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# Finite element investigation on parameters influencing the springback during sheet metal forming

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## 1. Introduction

Thin sheet metal forming (SMF) is one of the most common cold metal forming operations. The shapes of working punch and die surfaces are defined mainly by the required geometry of the product, however, not fully coincident with the latter due to finite thickness of the sheet and possible springback effects as the product is released from the die.

The possible springback effects are always to be taken into account in order to ensure the correct and precise geometric shape of the detail. Its physical essence is based on the inherent presence of elastic component of the strain tensor of the deformed sheet, which tends to be restituted by elastic forces after the constraining surfaces of the punch and die system are removed. A certain magnitude of springback effect is inevitable in every cold SMF operation, however, selection of the proper geometry of forming tools and other parameters of the forming process often enables to reduce its effect or to ensure that the shape of the detail after the springback is close as much as possible to the desired one. Many principles of the influence of parameters upon the final shape of the detail are known empirically basing on practical experience and experiments.

Nowadays many of very expensive experimental investigations of SMF processes can be simulated numerically by using the finite element (FE) techniques. The set of investigated parameters making essential influence on final shape of the detail consists of physical properties of the material, friction coefficient between the sliding surfaces, the magnitude of blankholder forces (BHF), the die shoulder radius, etc. In most cases SMF problems can be modeled by using the commercially available FE software systems. For obtaining reliable results a proper setup of model parameters is necessary, such as element type, number of through-thickness integration points, refinement and regularity of the FE mesh, possible effects of inertia, type of the contact search algorithm, etc. [1-4].

In many available publications (NUMISHEET'93 and later conferences [5-6]) the investigations have been performed by solving a benchmark-type problem of U-shaped detail forming by drawing. Many important numerical, as well as, experimental results are available, which have been used in order to verify and validate the FE model developed in this work by using LS-DYNA software. Here new results on parametric sensitivity of the sheet metal forming are presented providing further outlook into the essence of physical features of the SMF process on the base of the forming problem of U-shaped detail.

## 2. Formulation of the U-draw bending problem and FE model validation

Fig. 1 illustrates the basic scheme of SMF of U-shaped detail, and Fig. 2 presents the quantities used for evaluation of the magnitude of springback of the detail during experimental [1-6] and numerical investigations. $\theta_1$ is the angle between line *A-B* and axis of abscissas, $\theta_2$ is the angle between lines *A-B* and *E-F*, $\rho$ is defined by the circle radius drawn through *A*, *B* and *C*, where *C* is middle point of the segment *A-B*. During experiments the blankholder force was 2.45 kN and the stroke of the punch 70mm. The results of experiments referenced in [1-6] are presented in Fig. 3 and Table 1. The FE model used in this work is presented in Fig. 4.

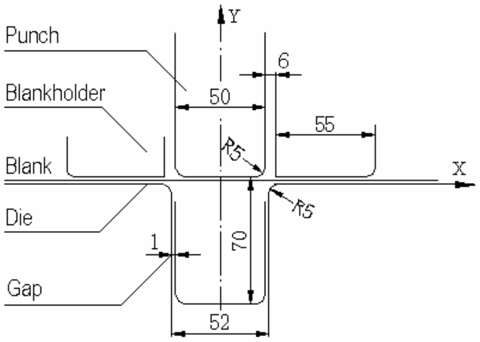

Fig. 1 Schematic U-draw bending process

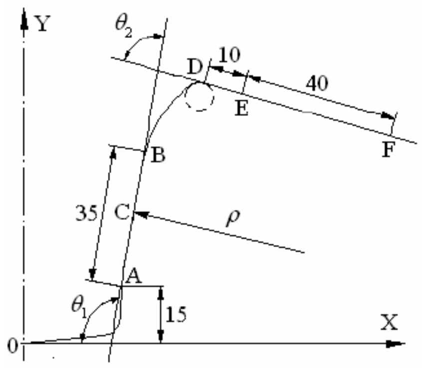

Fig. 2 Description of the angles $\theta_1$, $\theta_2$ and radius $\rho$

In order to validate the model, we used the blank element size 2×1.2mm as has been referenced in [2,3] and the number of die and punch corner elements 16 as a certain reasonable choice between accuracy of the results and the computation time. Belytschko-Tsay shell elements [7], CONTACT_AUTOMATIC_SURFACE_TO_SURFACE contact search algorithm, the explicit computational scheme during the drawing step and the implicit scheme during the springback have been used in this model.

Fig. 3 Experimental Part after springback [2]

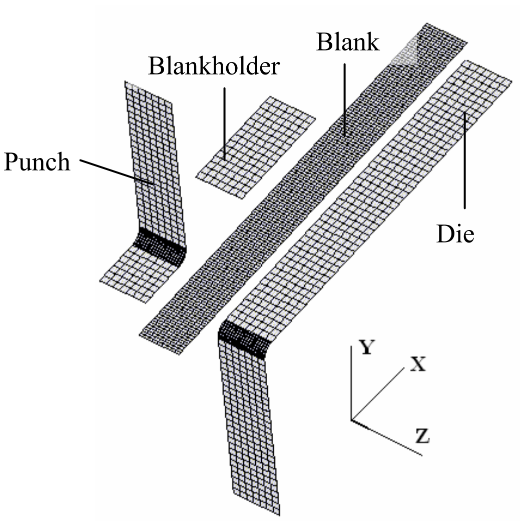

Fig. 4 Finite element model

The material of the sheet was the mild steel the properties of which were assumed as follows:

Young's Modulus: 206GPa
Poisson's Ratio: 0.3
Normal plastic anisotropy ratio R: 1.77
Friction: 0.144
Blank length×width×thickness: 350×35×0.78mm
True stress-strain curve:

$$\sigma = 565.32(0.007117 + \varepsilon^{p})^{0.2589}\,\text{MPa} \qquad (1)$$

The simulation results presented in Table 1 are in good agreement with the experiment and are closer to the minimal values of the measured range. Consequently, the model can be regarded as suitable to represent the real processes taking place during the SMF processes.

Table 1

Experimental and simulation results

| | $\theta_1$, ° | $\theta_2$, ° | $\rho$, mm |
|---|---|---|---|
| Experimental max. | 101.7 | 87.0 | 409.5 |
| Experimental min. | 96.0 | 78.0 | 112.0 |
| Simulation | 98.0 | 79.9 | 207.1 |

## 3. Analysis of the blankholder force (BHF)

The experimental data indicate that the decrease of BHF is followed by the increase of the magnitude of springback. Vice versa, larger BHF forces reduce the magnitude of springback. We obtained analogous results by FE simulation, Figs. 5-6. The springback is not sensitive to variations of BHF in the range of low values of BHF. However, after reaching a threshold value of BHF (in this analysis 3,75kN), the springback drastically decreases. It practically disappears at BHF value 10kN. The effect can be explained that at low BHF values bending strains are prevailing in the model, therefore elastic components are dominating due to small thickness of the blank. At high BHF values tensile strains begin to play a significant role, where plastic strains are dominating. BHF significantly influences the wall thickness of the detail, Fig. 7.

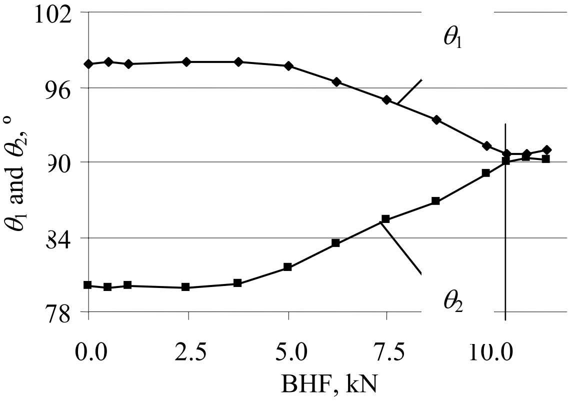

Fig. 5 Angles $\theta_1$ and $\theta_2$ versus BHF

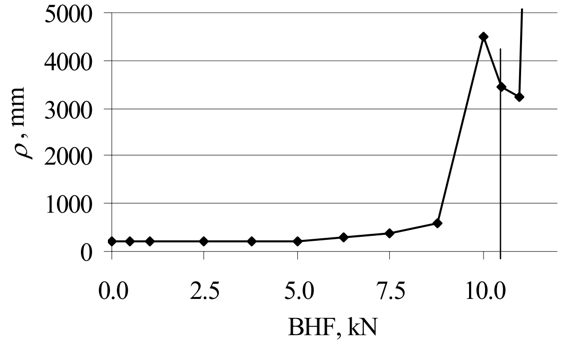

Fig. 6 Radius $\rho$ versus BHF

The increase of BHF is limited by the values at which strains in the sheet metal exceed their failure limit. In such case the sheet begins to rope and finally fails (Fig. 8). Initially the failure limit is reached at the central zone of the stretched wall (Fig. 9). The explanation of the effect can be based on simplified analytical estimations of the amount of plastic strain near the failure limit presented in [8]. The major strain at maximum tension is

$$\varepsilon_1^* = \frac{n}{1+\beta} \qquad (2)$$

where $\beta$ is strain ratio; $n$ is strain-hardening index (1).

The effective plastic strain at maximum tension is

$$\bar{\varepsilon}^* = \sqrt{\frac{4}{3}(1+\beta+\beta^2)}\,\varepsilon_1^* \qquad (3)$$

For plane strain $\beta = 0$ and

$$\bar{\varepsilon}^* = \frac{2}{\sqrt{3}}n \approx 0.299 \qquad (4)$$

For uniaxial tension $\beta = -\frac{1}{2}$ and

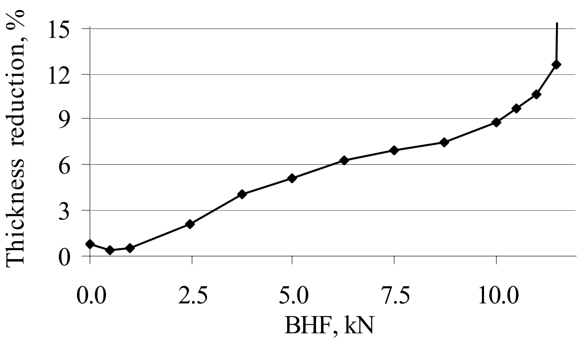

Fig. 7 Thickness reduction versus BHF

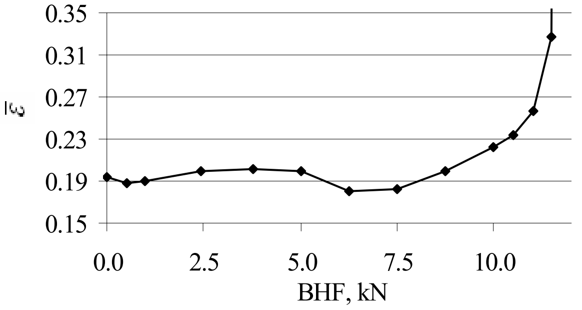

Fig. 8 Maximum effective plastic strain versus BHF

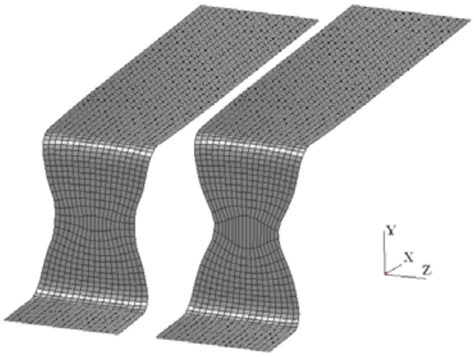

Fig. 9 Diffuse neck develops on the part

$$\bar{\varepsilon}^* = 2n \approx 0.518 \qquad (5)$$

At the centre of the wall plastic strain develops faster due to close-to-plain strain situation taking place at the centre. Consequently the failure limit is reached at the centre prior to the failure at the sides of the wall, as it follows from (4) and (5).

Fig. 5 and Fig. 6 illustrate that BHF value of 10.5kN (vertical line in Figs. 5-8) the springback is minimum and the developed plastic strains are significantly less than the failure limit, see (4) and Fig. 8. As a drawback here a significant decrease of the wall thickness can be mentioned, Fig. 7.

## 4. Sensitivity to the coefficient of friction

It is well-known that the friction coefficient is a very important parameter heavily influencing the SMF process and the final shape of the detail. In SMF by drawing the experimental measurement of the friction coefficients between the punch-die and the blank is very complicated. It may be expected that the friction coefficient is different in the blank-punch and blank-die contact interaction. At the same time, it is dependent on the velocity of sliding. The estimation of the friction coefficient necessary for obtaining proper simulation results is even more complicated because the simulated velocity of the punch is assumed to be much greater than it is in the reality.

The simulation time by using the explicit time integration scheme is inversely proportional to the rate of the simulated punch stroke referred to as the virtual rate of the punch. The real rate of the punch would make the computation time very long due to small time steps defined by the size of the smallest element in the model in accordance with the Courant criterion. With real rates of the punch the computation time of the simplest forming processes may take tens of hours. In the simulation practice, the virtual rate of the punch is assumed to be several tens or even hundreds times as large as the real punch rate. The only limitation of the virtual punch rate value is the absence of inertial effects, which should not play an essential role during simulation of SMF processes. One of the parameters controlling the negligibility of inertial effects is ratio $r_{\mathrm{ki}}$ of the kinetic energy to the internal energy of the system [2]. The calculation results of dynamic explicit FEM is close to the results of quasi-static process when $r_{\mathrm{ki}}$ <5%. The overall complexity of the problem and the lack of reliable values or relationships of the friction coefficient suggested as a reasonable choice to use a constant value of the friction coefficient for all contacting surfaces.

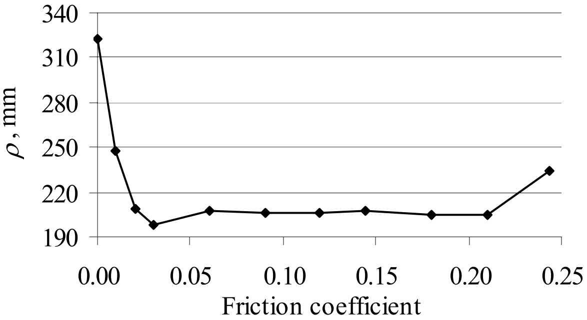

Fig. 10 Radius $\rho$ versus friction coefficient

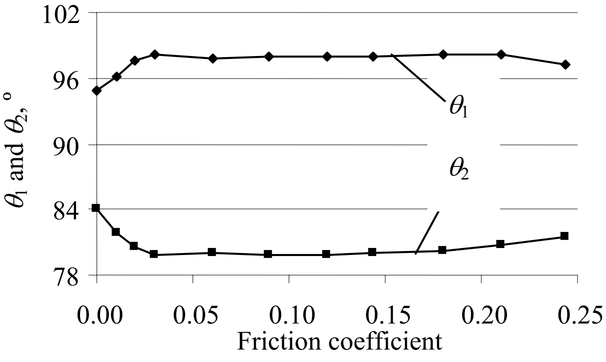

Fig. 11 Angles $\theta_1$ and $\theta_2$ versus friction coefficient

Different values have been used only for different simulations. The results of the numerical investigation are presented in Figs. 10-12. Figs. 10-11 indicate that the springback of the detail can be minimized only at a very low value of the friction coefficient, such as <0.03. If the friction coefficient is greater than this threshold value, the variation of it exhibits practically no influence on the springback. However, the wall thickness of the detail is very sensitive on the value of the friction coefficient over all the range of realistic values, Fig. 12. The analysis of the results indicates that thinning of the wall of the formed detail can be reduced only at very low values of friction forces.

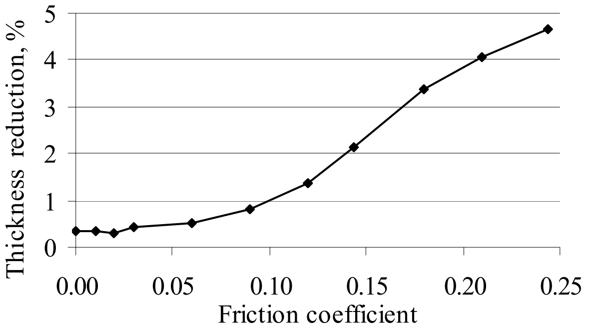

Fig. 12 Thickness reduction versus friction coefficient

## 5. Sensitivity to the die gap

The result of the SMF process is highly dependent on the magnitude of the die gap, Fig. 1. In our investigation we gradually decreased the die gap and observed its influence on the springback. The results are presented in Figs. 13-14. The springback gets gradually and slowly less with the decrease of the die gap.

The results obtained at the die gap values below 0.85mm are not reliable (see the dotted line in Figs. 13-14). Probably, a reverse bending occurred in the die gap [9], which can take place at a certain combination of physical properties of the material, thickness of the blank, the magnitude of stretching of the wall, the die shoulder radius and the magnitude of the die gap. On the other hand, at die gap values below 0.85 mm a clear influence of the FE mesh density on the accuracy of the numerical results is observed [2-3].

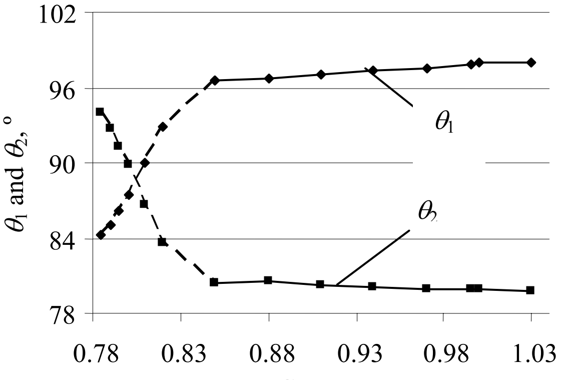

Fig. 13 Angles $\theta_1$ and $\theta_2$ versus die gap

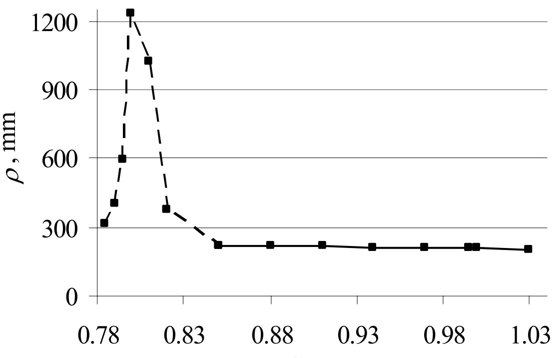

Fig. 14 Radius $\rho$ versus die gap

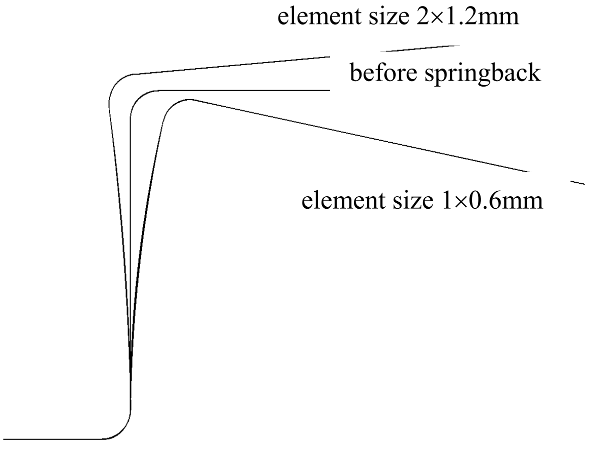

Fig. 15 Mesh size sensitivity

Using dense meshes could increase accuracy of the results and the range of values of the die gap at which the simulation results are reliable (Fig. 15), however, it leads to significant increase of the computation time. The decrease of the element edges sizes 2 times (Fig. 15) enlarged the computation duration 8 times, and the decrease of the element edges sizes 3 times enlarged the computation duration 60 times.

On the other hand, it is known that very dense meshes do not necessarily provide better results. The lack of adequacy is sometimes observed due to the material models, which are usually adjusted to certain mesh densities and are performing worse in the case of very small elements. Such an investigation could be the topic of a separate investigation and was not carried out in this work.

## 6. Conclusions

A FE model for sheet metal forming by drawing of a benchmark-type U-shaped detail has been developed in LS-DYNA and validated by comparing the results against the experimental ones published elsewhere.

The springback of the detail is not sensitive to the variation of the blankholder force in the range of low values of the force. After exceeding some threshold the springback rapidly decreased and practically disappeared at certain value of the blankholder force. That is the optimal blankholder force value at which the springback is minimal and simultaneously plastic strains are sufficiently far from the failure limit. As a drawback, a significant reduction of the wall thickness could be mentioned, since the wall thickness of the detail is very sensitive to the variation of the blankholder force and decreases with the increase of the force.

The springback of the detail may be diminished only at very low values of the friction coefficient between the surfaces of the blank and of the punch and die. At greater values of friction forces, within reasonable limits the forces do not influence significantly the magnitude of the springback. Meanwhile, the wall thickness of the detail is very sensitive to friction forces and rapidly decreases with the increase of them. Therefore the decrease of the magnitude of springback and the decrease of wall thinning simultaneously may be obtained only by minimizing the friction forces.

The decrease of the die gap diminishes the springback. However, the influence of very small gap values is not investigated thoroughly in this study.

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## PARAMETRŲ, TURINČIŲ ĮTAKOS TAMPRIAJAI DETALĖS FORMOS ATSTATAI ŠTAMPUOJANT METALO LAKŠTUS, TYRIMAS BAIGTINIŲ ELEMENTŲ METODU

### Reziumė

Straipsnyje pateikta parametrų, turinčių įtakos U formos detalės tampriajai atstatai štampuojant metalo lakštus, analizė baigtinių elementų metodu, naudojant LS-DYNA programinę įrangą. Sudarytos tampriąją formos atstatą aprašančių dydžių ir ruošinio prispaudiklio jėgos, trinties koeficiento ir tarpelio tarp matricos ir puansono tarpusavio priklausomybių kreivės. Ištirtas detalės sienelės suplonėjimas ir nustatyta kritinė ruošinio prispaudiklio jėgos vertė.

R. Ankėnas, R. Barauskas

## FINITE ELEMENT INVESTIGATION ON PARAMETERS INFLUENCING THE SPRINGBACK DURING SHEET METAL FORMING

### Summary

The article presents the results of finite element analysis of the parameters influencing the springback of a benchmark-type U-shaped detail after cold sheet metal forming process by using LS-DYNA software. The relationships of the quantities characterizing the springback against the blankholder force, the die friction coefficient and the die gap are analyzed. The wall thinning of the detail has been investigated and the critical value of the blankholder force obtained.

Р. Анкенас, Р. Бараускас

## ИССЛЕДОВАНИЕ ПАРАМЕТРОВ, ВЛИЯЮЩИХ НА ПРУЖИНЕНИЕ ДЕТАЛЕЙ В ЛИСТОВОЙ ШТАМПОВКЕ МЕТОДОМ КОНЕЧНЫХ ЭЛЕМЕНТОВ

### Резюме

В настоящей работе приведены результаты исследования методом конечных элементов параметров, влияющих на пружинение и упругое последействие деталей после завершения формоизменения гибкой с вытяжкой в листовой холодной штамповке используя программу LS-DYNA. Были получены зависимости величин, характеризующих пружинение и упругое последействие детали от силы прижимателя заготовки, коэффициента трения и зазора между матрицей и пуансоном. Было исследовано утонение стенки детали и получена критическая величина силы прижимателя заготовки.

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