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STUDY OF THE TOOL GEOMETRY IN RECONFIGURABLE MULTIPOINT FORMING

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ABSTRACT

In the present paper, some models for simulation the multipoint process of deformation using the finite element method were developed. The models were designed based on a program for contact points calculation between the part and the tool active elements. The localization of contact points is analyzed. For a fixed rigid configuration of the multipoint deformation tool without interpolator, the correlation between the contact points distribution and localized deformation is discussed. In the case of a flexible configuration of the multipoint deformation tool with interpolator the part quality is analysed in terms of surface quality, part profile deviation and elastic recovery. The results show the presence of spring forward which increased when the part profile angles are increasing, to the same interpolator thickness.

KEYWORDS: multipoint forming**,** spring forward, 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 is composed from a number of discrete punches, called pins. The desired surface of the part is obtained by adjusting, using CNC, the heights of these pins [1, 2, 5]. 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 [8].

During the process of deformation if no interpolator between the pins and the blank is used, a network of small dimples appears which affects the surface quality, mainly if such parts are used in automotive, aeronautical industry or in medicine. For other applications such as in civil and industrial construction, architecture and shipbuilding the appearance of such dimples is not the main problem. In these cases the problem of springback is more important and must be compensated.

The interpolator presences change the behaviour of the 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 assures a uniform material deformation [6].

There are also some disadvantages regarding the properties and thickness of the elastic interpolator used in the system. First disadvantage of using soft or thin materials is that the pins can push through the pad and dimple the sheet metal. Another one is that when the interpolator is hard, it will not conform to the blank geometry.

The paper focuses in a qualitative study of the tool geometry in the reconfigurable multipoint forming (RMPF) considering the influence of the contact points in deformation process and the presence and the absence of the interpolators in deformation system. Different tool geometries were considered. The study was made using a dynamic finite element program.

2. Analysis of contact points between the pins and the part

In this study were considered four tools geometries defined by four profiles. Figure 1 shows the characteristics of a profile.

Each profile has three regions. The region (I) has different angles for each of the four profiles, respectively 5^0, 20^0, 30^0 and 40^0. The middle region (II) has the same angle (10^0) for all profiles. The region (III) has, also different angles for each of the four profiles, respectively 10^0, 25^0, 35^0 and 45^0.

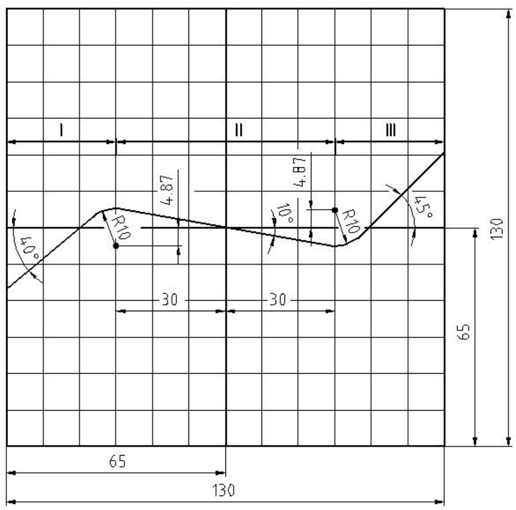

Fig. 1. *The profile characteristics, for 40-10-45 case*

Initial the profiles were enveloped by a pin matrix with dimensions 12x12, having the side length 120 mm. Each pin has the side length 10 mm and the end radius $R = 10\sqrt{2}$ mm.

The tool geometry in (RMPF) depends on the contact points between the blank and the part. So it is needed to known the position of the pins which materialize the die's active surface. The pins positions are given by the heights which they occupy in relation with the part.

Running the in-house program developed for the calculus of pin height it was observed that at the blank ends, due to the inclination angle, it is impossible to calculate the position of the pin. In order to avoid this mathematical error the blank surfaces was extended in *X* and *Y* directions with a virtual strip which bounded the blank. The width of this strip must assure a virtual contact between the pins of the die's ends and the blank. So the pin matrix was increased to a network of 13x13 pins.

The position of the points from the virtual strip was calculated with relation:

$$\begin{aligned} X &= X_A + R \cdot a \cdot \sin\alpha; \\ Y &= Y_A + R \cdot \sin\alpha + b; \\ Z &= Z_A + R \cdot a \cdot \sin\alpha \cdot \tan\alpha, \end{aligned} \tag{1}$$

where: X_A, Y_A, Z_A are the coordinates of points from the right and back border of the blank; a=1.2 and b=7 are technologic parameters; α is the angle of the part at the border,

$$\alpha = \arctan\left(\frac{Z_{n-1} - Z_n}{X_{n-1} - X_n}\right), \text{ for right border and,} \tag{2}$$

$$\alpha = \arctan\left(\frac{Z_{n-1} - Z_n}{Y_{n-1} - Y_n}\right), \text{ for back border,} \tag{3}$$

n is the pins number for the right and back border (in this case n=13).

For the left and front border the position of the points was calculated with relation:

$$\begin{aligned} X &= X_A - R \cdot a \cdot \sin\alpha; \\ Y &= Y_A - R \cdot \sin\alpha - b; \\ Z &= Z_A - R \cdot a \cdot \sin\alpha \cdot \tan\alpha, \end{aligned} \tag{4}$$

where: X_A, Y_A, Z_A are the coordinates of points from the left and front border of the blank; a=1.2 and b=7 are technologic parameters; α is the angle of the part at the border,

$$\alpha = \arctan\left(\frac{Z_1 - Z_2}{X_1 - X_2}\right), \text{ for left border and,} \tag{5}$$

$$\alpha = \arctan\left(\frac{Z_1 - Z_2}{Y_1 - Y_2}\right), \text{ for front border.} \tag{6}$$

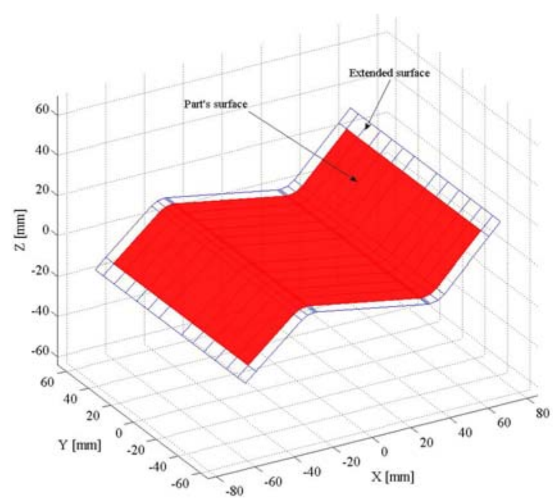

Fig. 2. *Part's surface and extended surface*

Using the above relations it is possible to calculate the equidistant to the surface in each direction (upper and lower surface of the blank) and to determine the position of contact points between the pins and the part.

The part’s surface and the extended surface are presented in figure 2.

For each of the four cases was calculated the pins position for upper and lower die matrix.

For one case, figure 3 shows the pins positions, where, for simplicity sake was drawing only one row of the pins. The external pins which haven’t contact with the part were drawn with light color.

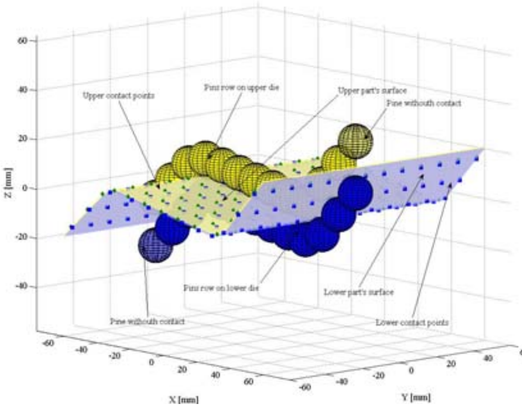

Fig. 3. *One row of pins on the upper and lower part’s surface*

Figures 4 and 5 show the contact points for the three analyzed cases, for the upper surface and respectively for lower surface.

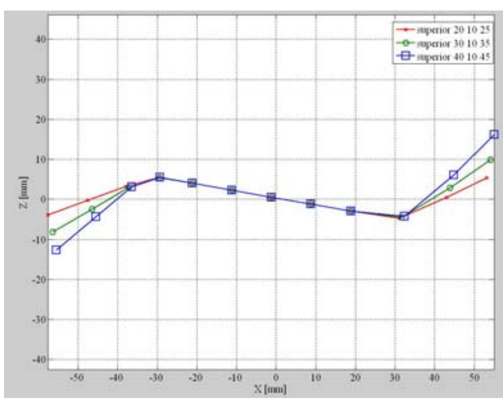

Fig. 4. *Contact points on the upper part’s surface*

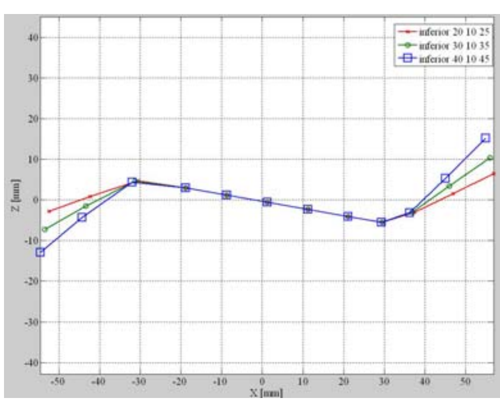

Fig. 5. *Contact points on the lower part’s face*

Tables 1 and 2 present a comparison of the difference in coordinate on X and Z. Note that with increasing the angle of profile inclination, the two surfaces coordinates differences of the pins contacts points increases. A situation is reached when for an inclination of 45^0, the last pins does not come in contact with the material. Of course, these differences will have an effect toward the material deformation.

Table 1. *Comparison of the coordinate differences in X direction*

No.	Xupper - Xdown, [mm]			
	5-10-15	20-10-25	30-10-35	40-10-45
1	1.232	4.838	7.079	9.151
2	1.232	4.837	7.064	9.028
3	1.138	4.383	6.231	7.856
4	-0.546	0.981	1.841	2.686
5	-2.285	-2.273	-2.254	-2.231
6	-2.456	-2.456	-2.456	-2.456
7	-2.456	-2.456	-2.456	-2.456
8	-2.456	-2.456	-2.456	-2.456
9	-2.265	-2.271	-2.249	-2.216
10	0.508	1.507	2.264	3.120
11	3.353	5.527	7.074	8.594
12	3.660	6.199	8.080	9.901
13	3.660	6.201	8.143	-

Table 2. *Comparison of the coordinate differences in Z direction*

No.	Zupper - Zdown, [mm]			
	5-10-15	20-10-25	30-10-35	40-10-45
1	1.112	2.825	5.242	8.984
2	1.112	2.825	5.233	8.881
3	1.104	2.672	4.776	7.676
4	0.970	0.932	1.033	1.233
5	1.420	1.418	1.415	1.411
6	1.449	1.449	1.449	1.449
7	1.448	1.448	1.448	1.448
8	1.449	1.449	1.449	1.449
9	1.417	1.418	1.414	1.409
10	0.935	0.969	1.104	1.394
11	1.939	3.836	6.112	9.503
12	2.016	4.136	6.878	11.317
13	2.016	4.137	6.922	-

3. FEM simulation models

The models (Figure 2) were developed using Dynaform finite element program

The first model is a tool geometry without interpolator and blankholder, according to figure 6.

The blank is a rectangular plate with the variable dimensions function of the bending angles.

The tool was modelled as rigid surfaces. The geometrical model of die-punch tool was composed from two working arrays with 91 pins for each array, 13 rows on *x*-direction and 7 rows on *y*-direction. The pins are disposed face to face, in both *x and y* directions

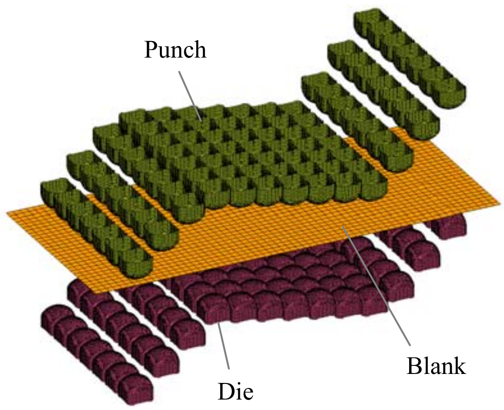

Fig. 6. *Tooling for reconfigurable multipoint forming without interpolator*

The second model is a tool geometry with interpolators and no blankholder, according to figure 7. The two interpolators are two rubber plates, which have the same dimensions as the blank.

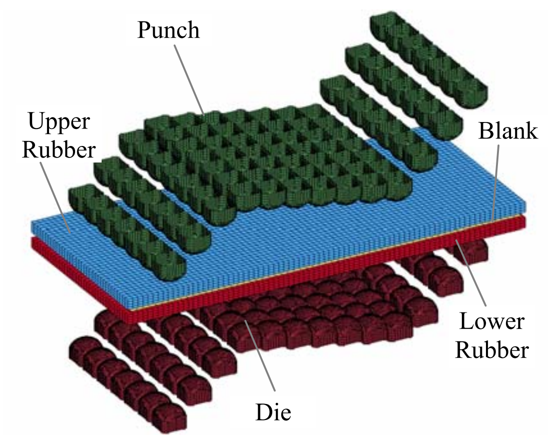

Fig. 7. *Tooling for reconfigurable multipoint forming with interpolator*

The blank material used in experiments was mild steel, with 1 mm thickness. The yielding of the material was modelled using a power law, as:

$$\sigma = K\,\varepsilon^{n} \tag{7}$$

In simulation, 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.

The FE blank mesh consists of 4-node Belytschko-Tsay shell elements, with five integration points through the thickness of the sheet [7]. The Coulomb friction law was used with a friction coefficient of 0.125. The punch speed was 1000 mm/mms.

For rubber interpolator was chosen the material Elvax 460. The properties of the material were: density, ρ – 0.946 g/cm^3; hardness Shore ASTM D2240 scale B – 40 and scale A – 80; tensile strength, Rm – 18 MPa; elongation – 750%; flexural modulus – 44 MPa; stiffness, k – 43 MPa; Poisson ratio, ν – 0.499. Solid elements were used for rubber interpolator discretization. The interpolator was modelled as an elastic material, *MAT_ELASTIC (LS-DYNA Type 1) according to [7]. The thicknesses of the rubbers were 4 mm.

4. Simulation results

During the simulations, the contact points positions produce the penetration of the pins into blank material, in the first case of simulation. Dimpling is a result of the discontinuous contacts between the pins and the sheet metal. In the contact zones the loads are strongly localized and this will generate particular maps of stresses and strains in material.

For small angles, 5-10-15, the contact points between the blank and the superior and inferior pins networks are appropriate (Figure 8).

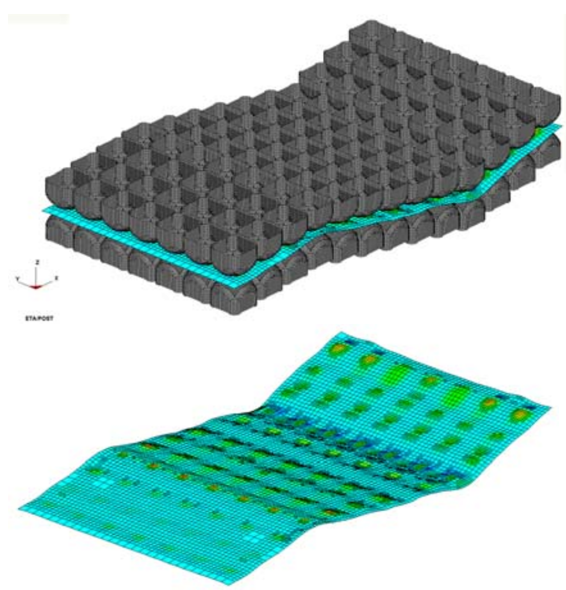

Fig. 8. *Qualitative image of the tool and blank deformation without interpolator, 5-10-15 case*

As a result in material no supplementary bending will appear. The local penetrations are small and the wrinkles at the part ends are also small.

With increasing the angles, the contact points between the blank and the superior pins network and the blank and inferior pins network moves away from each others. As a result in material supplementary local bending will appear. The local penetrations are high and the wrinkles at the blank ends are also high.

To 40 and 45 degree angles appear the situation in which the contact points between the superior and inferior pins networks at the ends of the part disappear (Figure 9).

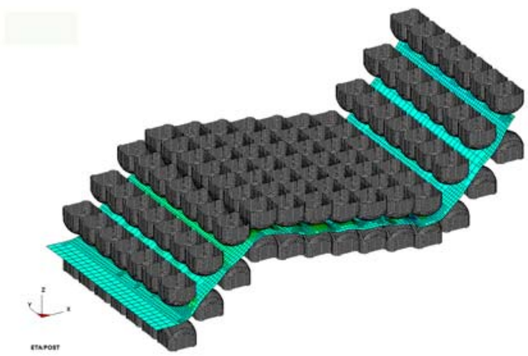

Fig. 9. *Qualitative image of the tool and blank deformation without interpolator, 40-10-45 case*

The last row from the left side of the die and the last row from the right side of the punch lose their contact with their correspondent rows from the die and punch. As a result important distortions of the part profile appear. The material displacement is not the same, and the material will flow more easily in the region with the biggest angle. In material the stresses alternate, in the zones of contact points the values of stresses are bigger and outside of these zones their values are smaller. Also the concentrated stresses cause wrinkles in the non-contact areas.

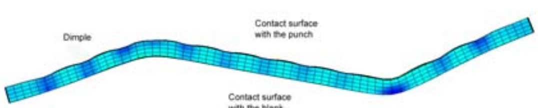

Fig. 10. *Qualitative image of the upper rubber 40-10-45 case*

The use of interpolators is necessary to avoid most of these phenomenons. The interpolators will take over the local effect of the pins pressure and will ensure a uniform pressure on the part which will give a good quality of the part surface (Figure 10).

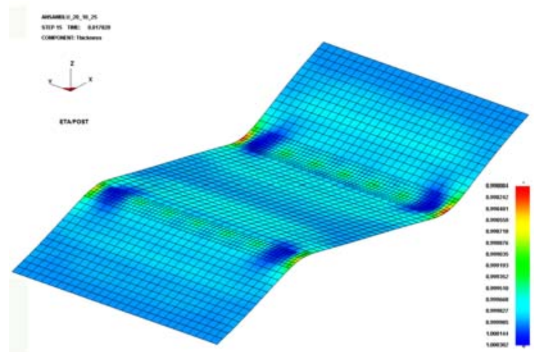

Fig. 11. *Qualitative image of the blank deformation with interpolator, 5-10-15 case*

Figure 11 presents the qualitative imagines of the thickness variations of the part using multipoint deformation with interpolator.

The figures show the improving of the parts surface but some profile distortions appears at the ends of the part. The difference in contact points between the punch/die and the two rubbers results in the supplementary deformation of the interpolators.

Figures 12-13 present the elastic recovery effect.

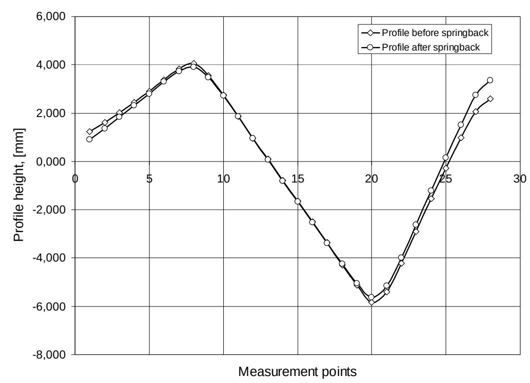

Fig. 12. *Profile 5-10-15 before and after elastic recovery*

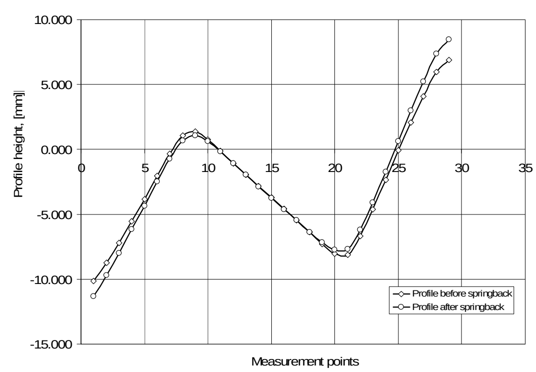

Fig. 13. *Profile 20-10-25 before and after elastic recovery*

The main observation is that the profiles after the elastic recovery will deform in the direction of the dimension reduction along the profiles lengths. This phenomenon is called spring forward and is opposite to springback. The spring forward values, calculated as the difference between the initial and final length of the profile, are presented in table 3.

Table 3. *Spring forward values for simulated cases*

No.	Profile	Value of profile length spring forward
1.	5-10-15	-0,114
2.	20-10-25	-0,725
3.	30-10-35	-0,886

The table 3 shows that by increasing the profiles angles the values of spring forward, in absolute values, are also increasing. The obtained results should be validated by an experimental work.

5. Conclusions

In the present paper, some models for simulation the multipoint process of deformation using the finite element method were developed. The models were designed based on a program for contact points calculation. The analysis shows that with increasing the angle of profile inclination, the coordinates differences of the pins contacts points increases. These differences will have an effect toward the material deformation.

For a fixed rigid configuration of the multipoint deformation tool, the effect of localized deformation is important and depends from contact points positions. As the result the surface quality of the part is poor, and the wrinkles appear in the non-contact areas.

To avoid these problems the solution is to use an interpolator between the sheet metal and the active elements of the die.

The presence of the interpolator has a positive effect toward the part surface quality. On the other hand the rubber deformation has a negative influence toward the sheet metal part profile when the coordinates differences of the pins contacts points increases. This depends of the profile angles.

The spring forward is present after multipoint deformation and part release. When the profile angles are increasing, the spring forward will increase also.

The obtained results should be validated by an experimental work.

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Studiu privind geometria sculelor
la deformare multipunct reconfigurabilă

—Rezumat—

In lucrare s-au dezvoltat câteva modele pentru simularea procesului de deformare multipunct. Modelele s-au proiectat pe baza unui program de calcul al punctelor de contact dintre semifabricat şi elementele active ale matritei. Este analizată localizarea punctelor de contact. Pentru o configuraţie rigidă, fixă a matriţei de deformare multipunct fără interpolator este discutată corelaţia dintre distribuţia punctelor de contact şi localizarea deformaţiei. În cazul unei configuraţii flexibile a matriţei de deformare multipunct cu interpolator este analizată calitatea piesei în funcţie de calitatea suprafeţei, deviaţia profilului piesei şi revenirea elastică. Rezultatele arată prezenţa spring forward care creşte când unghiurile profilului piesei cresc.