DETERMINATION OF SIMULATION PARAMETERS FOR FRACTURE CRITERION IN SHEARING

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Abstract

The prediction of a fracture in forming processes was analyzed strongly in recent years. A number of material tests for determining a fracture criterion were carried out. This study examines a fracture criterion on the basis of tension and torsion tests. The correct value of the fracture criterion is influenced by forces and fracture areas. Normalized Cockcroft-Latham and Oyane fracture criteria were used for comparison of a simulation and an experiment. Obtained values of the fracture criteria were consequently used in a simulation of the plate shearing. The description of the whole process of the plate shearing covers not only the initiation of a fracture but also the growth of the fracture until the material parts are separated. This issue was solved by means of two numerical methods, the softening and the element deletion. The simulations were performed using DEFORM software based on the finite element method.

Keywords: Fracture criteria, critical damage value, numerical simulation

1. INTRODUCTION

FEM analysis is widely used method for the evaluation of arbitrary metal forming processes. In this paper, the simulations were performed using DEFORM software. The main material characteristic required for the simulation of material's hardening behavior during any process is true stress-strain curve. The most common way to obtain true stress-strain curve is tensile test [1]. The torsion test was utilized for providing the experimental value of a critical value at fracture. In many processes, the critical damage value is defined as forming limit, but in others such as sheering operation, the critical damage value is one of necessary conditions for process. The determination of the critical damage value is dependent on the material being used, the processing methods to produce the material, deformation history, etc. The chemical composition of the tested sheet is listed in **Table 1**.

Table 1 Chemical composition used material

C	Si	Mn	P	S	Cr	Mo	Ni	Cu	Al
0.116	1.580	15.090	<0.005	0.002	0.085	0.124	0.072	0.078	0.380

As	B	Ce	Co	Mg	N	Nb	Pb	Sb	Sn
0.015	0.002	<0.005	0.008			0.022	0.090	0.029	0.008

Ta	La	Ti	V	W	Zn	Zr	Se	Fe	
0.261	0.016	0.003	0.014	0.100		0.015		81.534	

The main task of this work was the calibration used for hydraulic shears where the force is measured by the pressure on incoming pipe only. The fracture in the sheared material was studied by means of two ductile fracture criteria Normalized Cockcroft & Latham and Oyane. The empirical hypothesis is that the ductile fracture occurs when the maximum damage value exceed the critical damage value [2]. The obtained critical damage values were used afterwards in the simulation of plate shearing. The growth of the fracture in the simulation of shearing operation was ensured by means of two methods. The first method was the softening of material data and the second method was the element deletion, both methods are included in DEFORM software. Damage softening is a method by which the flow stress of an element above this critical value will be reduced to a specified percentage. For element deletion, elements which exceed a defined critical damage value are deleted from the mesh in the simulation.

In the end of this study the damage evolution in the sheet was investigated using scanning electron microscopy and indentation approach. Hardness-based damage quantification assumes that the hardness is proportional to the flow stress [3]. In addition, the obtained results are compared with the simulation of shearing process.

2. TENSION AND TORSION TESTS

The samples for the tension test and for the torsion test were made from the tested material. The part of the sample subjected to tension has the length 60 mm and the width 12.5 mm. An extensometer with 25 mm gauge length was used to measure displacement change of the central part of the sample. This uniaxial tension test was used for obtaining load-displacement curves. The shape of true stress-strain curve up to the ultimate tensile strength was directly calculated from these measured curves. The tension test was simultaneously simulated and the true stress-strain curve was fitted by trial-and-error method until the load data from the experiment corresponded well with the simulation. The temperature of the tested material was 20°C and the rate of the sample holder was 0.05 mm/s. The same conditions set during the experiment were for the simulation. The measured load-displacement curves compared with the fitted data from simulation are presented in **Figure 1**. It is evident from the graph that the measured length by extensometer elongated almost 9 mm before the fracture started on the sample.

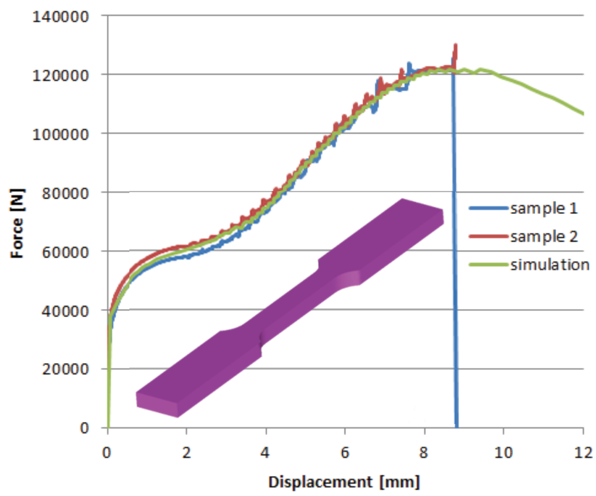

Figure 1 The comparison of measured and simulated tension test

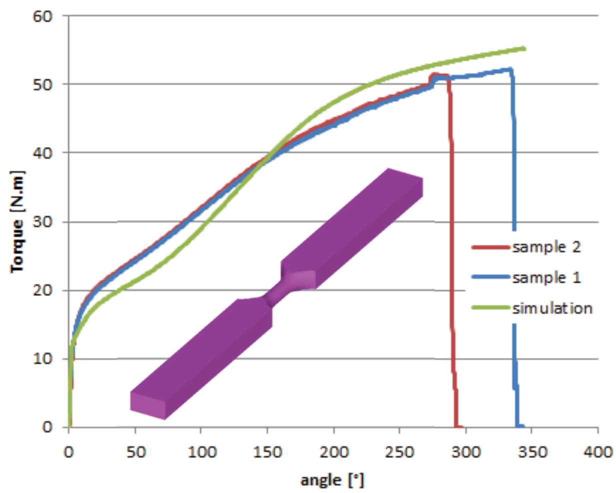

Figure 2 The comparison of measured and simulated torsion test

The sample for torsion test had the length 190 mm, the width 15 mm and the thickness 8 mm. The part of the sample subjected to torsion has the length 10 mm and the diameter 6 mm. The torsion test was carried out and simultaneously the simulation of the test was performed with the same process parameters. The rate of rotation was 2°/s. The material data model for the torsion test simulation was described by true stress-strain curves from the previous tension test. The comparison of measured and simulated torsion test is in **Figure 2**. The torsion angle of tested sample was about 300° when the fracture appeared.

During the simulation of the tension and the torsion test no fracture was included.

3. DETERMINATION OF THE CRITICAL DAMAGE VALUE

The prediction of the fracture site and its propagation depends on the working conditions, i.e. deformation history, state of stress, temperature and strain rate sensitivity, etc. In cold forming many publications are available about the use of damage criteria [4-10]. In this paper were examined two damage criteria Normalized Cockcroft & Latham (NCL) and Oyane. Damage is a cumulative parameter which evolves through the history material undergoes and its critical value needs to be determined experimentally through suitable workability tests, under defined and controlled conditions.

The damage criterion by Cockcroft & Latham (in normalized form) is defined:

$$D_C = \int_0^{\varepsilon_f} \frac{\sigma_1}{\sigma_{eq}} d\varepsilon \qquad (1)$$

It takes accent on max. principal stress σ_1, it means that the principal stress cause the fracture in the sample. Oyane damage criterion is based on stress triaxiality, which represents the main reason of fracture:

$$\mathrm{D_C} = \int_0^{\varepsilon_f} \left[1 + \frac{1}{a_0} \frac{\sigma_m}{\sigma_{eq}}\right] d\varepsilon \qquad (2)$$

where a_0 is another material coefficient to be determined experimentally.

An effect of the stress and strain growth during tests leads to the fracture. The crack formation in the sample is accompanied by quick drop of the load, see **Figure 1** and **Figure 2**. Many significant values can be obtained from simulation of performed tests, i.e. stresses, strains, damage, etc. In the literature, it is described great effect of stress triaxility on fracture behavior of materials. The stress triaxility is defined as: $\eta = \sigma_m / \sigma_{eq}$, where σ_m is hydrostatic stress and σ_{eq} is equivalent stress.

The condition of the fracture initiation [4] expresses dependence of reached effective strain on triaxiality according the equation: $\varepsilon_f = C_1.\exp(-C_2.\eta)$, where C1 and C2 are constants gained from tension or torsion tests. **Figure 3** shows this dependence calibrated using two points from the performed experiments.

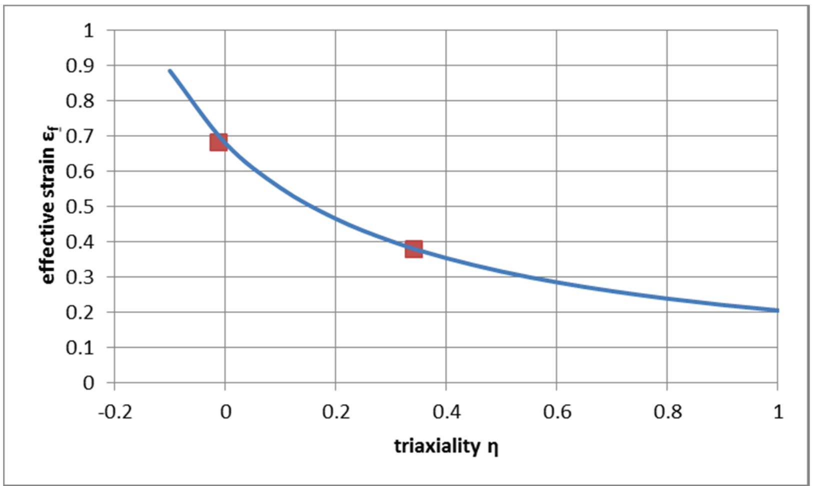

Figure 3 The dependence of effective strain on triaxiality

The significant results of the performed tension and torsion tests are reported in **Table 2**. The simulation was performed in the first iteration for NCL criterion, where no damage parameter was included. Calculated values were not enough for determining the critical damage. Moreover the critical damage coefficient from the tension was not possible to use for the prediction of the fracture. The tested sample broke even before the damage factor started cumulating.

Table 2 Results from simulation with NCL damage criteria without damage parameter

Test	Strain effective	Damage on the surface (D_C) - NCL criterion	Triaxiality
Torsion	0.68	0.39	-0.011
Tension	0.38	0	0.342

The accurate determination of critical damage value was performed by modification of the equation (1) where after a substitution of max. principal stress and using the calculated values we obtain $D_C = 0.383$. This value is the critical damage value for NCL criterion in the used material.

The calculation of critical damage value for Oyane equation needs to determine two parameters. As it is seen in the **Table 2** the triaxiality for the torsion is approximately zero which is the reason why was chosen this test. The equation (2) for the torsion test can be simplified: $D_C \approx \varepsilon_f$, which leads to Dc = 0.65 and the coefficient a_0 = 0.2875. These critical values were used in simulation fracture for Oyane damage criteria.

4. SHEAR TEST

Hydraulic shears was used for cutting of rolled sheets (**Figure 4**), with maximal hydraulic pressure 26(28) MPa, maximal cutting force 4.5MN and nominal vertical speed 5 (35 with accumulators) mm/s. For the test by measuring the shear force was used one analogue pressure transducer connected on incoming pipe to IBA system of pilot rolling mill. This configuration allows record the shear force during the test in dependence on time. During each shear test was measured width and height of the cut sample material.

In this paper, the critical damage value in the shearing operation was determined. The rolled sheet, see **Figure 4**, was used for definition of fracture in the simulation program DEFORM. Several experimental cuts had been performed using above mentioned “shearing device”. These cuts are numbered on a picture as 6 to 9 number, where cut 6 correspond to the length of cut 210 mm, cut 8 to 185 mm and cuts 7 and 9 had equal length 63.5 mm.

Figure 4 Tested rolled sheet

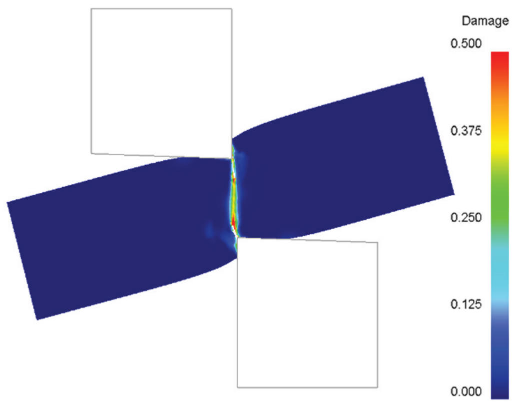

Figure 5 2D numerical simulation of shearing

The calculated critical damage values for both integral criteria NCL and Oyane were used in the subsequent calculation of fracture during shearing operation. The distribution of damage in the selected moment is seen in the **Figure 5**.

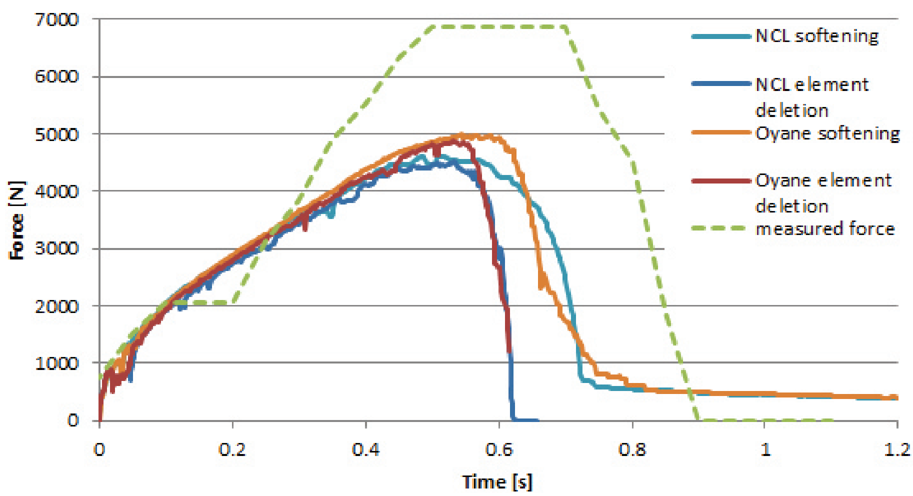

Figure 6 Measured and calculated force during shearing operation for selected methods

Shearing operation was calculated using two methods: the softening of material data and the element deletion. **Figure 6** shows the comparison of the calculated force from numerical simulation and the measured force. The only possible measurement of the shearing force is a pressure on incoming pipe. The simulation was done for calibration the actual force.

5. MICROHARDNESS MEASUREMENT

Microhardness was measured by hardness tester Struers Durascan. Microhardness profiles were measured on the longitudinal section by method HV0.1. They led from the farthest point of the shear surface 10mm into the undeformed material. Distance between indents was 0.2mm, profiles were laid with interval 1mm through whole thickness of the sheet, see **Figure 7**.

The microhardness varies from 250HV1 in undeformed material to the 540HV1 in vicinity of the shear surface. The hardness starts to raise 5mm from the reference point through whole sheet thickness, see **Figure 8**.

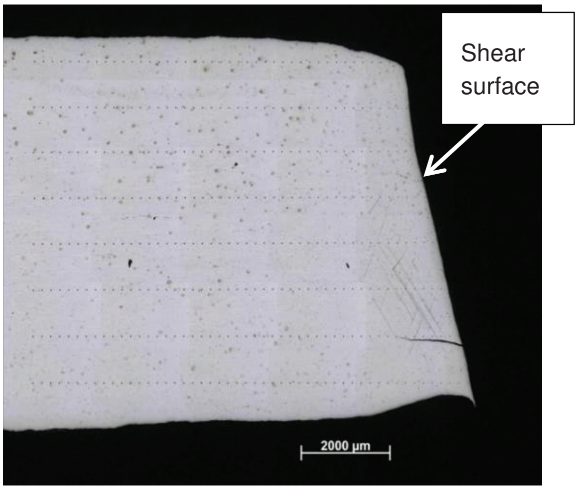

Figure 7 Overall view on the longitudinal section with microhardness profiles.

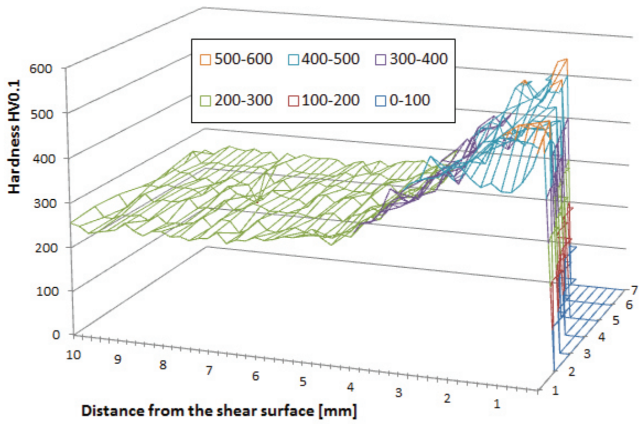

Figure 8 Visualization of microhardness-distance curves

Assuming (according to [9]) that the critical local fracture strain is proportional to the hardness, the graph on **Figure 9** shows dependence of reached strain from simulation on the distance from shear surface.

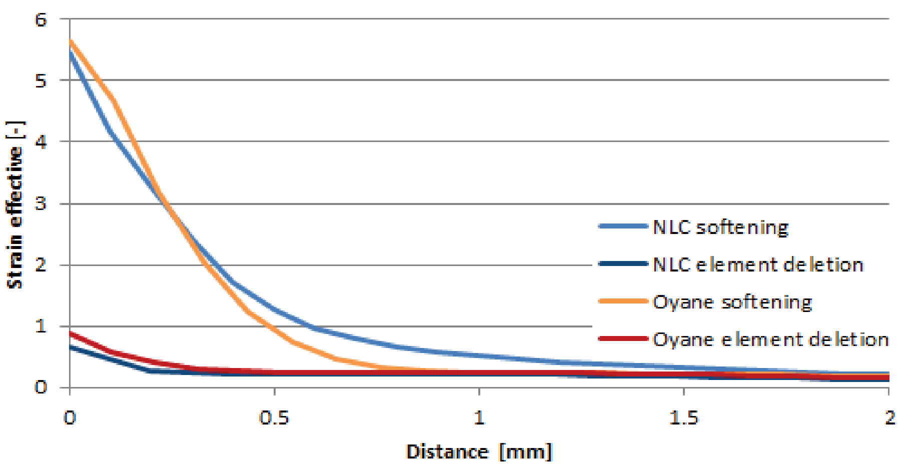

Figure 9 Calculated strain effective in the vicinity of shear surface

6. CONCLUSION

Using experimental measurements the calibration of two material models for simulation of ductile fracture were performed. The microhardness of undeformed material and material in the vicinity of the shear surface shows increase of hardening during shearing process. There is a correlation between the hydraulic pressure and shearing force.

ACKNOWLEDGEMENTS

This paper was created by project Development of West-Bohemian Centre of Materials and Metallurgy No.: LO1412, financed by the MEYS of the Czech Republic.

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