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SIMULATION OF STRAIN DISTRIBUTIONS FOR PLANE STRAIN TENSILE TEST USING DC05 COLD ROLLED STEEL

Raid-Fekhreddine MEKNASSI[1],
József-Gábor BÉRES[2], Lukács ZSOLT[3]

Rezumat. *Estimarea comportării unui material sub formă de tablă în cadrul unor operații de deformare reprezintă una dintre problemele critice ale acestui proces, în procesele industriale și procesele de formare a tablei, în special. Cunoașterea comportamentului materialului este o necesitate pentru a asigura acuratețea în timpul predicției pentru cea mai bună dimensiune și formă finală. În această lucrare este realizată o analiză numerică utilizând software-ul cu elemente finite ABAQUS, în cazul particular al unui test de tracțiune plană pentru un oțel laminat la rece DC05, cu geometrie diferită a probei, pentru a investiga efectul diferitelor geometrii asupra distribuțiilor tensiunilor.*

Abstract. *Material prediction behavior in the sheet metal forming operations is one of the critical fields of this process, especially for the industry and sheet metal forming processes in more precisely. Knowing the material behavior is a must to ensure the accuracy during the prediction for the best final size and shape. In this work we made a numerical investigation using a finite element software ABAQUS, of a plane strain tensile test for a DC05 cold rolled steel with different specimen geometry, to investigate the effect of different geometries on the strain distributions.*

Keywords: Plane Strain, Tensile Test, FE Method, FLD

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1. Introduction

Nowadays there are many new forming processes and materials in the automotive industry. Many of these new materials they have a high balance of strength and elongation [1]. This why many new technologies have been developed, and that conduct to use a complexes tools and multi-stage forming processes in the real industry. So, the classical technique for determining the forming limit diagram

[1] PhD, Raid Fekhreddine Meknassi, University of Miskolc, Faculty of Mechanical engineering, Miskolc, Hungary, (raidrawda@gmail.com).
[2]Dr, Gábor József Béres, John von Neumann University, GAMF Faculty of Engineering and Computer Science, Kecskemét, Hungary, (beres.gabor@gamf.uni-neumann.hu).
[3]Dr, Lukács Zsolt University of Miskolc, Faculty of Mechanical engineering, Miskolc, Hungary, (metzsolt@uni-miskolc.hu).

(FLD) with one linear path is not very accurate and we can say it's not suitable for these cases.

The Forming Limit Diagrams (FLD) is a graphical tool for predicting formability in one hand, and the safe forming zone in another of material in sheet metal forming processes, is considered as one of the widely used prediction tool for the sheet metal forming formability limits. regardless of that, it has many cons. There are many factors influencing the FLD, like the thickness of the sheet sample, grid measuring shape and size, the continuous or the discontinuous strain path, the material properties, and punch curvature, etc. When it comes to the non-linear strain paths (Fig.1), it always failed.

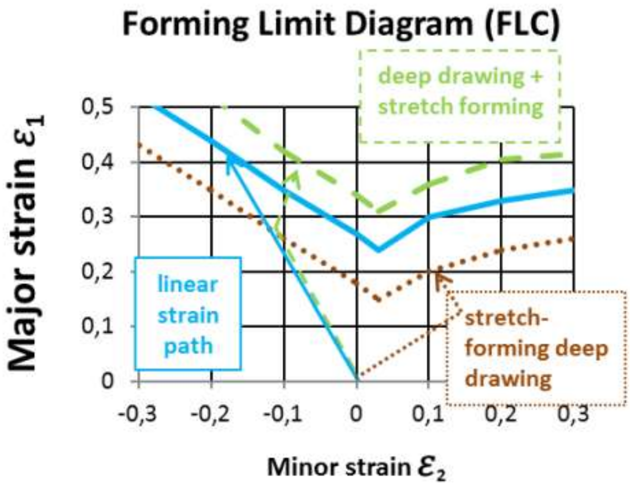

Fig. 2. Path-dependent FLD [2].

Because of these drawbacks of the FLD tool, a serious effort from both researcher and companies have been made to find other methods to predict the failure in a similar way to the real industry. In order to simulate the complex strain paths in the laboratory tests either applying two different load paths or design a new complex punch and sample geometry. In this work we wanted to focus on the first option. We would like to optimize a specimen that can allow us to determine the FLC after pre-strained it with plane strain uniaxial tension.

Regarding that, some literatures have been made in this topic. Wagoner and Wang [3] improve a method for near-plane strain tensile test. Also, Wagoner [4] study the plane strain tensile test with two material, dual-phase and aluminum-killed steel by modified geometries suitable for this test. He found that using the Hill's quadratic yield criterion we have the ability to predicts the plane strain behavior of both used material effectively. Flores et al. [5] used tensile test for near plane specimen to investigates the material behavior experimentally and numerically, by changing the materials and the test geometries, to be able to see the evolution of strain in the middle area during deformation. They found that, the material and the same as the geometry of the sample test affect directly to the strain distribution during plastic.

This work is a review of simulation investigation on the topic of non-linear path for sheet metal forming process. The next section shows our work plan and the results discussion.

2. Planning of the numerical analysis

In this work we will investigate the effect of the change in different dimension of the geometry (Fig. 2), on the strain field distributions due to tensile loading in plane strain specimen of different shapes. All specimens had a uniform thickness of 1 mm, griping area length: 30 mm x 2 and, mesh size: 0.8 mm.

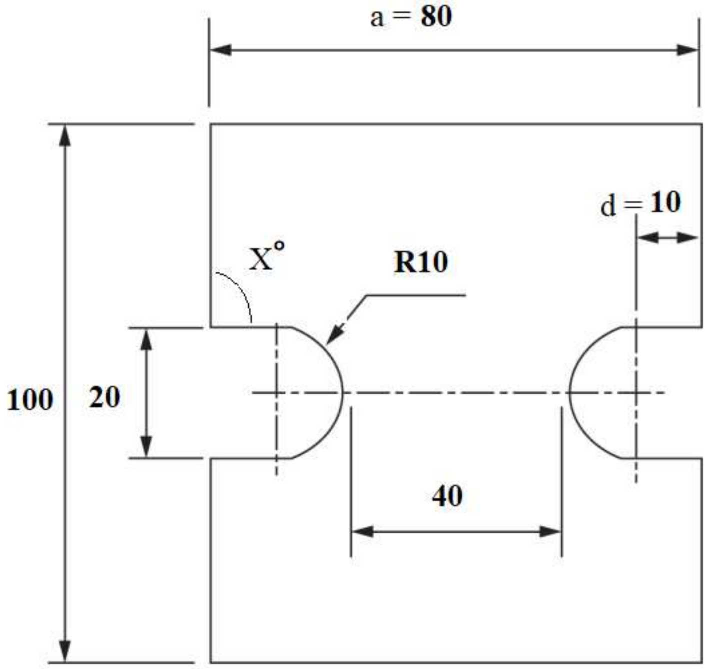

Fig. 2. Dimension of the standard geometry.

We considered one material for this study, which is DC05 cold rolled steel. The material properties used as an input for our finite element models showed in the next table (see Tables 1.).

Table 1. Data for yield parameters of DC05 material

rolling dir.	A_{80} (%)	A_{80_ave} (%)	r	$\bar{r}$	Δr	$R_{p0,2}$ (N/mm^2)	$R_{p0,2\_ave}$ (N/mm^2)	R_m (N/mm^2)	R_{m_ave} (N/mm^2)
0°	43,0	42,0	2,62	2,40	0,82	230	238	328	336

45°	42,0		1,99			240		346	
90°	42,0		2,99			240		325	

The code used for simulation is Abaqus 2021, and we chose to use the Hill (1948) yield criterion by defining the six plastic potentials R11, R22, R33, R12, R13, R23. using the next equations [6].

$$F = \frac{1}{2}\left(\frac{1}{R_{22}^2} + \frac{1}{R_{33}^2} - \frac{1}{R_{11}^2}\right) \tag{1}$$

$$G = \frac{1}{2}\left(\frac{1}{R_{11}^2} + \frac{1}{R_{33}^2} - \frac{1}{R_{22}^2}\right) \tag{2}$$

$$H = \frac{1}{2}\left(\frac{1}{R_{11}^2} + \frac{1}{R_{22}^2} - \frac{1}{R_{33}^2}\right) \tag{3}$$

$$L = \frac{3}{2R_{23}^2} \tag{4}$$

$$M = \frac{3}{2R_{13}^2} \tag{5}$$

$$N = \frac{3}{2R_{12}^2} \tag{6}$$

$$R_{11} = R_{13} = R_{23} = 1; \tag{7}$$

$$R_{22} = \sqrt{\frac{r_{90}\,(r_0 + 1)}{r_0\,(r_{90} + 1)}}; \tag{8}$$

$$R_{33} = \sqrt{\frac{r_{90}\,(r_0 + 1)}{r_0 + r_{90}}}; \tag{9}$$

$$R_{12} = \sqrt{\frac{3r_{90}\,(r_0 + 1)}{(2r_{45} + 1)\,(r_0 + r_{90})}} \tag{10}$$

Where the hill 48 yield stress ratio is R.

F, G, H and *N* are considered as the material parameters that characterize the anisotropy.
Table 2. shows the analytical results that we used it as an inputs parameter in our software.
The maximum major and minor strains in the middle area of all samples were gathered from 9 different points in the specimen as showed in Fig. 3.

Table 2. Analytical calculation results

	R11	R22	R33	R12	R13	R23
DC05	1	0.999241	1.24752237	1.14200355	1	1

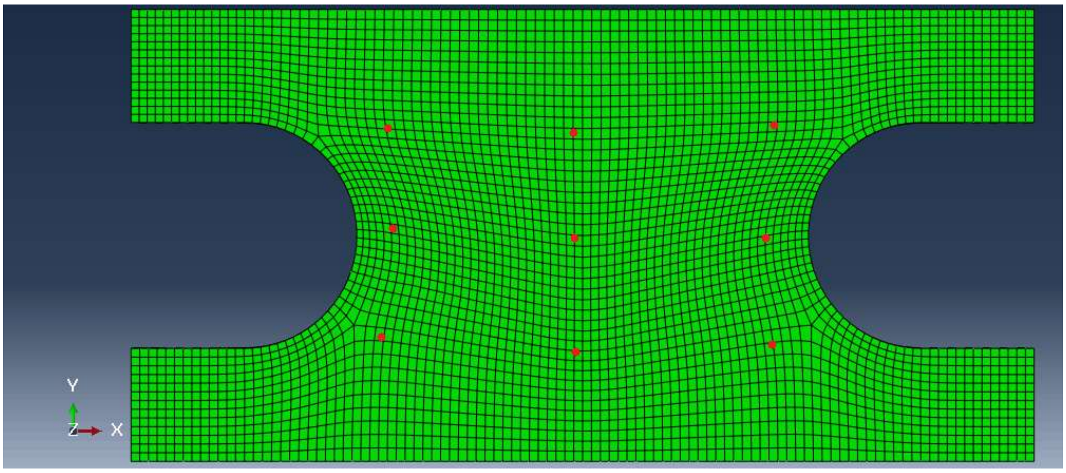

Fig. 3. Mesh and data points of the standard geometry.

The Swift non-linear isotropic hardening model used to calculate the plastic stress–strain response of our studied materials. The equation (11) was used with the related data showed in Table 3.

$$\bar{\sigma} = K(\varphi_0 + \bar{\varphi})^n \tag{11}$$

Table 3. Swift equation data

	Swift equation		
	K	**φ_0**	**n**
DC05	578	0.0173	0.220

For the comparison of the different specimen geometries, we used the following equations:

- **Plane strain state index (PSSI):** the closer the average minor strain ($A_{\varepsilon 2}$) to zero, the better it is.

$$PSSI = A_{\varepsilon 2} = \frac{\sum_{i=1}^{n} \varepsilon_2}{n} \quad (n = 1 \dots 9) \tag{12}$$

- **Homogeneity index (HI) (equivalent with standard deviation):** the smaller the HI, the better is the result.

$$HI = \sqrt{\frac{\sum_{i=1}^{n} (\varepsilon_1^n - A_{\varepsilon 1})^2}{n}} \quad (n = 1 \dots 9) \tag{13}$$

3. Results and Discussion

The next table (Table 4.) shows the effect of the notches angles (X°) on the major and minor strain distribution evolution at the middel area of the test specimen. It can be evidently detected that the bigger notches angles, the bigger PSSI values we got. Also, the results show the HI values increased together with the angle X. Which means decreasing the homogeneous strain field zone. Because the wide notch gives a small and sharp necking area which lead eventually to a low major stain.

Table 4. Simulation results for the first geometry (G1)

G1 (X°)	PSSI max	HI max
G1.1 (90°)	-0.03447	0.11996
G1.2 (95°)	-0.04819	0.16675
G1.3 (100°)	-0.08035	0.44237

Table 5 shows the effect of the specimen width (a) on the major and minor strain distribution evolution at the middel area of the test specimen. It can be seen that the bigger the specimen width, the smaller PSSI values we got. It could be explained that when we compared the major strain to the minor strain it could be neglect this last. For HI values, they are decreased together with the angle X. Which means increasing of homogeneous strain field zone.
Consequently, the bigger width of the specimen will be more important for the plane strain tensile test.

Table 5. Simulation results for the second geometry (G2)

G2 (a mm)	PSSI max	HI max
G2.1 (60)	-0.07149	0.383611
G2.2 (80)	-0.04342	0.14062
G2.3 (100)	-0.02453	0.081974

Similar to previous geometry. The results show the effect of the notch length (d) on the two strain distribution at the central zone of the specimen. We can observe that the PSSI and HI values decrease simultaneously with d length (Table 6). And that is because of the increasing resistance of free edges.

Table 6. Simulation results for the third geometry (G3)

G3 (d mm)	PSSI max	HI max
G3.1 (0)	-0.12286	0.580239
G3.2 (5)	-0.08777	0.438573
G3.3 (10)	-0.04342	0.14062

Conclusions

The simulation showed good results and strong effect of the geometry dimension on the plan strain distribution. Where we find that:

- the wide notch gives a small and sharp necking area which lead eventually to a low major stain;
- the bigger width of the specimen will be more important for the plane strain tensile test;
- The bigger notch length the better results and that because of the increasing resistance of free edges.

R E F E R E N C E S

[1] Meknassi, R. F, and Tisza Miklós. "Third generation of advanced high strength sheet steels for the automotive sector: A literature review." Multidiszciplináris Tudományok 11.4 (2021): 241-247.

[2] Bruschi, S., "Testing and modelling of material behaviour and formability in sheet metal forming." CIRP Annals 63.2 (2014): 727-749.

[3] Kuwabara, T., "Plane-strain tension test of steel sheet using servo-controlled biaxial tensile testing machine." J. Mater. Processing Technology 80 (1998): 81.

[4] Wagoner, R. H., "Plastic behavior of aluminum-killed steel following plane-strain deformation." Metallurgical Transactions A 14.7 (1983): 1487-1495.

[5] Flores, Paulo, "Plane strain test for metal sheet characterization." Key Engineering Materials. Vol. 344. Trans Tech Publications Ltd, 2007.

[6] Safdarian, R., "A comparative study of forming limit diagram prediction of tailor welded blanks." International journal of material forming 8.2 (2015): 293-304.