Influence of height and location of V-ring indenter on Void Volume Fraction variations during fine blanking process

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Abstract

In this paper a finite element simulation of fine blanking process has been demonstrated. The commercial finite element code ABAQUS has been used to simulate the large deformation in punch/die interaction area while a user written visual FORTRAN program has been developed to calculate the variations of void volume fraction (VVF) and incorporate it into crack initiation by specifying the crack propagation time. To prevent element distortion at the crack tip, the finite element mesh is locally remeshed. After each remeshing, the program maps solutions from the previous deformed mesh to the new model. The value of VVF at each element is obtained from Gurson\textsuperscript{[1]} and Tvergaard damage model.

Since the height and location of V-ring indenter have a great influence on the fine blanking process conditions, in the present research work, comparisons are made for different V-ring locations and heights. Describing the variations of VVF would lead to estimate crack initiation time and consequently the quality of sheared surface.

Keywords: Fine blanking, Finite elements, Void volume fraction, Gurson-Tvergaard damage model, V-ring, Remeshing, Solution map.

1 Introduction

Blanking process is mainly divided into two categories: conventional and fine blanking processes. Figure\textsuperscript{1} shows a comparison of sheared surface for two typical engineering products which have been produced by the conventional and fine blanking processes.

The main technological differences between fine and conventional blanking can be summarized as follows:

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1) Small clearance between die and punch
2) V-ring indentation that creates hydrostatic pressure and prevents premature fracture.
3) Application of counterforce punch that prevents ‘dishing’.

The existence of all the above mentioned features in the fine blanking process can create a narrow shear straining band, provided that compressive hydrostatic pressure is present. As a result, a straighter crack growth path is obtained. Furthermore the production of parts with close dimensional tolerances and higher sheared surface quality is possible.

In this paper the numerical studies of the simulations carried out for fine blanking process is presented and a ductile fracture oriented finite element procedure is used. The commercial finite element code ABAQUS along with a user written program in FORTRAN language has been employed to conduct the simulation of shearing process. The FORTRAN program controls the boundary conditions in each ABAQUS job during the load/displacement increments based on Gurson [1] and Tvergaard [2] damage model. Comparison of VVF variations in several conditions based on changing the height and location of V-ring is made and the results are represented as VVF-Punch penetration curve for each condition. Material that is considered in these simulations is steel St44 according to DIN1.0044 steel standard.

2 Literature review
An increasing trend of research studies in the development of both theoretical and experimental aspects of the fine blanking process can be seen in recent years. Chen et al. [3] studied hardness increase in sheared edges. They also showed that punch/die clearance reduction improves the quality of sheared edges [4]. Kwak et al. [5] studied the effect of punch/die clearance, V-ring height and location on the blanking process. They resulted that the burnish [6] zone increases as the V-ring become larger and closer to the punch. In their paper, no study has been reported about an optimum position for V-ring.

Hambli has presented a comparison between Lemaitre [7] and Gurson damage model during blanking process. He did not reach to logical results from Gurson model and concluded that the Lemaitre results are more relevant with experimental results. It should be attended that he did not use remeshing process in his work.

However, very limited attention has been paid to the nature of the shearing process and to numerical simulations of the cutting process in conventional and fine blanking processes.

3 Ductile fracture damage model
Ductile materials fail usually as the result of nucleation, growth and coalescence of microscopic voids that initiate at inclusions and second phases. Figure 2 shows the inclusions in a structural steel and void initiation, propagation and coalescence.
As mentioned above, there are three characteristics of the micro-separation mechanisms of ductile fracture. The first of them is the stage of formation of a free surface at an inclusion or second phase particle by either interface decohesion or particle cracking. The second stage, which also involves most of the plastic deformation work, is the growth of void around the particle by means of plastic strain and hydrostatic stress. The third stage in the ductile fracture is the coalescence of the growing void with adjacent voids. Figure 3 shows the first and second stages [9].

Based on an upper-bound solution for deformation around a single spherical void under the assumption of rigid plastic isotropic material, the Gurson yield function [10] which has been modified by Tvergaard is given by

\[
\Phi = \left( \frac{\sigma_{eq}}{\sigma_0} \right)^2 + 2q_1 f_v \cosh \left( \frac{3 q_2 \sigma_{eq}}{2 \sigma_0} \right) - (1 + q_3 f_v^2) 
\]

(1)

The above flow potential \( \Phi \) characterizes the porosity in terms of a single scalar internal variable; \( f_v \) is the void volume fraction. The parameters \( q_1, q_2 \) and \( q_3 \) were introduced by Tvergaard to make the predictions of the Gurson model agree with his numerical studies of materials containing periodically distributed circular cylindrical and spherical voids. A void volume fraction \( f_v = 0 \) implies that the material is virgin. \( f_v = 1 \) implies that the material is fully voided and has no stiffness. According to Tvergaard, the rate of increase of the micro void volume fraction is given by

\[
\dot{f} = \dot{f}_n + \dot{f}_g 
\]

(2)

\( \dot{f}_n \): Nucleation rate of micro voids \quad \dot{f}_g \): Growth rate of micro voids
\[ \dot{f}_s = (1-f_v)T_r(\dot{\varepsilon}_{pl}) \]  

(3)

\[ T_r(\dot{\varepsilon}_{pl}) : \text{First invariant of the plastic strain rate tensor} \]

\[ \dot{f}_s = \left( \frac{f_N}{S_N\sqrt{2\pi}} \right) \exp \left[ -\frac{1}{2} \left( \frac{\varepsilon_{eq} - \varepsilon_N}{S_N} \right)^2 \right] \varepsilon_{eq} \]  

(4)

\[ f_N: \text{Volume fraction of void-forming particles} \]
\[ S_N: \text{Corresponding standard deviation} \]
\[ \varepsilon_N: \text{Mean plastic strain value for void nucleation} \]

Typically, for carbon steel, Gurson damage parameters take the following values:

\[ q_1 = 1.5, \quad q_2 = 1.0, \quad q_3 = 2.52, \quad \varepsilon_N = 0.3, \quad f_N = 0.04, \quad S_N = 0.1 \]

More than the above parameters, the initial VVF should be defined. Initial volume fraction of spherical voids can be calculated from Franklin's formula [10] as follows:

\[ f_0 = 0.054(S\% - \frac{0.001}{Mn\%}) \]  

(5)

This parameter is related to the inclusions of the material which in carbon steels mostly caused by \( S\% \) and \( Mn\% \) elements in the alloyed material. Since St44 is assumed for the FE simulations in this paper, the value of above equation is equal to \( 2.39 \times 10^{-3} \).

4 Finite element simulation

In order to simulate the fine blanking process, a finite element model including a blank, punch, die and blank holder with a V-ring was developed using ABAQUS CAE code. The model is consisted of approximately 2500 elements which vary in size from 0.02mm to 0.18mm. Figure 4 shows the initial mesh that is employed in this simulation.

![Initial mesh that is employed in this simulation](image)

Fig.4. Initial mesh that is employed in this simulation

As the figure illustrates, the element size under V-ring and in the shear zone are refined since they are subjected to the large deformation. In order to prevent element distortion the process is ended after a small time increment, because an over distorted mesh would lead to poor results. A FORTRAN user written program is employed to analyze the results of the FE job with small time increment, defining the outer boundary of the deformed blank and the amount of VVF for each element. As a
result, the program can decide for the next time increment crack length specifying both boundary and inner mesh for the next FE job. The whole process is completed when the crack has extended through the whole thickness of the blank. Figure 5 shows typical mesh distortion under V-ring at the end of an old FE job and remeshing at the beginning of the next time increment FE job (new FE job).

![Figure 5](image)

**Fig.5.** The remeshing under v-ring, (a) at the end an old FE job and, (b) after remeshing, at the beginning of the new FE job.

The most important task in this simulation is transferring the field solutions from an old mesh to the new mesh that contains extended crack length. For this purpose, the field solutions and variables are defined at each integration and nodal points and mapped to the new mesh. New field variables are defined at the integration and nodal points and interpolated from those in the old mesh. This interpolation for field variables such as stress and strain fields may take place using built in map solution function in ABAQUS code. However, this method cannot be used in conjunction with VVF because the recent variable is a material property. In order to solve this problem the so-called FORTRAN program defines the initial VVF for each job as initial condition for each node. These initial values are interpolated from the values in the old mesh.

### 5 Results And Discussion

In this paper, the results of simulation for various conditions of V-ring such as height and distance from die edge in fine blanking process is presented. During the simulation, punch is moved towards the die for a small amount in each small time step. In each time step, values of VVF are calculated. The maximum value of VVF is considered as the VVF value for that penetration time step.

Figure 6 shows the hydrostatic, principle stresses and VVF contour plots for 80% punch penetration. In figure 6, all stresses are in MPa. It can be observed from this figure that for those area that the principle stress is high the hydrostatic stress is low and the VVF value is high.

![Figure 6](image)

**Fig. 6:** The effect of V-ring indenter on (a) VVF, (b) Principle stress and (c) Hydrostatic stress during fine blanking process. V-ring height = 0.3mm, V-ring distance= 0.4mm
Figure 7 and 8 show the variation of VVF values during punch penetration. A V-ring which is located 0.4mm distant from the die edge indents the blank in this figure. The height of the V-ring varies in each curve and indicated in the legend. As it can be seen, a height of 0.3mm for the V-ring results in a very low value of VVF. When V-ring height is reduced to 0.2mm and 0.1mm the condition becomes more sensitive. The effect of V-ring penetration on the increase of principle stress is considerable so the larger V-ring causes more effects on VVF. After 50% of punch penetration the effect of the V-ring height on the hydrostatic stress plays the important role and VVF is increased drastically.

![Graph 1](image1.png)

**Fig.7.** Variations of VVF values during punch penetration for various heights of V-ring, distance of V-ring from matrix edge is 0.4 mm

If the distance of the V-ring is increased from the die edge, the effect of V-ring height becomes less. This could be seen in figure 8. This diagram shows the effect of V-ring height on VVF values when the distance of the V-ring from the die edge is 1.0mm. The plots in this diagram are obviously near to each other; however farer V-ring locations causes lower VVF values.

![Graph 2](image2.png)

**Fig.8.** Variations of VVF values during punch penetration for various heights of V-ring, distance of V-ring from matrix edge is 1.0 mm
Figure 9 shows the effects of V-ring location on variations of VVF values during punch penetration when the height of V-ring is 0.3mm. The VVF values have been obtained for distances of 0.4, 0.7 and 1mm from die edge. As the diagram shows, a distance value of 0.7mm for V-ring location has more effect than 1.0mm. The reason of this phenomenon is that for the closer V-ring location to the die edge, the effect of V-ring on principle stresses is considerable. The effect of V-ring distance from die edge, is not much and the hydrostatic pressure remains relatively constant, and VVF value is decreased.

![Variations of VVF values during punch penetration for various distances of V-ring, height of V-ring is 0.3 mm](image)

Fig.9. Variations of VVF values during punch penetration for various distances of V-ring, height of V-ring is 0.3 mm

Figures 10 and 11 show the principle stress and hydrostatic stress contours, respectively for V-ring distances of 0.7 and 1.0 mm. As it is illustrated in these contour plots, by increasing the V-ring distance to 1mm, the hydrostatic pressure decreases and VVF values increases. This emphasizes the fact that there may be an optimum distance of V-ring from the die edge.

![Contours of principle stress during punch penetration. The distance of V-ring from matrix edge is (a) 0.7, (b) 1.0 mm.](image)

(a)  
(b)
6 Conclusions

In this paper the influences of V-ring height and location have been described. The void volume fraction (VVF) based fracture mechanics has been used to define the crack initiation during the punch penetration in fine blanking process. Generally larger and closer V-ring indenter causes less VVF values. It has been observed in this simulation that the optimum height and location of V-ring is 0.3mm and 1.0mm, respectively.

1. REFERENCES:


[8] “Ductile fracture simulation of structural steel”. Internet: [WWW.CSM.uwe.ac.uk/~gshatil/ductile%20fract%20page.htm]
