Publishing House
AKAPIT

COMPUTER METHODS IN MATERIALS SCIENCE
Informatyka w Technologii Materiałów

Vol. 7, 2007, No. 2

FINITE ELEMENT ANALYSIS OF NODAL RELEASE APPROACH TO MODEL DUCTILE FRACTURE IN METAL SHEETS

BERND-ARNO BEHRENS, KANWAR BIR SIDHU

Institute of Metal Forming and Metal Forming Machines
An der Universität 2, 30823 Garbsen, Germany
sidhu@ifum.uni-hannover.de, http://www.ifum.uni-hannover.de

Abstract

The FE-simulation of ductile fracture processes for discrete crack propagation using nodal release approach is well established for modelling crack in metal sheet. In this method, the crack is assumed to initiate or propagate along the element edges; hence, this way new crack boundary is generated in the FE mesh. Therefore, when a critical value of fracture criterion is reached at a node then that particular node is duplicated having same initial co-ordinates, and hence under subsequent load increment a new crack is generated in the FE-mesh, thus, this way crack is extended by one or more element length per increment.

Therefore, in this paper, a FEM model is presented with an attempt to model ductile fracture using the nodal release approach, which is implemented in commercial FE software - MSC.Marc® together with predefined user-subroutines. Consequently, the ability of this approaches to predict the blanked edge profile are analysed and compared with micrograph from experiments.

Key words: Sheet Metal Forming, Blanking, Ductile fracture, Compact Test specimen, Nodal release, FEM, MSC.Marc®

1. INTRODUCTION

For almost all sheet metal part which goes through manufacturing process has to be cut before it can formed into a specific shape, therefore, in order to achieve fast and high quantity production, blanking process is implemented. An optimised quality of the blanked cut shape depends on various factors such as sheet metal properties, blank shape and cutting tool geometry. Furthermore, the Blank's cut-profile as shown in figure 1 is highly dependent on the cutting tool clearance from the die (Choy, 1996 ; Schmuetsch, 1990).

Numerous researches have been done in order to understand the mechanism of ductile fracture which governs the final shape of the cut-profile (Chang, 1951; Samuel, 1998; Taupin, 1996, Goijaerts, 1998;). However, to describe the ductile fracture occurring in blanking it is very essential to find an appropriate numerical model which is not only capable of simulating the complete blanking process but also capable to predicting the cut-profile with relatively good accuracy (Goijaerts, 1998; Brokken, 1998; Fang, 2002).

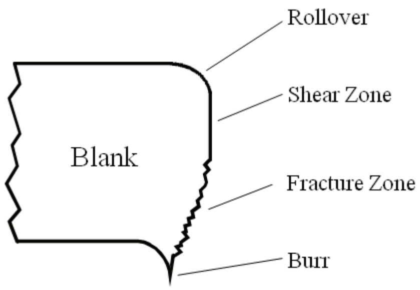

Fig. 1. Cut-profile of the blanked sheet.

Therefore, this paper presents a basic numerical model based on FEM in order to simulate blanking considering the characteristic very large and local

 ISSN 1641-8581

elasto-plastic deformation, and eventually ductile crack which is modelled using nodal release approach.

2. INITIAL SET-UP MODEL

The schematic sketch of the model with boundary conditions is shown in figure 2. A plane strain, 2 - D model of sheet-strip of 25 mm width was implemented in commercial FEM package MSC-Marc®, which makes FE simulations easier for large elasto-plastic deformation with its inbuilt automatic remesher. An isotropic sheet metal of Aluminium Alloy (AlMg3) was taken with its elasto-plastic behaviour described based on criteria from von Mises. The flow curve for this sheet of 1 mm thickness was derived by uniaxial tensile tests, and was further implemented in MSC-Marc®. The tools were modelled as rigid bodies, and velocity of the cutting was assumed to be of 0.1 mm/s; therefore, thermal effects can be ignored.

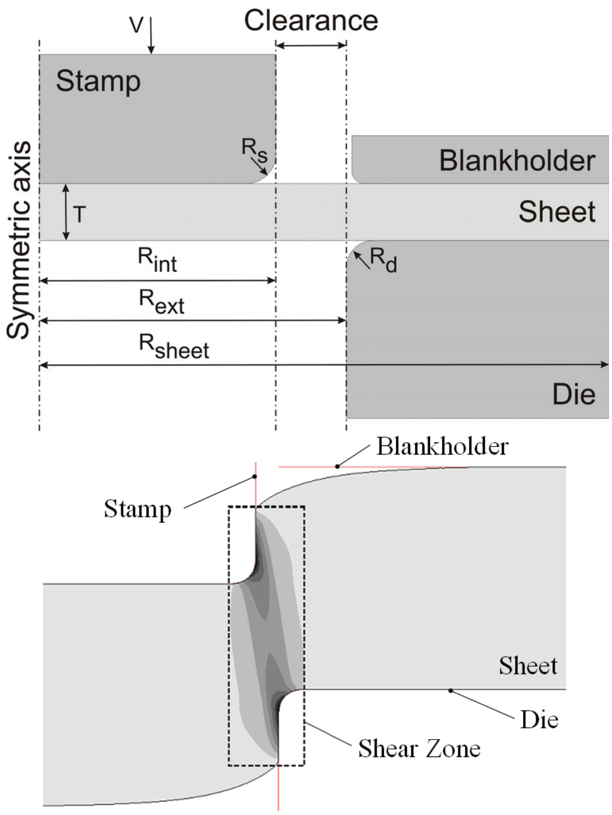

Fig. 2. Plane strain model for blanking (up) and localised sheet deformation (down).

As shown in figure 2, taking the advantage of the symmetry of the set-up, the sheet strip was taken to be of half-length, R_{sheet}, of 32 mm and thickness of 1 mm, and part-A of the sheet is taken to be of length 5 mm as shown in figure 3. The part-A is defined as the remeshing zone with an element length of 0.015 mm. The clearance is taken to be 10 % of sheet thickness, along with Radius of Stamp-edge R_s, as well as Radius of Die-edge R_d taken to be of 0.1 mm as shown in figure 2. In addition, the width of the stamp R_{int} is set to be 25 mm as represented in figure 3.

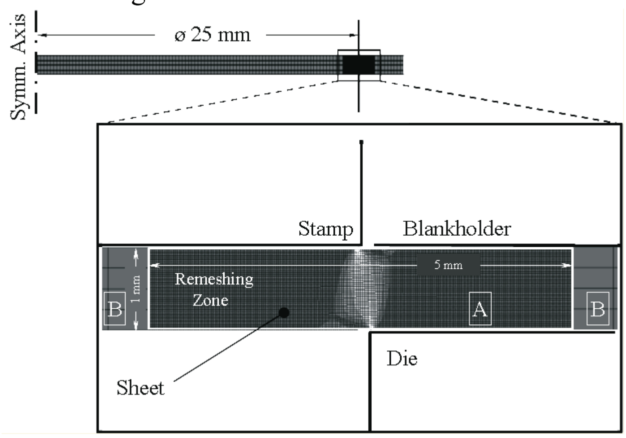

Fig. 3. FE model with Remeshing zone.

3. MODELLING OF DUCTILE FRACTURE

The ductile fracture that leads the final cut-edge of the blanked sheet is shown in figure 1. Hence, in order to predict shape of the typical cut-profile which generally consists of four distinguished zones, it is required to implement appropriate fracture criteria for crack initiation and propagation (Hambli, 2001) However, to find an appropriate fracture criterion is not trivial since the initiation and propagation of crack depends on the growth and coalesces of microscopic-voids of the metal alloy, and the nature of loading. (Dood, 1987; Thomason, 1990)

In order to incorporate the material separation process in FE model, nodal release was implemented in MSC-Marc® using the appropriate user subroutines as shown in flow chart in figure 4. The fracture criterion implemented in this method is based on integral of stress function provide by Oyane et. el (Oyane, 1980) over the plastic strain as given in equation 1. The value of this integral is calculated on the nodes and when the value of this integral gets larger then the threshold value then the crack is extended further. It has been observed that the value of the integral is higher at nodes around the crack-tip. Therefore in order determine the probable direction of the crack, a contour plot of this integral is determined. Hence, based on this information, the approximate path of crack in next increment is determined as presented in figure 5.

$$\int_{\varepsilon_0}^{\varepsilon_n} \left(1 + 3.9 \frac{\sigma_h}{\bar{\sigma}} \right) d\varepsilon_p > C \qquad (1)$$

Where $\frac{\sigma_h}{\bar{\sigma}}$ is the triaxiality which is hydrostatic pressure over equivalent (von Mises) stresses, C are material dependent as well as experiment set-up dependent constants. For blanking process simulated in this paper, the value of C was determined to be 7.7.

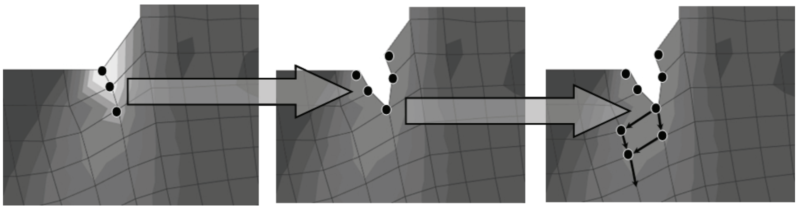

Fig. 5. Concept of nodal release and possible trajectories of crack extension along the element edges.

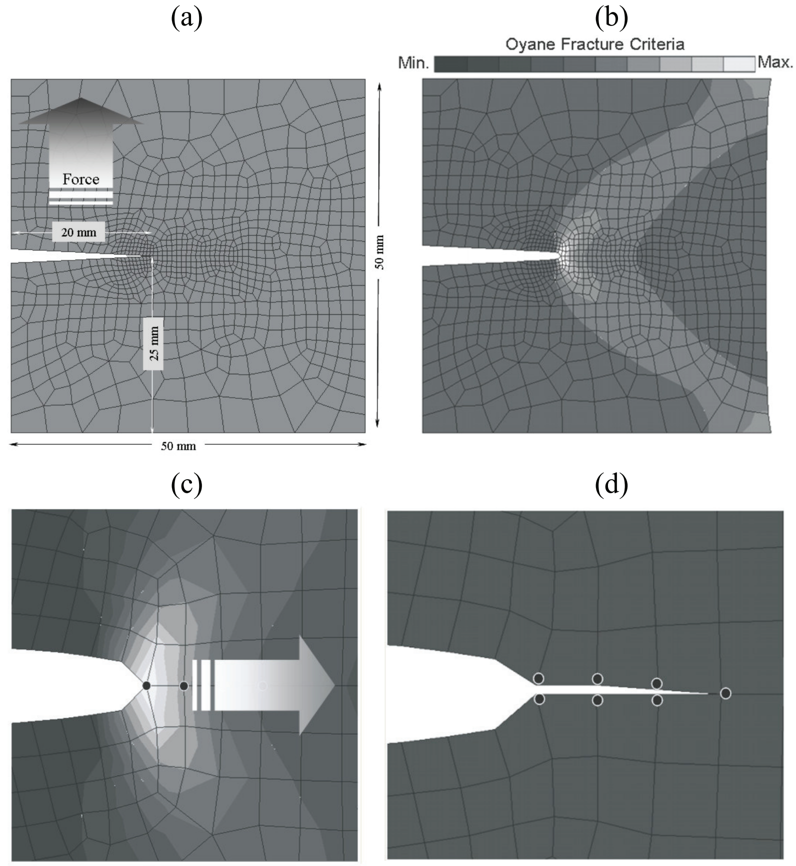

Fig. 6. (a) CT-specimen (b) Deformed till crack initiates (c) Duplicated nodes & Crack direction (d) Crack increment before history variables interpolation.

3.1. Nodal release method

In node release method, the crack is assumed to initiate or propagate at the element edges; hence, a new crack boundary is generated in the FE mesh, as shown in figure 5. Therefore, when a criterion at a node is reached then that node is duplicated and crack is extended further. The advantage of this method is that remeshing can reduced to a greater extend during the crack propagation increments.

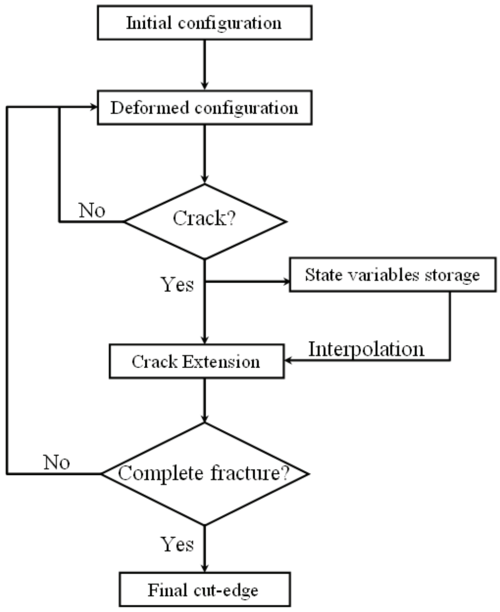

Fig. 4. Flow chart representing the implementation of nodal release method using subroutines.

3.1.1. Compact test specimen

The Compact test specimen *(CT-specimen)* is the standard specimen used to experimentally investigate the fracture behaviour of material as shown in figure 6 a. Since the deformation involved in this specimen was of small degree therefore remeshing was not required, hence it is easier to implement the algorithm for nodal release approach with the subsequent interpolation of history variables from previous increment to current increment. Based on Oyane's fracture criteria the crack propagation increments were implemented. The tensile force was applied perpendicular to the initial cut, and therefore there is mode-I type fracture taking place in CT-specimen where the crack propagation is perpendicular to the applied force figure 6 c. Hence the successful implemented of this approach and developed algorithm shows promising results to simulate ductile fracture taking place in blanking.

3.1.2. Blanking

In case of blanking, the direction of the crack propagation is not known before-hand therefore very fine mesh is required to realistically model crack propagation. Further, in order to determine the critical value of Oyane's integral which would indicate crack initiation and propagation increments, the deformation history of the sheet-strips in FE analysis were compared with experimentally observed results. Hence, it was experimentally found that crack initiates in the Aluminium Alloys sheets at approximately 40-45 % of sheet deformation. Therefore, the value of Oyane's integral determined at this deformation using FE-analysis was assumed to be the critical value for crack initiation and propagation. Hence, as shown in flow chart in figure 4, after every increment further direction of the crack and crack propagation increment is checked using the subroutines if the critical values at the nodes around the vicinity of crack tip are greater than the determined value. With the help of this approach, modelling of ductile crack propagation in sheet during blanking shows relatively good results as shown in figure 7.

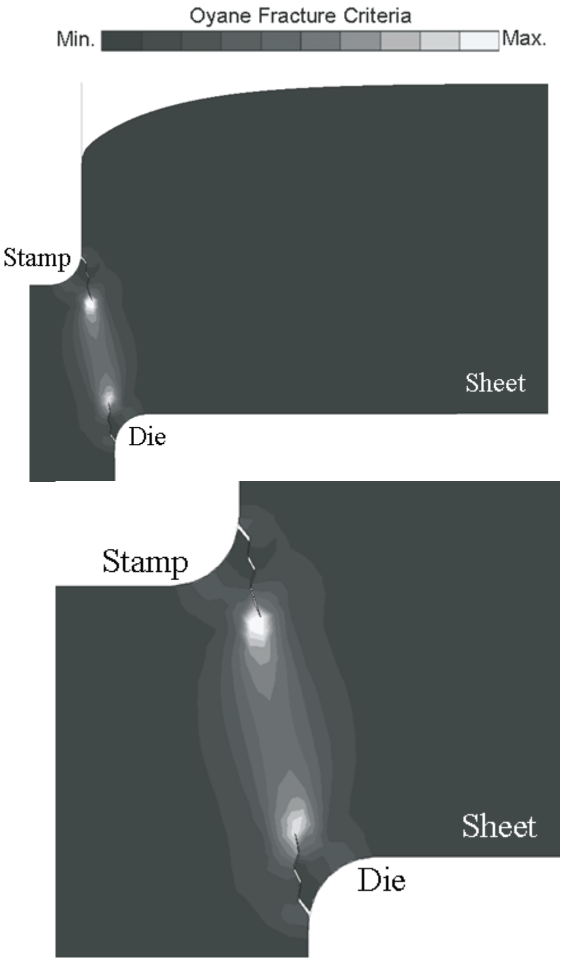

Fig. 7. Modelling ductile crack propagation with Nodal release approach in blanking (zoomed in right).

However, the disadvantage of this method is that a very fine mesh is required to realistically model ductile fracture in blanking. Moreover, the fracture propagation greatly depends on the type FE-mesh as well as the size and shape of the local element near to crack tip.

The prediction of rollover shape at least for Aluminium alloys sheets of 1 mm thickness is fairly well as shown in figure 8. Using the Oyane's fracture criteria and nodal release approach, the sheared edge can also be calculated within the experimentally observed range for 10 % clearances as given in table 1; however the burr height cannot be predicted correctly.

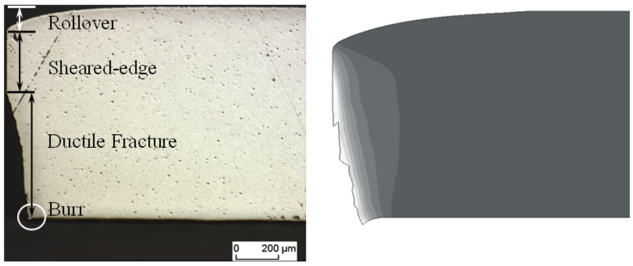

Fig. 8. Comparison micrograph with nodal release approach for blanking simulation.

Table. 1. Comparison of experiment and simulation (mm).

	Experiment	Simulation
Roll Over	0.115	0.152
Sheared Edge	0.284	0.296

4. CONCLUSION AND OUTLOOK

Although the nodal release method is successfully implemented in modelling and simulation of ductile fracture in CT-specimen and blanking, however the crack propagation is still very dependent on mesh type and local element size. Moreover, the requirement of very fine mesh to realistically model ductile fracture in blanking is another disadvantage of this approach. However these limitations are removed by modified nodal release approach in which the nodes near to predicted trajectory of the crack are moved to the new position, as shown in figure 9, and consequently interpolation the history variables is done for new elements.

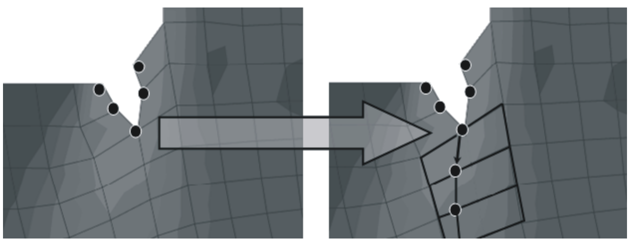

Fig. 9. Concept of modified nodal release with nodes of the element moved to accommodate crack extension.

Another important factor is to identify reliable crack initiation and propagation criteria in order to predict the final cut-profile of the blank. Therefore, a better criteria for ductile fracture based on experimentally observed data should be developed.

Acknowledgements. The authors would like to thank the *"German Research Foundation"* (DFG) for the financial support of the project B8 of Graduiertenkolleg 615 (GRK615).

REFERENCES

Brokken, D., Brekelmans, W. A. M., Baaijens, F. P. T., 1998, Predicting the shape of blanked products: a Finite Element approach, *Int. She. Met. Conference*, Twente, 1, 195-204.

Chang, T. M., 1951, *Shearing of metal blanks*, Inst. of Metals, 78, 393-414.

Choy, C. M., Balendra, R., 1996, Experimental analysis of parameters influencing the sheared-edge profiles, *4th Int. Conference on She. Met.*, Twente, 101-110.

Dood, B., Bai, Y., 1987, *Ductile fracture and ductility – with applications to metalworking*. Academic Press, London.

Fang, G., Zeng, P. Lou, L., 2002, Finite element simulation of the effect of clearance on the forming quality in the blanking process, *Mat. Process. Techn*., 122, 249-254.

Goijaerts, A.M., Stegeman, Y.W., Govaert, L. E., Brokken, D., Brekelmans, W. A. M., Baaijens, F. P. T., 1998, Can a new experimental and numerical study improve metal blanking?, *Int. She. Met. Conf.*, Volume 1, Twente, 185-194.

Goijaerts, A.M., Stegeman, Y.W., Govaert, L. E., Brokken, D., Brekelmans, W. A. M., Baaijens, F. P. T., 1998, A validated FEM model to improve metal blanking, *Simulations of Materials Processing: Theory, Methods and Appl*., Rotterdam, 979-984.

Hambli, R., 2001, Finite element model for fracture prediction during sheet metal blanking process, *Engg. Frac. Mech*., 68, 365-378.

Oyane, M., Sato, T., Okimoto, K., Shima, S., 1980, Criteria for ductile fracture and their applications, *J. Mech. Work. Techn*., 4, 65-81.

Schmuetsch, H.-H., 1990, *Einflussgroessen auf das Schneidergebnis beim Scherschneiden von Feinblechen*, Ph.D thesis, IFUM, University of Hanover,

Samuel, M., 1998, FEM simulations and experimental analysis of parameters of influence in the blanking process, Mat. Proc. Techn., 84, 97-106, (in German).

Taupin, E., Breitling, J., Wu, W-T., Altan, T., 1996, Materials fracture and burr formation in blanking results of FEM simulations and comparison with experiments. *J. Mat. Proc. Techn*., 59, 68-78.

Thomason, P. F., 1990, *Ductile Fracture of Metals*, Pergamon press.

SYMULACJA PROPAGACJI PLASTYCZNEGO PĘKNIĘCIA Z WYKORZYSTANIEM PODEJŚCIA „NODAL RELEASE APPROACH"

Streszczenie

Modelowanie sił plastycznego pękania przy dyskretnej reprezentacji pęknięcia z wykorzystaniem metody elementów skończonych jest powszechnie wykorzystywane w symulacji propagacji pękania w blachach stalowych. Zazwyczaj w MES zakłada się powstanie i propagację pęknięcia wzdłuż krawędzi elementów. Jednak to powoduje powstanie nowej granicy pęknięcia w siatce MES. Dlatego w przypadku kiedy krytyczna wartość pękania w danym węźle jest przekroczona, węzeł zostaje zduplikowany i podczas kolejnych kroków obliczeń nowe pęknięcie inicjalizuję się w siatce MES. W wyniku tego, pęknięcie propaguje się o kilka długości elementów w danym kroku obliczeń.

W niniejszej pracy, zaprezentowane podejście „nodal release approach" wykorzystano do symulacji propagacji plastycznego pęknięcia. Obliczenia wykonano w komercyjnym pakiecie MSC.Marc® wzbogaconym o procedury Autorów. Wyniki uzyskane z symulacji porównano z wynikami eksperymentu.

Submitted: October 3, 2006
Submitted in a revised form: October 25, 2006
Accepted: November 8, 2006