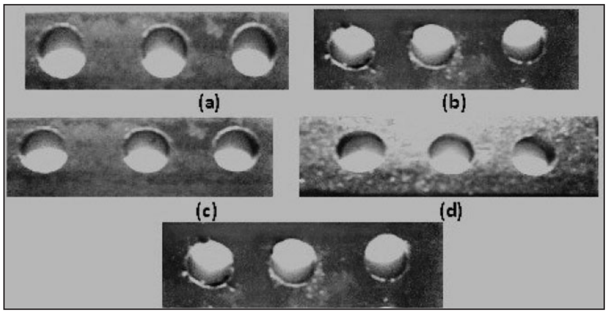

Fig. 3. Photographs of typical drilled workpiece [(a) For Experiment Sl. No.1, 2, 3 (L-R-Top Row), (b) For Experiment Sl. No. 7,8,9 (L-R-Top Row), (c) For Experiment Sl. No. 10,11,12 (L-R-Top Row), (d) For Experiment Sl. No. 13,14,15 (L-R-Top Row), (e) For Experiment Sl. No. 22,23,24 (L-R-Top Row),]

are presented in Table 3. Comparing the experimental results, it can be said that negligible burrs are formed at an exit bevel edge angle of 20^0 and 15^0. This may be due to exit edge bevel of this workpiece causing gradual decrease in depth of cut. It decreases cutting force and also torque, subsequently requiring less back up support material at the exit edge. Typical photographic views of drilled holes as shown in Fig. 2 (c,d) under experiment set II showing typical exit burrs formed after drilling operation. In experiment Sl. No. 16, small size burr above 0.2mm is seen, while in experiment Sl. No. 10, 12, 13, 17 and 18, considerable not visible burr less than 0.2mm is noticed. Negligible bur is there at experiment Sl. No. 11, 14 and 15. Exit edge bevel angle is 20^o for experiment Sl. No. 11 and 14 with 0.1 and 0.2 mm/rev feed respectively. For experiment Sl. No. 15, feed is 0.2 mm/rev and bevel angle provided is 15^o. At these feed-exit edge bevel combination, reduction of exit edge burr is quite evident.

Experiment set III has been performed keeping cutting velocity constant at 26 m/min with three different exit edge bevel angles and feed to find out the trend of burr formation. Measured burr height in these conditions has been observed, classified and is presented in Table 3. A photographic view of through drilled hole with burr formation at these machining conditions is shown in Fig.2 (e) under experiment set III. It can be easily found out that at 20^o exit edge angle, for 0.1 and 0.2 mm/rev feed, minimum burr height is obtained in this experimental work, whereas small burr above 0.2mm is got at 25^o exit edge bevel angle at the higher feed of 0.2 and 0.3 mm/rev. At other conditions at this 26 m/min cutting velocity, burr height of 0.1 to 0.2 mm is formed. From the experimental results, it is found that largest burr height is formed only at 25^o exit edge bevel angle indicating unsuitability of using this exit edge bevel. On the contrary, at 20^o exit edge bevel angle with 0.2 mm/rev feed and in some other case at 0.1 mm/rev feed, negligible burr formation occurs. Therefore, feed within 0.1 and 0.2 mm/rev and provision for 20^o exit edge bevel may be recommended for sizeable control of exit edge drilling burr. Gradual reduction of depth of cut from the central or axial point within the chisel edge towards the periphery requiring less force or torque may have facilitated no requirement of any back-up support and hence, less burr formation.

4. Conclusions

In this experimental investigation, burr formation in vertical drilling operation has been noted under different feed, cutting velocity and edge bevel to explore the condition for minimum exit burr formation under wet condition. Following conclusions may be drawn from the results obtained:

1. An appropriate exit edge bevel at the exit edge of the job during drilling operation may reduce burr formation to a great extent.
2. Negligible burr formation is observed mostly at 15^0 and 20^0 exit edge bevel angle during drilling that may be due to less need of back up support material at the exit edge of the drilled piece. The reason of this suppression of burr formation may be the gradual reduction of depth of cut along the bevel edge thereby requiring less force for friction force requirement.
3. At water soluble oil cooled condition, substantial reduction of drilling burr formation has been observed. This wet condition may reduce burr formation by reducing temperature that causes reduced plasticity of workpiece material.

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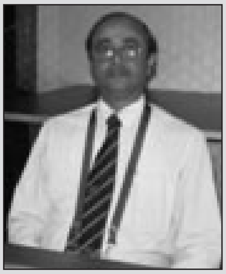

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