NUMERICAL SIMULATION RESULTS OF DIE FORMING OF DEEP-DRAWN AND CHROMIUM-NICKEL SHEETS

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The article deals with the prediction of pressability results (distribution of residual stress or plastic strain in the workpiece, thickness distribution in the workpiece, etc.) of deep-drawing (DC 04, DC 05) and chrome-nickel (DIN 1.4301) sheets. For the needs of computer numerical simulation, material parameters for individual sheets were calculated using Matlab software, and the simulation itself was performed using Comsol Multiphysics software. In this model, a flat metal sheet is pressed onto a curved die with a similarly shaped punch. From a simulation point of view, the problem is significantly nonlinear due to contact, large strain plasticity, and geometric nonlinearity. In order for the solution to be convergent, it is necessary: carefully select the source and target in pairs of contacts, parametrically use steps that are small enough to avoid the divergence of the solution, to calculate the thickness of the deformed shape, a non-local projection coupling is used to define the variable th - the augmented Lagrange method [COMSOL Multiphysics 2020].

KEYWORDS

Matlab, COMSOL Multiphysics, material parameters, punch, hardening function, large plastic strain, blank, holder, die

1 INTRODUCTION

Powerful computer technology in conjunction with program files for simulation of technological processes provides invaluable information. The accuracy of the prediction of the results of pressability by numerical simulation depends on the material models used, friction models, input material data, limiting conditions, etc. The simulation program files bring elements of accuracy, reduction of labor and costs to the development and preparation phase of the production of the stamped part. The possibility of verifying the pressability of the material and the correctness of the design of the pressing tool in the virtual prototype environment brings savings in tool production costs compared to the classic approach, because the tool does not have to be physically manufactured. Predicting pressability in the case of more complex shapes of stamped parts made of new special materials is almost impossible without computer support [Labellarte 2000].

2 SAMPLES FOR NUMERICAL SIMULATION PURPOSES

For numerical simulation purposes, the following materials were used: material number 1.4301 (STN 17 241 /DIN X5CrNi18-10/AISI 304) - it is a chrome-nickel stainless steel suitable for cold forming, which has high corrosion resistance (material D), DC 04 steel sheet - especially deep drawing, suitable for demanding external and internal parts of car bodies and other stampings (material B), DC 05 steel sheet - extra deep drawing, suitable for complex large-area stampings of car bodies and other stampings (material A). Samples for testing mechanical properties were taken in the direction of 90°, 45°, 0° to the direction of rolling and produced according to STN EN ISO 6892-1 (420310). Tensile tests to determine the material parameters were carried out on the INSTRON tensile testing machine in the U.S. Steel at the selected reference strain rate of $0.0014 s^{-1}$ [Evin 2016, Labellarte 2000].

3 CHOISE OF EVALUATION SOFTWARE

The Matlab computing core was used to evaluate the material parameters of the mentioned deep-drawn and chrome-nickel sheets. ***Matlab*** is an integrated environment for scientific and technical calculations, modeling, simulation, presentation and data analysis. It is a tool both for comfortable interactive work and for the development of a wide range of applications. Matlab provides powerful graphics, calculation tools and extensive libraries of functions. The extremely fast computing core with optimal algorithms is considered to be Matlab's strongest point. Matlab allows you to import standard data files into your environment, to which the *Curve Fitting toolbox* is applied for their quick processing **[Mathworks R2014a].**

The **Comsol Multiphysics** software package was used to predict the simulation results. This product is a tool designed for modeling and simulating physical events. Most of the tasks we encounter in real life have a multiphysics character. Therefore, when developing products or processes and studying the behavior of systems, it is often necessary to consider the mutual interaction of several physical influences at the same time [Dyadyura 2021]. Comsol Multiphysics consists of a core and a whole range of add-on modules [COMSOL Multiphysics 2020].

4 ACHIEVED RESULTS AND THEIR DISCUSSION

The stamping is permanently reshaped around a die through plastic deformation by forming and drawing processes. Simulations can be carried out in order to avoid cracks, tears, wrinkles, and too much thinning. When the forming process is finished and the forming tools are removed, the stamping attempts to partially recover its initial shape through relaxation of the elastic stresses. From a simulation point of view, the problem is nonlinear due to contact, large strain plasticity, and geometric nonlinearity.

The model geometry is shown in Figure 1. 2D axisymmetric formulation can be used. The die and the blank-holder together clamp the blank to be reshaped, while the punch performs the drawing, stretching, and bending. The punch is pushed towards the sheet through a displacement of 40 mm. This step aims to simulate the forming and drawing processes. The punch is released progressively to model the springback phenomenon. An isotropic elastoplastic material with user-defined isotropic hardening and large plastic strain formulation is used to characterize the plastic deformation (here used hardening function) [Wang 2021, Lin 2010].

The die and the punch are made of structural steel. The die and holder are fixed, and the punch deforms the blank with a prescribed vertical displacement, which is ramped linearly.

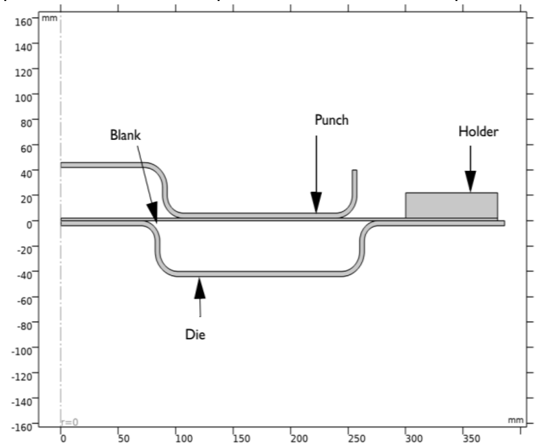

Figure 1. The model geometry

To characterize plastic deformation, an isotropic elastoplastic material with a user-defined isotropic hardening and a large plastic deformation formulation is used (Hardening function, see Figure 2) [Kuncicka 2021, COMSOL Ver. 6].

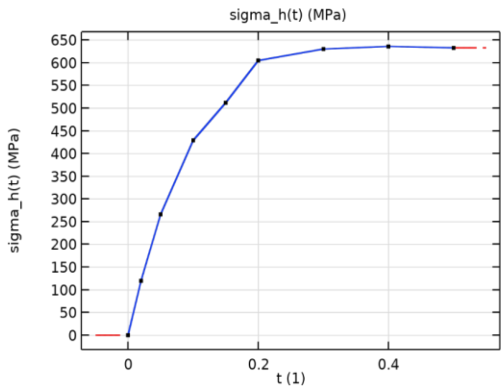

Figure 2 . Hardening function names sigma_h (Function type Interpolation for materal D)

The global material parameters for material D are given in Table 1.

Table 1. The global material parameters for material D , i.e. for AISI

Name	Expression	Value	Description
sigma_y0	266[MPa]	2.66E8 Pa	Initial yield stress
U_p	40[mm]	0.04 m	Punch displacement
R0	0.9	0.9	Lankford's coefficient r0
R45	0.9	0.9	Lankford's coefficient r45
R90	1	1	Lankford's coefficient 90
F	R0/(R90*(R0 + 1))/sigma_y0^2	6.6946E−18 $m^2 \cdot s^4/kg^2$	Hill's coefficient
G	1/(R0 + 1)/sigma_y0^2	7.4385E−18 $m^2 \cdot s^4/kg^2$	Hill's coefficient
H	R0/(R0 + 1)/sigma_y0^2	6.6946E−18 $m^2 \cdot s^4/kg^2$	Hill's coefficient
L	0	0	Hill's coefficient
M	0	0	Hill's coefficient
N	0	0	Hill's coefficient

Figures 3-5 show the residual stresses after the release of the punch, where higher stresses are present in the deformed corners of the blank. For material A (see Figure 3) at a distance (0-60)mm to the edge of the rounding (400-600)MPa, on the radius of rounding of the edge of the die (600-800)MPa and on the drawing edge of the punch 900 MPa, on the bottom of the stamping less than 400MPa. For material B (see Figure 4) it is similarly. For material D (see Figure 5) in the order of material A (520-780) MPa, (780-1020) MPa, 1050MPa and at the bottom less than 500 MPa.

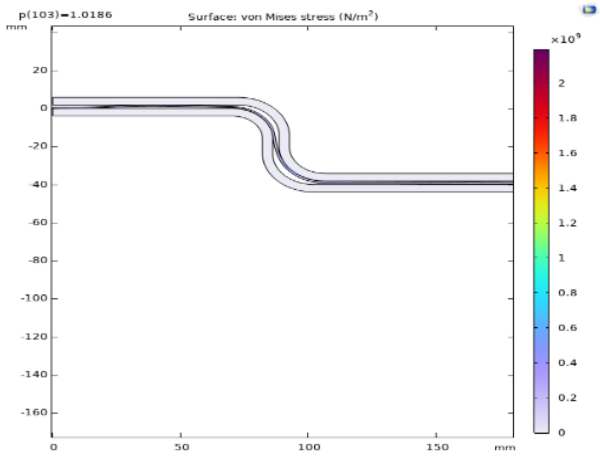

Figure 3. Residual stress after release of the punch (material A)

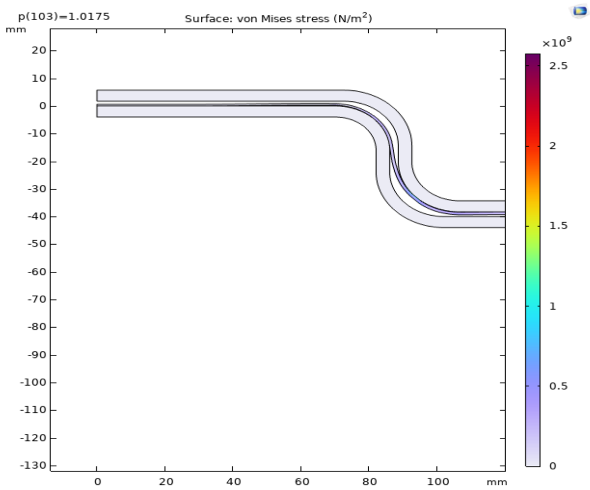

Figure 4. Residual stress after release of the punch (material B)

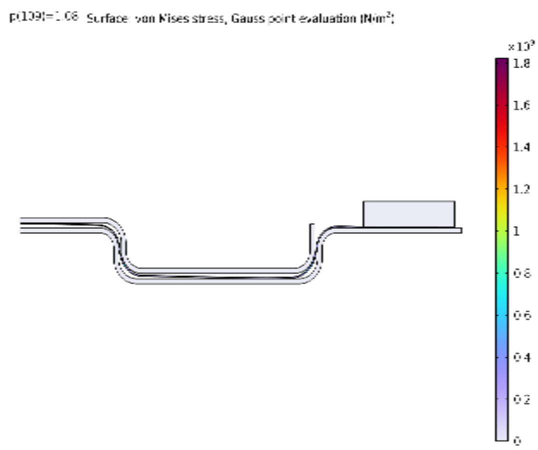

Figure 5. Residual stress after release of the punch (material D)

For material A (figure 6), the largest deformations in the flange at a distance of (0-60) mm 0.32-0.46. For material B (figure 7) 0.34-0.47 and for material D (figure 8) 0.36-0.49 at the bottom of the stamping is the smallest deformation for all materials . The higher the anisotropy, the greater the resistance of the material to the thinning of the stamping wall [Evin 2016, Vlk 2003].

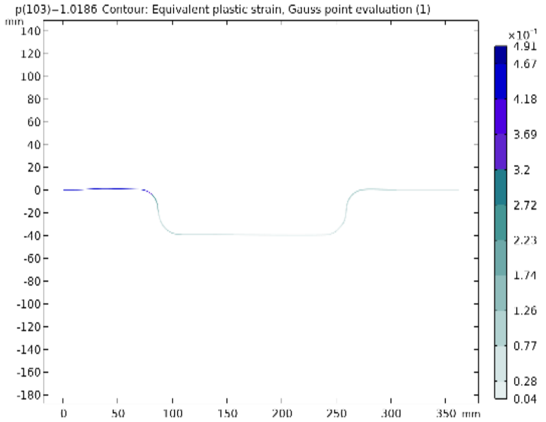

Figure 6. Plastic strains after release of the punch (material A)

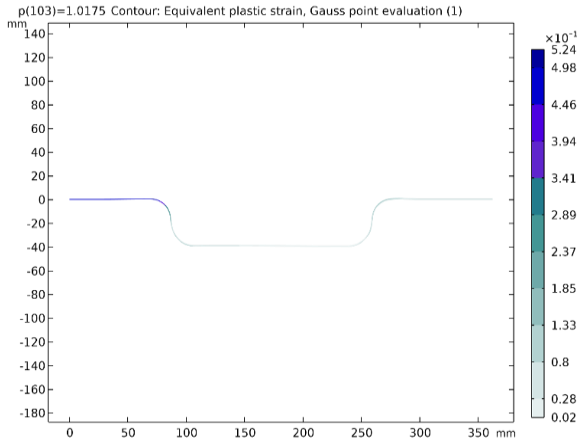

Figure 7. Plastic strains after release of the punch (material B)

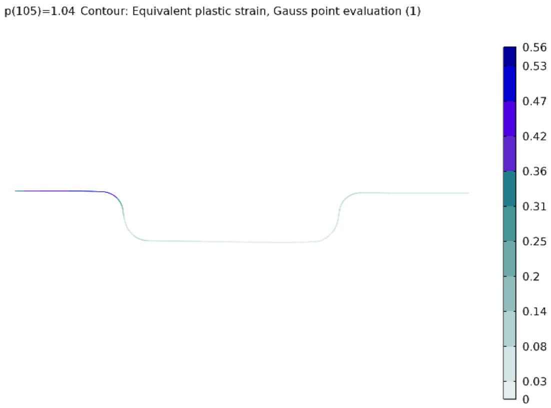

Figure 8. Plastic strains after release of the punch (material D)

In the forming process, the calculated forces have two peaks. The forces keep increasing to get the blank into the die; when the blank is sufficiently deformed, it requires less force to push the blank in the die. Just before the punch reaches the forming shape, the blank touches the bottom of the die and the force increases significantly to complete the forming step. In the release step, punch forces continue to decrease. For material A first peak 430 kN- punch force at 35mm, second peak 550kN at 40mm, see figure 9, for material B (see figure 10) first peak 510 kN- punch force at 35mm, second peak 640 kN at 40mm, for material D (see figure 11) first peak 700 kN- punch force at 35mm, second peak 800 kN at 40mm

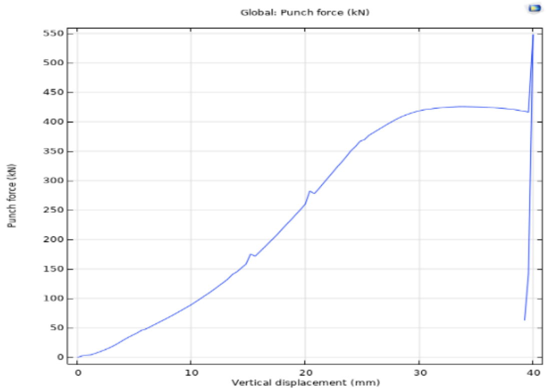

Figure 9. Punch force during the die forming (material A)

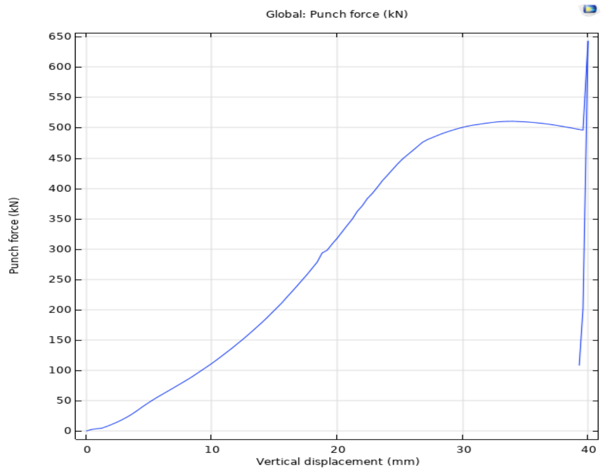

Figure 10. Punch force during the die forming (material B)

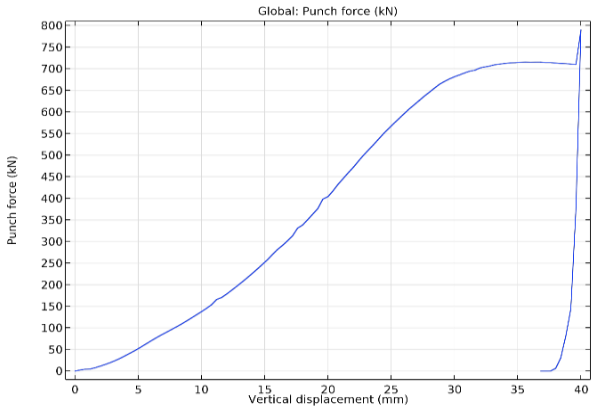

Figure 11. Punch force during the die forming (material D)

The initial thickness of the blank is 1 mm. The maximum thinning is observed in the middle of the stamping, see Figure 13. For material A (see Figure 12) it ranges from 0.65 mm, after the first bend of the blank the thickness increases until after the second bend it is equal to 1 mm (Figure description from left to right). For material B (see Figure13) it is from 0.65 mm, for material D (see Figure 14) it is from 0.6 mm.

In order to ensure a convergent solution, it is necessary to: carefully select the source and target in pairs of contacts, use steps that are small enough, to calculate the thickness of the deformed shape, a non-local projection coupling is used – the augmented Lagrange method [COMSOL Multiphysics 2020].

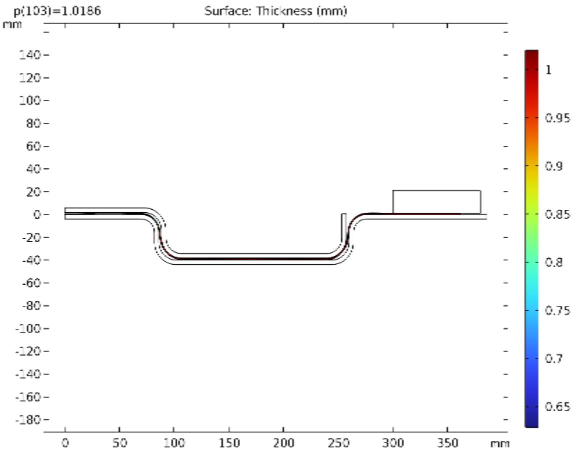

Figure 12. Thinning process of the stamping for material A

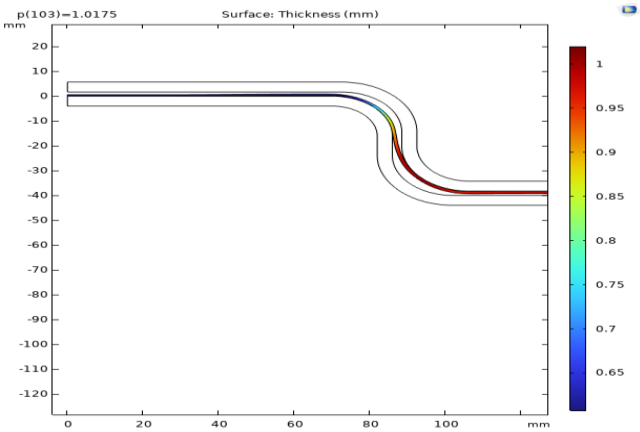

Figure 13. Thinning process of the stamping for material B

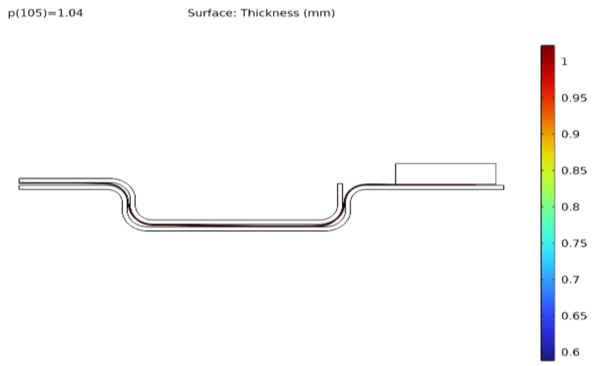

Figure 14. Thinning process of the stamping for material D

5 CONCLUSIONS

The achieved results can be summarized as follows:

- For the prediction of the die forming results, the hardening function is used here instead of the material model. This function is obtained from the digital recording of the tensile test and the material parameters [Huang 2002, Kuncicka 2021].
- The highest stress value occurs at the drawing edge of the punch, 900 MPa for deep-drawn sheets and 1050 MPa for chrome-nickel steel the lowest values appear at the bottom of the stamping, less than 400 MPa for deep-drawn steels and less than 500 MPa for chrome-nickel steel.
- The highest strains appear in the flange in the order of materials A: (0.32-0.46), B: (0.34-0.47), D: (0.36-0.49) and the smallest strains occur at the bottom of the stampings
- Dependence of punch force on vertical displacement for material A the first peak of 430 kN is reached at 35 mm, the second peak of 550 kN at 40 mm, for material B the first peak of 510 kN at 35 mm, the second peak of 640 kN at 40 mm, for material D the first peak 700 kN at 35 mm, second peak 800 kN at 40 mm [Huang 2002].
- The maximum thinning is observed in the middle of the stamping. For material A it ranges from 0.65 mm, for material B it is from 0.65 mm, for material D it is from 0.6 mm.

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