NUMERICAL STUDY ON THE BURR FORMATION IN BLANKING PROCESSES

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Abstract

Shear cutting operations, such as blanking, are critical in forming technology but often oversimplified in FE simulations, reducing predictive accuracy for cut edge quality. This study evaluates three failure modelling approaches for a FE model of DC04: the modified porous Gurson model and the Johnson-Cook model with element deletion and mesh separation. Experimental validation of the cutting characteristics rollover, burnish, fracture and burr showed that the JC model with mesh separation produced the most accurate results, with up to 99.86 % certainty. Based on this validated model, a factorial parameter study identified punch radius and sheet thickness as the dominant factors influencing burr height, while die radius and clearance exhibited minor effects. Numerical investigations of alternative blanking processes demonstrated that fine-blanking, counter-blanking and notch-blanking produced burr-free cuts, while hollow-blanking and two-stage blanking showed a less strong influence. These results confirm the capability of validated FE simulations for process optimisation.

Keywords: DC04, shear cutting, numerical simulation, effect analysis, fine cutting

1. INTRODUCTION

Deep drawing is one of the most important processes in forming technology due to its high cost-effectiveness. In Germany, more than half of the 290 million components in a car body were shaped using deep drawing [1]. Shear cutting operations are frequently used in addition to the usual deep drawing operations and are therefore an essential part of the production process [2]. The two most used shear cutting operations are blanking and punching. Blanking is the process of seperating a piece of material, subsequently called the blank, from the surrounding scrap. Punching is similar to blanking, except the cut-out material is considered scrap [3]. Using finite element (FE) simulation offers various advantages, such as reducing the time and cost of developing a production process. However, shear cutting operations are often neglected in FE simulations due to their dependence on modelling material failure behaviour, and are therefore simplified using a Boolean operation [4]. In order to take the entire production process into account, shear cutting operations also need to be simulated. To get accurate cutting characteristics, such as the burr height, it is essential to use a correct failure model and to validate the simulation. In this paper, three different failure modelling approaches are used for a FE simulation of a blanking process and compared with an experiment regarding the cutting characteristics. A numerical effect analysis of geometrical parameters on the burr height was performed using the failure modell with the highest agreement. Finally a study varying the blanking process is presented and analysed.

2. MATERIALS AND METHODS

An industrial blanking tool was considered for the numerical modelling of a shear cutting process. The punch diameter and radius were 27.92 mm and 0.1 mm, the die diameter and radius 28.08 mm and 0.1 mm. A sheet metal with a diameter of 36 mm and a thickness of 0.8 mm was used. Therefore the clearence was 10 % or 0.08 mm. The previously designed CAD files were simplified and used to create a rotationally symmetric 2D FE model in Simfact Forming 2024-4. The sheet metal was meshed using an advancing front algorithm and

quad elements with a size of 0.01 mm. A remesher was triggered when the accumulated plastic strain reached a value of 0.4. The die was fixed in all room directions, while the punch and the downholder had moving boundary conditions in z-direction: A downholder force of 5 kN and a forming speed of 0.5 mm/s were applied until the blank was seperated from the scrap. For the contact and friction between the sheet metal and the tools, a surface-to-surface contact and Coulomb's law with a friction coefficient of 0.9 were used. **Figures 1 (A)** and **(B)** are showing the FE model with its corresponding boundary conditions in 3D and 2D. The punch, die, downholder and sheet metal are visible. The models were analysed using the "Paradiso Direct Sparse Solver".

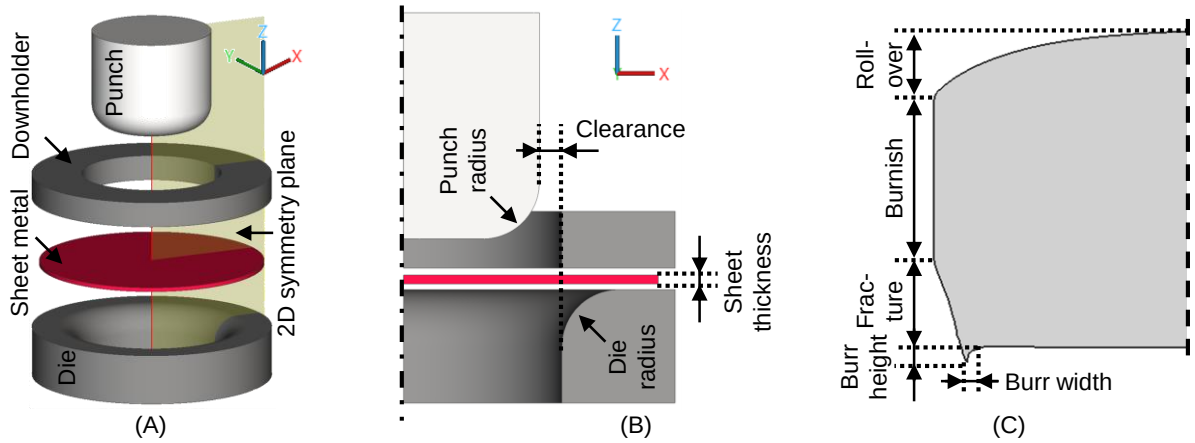

Figure 1 FE model of the blanking process in 3D (A) as well as 2D (B) and cutting characteristics (C)

A DC04 material was chosen for the sheet metal. The material behaviour was modelled elasto-plastically with conventional values of steel: density 7.85 E-9 ton/mm^3, Young's modulus 210 GPa and Poisson's ratio 0.3. To model the flow behaviour, the Swift approach [5] was used with parameters from Isik et al. shown in **Table 1** [6]. The modified porous Gurson failure model [7] was implemented for the failure behaviour, with coefficients from Isik et al. [8]. To compare the failure modelling, the Johnson-Cook (JC) failure model was also considered [9]. Therefore, the GISSMO damage model was added with a nonlinear damage exponent [10]. The JC model parameters were previously determined and fitted experimentally by Euscher, and are also shown in **Table 1**. For further comparison both an element deletion and a mesh seperation algorithm were used. The Gurson failure model describes the cause of material failure as initial voidage, void nucleation and growth within the material. In contrast, the JC model defines failure as a crack based on a critical plastic strain as a function of the stress state. The tools were modelled as rigid bodies.

Table 1 Material properties of the used DC04

Swift hardening model			**GISSMO**	**JC failure model**			
K in MPa	ε_0	n	n_D	D_1	D_2	D_3	
619	0.00939	0.296	2	0.02	3.45	-0.9	
Gurson failure model							
f_0	q_1	q_2	f_N	s_N	e^P_N	f_c	f_f
0.000269	1.5	1	0.003273	0.1	0.03	0.15	0.25

Experimental tests were carried out and in order to compare the suitability of the various failure models for the DC04 and to validate the FE simulation. The blanking tool was utillised in a transfer press manufactured by the company Industriewerke Karlsruhe AG (IWK). Experimental parameters were chosen according to the numerical simulation: forming speed of 0.5 mm/s and downholder force of 5 kN. Seven experiments were carried out and cross sections of the blanks and scrap were created on different positions around the cut. To

validate the simulation, the cutting characteristics of the cross sections from the simulations and experiments were measured and compared. The considered cutting characteristics are depicted in **Figure 1 (C)**.

A numerical effects analysis was performed based on the validated FE simulation of the blanking process. A fully factorial statistical test plan was created varying the sheet thickness, punch radius, die radius and clearance. Three values were considered for these geometric parameters, as also shown in **Figure 1 (B)**, resulting in 81 FE simulation variants. The studied values for the geometrical parameters, shown in **Table 2**, were chosen based on the materials processed and components manufactured by Euscher. Finally, the effect of each value on the burr height while blanking was studied.

Table 2 Values of the geometrical parameters studied in the effect analysis

Punch radius in mm	Die radius in mm	Clearance in %	Sheet thickness in mm
0.01; 0.05; 0.1	0.01; 0.05; 0.1	1; 5; 10	0.5; 0.8; 1.5

In a further investigation a conventional blanking process was compared with fine-blanking, hollow-blanking, counter-blanking, notch-blanking and two-stage blanking. Unless otherwise specified, the same parameters were used as in the conventional blanking process. First, the fine-blanking process was considered. In conventional blanking, punch and die radii of about 0.1 mm and a clearance between 5-10 % of the sheet thickness are used. Fine blanking uses a downholder with a ring tooth, small punch and die radii of up to 0.01 mm, a small clearence of about 0.5-1.5 % of the sheet thickness and a counterholder [11]. These modifications are introducing compressive stresses into the shear-affected zone, resulting in a larger burnish. In this study, punch and die radii of 0.01 mm and a clearence of 0.08 mm or 1 % were used as shown in **Figure 2 (A)**. The forces of the counterholder and of the downholder with the ring tooth were 1 kN and 30 kN.

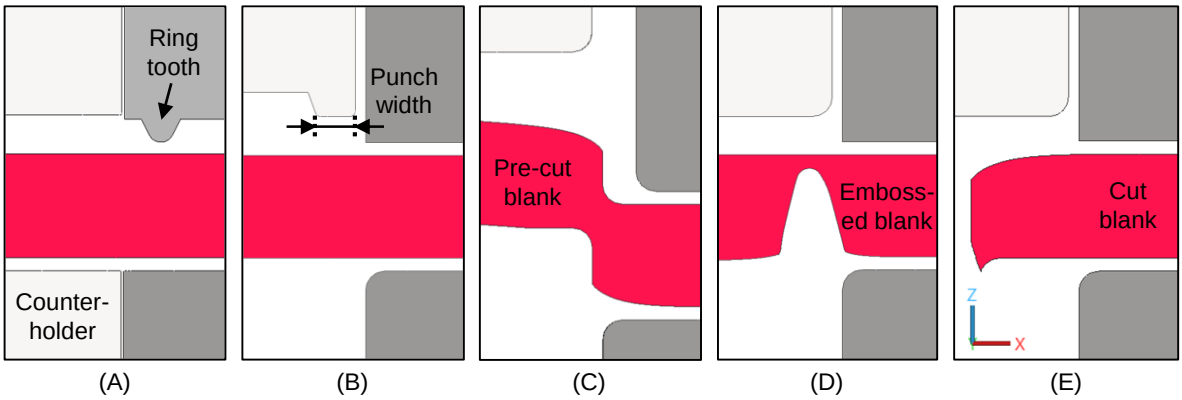

Figure 2 2D FE models of fine-blanking (A), hollow-blanking (B), counter-blanking (C), notch-blanking (D) and two-stage blanking (E)

Hollow-blanking is a conventional shearing process that uses a punch with a concave design [12]. Similar to fine-blanking, it creates compressive stresses in the shear-affected zone, resulting in a larger burnish. A punch radius of 0.05 mm and punch width of 0.3 mm were used as shown in **Figure 2 (B)**. In counter-blanking, the blank is cut by shearing in several stages, with at least one reversal of the cutting direction to avoid burr formation [13]. In two-stage counter-blanking, the blank is first cut in one direction to form a radius in the sheet metal, and is then separated by forming in the other direction, as depicted in **Figure 2 (C)**. For this investigation, the blank was pre-cut to a remaining thickness of about 0.3 mm. In notch-blanking, a notch is pressed into the sheet metal. The blank is then cut with a conventional shearing process at the notch position, against the prior forming direction, as indicated in **Figure 2 (D)**. The notch reduces the formability of the sheet metal, resulting in a burr-free cut [14]. In this case, the blank was embossed with a punch radius of 0.1 mm reducing the remaning thickness to about 0.1 mm. The aim of two-stage blanking is to reduce edge cracking

and improve the formability of the shear cut edge [15]. After an conventional shear cut, the damaged shear-affected zone is cut off in the second stage, as shown in **Figure 2 (E)**. This leaves only minimal deformation in the final edge. For this study, about 1 mm of the prior cut blank was removed in the second stage.

3. RESULTS AND DISCUSSION

3.1 Comparison between simulation and experiment

Figure 3 (A) depicts the cross section of a blank and a scrap. The average cutting characteristics from seven blanks are: 0.237 mm rollover, 0.481 mm burnish, 0.083 mm fracture, 0.129 mm burr height and 0.152 mm burr width. **Figures 3 (B)**, **(C)** and **(D)** are showing the FE results for the Gurson and JC failure models with element deletion as well as the JC failure Model with mesh separation. Although the shear-affected zones of the three variants look similar, the differences between the failure models are visible on closer inspection. While the Gurson model replicates the experimental cross section well, it removes a few elements resulting in a rougher fracture compared to the experiment. The JC model with element deletion removes more elements than the Gurson model. Hence, the fracture is smoother, but the burnish and the fracture are not well predicted. Since no elements are deleted, the JC model with mesh separation produces a proper burnish and a smooth fracture. **Figure 3 (E)** shows a comparison of the cutting characteristics. The average values of the experiments with minimum and maximum values of seven blanks are depicted next to the three simulation variants. The simulation using the JC failure model combined with mesh separation matches the experiment best, all the results are within the minimum and maximum differences. The rollover differs about 0.91 %, the burnish 3.26 %, the fracture 15.75 %, the burr height 10.32 % and width 1.8 %. The degrees of certainty for the simulation variants using Gurson, JC with element deletion, and JC with mesh separation are 99.68 %, 95.26 % and 99.86 %. Therefore, the JC model with mesh separation was used for further investigations.

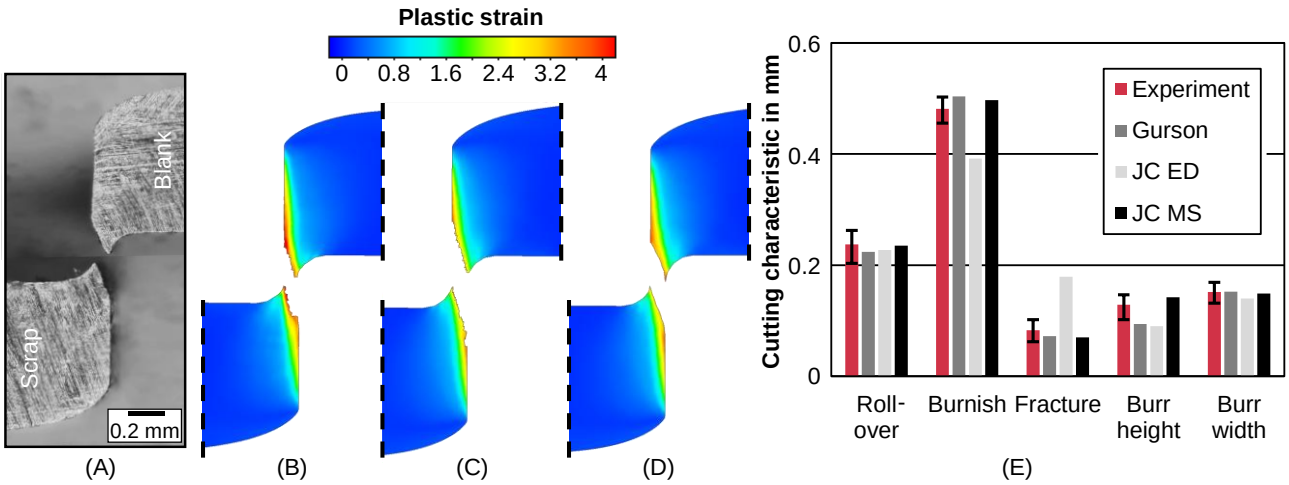

Figure 3 Cross section of a cut (A), FE results using the failure model according to Gurson (B), JC element deletion (C) as well as JC mesh separation (D) and comparison of the cutting characteristics (E)

3.2 Effect analysis on the burr height

Figure 4 shows the main effect diagram of the burr height. Each point of the diagram is calculated as the average burr height of all associated simulations. Consequently, 27 of the 81 simulations were used to calculate each point. The effect strength is represented by the slope of the graphs. Clearly, the punch radius has the highest impact on the burr height. The burr height rises from 0.0068 mm to 0.0888 mm for an increase of the punch radius from 0.01 mm to 0.1 mm. The influence of the die radius is comparatively smaller: the burr height only rises from 0.0407 mm to 0.0524 mm for the die radii 0.01 mm and 0.1 mm. Likewise, the clearance changes the burr height slightly. It rises from 0.0419 mm to 0.0543 mm for clearances of 1 % and 10 %. The

sheet thickness shows contrary correlation as before. The burr height is reduced from 0.0750 mm to 0.0244 mm increasing the sheet thickness from 0.5 mm to 1.5 mm, indicating a high influence of the sheet thickness. In addition, the interaction diagram of the burr height was considered. It illustrates the influence of a parameter on the level of another parameter and showed mostly parallel lines. Therefore, there are no significant effects between the geometrical parameters.

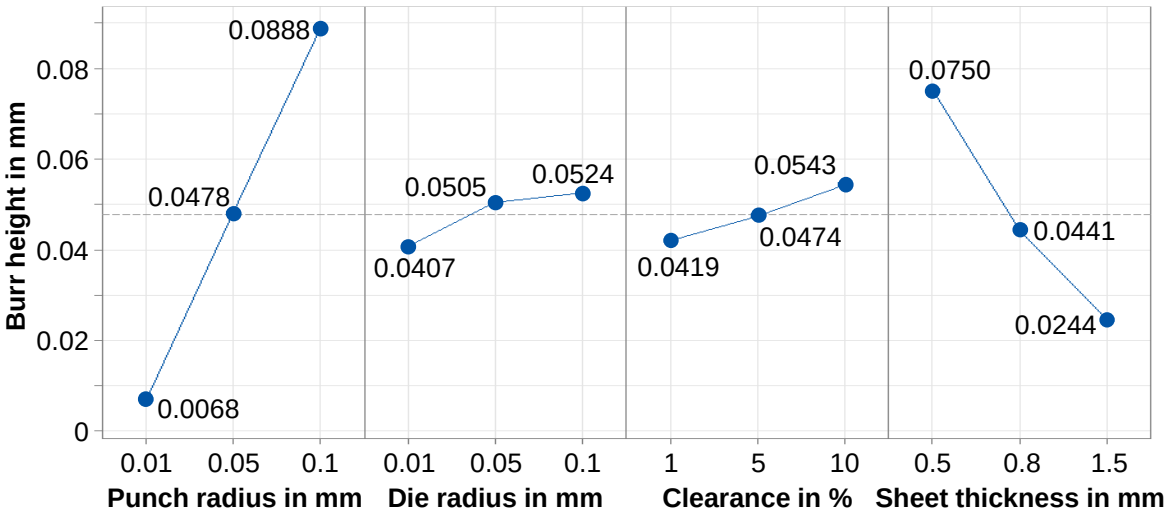

Figure 4 Main effect diagram for the burr height

3.3 Comparison of different blanking processes

The numerical study of the blanking process is depicted in **Figure 5**. Comparing the conventional blanking process in **Figure 5 (A)** with the fine-blanking in **Figure 5 (B)** the impact of the small clearance, the small radii, the ring tooth and the counterholder on the characteristics of the blank is clearly noticeable. Fracture height and burr height are both reduced significantly: fracture height by 100 %, from 0.07 mm to 0 mm, and burr height by 92.96 %, from 0.142 mm to 0.01 mm. At the same time, the burnish height increases by 48.69 %, from 0.497 mm to 0.739 mm. Compared to hollow-blanking, shown in **Figure 5 (C)**, the effect of the compressive stresses in the shear-affected zone is less distinct. Burnish and fracture are increased by 4.02 % to 0.517 mm, and by 71.43 % to 0.12 mm. The burr height is decreased by 26.06 % to 0.105 mm. Counter-blanking and notch-blanking are creating burr-free blanks as indicated in **Figure 5 (D)** and **Figure 5 (E)**. In this study, the two-stage blanking, as depicted in **Figure 5 (F)**, increased the burnish by 13.28 % to 0.563 mm. It also reduced the fracture and burr height by 1.43 % to 0.069 mm and by 18.31 %.to 0.116 mm.

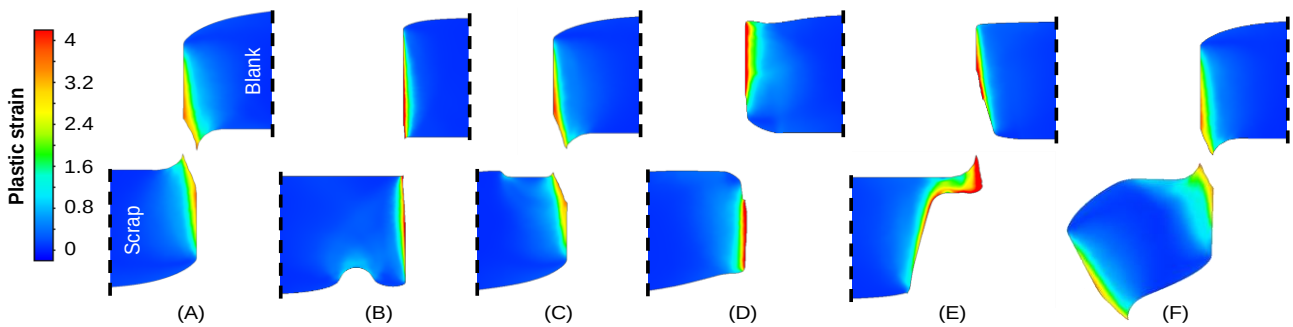

Figure 5 FE results for the conventional blanking (A), fine-blanking (B), hollow-blanking (C), counter-blanking (D), notch-blanking (E) and two-stage blanking (F)

4. CONCLUSION

The investigation confirmed that the accuracy of shear cutting simulations strongly depends on the implemented failure model. Among the tested approaches, the Johnson-Cook model combined with mesh separation produced the most accurate predictions of rollover, burnish, fracture and burr for DC04, compared to experimental blanking results. This validated modelling framework enabled a systematic parameter analysis, demonstrating that burr height is primarily governed by punch radius and sheet thickness, while die radius and clearance exert only secondary effects. Furthermore, the comparative assessment of process variants established that fine-blanking, counter-blanking and notch-blanking substantially suppress burr formation. These findings highlight the potential of physically motivated and experimentally validated FE models to replace oversimplified Boolean operations, thereby enabling the predictive simulation of shear cutting.

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