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Finite element calculation of forming limit curves*

L. Paraianu, D.S. Comsa, P. Jurco, G. Cosovici, D. Banabic

Department of Mechanical Engineering, Technical University of Cluj-Napoca
Bulevardul Muncii, 103-105, 3400 Cluj-Napoca, Romania

The article presents a strategy to determine an FLD using the finite element method. The simulation has been performed with the Abaqus/Standard FEA code. The calculated curve has been compared with the predictions given by the classical model Marciniak – Kuczynski. The comparison shows the possibility to use FEM to determine FLD's.
Keywords: metal forming, sheet metal formability, forming limit diagram, finite element method.

1. INTRODUCTION

The Forming Limit Diagram (FLD) is a useful concept for characterizing the formability of sheet metals. The concept of FLD associates the determination of the local limit strains, which can be obtained at the surface of the sheet metal by forming to the occurrence of surface defects (necking, fracture). It was introduced in the 60's by Keeler (1964)[1] and Goodwin (1968)[2], and presents pairs of maximum principal strains producing some surface defects using only an experimental method.

After the introduction of the FLD concept by Keeler, Marciniak and Kuczynski [3] have developed a theoretical model aiming to predict the occurrence of sheet metal instability. The first results were published in 1967. That paper presented a complete and coherent mathematical model for FLD's (for biaxial stretching with $0{,}5 \le \sigma_2/\sigma_1 \le 1$). This has been named "Marciniak – Kuczynski model" and it is frequently used in mathematical description of FLD's.

Let us consider two regions ("a" and "b") in the plane of the sheet metal having the initial thickness t_0^a and t_0^b (see Figure 1). The thinner region is perpendicular to the direction of the maximum principal stress (σ_1). The strain in region "b" is generally greater than in region "a" and tends to become dominant. At some stage of the forming process, the difference between the strain rates in these regions is so large that necking appears in region "b".

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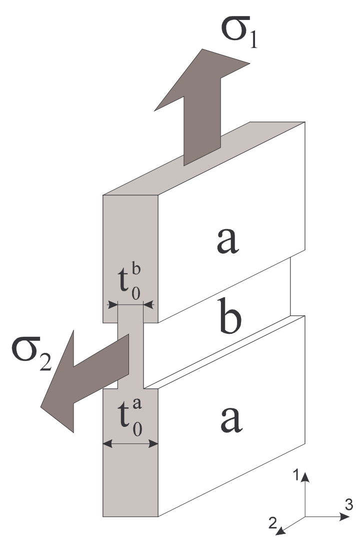

Figure 1. Marciniak – Kuczynski model

2. FINITE ELEMENT MODEL OF THE REGION CONTAINING A SURFACE DEFECT

The biaxial stretching process has been simulated using a commercial FEM package - ABAQUS/Standard [4]. Due to the geometrical and mechanical symmetry, only one quarter of the region shown in Figure 1 has been meshed. The faces corresponding to the cutting planes are subjected to displacement restrictions according to this symmetry. In order to improve the accuracy of the numerical solution, the transition between region “a” and region “b” should be smoother. As a consequence, the mesh will use 3D elements and will pass gradually from region “a” to region “b” (see the fillet shown in Figure 2). The type of the finite elements is C3D8R (solid continuum elements with 8 nodes and reduced integration). The free faces of the finite element model (right and back faces in Figure 2) will get imposed displacements reflecting the deformation of the sheet in region “a”.

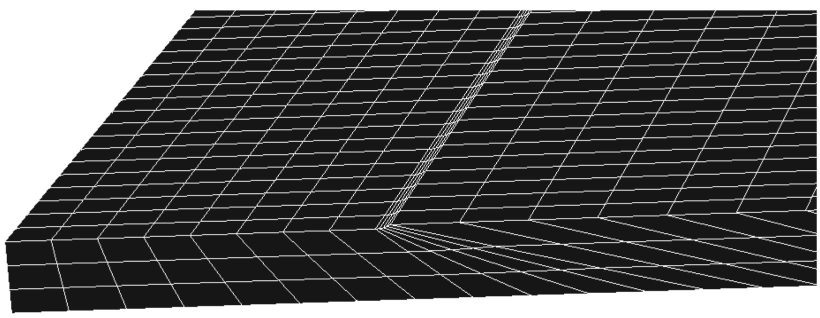

Figure 2. Finite element model used in the ABAQUS simulation

An elastoplastic material model based on the classical Hooke’s law and the von Mises yield criterion has been used in the simulation. The elastic parameters of the material are as follows: Young's modulus E = 6.9×10^4 MPa and Poisson's ratio $\nu = 0.33$. The hardening is assumed to be purely isotropic, as described by the Swift law:

$$Y\left(\bar{\varepsilon}\right) = K\left(\bar{\varepsilon}_0 + \bar{\varepsilon}\right)^n \tag{1}$$

The material parameters included in this relationship are: C=530 MPa, $\bar{\varepsilon}_0$=0.008, n=0.25. The initial thickness of the sheet metal in regions "a" and "b" are $t_0^a = 1$ mm, $t_0^b = 0.95$ mm.

3. STRATEGY USED IN ORDER TO OBTAIN AN FLD BY FINITE ELEMENT SIMULATION

Each point on the FLD has been obtained from a simulation with ABAQUS/Standard[4]. We have made seven simulations with seven different displacement ratios imposed along the principal stress directions. At the end of the simulation, we have evaluated the results to identify the simulation step when region "a" has logarithmic strain fluctuations. After we identify the step, we pick-up the values from the output file.

Figure 3 shows the moment of necking for a displacement of 24 mm along the x axis, and 24 mm along the y axis.

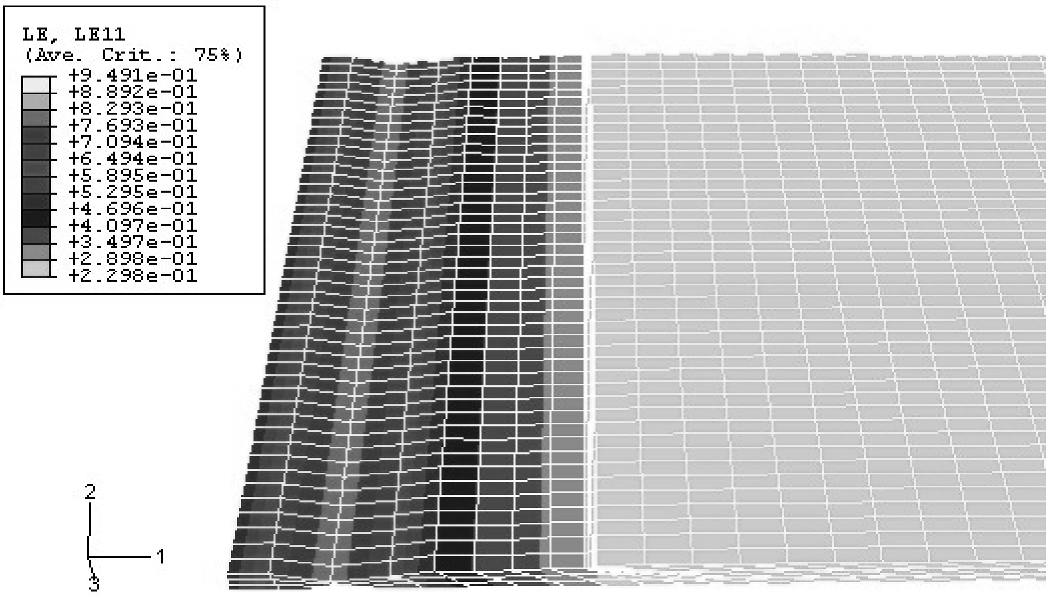

Figure 3. Logarithmic strain along x axis (identified as "1" on the diagram)

4. RESULTS AND DISCUSSIONS

The strategy described above is repeated for each point on the FLD. Figure 4 presents the points obtained by imposing seven different displacement ratios for the x and y axes (24:0, 24:4, 24:8, 24:12, 24:16, 24:20, 24:24). The FLD has been constructed as an interpolation of these discrete points. The theoretical FLD predicted by a classical M.K. model [5] is superimposed on the same plot. One may notice a satisfactory agreement between the results of the FE simulation and the M.K. model.

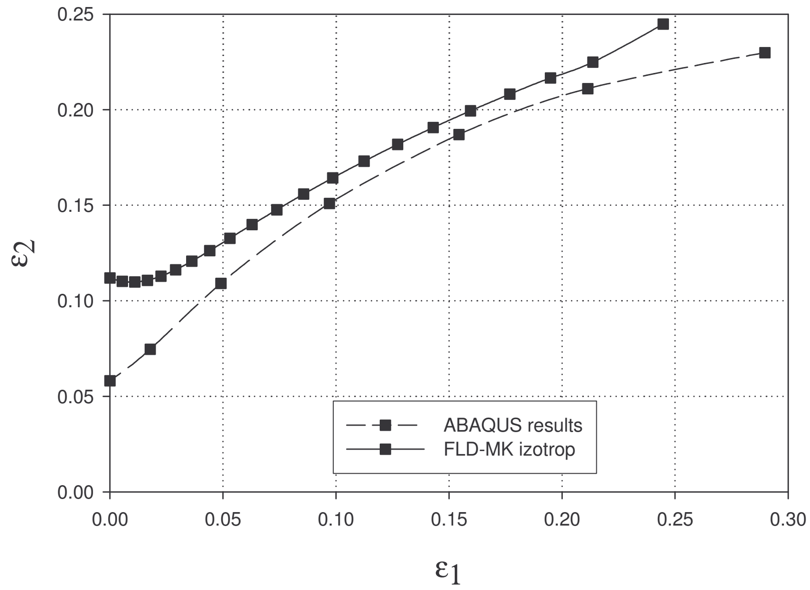

Figure 4. Comparison between the FLD obtained by FE simulation and the FLD predicted by the M.K. model for the same material

5. CONCLUSIONS

The paper shows the possibility to use FEM to determine FLD's. The authors intend to extend the model to the case of anisotropic sheet metal, using new material laws [6] and complex strain paths [7].

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