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AN INVESTIGATION ON REDUCING BURR IN SHAPING MEDIUM CARBON STEEL THROUGH STRESS ANALYSIS

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ABSTRACT
Burr is formed during shaping at the edge when the tool exits the workpiece. It causes handling and assembly of machine parts difficult, and also may cause injury to the operator. Additional, non-productive deburring process is employed for removal of burr in practice. Numbers of experimental observation have been performed on burr formation for its minimization. This work is taken up to investigate the influence of different exit-edge bevel angles on burr formation in shaping of medium carbon steel in dry environment. Height of burr becomes quite less at an exit edge bevel angle of 15°. To validate the experimental findings, stress analysis using FEA is done at different tool positions. Maximum equivalent stress distribution near the exit edge of the job is analyzed with or without exit edge bevel. Minimum value of maximum equivalent stress is found at an exit edge bevel angle of 15° validating the experimental results.

Keywords: Edge Bevel, Burr, Stress Analysis.

1. INTRODUCTION
Burrs are undesirable projection of plastically deformed material attached to edges of a workpiece. It causes difficulty in assembly of components and possible injury to the operator. Additional cost involving deburring process is required for its removal. Precision components may constitute 30% of the total part cost during deburring and edge finishing operation [1].

Many research works were done on burr formation mechanism along with its minimization strategies. Nakayama et al [2] studied side burr formation mechanism in orthogonal cutting operation. The formation of negative shear plane plays an important role in mechanism of burr formation and break out [3]. Olvera and Barrow [4,5] and Silva et al. [6] studied the influence of different cutting parameters (i.e. cutting velocity, axial depth of cut, exit angle, tool nose geometry) on exit burr formation in face milling operations. Pekelharing [7] experimented with sharp tools for workpieces having different exit angles to find out poor tool life in interrupted cutting. He found that tool exits lead to negative shearing or foot formation. Chern [8] conducted an experiment on aluminum alloy, and found out the effect of in-plane exit angle on burr formation. Chu and Dornfeld [9] designed new tool path planning for minimizing burr size.

Many other research works [10-14] were done to control the size of burr height by developing suitable algorithm, modeling, and process planning. Bierman and Haeilmann [15] did modification on machining processes for minimizing burr formation to avoid deburring, while Shefelbine [16] found out that a worn out tool increases burr formation than a new one.

Many works [17-19] were performed on burr formation mechanism using FEM, and to demonstrate the mechanism through simulation. Saha et al. [20], and Saha and Das [21,22] experimentally found out that there is a significant influence of exit edge beveling on burr formation in milling. Saha and Das [23-25] and Das et al. [26,27] carried out experimental investigation and stress analysis by using FEM to find out significant influence of exit edge bevel angle on burr and foot formation during orthogonal machining.

The objective of the present work is to study the influence of exit edge bevel angle on burr formation in orthogonal shaping of medium carbon steel (45C8) flats under different machining conditions. The stress analysis using FEM is done to simulate the burr formation process and to find out the optimum condition towards burr minimization.

2. EXPERIMENTAL INVESTIGATION

2.1 Experimental Conditions
Experiments are carried out on a Pathak Industries, India make shaping machine with brazed HSS tipped broad nose tool to investigate the effect of edge beveling of medium carbon steel (45C8) flats along with the variation of orthogonal rake angle (+5°, 0°, -3°) on burr

formation under dry environment. Depth of cut is kept constant at 0.05 mm with 2.5 mm width of cut and 10 m/min cutting velocity. 0°, 15°, 20°, 25° and 30° exit edge bevel angles are used. At the exit end of the workpiece, where the tool leaves the workpiece, a bevel is made of a height of a 3mm. Experimental details are shown in Table 1. Five experiments and one repeat experiment are carried out for five exit edge bevel angles. Tool makers microscope is used to measure the burr height at the exit end of the workpiece. The burr height is classified in a 10 point scale as shown in Table 2. Cutting force components (P_y and P_z) are measured during shaping using a Sushma, Bangalore, India made tool dynamometer, and this force value is used for stress analysis using FEM.

Table 1: Experimental details

Machine Tool	Shaping Machine, Make: Pathak Industries, Howrah, India Main motor power: 5.5 kW
Cutting Tool	Brazed HSS tipped broad nose tool: ISO 7 L.H
Tool Geometry	Orthogonal rake angle: - 3°, 0° and +5° for three different cutting tools Orthogonal clearance angle: 3°, Inclination angle: 0°
Exit Edge Bevel Angle	0°, 15°, 20°, 25°, 30°
Job Material	Medium carbon Steel (45C8), Hardness: 175 BHN
Job Size	90 mm x 65 mm x 2.5 mm
Machining Condition	Cutting velocity (V_c): 10m/min, Depth of cut (t): 0.05 mm (constant), width of cut: 2.5 mm (constant), Environment: Dry

Table 2: classification burr height in 10 point scale

Scale value	**Height of burr observed**
1	Negligible burr up to 20 micron height
2	Very tiny burr having height in between 20 micron to less than 50 micron
3	Tiny visible burr having height in between 50 micron to less than 0.1 mm
4	Small burr having height in between 0.1 mm to less than 0.15 mm
5	Significant burr having height in between 0.15 mm to less than 0.2 mm
6	Medium size burr having height in between 0.2 mm to less than 0.225 mm
7	Medium to large size burr having height in between 0.225 mm to less than 0.25 mm
8	Large burr having height in between 0.25 mm to less than 0.5 mm
9	Quite large burr having height from 0.5 mm to less than 1 mm
10	Very large burr having height greater than 1mm.

Table 3: Experimental results in shaping

Exp. set No.	**Cutting velocity** (m/min)	**Orthogonal rake angle** (°)	**Burr height in 10 point scale at different exit edge bevel angles**				
			0°	**15°**	**20°**	**25°**	**30°**
1	22	5	8	1	3	3	5
2	22	-3	9	1	2	2	4
3	15	0	6	1	3	5	6
4	15	0	6	1	3	5	6
5	10	5	7	1	3	4	5
6	10	-3	8	1	2	2	3

2.2 Results and Discussion

Detailed experimental observations are shown in Table 3, where formation of burr is compared qualitatively at different orthogonal rake angles and exit edge bevel angles. From experimental observation, it is observed that at 15° exit edge bevel, minimum burr is formed. This may be due to less requirement of back up support material at the beveled exit edge, and less chance of formation of negative shear plane. Another cause may be due to gradual decrease in cutting force with gradual reduction in depth of cut along the beveled exit edge. On the other hand, test pieces without any edge bevel, have quite large burr height is for all rake angles. This is due to non-availability of back up support material, and formation of negative shear plane.

3. STRESS ANALYSIS USING FEM

To get the general idea of burr formation in orthogonal shaping operation, stress distribution pattern is found out using finite element analysis. Cutting forces measured during shaping using different rake angles tools (+5°, 0° and -3°) under given machining conditions of 45C8 steel are shown in Table 4. Finite element analysis is done at each exit edge bevel angle at three different positions using force results.

The chip is initially considered to be in contact with the rake face of the tool, and no stress is present between the chip and tool at the initial condition to simplify the model. During cutting, tool moves along the workpiece, and chip flows along the rake face. To observe the effect of tool position, stress is analyzed for various tool positions at a distance of 45mm, 3.464 mm and 1.732 mm from exit end of the workpiece. General purpose finite element analysis software, Autodesk Inventor 8 is used. The base of the constructed model corresponding to the clamping position is considered to be of fixed support type boundary condition. The maximum equivalent stress is based on maximum equivalent stress failure theory, or von Mises-Hencky theory, applicable for ductile materials. In this model +90 mesh relevance setting is used.

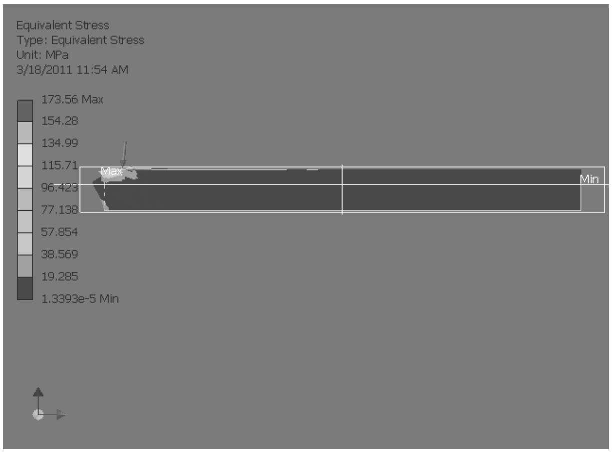
Variation of maximum equivalent stresses at different tools with varying exit edge bevel angles and rake angles are shown in Table 5. Typical shear stress distributions inside the workpiece with exit edge bevel angles of 15°, 20°, 25° and 30° and without any exit edge bevel at +5°, 0^o and -3^o orthogonal rake angles of tool are shown in Fig. 1(a-k). It is seen that with the decrease in rake angle, at all the positions, increase in maximum equivalent stresses without edge bevel is noticed, expectedly as forces increase with the decrease in rake angle. Maximum equivalent stresses along the exit edge bevel are observed to be lesser than that without edge bevel. Minimum value of equivalent stress is induced at 15° exit edge bevel for orthogonal rake angles of +5° at positions of 3.464 mm and 1.732 mm from exit end of the workpiece.

Table 4: Cutting forces observed in shaping of 45C8 steel

Sl No.	**Orthogonal rake angle** (°)	**Tangential cutting force** (N)	**Normal cutting force** (N)
1	+5°	638.6	39.4
2	0°	686.7	103
3	-3°	766.2	153.3

Table 5: Results of stress analysis for medium carbon steel (45C8)

Sl No.	**Orthogonal rake angle** (°)	**Max. equivalent stress without exit edge bevel** (MPa)			**Exit edge bevel angle** (°)	**Max. equivalent stress with exit edge bevel** (MPa)	
		At mid point	**At 3.464 mm from exit edge**	**At 1.732 mm from exit edge**		**At 3.464 mm from exit edge**	**At 1.732 mm from exit edge**
1	+5	377.1	392.1	429	15	173.6	60.8
2					20	241.7	82.9
3					25	312.9	124.4
4					30	388.6	135.3
5	0	425.8	433.4	466.8	15	189.1	67.9
6					20	266.3	93.3
7					25	347.1	121.6
8					30	433.1	151.5
9	-3	489.2	587.7	524.6	15	214.3	77.6
10					20	302.6	107.6
11					25	395.3	159.5
12					30	495.8	175.3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57.854
38.569
19.285
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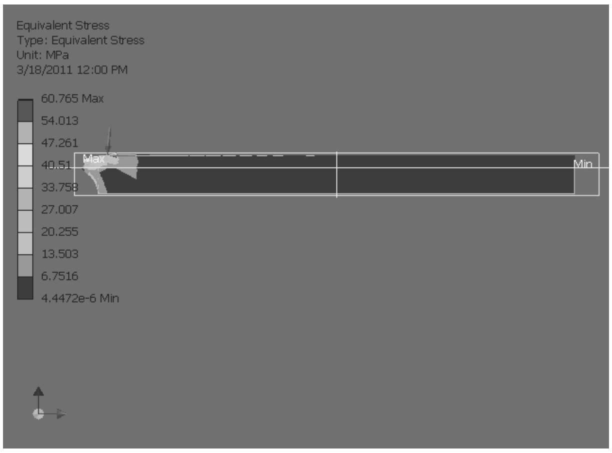
Max
Min

(a)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13.503
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4.4472e-6 Min
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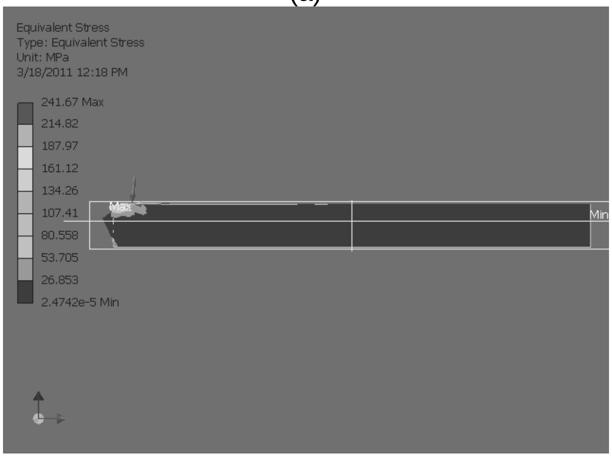
Min

(b)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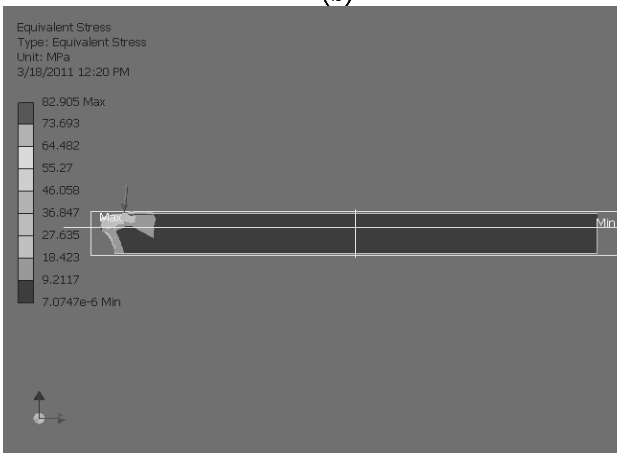
Max
Min

(c)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Max
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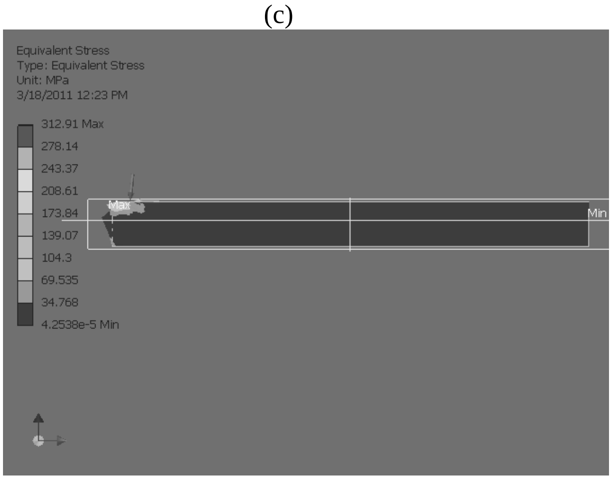
(d)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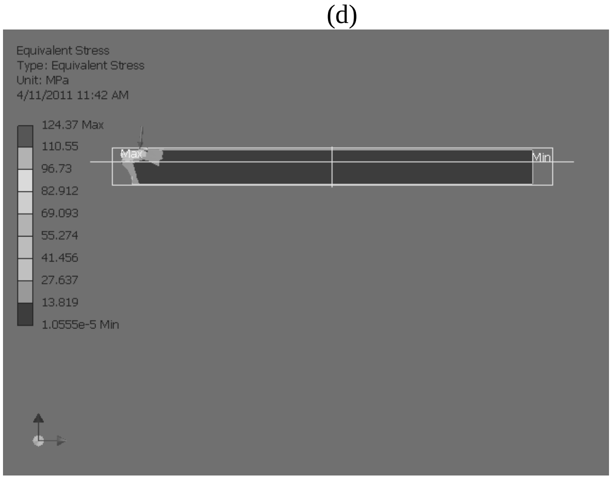
Min

(e)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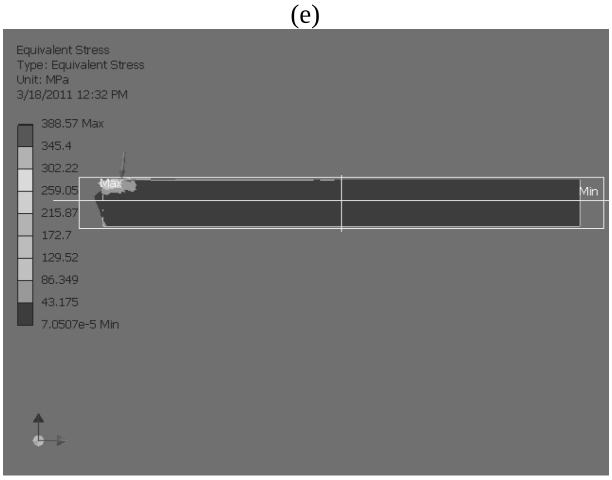
Max
Min

(f)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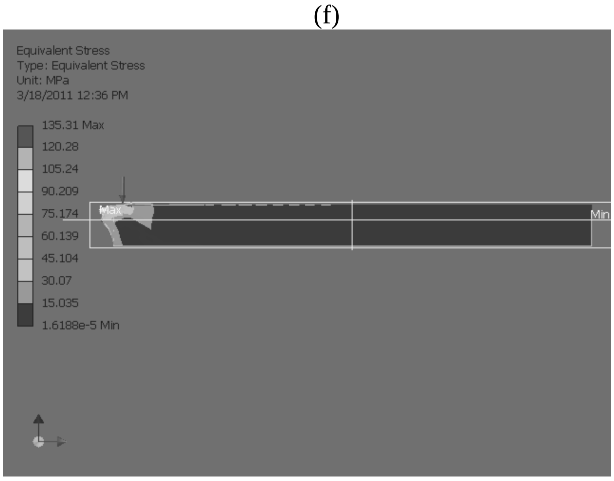
Max
Min

(g)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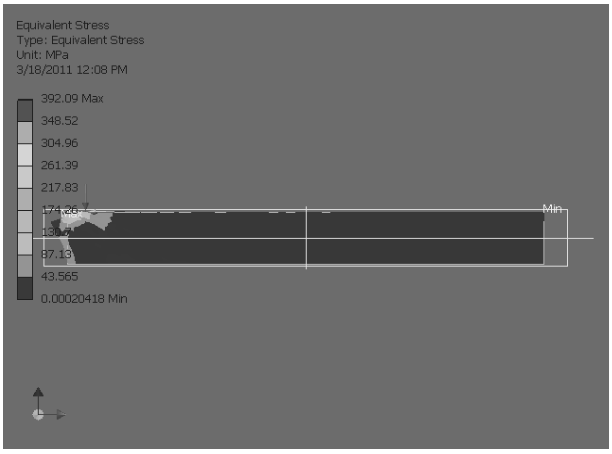
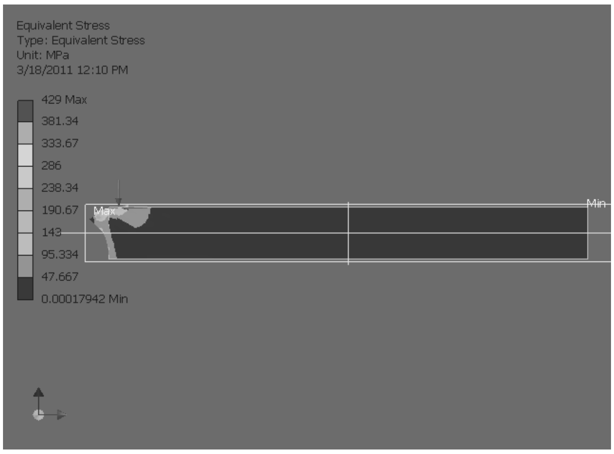
Min

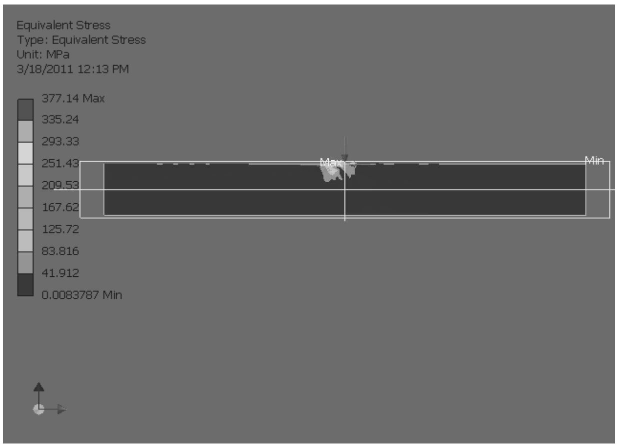
(h)



(i)



(j)



(k)

Fig 1. Equivalent stress analysis results with 5^0 orthogonal rake angle tool at (a) 15^0 exit edge bevel angle at a distance of 3.464 mm, (b) 15^0 exit edge bevel angle at a distance of 1.732 mm, (c) 20^0 exit edge bevel angle at a distance of 3.464 mm, (d) 20^0 exit edge bevel angle at a distance of 1.732 mm, (e) 25^0 exit edge bevel angle at a distance of 3.464 mm, (f) 25^0 exit edge bevel angle at a distance of 1.732 mm, (g) 30^0 exit edge bevel angle at a distance of 3.464 mm, (h) 30^0 exit edge bevel angle at a distance of 1.732 mm, (i) without exit edge bevel at a distance of 3.464 mm, (j) without exit edge bevel at a distance of 1.732 mm and (k) at a distance of 45 mm from exit end.

5. CONCLUSION

From this investigation on burr formation in orthogonal shaping of 45C8 steel flats under dry condition, following conclusions may be drawn;

(1) Minimum burr is observed at 15^0 exit edge bevel angle at all machining conditions. This may be due to less requirement of back up support material at the exit bevel edge of the workpiece with decreasing depth of cut that requires less cutting force.

(2) Stress analysis through FEM shows that the amount of stress at 15° edge bevel and close to the exit edge is remarkably less than that without exit edge bevel for +5° rake angle. It validates the experimental findings of negligible burr formation at exit edge bevel of 15°.

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