Burr formation and shear strain field evolution studies during sheet metal blanking

Jyotiranjan Barik, Vijayalaxmi Sonkamble and K Narasimhan
Department of Metallurgical Engineering & Materials Science
Indian Institute of Technology Bombay, Mumbai, Maharashtra – 400076, India

nara@iitb.ac.in

Abstract: Sheet metal blanking is an industrial process widely used in automotive, electronics, aerospace and several other industrial applications. Burrs are the hard and sharp-raised edges formed at the cut edge of the blank during blanking process. Presence of a burr reduces the quality, accuracy and usability of the blank. So, it has to be removed by further processing like machining or deburring, which further increases the cost of production. Choosing proper process and geometric parameters can reduce the extent of burr. In this paper, finite element simulations of the blanking process for AA6082-T6 were carried out using the ABAQUS-CAE software package with various process and geometric parameters. Design of experiments (DoE) methodology was applied to understand the effects of the process and geometric parameters on the burr formation during blanking of metal sheets. This effort will not only help to optimize the blanking process, but also to increase the product quality and reduce the cost of production. Typical pattern of shear strain field evolved at various punch penetrations of sheet metal blanking is being studied.
Keywords: Sheet metal Blanking, Burr, Simulation, FEM, Design of Experiments, Shear strain.

1. Introduction

Sheet metals are extensively used in the manufacturing industries like automobile, aerospace, electronics, etc. Blanking is mostly applied as a primary process to bring down the large rolled sheet into a near-shape of the product. Further other manufacturing processes are used to get the final shape of the product. There is always a demand of less manufacturing time and accurate product dimensions, which ultimately affects the cost and usability of the product. Unwanted burrs are formed at the edges of the blank during blanking. Manufacturers always target to produce blank with a minimum amount of burr. For that, they generally use standard empirical rules. Further, to find the optimum tool setup generally hit and miss methods are being followed, which is very costly and not particularly effective due to limitations of the number of experiments that can be done [1].

Finite element simulations with the help of design of experiments (DoE) can help in this regard to find the optimum set of input parameters [2]. In this paper, blanking simulations are performed with the help of the ABAQUS-CAE/Explicit software package. The Taguchi method is used to find out the best set of parameters and also to get the most influencing parameter for the burr formation.

1.1 The Blanking process

A blanking tool setup consists of a punch, die, and blank holder. The punch pushes the sheet into the die cavity, which produce a cut piece called a blank having the shape of the die contour. Initially, during pushing the sheet into the die, the sheet gets deformed elastically in the clearance region. The sheet tries to roll over and takes the shape of the die edge and punch edge. Initially the outer fibre reaches the yield strength and then the inner fibres. Generally, the sheet beneath the punch starts thinning. During the plastic deformation and thinning stage, the crack nucleation generally starts at the punch edge and at die edge and the two cracks propagates towards each other. When both the cracks meet, the material fails. Mostly ductile shear fracture occurs during blanking after shear deformation [3].

Quality of a blanking is mostly characterized by the quality of the edge. Figure 1 shows a typical edge of a blank, which shows the four characteristic zones as roll over, burnish zone (shear zone), fracture zone and burr height. A good blanking needs to minimize the burr height, rollover,and the fracture depth .

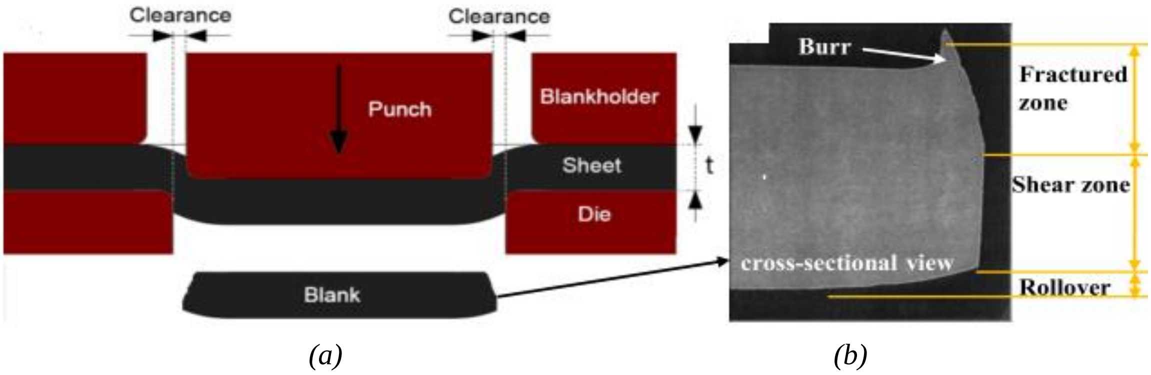


Figure 1. (a) Schematic of sheet metal blanking (b) Front view of sheared edge with different zones [4].

2. Finite Element Simulation

An axi-symmetric 2D model was developed in ABAQUS/explicit as shown in Figure 2. The punch, die and blank holder are considered as rigid bodies while the sheet is considered as elastic-plastic [5]. As from the literature, it was known that clearance, punch edge radius, die edge radius and sheet thickness are some of the major factors which affect the burr height. To understand the effects of these parameters three values of each parameters are taken as shown in Table 1. Taguchi L9 fractional factorial design of experiments is used to make a nine set of parametric combinations as shown in Table 2. The simulations are performed for these nine parametric combinations by reduced integration method [2].

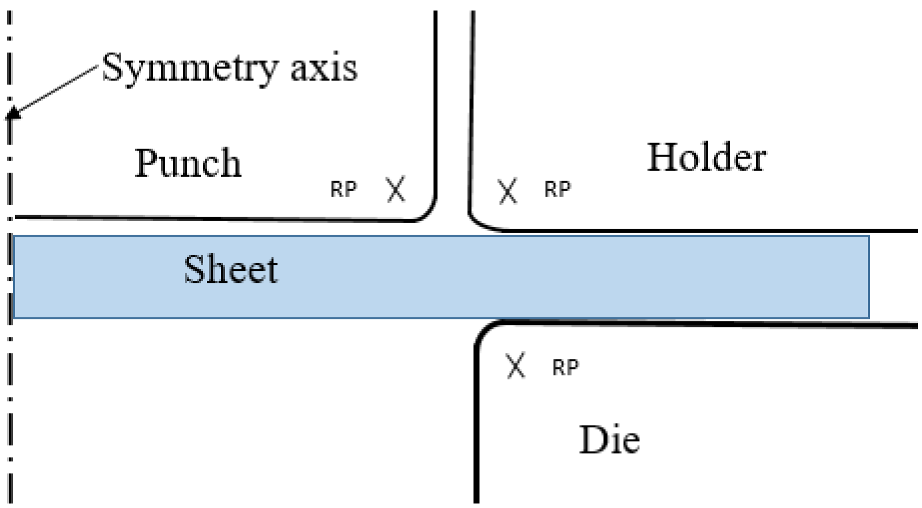


Figure 2. A typical axi-symmetric 2D FEM model.

Table 1. Various Input Parameters.

Parameters	1st value	2nd value	3rd value
Clearance (C) (%)	20	10	5
Punch edge radius(Pr) (mm)	0.25	0.2	0.125
Die edge radius(Dr) (mm)	0.25	0.2	0.125
Sheet Thickness (t) (mm)	1.5	1.2	0.75

It is recognized that the current punch edge and die edge radii are not as sharp as those used in current industrial practice; however, the values selected simplify numerical simulation and represent a first step to modelling this process.

Table 2. Taguchi L9 Design of experiments.

Sr. No.	Clearance (%)	Pr (mm)	Dr (mm)	T (mm)	Burr height (Results) (mm)
1	20	0.25	0.25	1.5	0.231
2	20	0.2	0.2	1.2	0.186
3	20	0.125	0.125	0.75	0.08
4	10	0.25	0.2	0.75	0.0864
5	10	0.2	0.125	1.5	0.165
6	10	0.125	0.125	1.2	0.064
7	5	0.25	0.125	1.2	0.14
8	5	0.2	0.25	0.75	0.136
9	5	0.125	0.2	1.5	0.042

In order to obtain accurate results, a high-density mesh is used at the shearing region (the region between the punch and the die) as shown in Figure 3. 72 elements are taken for the 1.5 mm thick sheet.

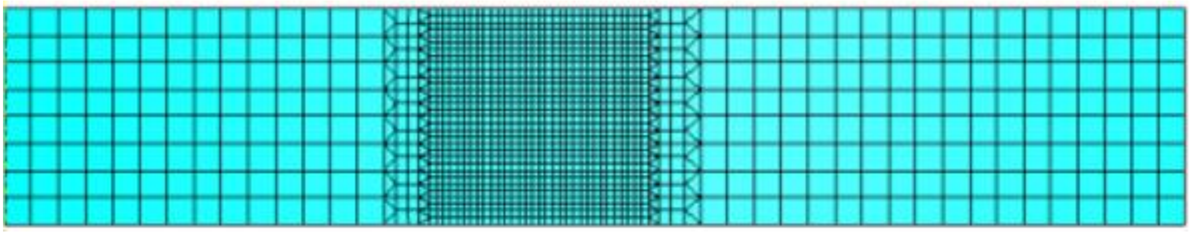


Figure 3. A typical meshing done on sheet for simulation.

2.1. Material model

Here aluminium alloy (AA6082-T6) is taken, whose chemical composition and the tested mechanical properties are given in Tables 3 and 4 respectively.

Table 3. Chemical Composition of AA6082-T6 (wt. %).

Al	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
87.5	1.01	0.31	0.09	0.4	0.61	0.02	0.02	0.03

Table 4. Mechanical Properties of AA6082-T6.

Tensile Strength	Yield Strength	Young's Modulus	Poisson's ratio	Density
330 MPa	300 MPa	70 GPa	0.33	2.71

The material is considered as isotropic, and the plastic behaviour is defined by the von-Mises yield criterion. Isotropic hardening is considered during plastic deformation, and the strain hardening data are taken from the tensile test.

2.1.1. Fracture criterion: In the present work, an inbuilt damage model of ABAQUS is used to simulate the failure (Shear damage model). This shear criterion is a phenomenological model for predicting the onset of damage due to shear band localization. This model in ABAQUS needs three parameters as input, those are equivalent plastic strain at the onset of damage $\bar{\epsilon}^{pl}$, shear stress ratio θ_s, and strain rate $\dot{\bar{\epsilon}}^{pl}$. The model assumes that the equivalent plastic strain at the onset of damage $\bar{\epsilon}^{pl}$, is a function of the shear stress ratio and strain rate: $\bar{\epsilon}^{pl}(\theta_s, \dot{\bar{\epsilon}}^{pl})$. Here the shear stress ratio $\theta_s = (q + \mathrm{k}_s p)/\tau_{max}$, where τ_{max} is the maximum shear stress, and k_s is a material parameter, p is the pressure stress, q is the Mises equivalent stress [6]. The criterion for damage initiation is met when the following condition is satisfied:

$$\omega_s = \int \frac{\mathrm{d}\bar{\epsilon}^{pl}}{\bar{\epsilon}^{pl}(\theta_s, \dot{\bar{\epsilon}}^{pl})} = 1.$$

Figure 4 and 5 shows the punch penetration and how the fracture had occurred in the blank resulting in burr formed.

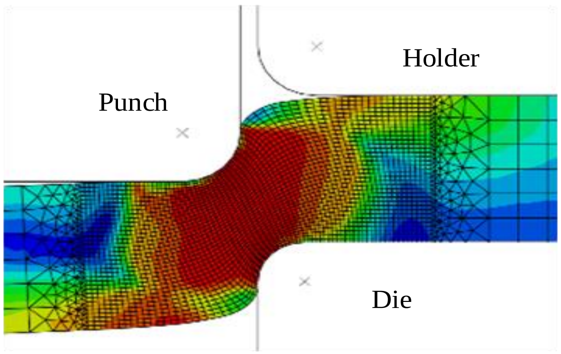


Figure 4. Punch penetration and shearing.

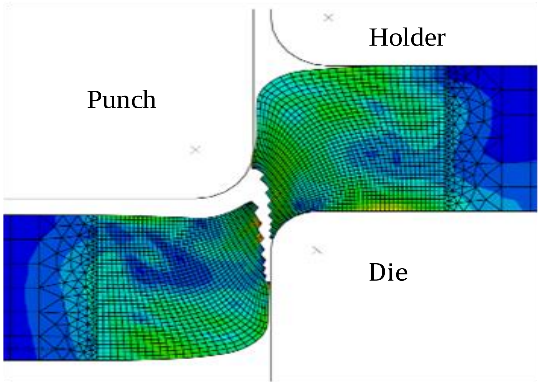


Figure 5. Fracture and separation of blank.

3. Experimental validation

Before proceeding to the detailed work, the validity of the simulation was checked with experimental results. Two sets of punch and die were manufactured from CNC machines. Blanking experiments were performed by fixing the punch and the die through the fixtures in a universal testing machine (UTM) with 100kN capacity. The comparison on simulation and experiment results of burr height is shown in Table 5. The simulation results are found nearly same as that of the experiments. Burr heights was measured with help of a Zeta instrument and Zeta 3D software.

Table 5. Validation of simulation.

Experiment No.	Clearance (mm)	Pr (mm)	Dr (mm)	t (mm)	Burr height (mm) (Experiment)	Burr height (mm) (Simulations)
1	0.075	0.25	0.125	1.2	0.12	0.119
2	0.075	0.2	0.25	0.75	0.146	0.142

4. Results and discussion

The main parameters effect is given in the Figure 6.

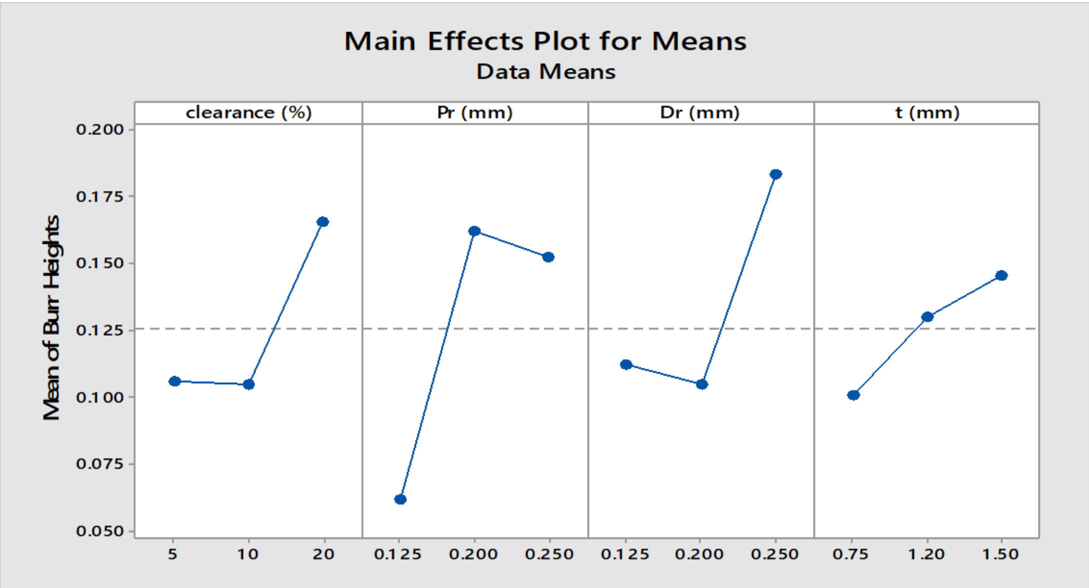


Figure 6. Taguchi analysis showing the variation of burr height in relation to the various input parameters.

With the increase in clearance from 5% to 10%, there is less change in the burr height while there is a drastic increase in the burr height when it changes from 10% to 20%. There is a substantial increment in the burr height by increasing the punch edge radius from 0.125mm to 0.2mm, but after that, it is not affected significantly. Similarly, there is also an increment in the burr height with the increment of die edge radius, but it is significant after the die edge radius of 0.2mm. With the increment in the sheet thickness, there is a continuous increment in the burr height. In general, it was found that a 10% clearance, 0.125 mm punch edge radius, 0.2 mm die edge radius, and 0.75 mm sheet thickness gives the best set of combinations of parameters for minimum burr height.

4.1 ANOVA analysis

Anova analysis is done to find out the percentage contribution of various parameters on the resulting burr height. As shown in Figure 7, the punch edge radius (Pr) has the highest contribution of nearly 50%, while the die edge radius (Dr) has the least contribution. Clearance also has a substantial contribution to the burr height.

IOP Conf. Series: Materials Science and Engineering **418** (2018) 012068 doi:10.1088/1757-899X/418/1/012068

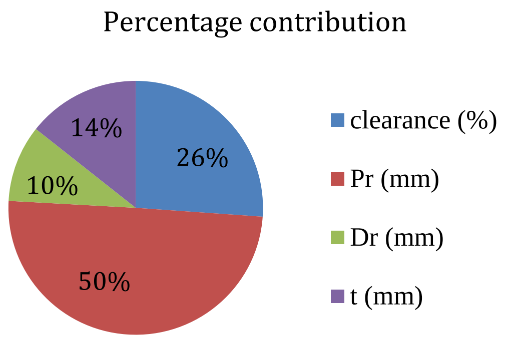
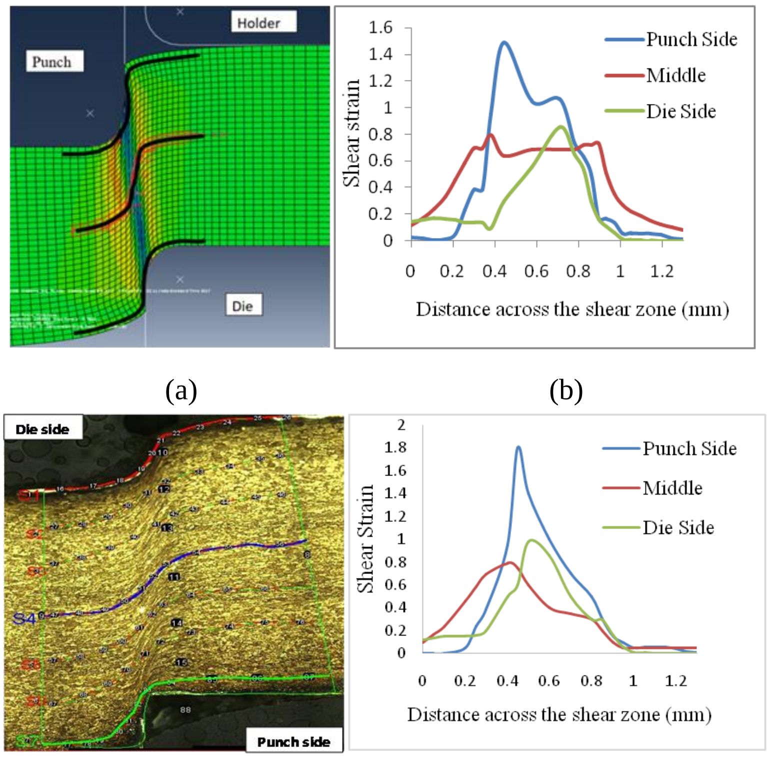


Figure 7. Anova analysis shows the percentage contribution of various parameters on the change in burr height.

4.2 Shear strain field evolution

During punch penetration, shear strain develop near the shear zone. To understand its pattern of evolution, three partial blanking (both experiments and simulations) are done separately. The punch was penetrated up to a known depth of 0.23mm, 0.46 mm, and 0.72 mm into a 1.5 mm thick sheet.



(a) (b)

(c) (d)

Figure 8. (a) Path drawn across the shear zone for the shear strain measurement (Simulation), (b) Distribution of shear strain field across shear zone for 0.72mm punch penetration (Simulation) (c) Path drawn across the shear zone for the shear strain measurement (experiment), (d) Distribution of shear strain field across shear zone for 0.72mm punch penetration (experiment).

Figure 8(a) and Figure 8(c) shows the deformation of the sheet at 0.72mm punch penetration. Three paths are being drawn across the shear zone following the grain rotation, one near the punch edge, one at the middle and the last one near the die edge as shown in Figure 8(a) and Figure 8(c). Figure 8(b) and Figure 8(d) shows the distribution of shear strain along these three paths obtained from experiment and simulations, respectively. Experimentally the shear strain is measured by the grain rotation angles (θ) for the grains in the shear zone. The grain rotation angle (θ) and the shear strain (γ) is related through the expression $\gamma = \tan\theta$. Grain rotation angles are measured from the montage images taken from optical microscopy and stitched in ImageJ software [7, 8].

This results obtained by simulation are compared with the experimental results. It can be clearly seen from both graphs that there is a highest peak of shear strain in the punch side and the lowest peak at the centre line of the sheet. This distribution is due to the punch edge and the die edge radius shapes that gives a peak strain. As a result the crack generally initiates first from the punch side and later at the die side. But in the middle, there is no sudden rise or fall of shear strain. The peak shear strain near to the die edge is slightly at the right side relative to punch side, probably because of the relative position of the die edge compared to the punch edge.

Figure 9 shows the comparison between simulation and experimental values of maximum shear strain obtained at various punch penetrations. The shear strain is strongly localized at punch edge and continuously increases with an increase in punch penetration. All the shear strain values are in good agreement with the experimental results. The maximum shear strain values at the punch increases drastically, so it enhances the probability of the initiation of damage.

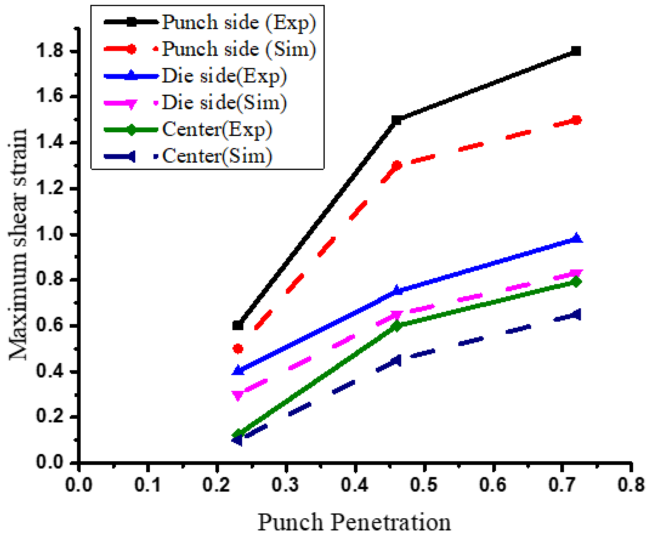


Figure 9. Comparison of peak shear strain obtained during simulations and experiments.

5. Conclusion

Finite element simulation of blanking provides platform to understand the effect of various input geometric parameters like clearance, punch edge radius, die edge radius and sheet thickness, etc. on burr height in comparison to experimental methods. In combination with design of experiments and ANOVA analysis, we can get a better understanding of the sensitivity of various parameters. Burr height is highly sensitive towards the change in punch edge radius and clearance. Overall an increase in punch edge radius and clearance increases the burr height. The Pattern of shear strain field evolution across the shear zone shows the probability of occurrence of fracture initiation near the punch side.

IOP Conf. Series: Materials Science and Engineering **418** (2018) 012068 doi:10.1088/1757-899X/418/1/012068

References

[1] Taupin, E. et al. 1996 'Material fracture and burr formation in blanking results of FEM simulations and comparison with experiments', *Journal of Materials Processing Technology*, **59(1–2)**, pp. 68–78.
[2] Hambli, R., 2002. Design of experiment based analysis for sheet metal blanking processes optimisation. *The International Journal of Advanced Manufacturing Technology*, ***19*(6),** pp.403-10.
[3] Totre, Amol, Rahul Nishad and SagarBodke. March 2013 "An overview of factors affecting in blanking processes."*International Journal of Emerging Technology and Advanced Engineering*, Volume **3**, Issue 3, pp. 390-395.
[4] L. Bohdal, L. Kukielka, K. Kukielka, A. Kulakowska, L. Malag and R. Patyk, 2014 "Three-dimensional finite element simulation of sheet metal blanking process," *Appl. Mech. Mater.*, vol. **474**, pp. 430–35,
[5] Söderberg, Magnus. 2006 "Finite element simulation of punching.". ISSN:1402-1617
[6] Version, A. B. A. Q. U. S. 6.13, 2013 Analysis User's Manual. *Dassault Systemes Simulia Corp., Providence, RI*, 24.2.2.
[7] Chen, Z. H., Chan, L. C., Lee, T. C., & Tang, C. Y. 2003. An investigation on the formation and propagation of shear band in fine-blanking process. *Journal of materials processing technology*, ***138*(1-3),** 610-614.
[8] Cho, K. M., Lee, S., Nutt, S. R., & Duffy, J. 1993. Adiabatic shear band formation during dynamic torsional deformation of an HY-100 steel. *Acta metallurgica et materialia*, ***41*(3),** 923-932.