

NUMERICAL STUDY ON THE INFLUENCE OF INTERPOLATOR ELASTIC MODULUS IN RECONFIGURABLE MULTIPOINT FORMING

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ABSTRACT

The elastic interpolator between the pins active elements and the blank leads to increasing the quality of the reconfigurable multipoint formed parts. The paper presents a simulation model based on the presence of a flexible interface in the system assembly. In the first part of the paper are discussed the general aspects of material behaviour laws in the studied reconfigurable multipoint forming system. Then in the paper are presented the simulations results, using finite element approach, regarding the influence of the interpolator elastic modulus, interpolator thickness and pins strokes toward the parts quality. The parts quality is evaluated in terms of springback. The results could lead to the development of these new types of equipments which ensure the decreasing of the cost testing and production.

KEYWORDS: multipoint forming, rubber forming, numerical simulation

1. Introduction

Forming with multipoint reconfigurable dies is a flexible manufacturing stamping technology based on a pair of discrete active elements networks which materialize the continuous 3-D surface of the part. The discrete active element network consists on a number of discrete punches, called pins (figure 1). The desired surface of the part is obtained by adjusting, using CNC, the heights of these pins. Using a geometrically reconfigurable die, precious production time is saved because several different products can be made without changing tools. Also a lot of expenses are saved because the manufacturing of very expensive rigid dies is reduced.

One of the methods utilized for increasing the reconfigurable multipoint formed parts quality is to interpose an elastic plate (interpolator) between the pins active elements and the blank [6].

The interpolator presences change the behaviour of the whole system of deformation, resulting both some advantages and disadvantages of this type of process.

The advantages using the elastic interpolator

are: good surface quality of the part as a result of dimpling phenomenon elimination; a uniform pressure distribution upon the blank which ensures a uniform material deformation.

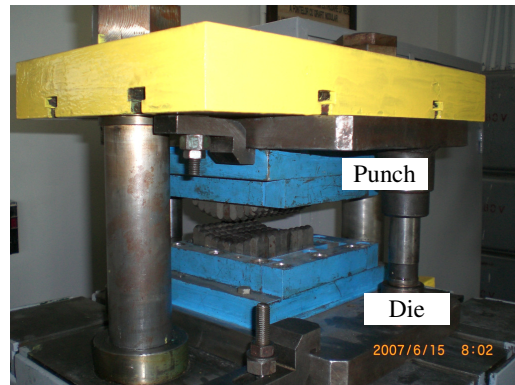


Fig. 1. Technological equipment for reconfigurable multipoint forming

There are also some disadvantages regarding the properties and thickness of the elastic interpolator used in the system. The first disadvantage of using soft materials is that the pins can push through the pad

and dimple the sheet metal. Also this thing happens when the interpolator is too thin. Another one is that when the interpolator is hard, it will not conform to the blank geometry. According to [1], the perfect interpolator would be very soft initially until all the gaps have been filled, then it would become perfectly rigid so that it would not fail.

The paper focuses on the influence of the interpolator elastic modulus, interpolator thickness and pins stroke toward the part quality in terms of springback. The study was made using finite element method implemented in Dynaform program.

2. Materials behaviour laws for the studied system

From the point of view of material behaviour, the studied system is composed of rigid, elasto-plastic and hyperelastic elements which correspond to punch and die, to blank and to elastic interpolator.

The rigid material is used for tooling modeling. In finite element method, elements which are rigid are bypassed in the element processing and no storage is allocated for storing history variables; consequently, the rigid material type is very cost efficient. All elements which correspond to the rigid material should be contiguous, but this is not a requirement. If two disjoint groups of elements on opposite sides of a model are modeled as rigid, separate part IDs should be created for each of the contiguous element groups if each group is to move independently. Young's modulus, E , and Poisson's ratio, ν , are used for determining sliding interface parameters if the rigid body interacts in a contact definition.

The elasto-plastic material is used for modeling the sheet metal behavior [8]. One model developed by Barlat, Lege, and Brem [9] for modeling material behavior is that the anisotropic yield criterion Φ for plane stress is defined as:

$$\Phi = a|K_1 + K_2|^m + a|K_1 - K_2|^m + c|K_2|^m = 2\sigma_Y^m \quad (1)$$

where σ_Y is the yield stress and $K_{i=1,2}$ are given by:

$$K_1 = \frac{\sigma_x - h\sigma_y}{2} \quad (2)$$

$$K_2 = \sqrt{\left(\frac{\sigma_x - h\sigma_y}{2}\right)^2 + p^2 \tau_{xy}^2}$$

The anisotropic material constants a , c , h and p are obtained through R_{00} , R_{45} and R_{90} :

$$a = 2 - 2\sqrt{\frac{R_{00}}{1+R_{00}} \frac{R_{90}}{1+R_{90}}}$$

$$c = 2 - a \quad (3)$$

$$h = \sqrt{\frac{R_{00}}{1+R_{00}} \frac{1+R_{90}}{R_{90}}}$$

The anisotropy parameter p is calculated implicitly. For FCC materials $m=8$ is recommended and for BCC materials $m=6$ is used.

The yielding of the sheet material is modeled using a power law:

$$\sigma = K \varepsilon^n \quad (4)$$

where: K is the material constant; n – hardening exponent.

For the elastic interpolator, an incompressible Mooney-Rivlin Rubber model could be used [8]. The Mooney-Rivlin material model is based on a strain energy function, W , as follows:

$$W = A(I_1 - 3) + B(I_2 - 3) + C\left(\frac{I_1}{I_3} - 1\right) + D(I_3 - 1)^2 \quad (5)$$

A and B are user defined constants, whereas C and D are related to A and B as follows:

$$C = \frac{1}{2}A + B \quad (6)$$

$$D = \frac{A(5\nu - 2) + B(11\nu - 5)}{2(1 - 2\nu)}$$

where ν is the Poisson's ratio, I_1 , I_2 , I_3 are the invariants of the Cauchy-Green Tensor.

More details about the above models are presented in [8]

3. FEM simulation model

The model was developed using Dynaform finite element program (Figure 2).

For the process simulation, in the first step it was constructed the tool geometry with fixed configuration without interpolator, considering the obtaining of a single curvature plate with an interior radius of 95 mm, a width of 120 mm (maximum depth is 21.345 mm) and a length of 130 mm. In the second step in the model between the active elements and the blank were included two interpolators (upper and down rubber). No blankholder was used so the ends of the rubbers are free to expand.

The blank material used in experiments was mild steel, with 1 mm thickness. In simulation,

according to equation (4) the n – value = 0.22 and $K = 648$ MPa. The R values were set to: $R_{00} = 1.87$; $R_{45} = 1.27$; $R_{90} = 2.17$.

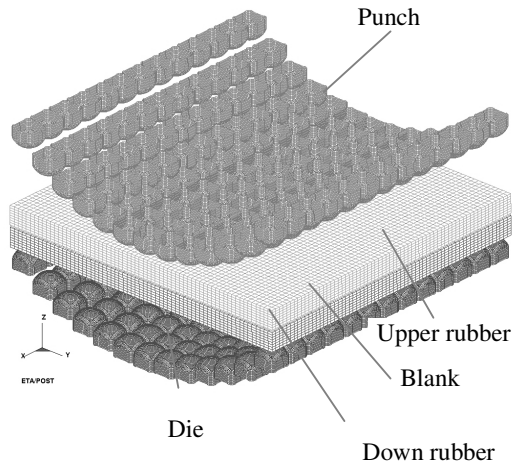


Fig. 2. Tooling for reconfigurable multipoint forming

The blank is a rectangular plate with the dimensions of 120x130x1 mm and the mesh consists of 900 finite elements.

The FE blank mesh consists of 4-node Belytschko-Tsay shell elements, with five integration points through the thickness of the sheet [4]. The Belytschko-Lin-Tsay shell elements are based on a combined co-rotational and velocity-strain formulation. The Coulomb friction law was used with a friction coefficient of 0.125. The punch speed was 100 mm/second.

The tooling was modelled as rigid surfaces. The geometry of the tool is characterized in terms of an array of pin positions. The geometrical model of die-punch tool was composed of two working arrays with 100 pins for each array, 10 rows on x -direction and 10 rows on y -direction. The pins are disposed face to face, both on x -direction and y -direction. The mesh consists of 488744 numbers of finite elements.

For rubber interpolator was chosen a material type Elvax 460. The properties of the material were: density, $\rho = 0.946$ g/cm³; hardness Shore ASTM D2240 scale B – 40 and scale A – 80; tensile strength, $R_m = 18$ MPa; elongation – 750%; flexural modulus – 44 MPa; stiffness, $k = 43$ MPa; Poisson ratio, $\nu = 0.499$. Solid elements were used for discretization of the rubber interpolator. The interpolator was modelled as an elastic material, *MAT_ELASTIC (LS-DYNA Type 1) according to [8]. In this study, the density and the Poisson ratio were maintained constant, at the above values. The flexural moduli varied between 14 and 44 Mpa. The thicknesses of the rubbers varied between 2 and 10 mm. The simulations were done also with the different strokes for the punch.

4. Simulation results

During these simulations, the penetration of the pins into the interpolator was observed in order to determine its influence. Also the effect of the interpolator elastic modulus toward the part quality was determined.

4.1. Rubber deformation

Some observations could be made regarding the rubber deformation.

Figures 3 and 4 present the images of the rubber interpolators forms during deformation, thickness of 8 mm, elasticity modulus of 5 Mpa and 24 Mpa.

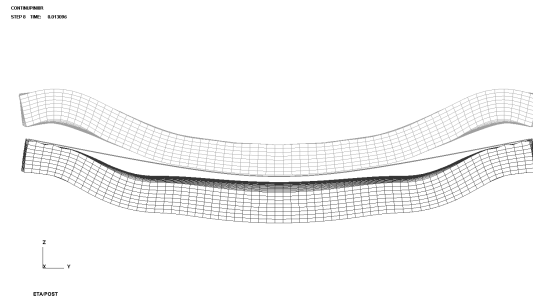


Fig. 3. Rubber interpolator after deformation, elasticity modulus of 5 MPa

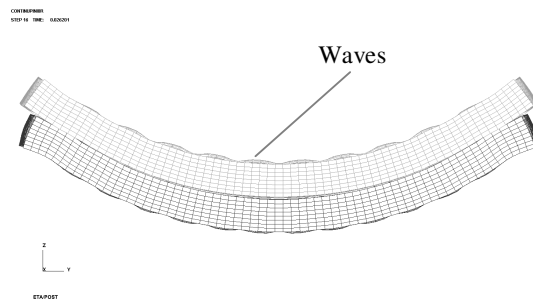


Fig. 4. Rubber interpolator after deformation, elasticity modulus of 24 MPa

The elasticity modulus of the rubber influences in a large extent the sheet metal deformation. In Figure 3, a very low elasticity modulus of the rubber leads to an uneven rubber deformation, which finally, in this case, will stop the simulation, due to the contact condition.

With increasing the elasticity modulus of the rubber, the deformation conditions are improving, having as the results the sheet metal deformation.

As the part is formed on the die, the interpolator is compressed in the thickness direction by the pins, and thus tends to expand in x direction and bends in y direction (Figure 5). This depends on the rubber

thickness and the pins strokes for the same rubber material.

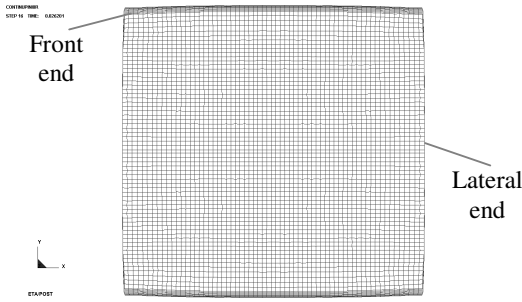


Fig. 5. Upper view of the rubber interpolator

The rubber deformation is characterized by the wave appearance (Figure 4). Their form depends on the gap between the pins, the pins stroke and the rubber thickness.

The presence of an interpolator with a greater thickness in the system could ensure a uniform pressure toward the blank. The mean stress is given by the relation:

$$\sigma_{med} = \frac{\sigma_1 + \sigma_2 + \sigma_3}{3} \quad (7)$$

where $\sigma_i, i=1,2,3$ are the principal stresses.

Figure 6 presents the mean stresses variation in the upper and down rubber interpolators for different rubber thickness and the same pins strokes. As it can be seen, the increasing of the rubber thickness leads to the reduction of the means stress in the rubber material which will affect the blank deformation.

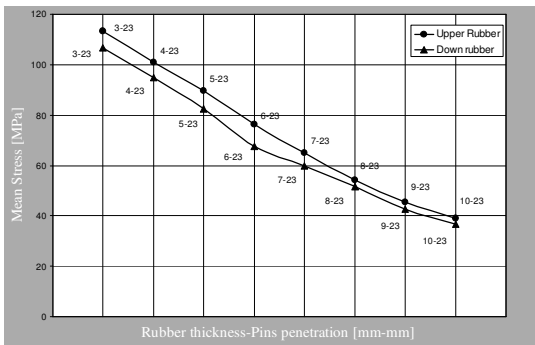


Fig. 6. Mean stresses variation in the rubber interpolator

In the considered fixed configuration of the pins, for the considered geometry and a greater rubber thickness, appears a phenomenon of supplementary

bending of the lateral ends of the rubber along y direction which will affect the part geometry.

4.2. Blank deformation

The geometry considered is affected by the rubber presence in terms of profile radius and depth.

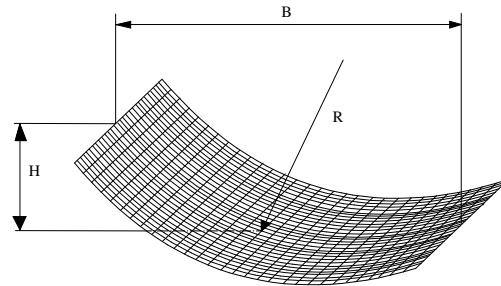


Fig. 7. Parameters for springback definition

The blank deformation was evaluated in terms of springback. The springback could be defined function of the three parameters presented in Figure 7.

The springback was calculated using the relation:

$$\Delta S = \frac{V_i - V_f}{V_i} \quad (8)$$

where: ΔS is the value of the springback, S is one of the three parameters; V_i – initial value of one of the three parameters; V_f – final value of one of the three parameters.

Only the value of springback in width direction will be discussed.

For the same depth of penetration, and different rubber thickness, the springback variation is presented in Figure 8, function of elastic modulus.

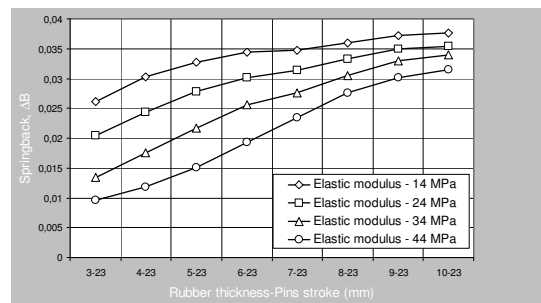


Fig. 8. Springback variation for the same pins stroke and different rubber thickness

So, when the rubber thickness is increasing, the values of the springback reported to the width are

increasing to the same pins stroke. This is due to the fact that by increasing the rubber thickness, the rubber transfers a decreasing pressure to the sheet, thus affecting the amount of the springback. This is in accordance with Figure 6, which shows the variation of mean stresses in the rubber interpolator.

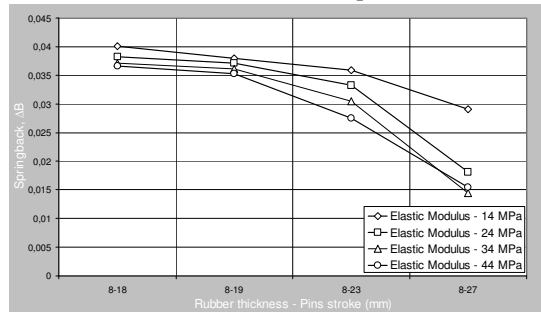


Fig. 9. Springback variation for the same rubber thickness and different pins stroke

With increasing the elastic modulus of the rubber, the values of the springback are decreasing, because of the increasing of the plastic state induced in material at the same pins stroke.

For the same rubber thickness, and different depth of penetration, the springback variation is presented in Figure 9, function of elastic modulus.

According to Figure 9, when the pins stroke are increasing the values of the springback reported to the width are decreasing to the same rubber thickness. This is due to the fact that by increasing the pins stroke, the rubber transfers an increasing pressure to the sheet, thus affecting the amount of the springback.

With increasing the elastic modulus of the rubber, the values of the springback are decreasing, because of the increasing of the plastic state induced in the material at the same rubber thickness and different pins stroke.

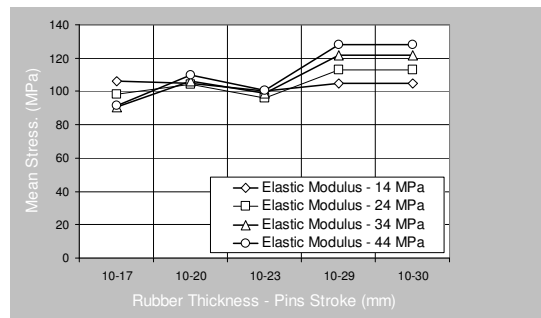


Fig. 10. Springback variation for the same rubber thickness and different pins stroke

Figure 10 presents the variation of mean stress function of elastic modulus and pins stroke, to the same rubber thickness. With increasing the values of

elastic modulus and pins stroke, the values of mean stresses are increasing. It is interesting to note that in the current simulation conditions, at a value of 10 mm rubber thickness and 23 mm pins stroke, the values of mean stresses are almost the same, no matter that the rubber elastic modulus is.

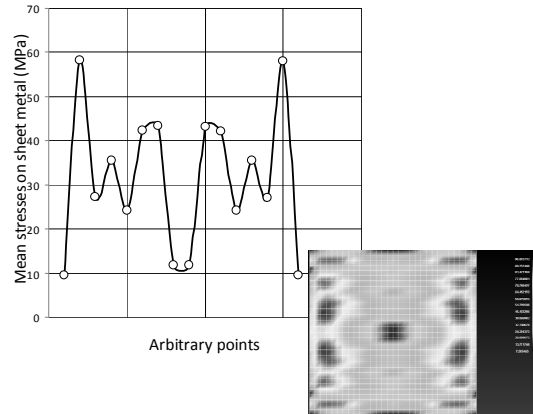


Fig. 11. Springback variation for the same rubber thickness and different pins stroke

Figure 11 presents the distribution of the mean stresses along the length of the part, at the middle of the part, measured in some nodes, from left to right.

The interesting variation of the mean stresses is due to the pressure local effect of pins penetration in the rubber, which transmit the same effect in the material.

5. Conclusions

In the present study, it was considered a fixed rigid configuration of the tool, the same friction coefficient between the system components, different rubber thickness and elastic moduli, different pins penetrations, and free rubber expansion.

The presence of the interpolator changes the behavior of the sheet metal blank which affects the part quality.

When the interpolator thickness and the elastic modulus of the rubber are increasing, to the same pins stroke, the springback will increase. When the pins stroke and elastic modulus of the rubber are increasing, to the same interpolator thickness, the springback will increase.

On the other hand, the geometry of the part will affect the rubber deformation with a negative influence toward the sheet metal part quality. At a big thickness of the elastic interpolator, one could obtain different part curvatures, depending on the pins stroke.

The obtained results could lead to the development of these new types of equipments which

ensure the decreasing of the cost testing and production.

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Studiu numeric despre influența modului de elasticitate al interpolatorului la deformare multipunct reconfigurabilă

—Rezumat—

Prezența interpolatorului elastic între semifabricat și elementele active tip pini determină creșterea calității pieselor obținute prin deformare multipunct reconfigurabilă. Lucrarea prezintă un model de simulare bazat pe prezența unei interfețe flexibile în ansamblul sistemului. În prima parte a lucrării se prezintă aspecte generale privind legile de comportare ale materialelor utilizate în sistemul de reconfigurabilitate considerat. Apoi, în lucrare, se prezintă rezultatele simulărilor numerice, în element finit, privind influența grosimii interpolatorului, a modului de elasticitate a interpolatorului și a cursei pinilor asupra calității pieselor deformate. Calitatea pieselor este evaluată în funcție de variația revenirii elastice. Rezultatele obținute pot conduce la dezvoltarea acestor noi tipuri de echipamente care asigură scăderea costurilor de testare și de fabricare.