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ANALYSIS OF DEEP DRAWING PROCESS USING FEA AND FLD

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1. Introduction

The forming limit diagram (FLD) of sheets is determined experimentally. The diagram is often called the Keeler-Goodwin diagram named for the engineers who defined it. There are several ways to determine the diagram, but the most commonly used method is the fixed-edge tensile method. FLD is defined in the coordinate system of the principal strains in the plane of the sheet. The problem of the limit deformability of sheets is presented in the papers [1] and [2].

In this paper, first a review of the experimental determination of the FLD will be given and then it will be integrated into a numerical simulation. The FLD of DC04 steel was determined and the case of deep drawing of a non-standard box section was analyzed using the Simufact.forming software.

Two numerical experiments were performed, with two different lubrication conditions. Based on the results of the numerical simulation, it will be interpreted whether both cases satisfy, i.e. whether fracture occurs. The goal of the numerical experiment is to show how much using of FLD into the numerical simulation can improve the analysis of the sheet metal forming process.

2. Experimental determination of FLD

Based on the principle of the invariance of volume, the following relationship always holds:

$$\varphi_1 + \varphi_2 + \varphi_3 = 0, \qquad (1)$$

where φ_1, φ_2 and φ_3 in Eq. (1) are the principal strains and based on the two main strains, a third one can be calculated, which represents the thinning of the sheet.

In the experimental part, sheet metal test samples (Fig. 1) with one dimension of 120 mm, which does not change, were used. The second dimension starts from 20 mm and increases in steps of 10 mm. This results in 11 test tubes.

Fig. 1. Sheet metal samples made of DC04 material for FLD determination

Before cutting the test piece, it is necessary to apply a measuring grid consisting of circles with a nominal diameter of 3 mm to the surface of the sheet (Fig. 2).

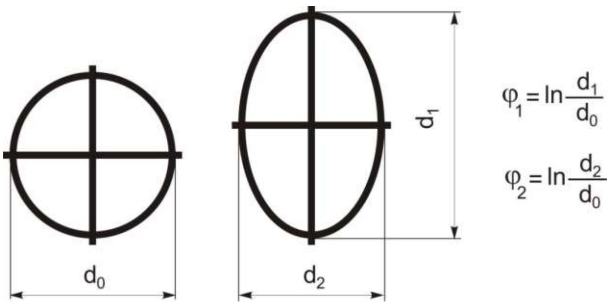

Fig. 2. Measuring grid element with equations for defining local strains

Each test sample is deformed in the tool under conditions of complete fixation of the peripheral zone (rim). In this way, the deformation zone is focused on the space under the punch cap and the so-called sheet stretching process is realized. Each deformed test piece corresponds to a specific stress-strain state. Narrower test pieces correspond to deformation states to the left of the ordinate axis, and wider ones (up to the largest square) to the right. In the right zone there is a biaxial tension region, and in the left zone there is a uniaxial tension region with negative strain φ_2 and biaxial deformation also with negative strain φ_2. The forming process is carefully monitored and interrupted at the moment of the appearance of a crack in the sheet. The position of the crack should be precisely located in relation to the pole of the punch cap. The symmetrical position on the other side of the pole determines the position of the measurement point of localization. Most often, both measurement points are easily visible visually.

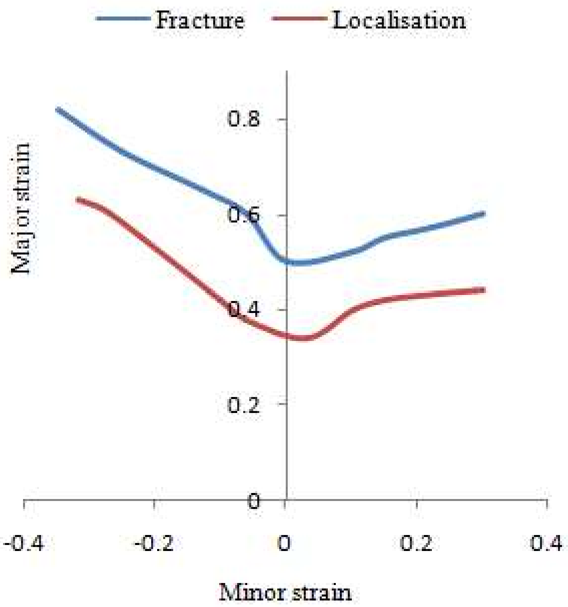

Fig. 3. Experimentally obtained FLD for material DC04

For both places, the dimensions d_1 and d_2 should be measured precisely (with a minimum measuring accuracy of 0,1 to 0,05 mm) and φ_1 and φ_2 should be calculated. In this way, the coordinates of two FLD points are obtained. One point corresponds to localization, and the other to fracture. Therefore, with 11 successfully deformed test samples, 11 pairs of points are obtained, which is sufficient to construct both the limit curve and the localization zone. All of the above experiments were performed in the metal forming laboratory of the Faculty of Engineering. The FLD for the DC04 material was determined. The experiment was performed on the ERICHSEN 142/12 machine.

Based on the results, the FLD curve is constructed, which is shown in Fig. 3.

3. Defining FLD in FEA

For numerical simulation the Simufact.forming software was used, which has the ability to define FLD for materials. Carbon steel DC04 was taken from the material database and then the properties were changed, data for the flow curve and FLD were added. The use of FLD is only possible for 3D simulations. The diagram is defined by an equation for two cases $\varepsilon_2<0$ and $\varepsilon_2>0$. In Simufact.forming software minor strain is marked as ε_2 and major as ε_1. In order to assess the risk of failure, a forming limit parameter was introduced, which has a value between 0 and 1. When this parameter has a value of 1, the material fracture occurs. This parameter [3] is calculated according to the formula given in Eq. (2):

$$F = \frac{\varepsilon_1}{\varepsilon_1^{crit}(\varepsilon_2)}, \qquad (2)$$

where ε_I^{crit} is the maximum major strain that can be reached. In addition to determining the value of the factor, the simulation result is a simplified representation of the zones on the material that are "critical", "at risk" and "uncritical". The flow curve was determined by a uniaxial tensile test and is defined by the Eq. (3):

$$K = 542{,}66 \cdot \varphi^{0{,}2259}. \qquad (3)$$

The froming limit diagram is defined in the Simufact.forming software by the equations of two lines. The DGD is shown in Fig. 4 and is defined by the Eq. (4) and Eq. (5):

$$FLD(\varepsilon_2) = C_0 + D_1\varepsilon_2 \quad \text{и} \qquad (4)$$

$$FLD(\varepsilon_2) = C_0 + C_1\varepsilon_2 \qquad (5)$$

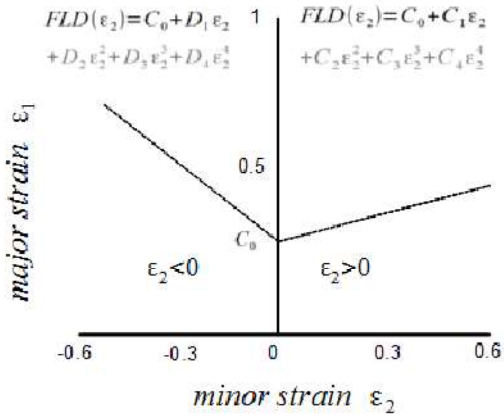

Fig. 4. Defining FLD in FEA software

Based on the experimental results, two equations of the line, Eq. (6) and Eq. (7), were defined:

$$FLD(\varepsilon_2) = 0{,}51 + (-0{,}85)\varepsilon_2 \text{ и} \quad (6)$$

$$FLD(\varepsilon_2) = 0{,}51 + 0{,}34\varepsilon_2. \quad (7)$$

4. Numerical simulation of the deep drawing process

Numerical simulation of deep drawing was performed in the Simufact.forming software as cold forming, the simulation type is 3D and the process type is stamping. The element type used is solid-shell and the mesher is sheetmesh. The element size is 2 mm.

Deep drawing was performed on a hydraulic press with a velocity of 10 mm/s. The tool consists of a die, a punch and a blankholder. The layout of the tool set up for numerical simulation is shown in Fig. 5.

It is possible to define the value of the blank holding force in the software, but in this case the blankholder is defined as a rigid body that completely prevents the appearance of wrinkles in the sheet metal. The stroke of the punch is defined as 20 mm.

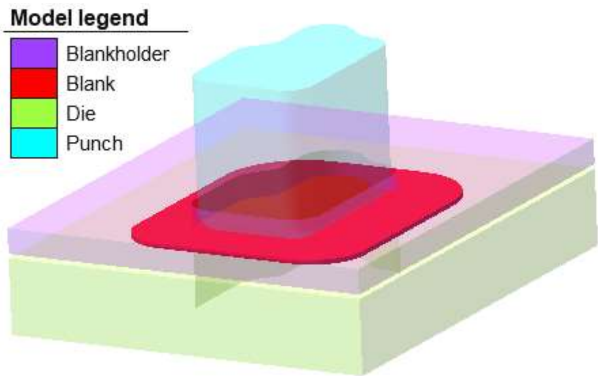

Fig. 5. Deep drawing tool set for simulation

In this numerical experiment, the deep drawing operation was analyzed for two cases of tribological conditions. For cold forming when lubrication is applied, the friction coefficient value is between 0,08 and 0,15, while in the case of no lubrication, the coefficient value increases to 0,2 – 0,3.

In this paper, a numerical simulation was performed for two cases of lubrication, the first with a friction coefficient of 0,08 and the second with a value of 0,15. The aim of the research is to determine whether friction conditions can endanger the stability of the deep drawing process.

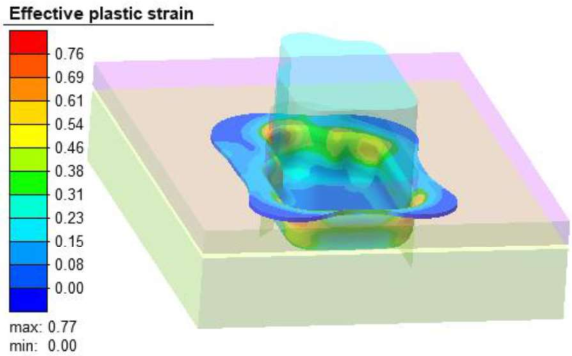

Fig. 6. Effective plastic strain (μ=0,08)

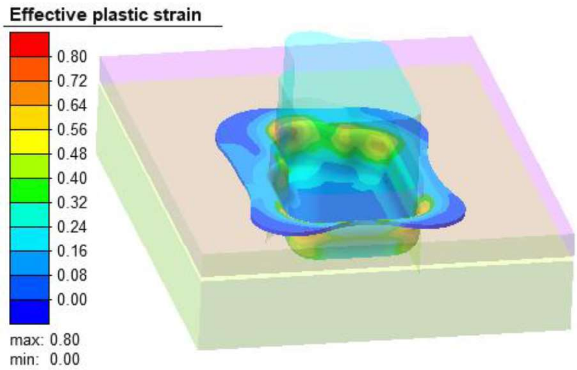

Fig. 7. Effective plastic strain (μ=0,15)

The results of the numerical simulations are shown in Fig. 6 and Fig. 7. In the first case, the value of the effective plastic strain is 0,77 and in the case of a higher friction coefficient value of strain is 0,8. After these values, it is necessary to review the simulation results related to fracture. Fig. 8 and Fig. 9 show the results of the forming limit parameter. In the first case, when lubrication is very good and the friction coefficient is 0,08, this parameter is 0,97, which means that fracture will not occur (Fig. 8).

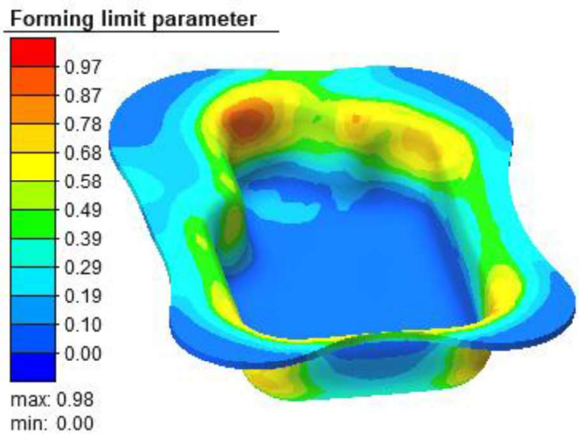

Fig. 8. Forming limit parameter for the first case (μ=0,08)

In the second case, when the lubrication conditions have deteriorated slightly and the friction coefficient has a value of 0,15, the parameter value is 1, which means that fracture will occur at a certain point (Fig. 9).

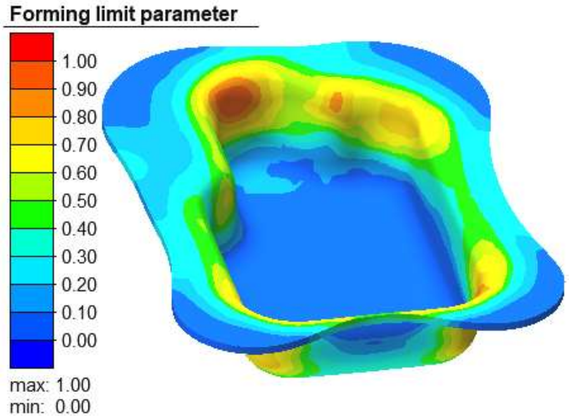

Fig. 9. Forming limit parameter for the second case (μ=0,15)

Based on the results of the forming limit parameter, the software provides the ability to show critical areas on the sheet. These areas are shown in Fig. 10 and Fig. 11. Fig. 10 shows the simulation result for the first case. Green indicates the area where there is no risk of failure, and yellow indicates the zone where there is thinning and the possibility of failure.

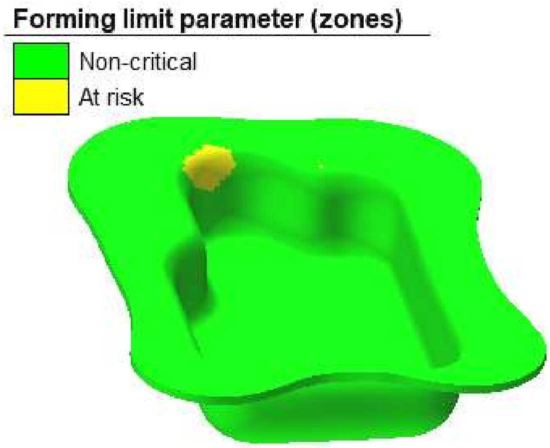

Fig. 10. Areas on the sheet metal (μ=0,08)

Fig. 11 shows the areas for the second case when the friction coefficient is 0,15. The figure shows the area that is significantly at risk and the area where the fracture will occur.

The results showed that friction has a great influence and importance on the success of the deep drawing operation. This way of using FLD can be extremely useful for checking the design of the tool.

By directly applying FLD, it is possible to detect zones that may be at risk and, based on the results, implement measures to reconstruct the sheet metal part or tool. It is also possible to detect the influence of production conditions such as lubrication conditions, as was done in this case.

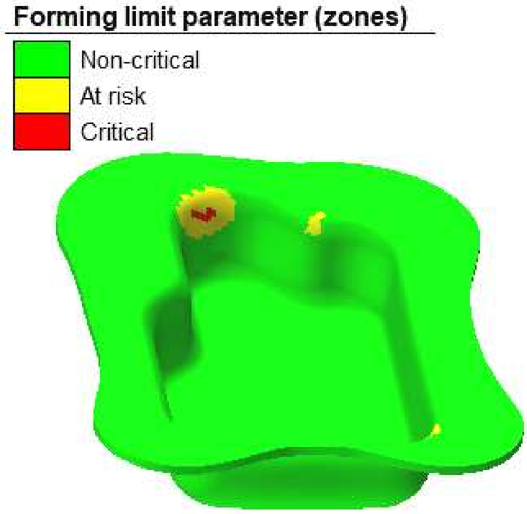

Fig. 11. Areas on the sheet metal (μ=0,08)

Based on the simulation results, it was concluded that the deep drawing process with existing tools can only be successfully performed if the lubrication is very good. Based on these results, the technologist can determine the appropriate lubricant and ensure the success of the process.

5. Conclusions

Using FLD in numerical simulations of sheet metal forming significantly improve the analysis of results. By defining FLD, a specific area that is critical is obtained as a result of the simulation, and based on this result, the design engineer can take certain actions and, after constructive changes, repeat the simulation and find out whether the problem of the endangered region has been overcome.

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