NUMERICAL ANALYSIS OF MULTIPOINT FORMING PROCESS

Viorel Păunoiu, Catălina Maier, Virgil Teodor & Eugen Găvan

“Dunarea de Jos” University of Galati, Department of Machine Manufacturing Technology, Domneasca Street, No. 47, 800008 Galati, Romania

Corresponding author: Viorel Paunoiu, viorel.paunoiu@ugal.ro

Abstract: Multipoint forming of steel plates is based on the discrete die-punch reconfigurable tooling concept. The geometric modeling of the die-punch tool requests calculations of the characteristic profiles coordinates of the working surfaces materialized by a number of punches on the height positioned. The paper is concerned with the development of a method for die – punch geometry configuration using Matlab program. On this basis, the theoretical analysis is particularly applied to the simulation of a curved thin steel plate deformation using finite element method. An analysis of spring back dampling and force variation function of material thickness and parts radii values is performed. The conclusions obtained from the numerical simulation certify the validity of the developed method.

Key words: multipoint die, multipoint forming, CAD, sheet metal forming, reconfigurable systems.

1. INTRODUCTION

The surface tooling in reconfigurable multipoint forming (RMF) is based on the concept of a die continuous surface discrete approximation (Figure 1), (Walczyk, D.F., Hardt, D.E., 1998). It consists of a number of closely spaced multiple rigid surface tool elements, known as pins, each of which is a surface element of an expected contour, (Păunoiu, V., et al., 2006).

Fig. 1. Reconfigurable tooling in RMF

The heights of the pins can be adjusted to approximate the desired surface shapes either manually or using a computer control, (Păunoiu, V., et al., 2008). A variety of surface shapes can be realized by properly adjusting the heights of surface tool elements because such a tooling is reconfigurable.

The principles of tooling for flexible fabrication in sheet metal forming were introduced by Hardt (RTFF – Rapid Tooling for Flexible Fabrication), (Hardt, D.E., et. al., 2010). Boyce and Walczky (Socrate, S., Boyce, M.C., 2000, Walczyk, D.F., Hardt, D.E., 1998) developed numerical control algorithms for vertical displacement of the pins in order to generate the working surface of active elements.

Li and coworkers (Li, M.Z., Cai, Z.Y., Sui, Z., Yan, Q.G., 2002) developed the concept of Multipoint Forming for sheet metal (MPF). Derived from MPF technology they developed another concept of deformation, Digitized Die Forming (DDF). The principle of DDF consists in obtaining the part, section by section, which gives a more flexibilty in comparison with MPF. The Closed-loop forming process technics which consists in integration the DDF system with a shape feedback system is used in the field of deformation with multipoint dies deformation. Cai and Li (Cai, Z.Y., Li, M.Z., 2006), propose a new technology for obtaing complex parts with multipoint dies, so called VP-DDF (Varying path DDF) technics. In this case the final shape of the digitized-die is described by a series of intermediare shape at a series of specific time t_0, t_1, …, t_i, … t_f. The calculus of each pin position at the moment is realized based on a geometrical criterion, on a-priori calculated height, not on a material response reaction during the deformation. Multi-step DDF approximate VP-DDF technics and consists in obtaining the part by succesive small deformation steps. This method is more easily to implement in practice than VP-DDF technics maintaining the majority of its advantages, (Gavan, E., Paunoiu, V., Dimache, A, 2005).

In the paper is presented a MATLAB method for pins heights calculation and an analysis of springback, dimpling phenomenon in RMPF (reconfigurable multipoint forming).

2. A MATLAB METHOD FOR PINS HEIGHTS DETERMINATION

2.1. State of art

Different methods have been proposed for established the contact points coordinates. These methods could be divided in two categories, function of how is defined the part geometry surface.

The first category considers that the equation of the part geometry surface is known. This leads to the use of the classical analytical methods for contact points estimation. Thus, Hardt, Karafillis, Walczky and Papazin (Hardt, D.E., et al., 2002, Karafillis, A. P., Boyce, M. C., 1992, Hardt, D.E., et al., 2010, Walczyk, D.F., Hardt, D.E., 1998) used such methods in design the multipoint forming die with application in the field of strech-forming, known as reconfigurable tooling for flexible fabrication (RTFF).

The second category, which assures the greatest generality, considers that the part geometry surface is defined by a number of points, this means that the equation of the surface is unknown. These points could be the result of a measuring process using CMM or could be the result of surface discretizations. In this case, the problem of contact points estimation is more complicated. For multipoint forming, Cai (Cai, Z.Y., Li, M.Z., 2006) proposed a method often use in surface modelling based on NURBS surface, in which the equation of the desired part is parametric defined using NURBS surface with control points. Also, Cai (Cai, Z.Y., Li, M.Z., 2001) developed another method where using the interpolating formulation of finite element method the pins positions are given by a series of 3 non-linear equations.

Paunoiu (Paunoiu, V., Oancea, N., Nicoara, D., 2004) proposed a method for primary configure of the multipoint forming die based on the surface generation method.

2.2. The proposed method

The punches heights calculation implies to determine the contact points with the sheet of each pin which belongs to the superior and inferior matrix arrays of pins.

The parameters for contact point calculation depend of pin radius and shape, pin width and number, surface geometry and dimensions and material thickness.

In the final position the pins are in contact with sheet, which has taken the part form.

The calculus started from the known surface of the part to be obtained.

A points matrix with *n* points on direction *x* and *m* points on direction *y* are considered. On each point using MatLab program the normal direction at the surface are calculated.

The vector is obtained:

$$N = N_x \cdot \vec{i} + N_y \cdot \vec{j} + N_z \cdot \vec{k} \tag{1}$$

where: N_X, N_Y and N_Z are the component of normal direction on axis *X*, *Y* and *Z*.

Knowing the radius *R* of the pin hemispherical end and the blank thickness *g*, for each node *ij*, the distances ($R + 0.5g$) along the normal direction is calculated. In this way a surface equidistant to the initial surface is obtained. So two equidistant corresponding to the upper and lower half die are calculated (Figure 2).

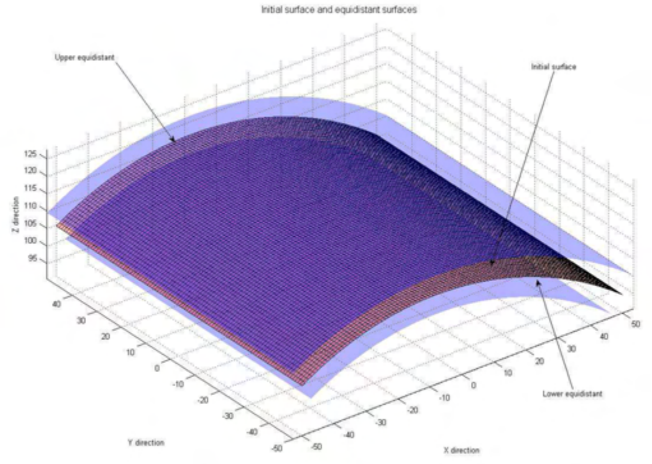

Fig. 2. Initial surface and upper and lower equidistant

The two surfaces will have the equations:

$$S_U : \begin{cases} X_{Uij} = x_{ij} + \left(R + \dfrac{g}{2} \right) \cdot N_x ; \\ Y_{Uij} = y_{ij} + \left(R + \dfrac{g}{2} \right) \cdot N_y ; \\ Z_{Uij} = z_{ij} + \left(R + \dfrac{g}{2} \right) \cdot N_z , \end{cases} \tag{2}$$

for upper equidistant and:

$$S_L : \begin{cases} X_{Lij} = x_{ij} - \left(R + \dfrac{g}{2} \right) \cdot N_x ; \\ Y_{Lij} = y_{ij} - \left(R + \dfrac{g}{2} \right) \cdot N_y ; \\ Z_{Lij} = z_{ij} - \left(R + \dfrac{g}{2} \right) \cdot N_z , \end{cases} \tag{3}$$

for lower equidistant, *i=1…m, j=1…n,* $[x_{ij}, y_{ij}, z_{ij}]$ coordinates of node *ij*.

With MatLab capabilities two new surfaces (S_{US} and S_{LS}) overlapped to surfaces S_U and S_L, with nodes at even pitch on *x* and *y* directions are generated.

If the surfaces pitch corresponds to the pin half side, the nodes of these surfaces will be the position of the hemispheric end of each pin in the upper half die and respectively lower half die.

In order to determine the coordinates of contact points between the pin and the part, in each of the S_{US} and S_{LS} surfaces nodes, the normal at these surfaces will be calculated:

$$n = n_x \cdot \vec{i} + n_y \cdot \vec{j} + n_z \cdot \vec{k} \tag{4}$$

The contact points coordinates are given by:

$$P_U : \begin{cases} X_{UC} = X_{US} - R \cdot n_x ; \\ Y_{UC} = Y_{US} - R \cdot n_y ; \\ Z_{UC} = Z_{US} - R \cdot n_z ; \end{cases} \tag{5}$$

respectively:

$$P_L : \begin{cases} X_{LC} = X_{LS} + R \cdot n_x ; \\ Y_{LC} = Y_{LS} + R \cdot n_y ; \\ Z_{LC} = Z_{LS} + R \cdot n_z ; \end{cases} \qquad (6)$$

and are presented in figure 3.

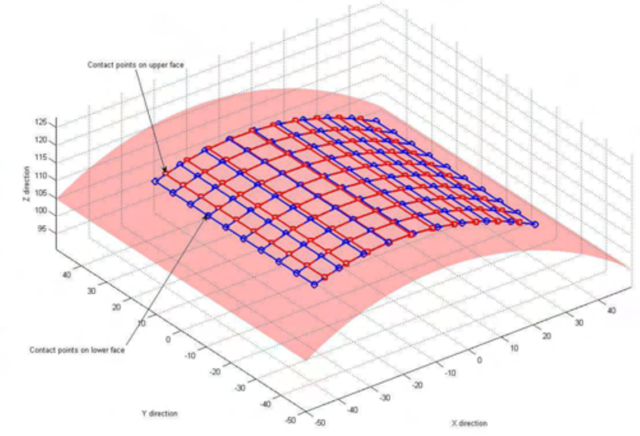

Fig. 3. Contact points on upper and lower face of the blank

3. MODEL FOR SIMULATATED THE RECONFIGURABLE MULTIPOINT FORMING

The quality of the parts obtained by using the reconfigurable MPF - RMPF process is affected by two factors: dimpling and spring back.

Both factors could be analysed using the power of finite element method.

In figure 4 is presented the model of deformation using the FEM program Dynaform. Only a half of model is presented.

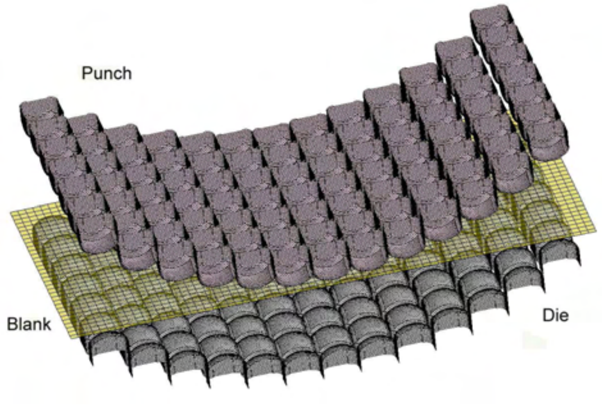

Fig. 4. Tools in modeling the RMPF

The tool geometry without interpolator is configured for obtaining a single curvature plate with different radii (see table 1). No blankholder was used so the ends of the blank are free to deform.

The FE mesh consists of 4-node Belytschko-Tsay shell elements, with five integration points through the thickness of the sheet. The Belytschko-Lin-Tsay shell element are based on a combined co-rotational and velocity-strain formulation.

The material used in experiments was mild steel. The yielding of the material was modelled using a power law:

$$\sigma = K\, \varepsilon^{n} \qquad (7)$$

where: K is the material characteristic; n – hardening exponent. This model is used for the anisotropic elastic-plastic materials under plane stress conditions. Since it considers the effect of both material transverse anisotropy and the anisotropy in sheet plane to the yield surface, this model can better show the effect of anisotropy to the stamping forming. In simulation 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. The Coulomb friction law was used considering a friction coefficient of 0.125. The punch speed was 100 mm/second.

The tooling was modelled as rigid surfaces. The geometrical model of die-punch tool was composed from two working networks with 100 pins for each network, The pins are disposed face to face, both on x-direction and y-direction.

The values of material thickness and radii of parts are presented in table 1. In accordance with the part radius, the punch travel was established for each case.

Table 1. Material thickness and parts radii values

Material thickness, g, [mm]	Part radius, R, [mm]
1	80
2	85
3	90
4	95
5	100

The Dynaform use an implicit scheme for springback calculation. Simulation of springback comprises of two major steps: loading (actual forming) and unloading. In most springback analysis the instantaneous release method is employed. According to this method the change of shape of the drawn product due to the release of the tools is calculated in one increment. Sometimes this increment is subdivided into a number of sub increments to avoid numerical instabilities.

4. RESULTS OF FEM SIMULATION

In RMPF without interpolator, the part accuray is affected by the dimpling phenomenon, which characterises the local effect of pin radius.

Figure 5 presents an example of the part geometry obtained by simulation the RMPF process, for a material thickness of 3 mm and a part radius of 90 mm.

Ones could observe variations along the part surface.

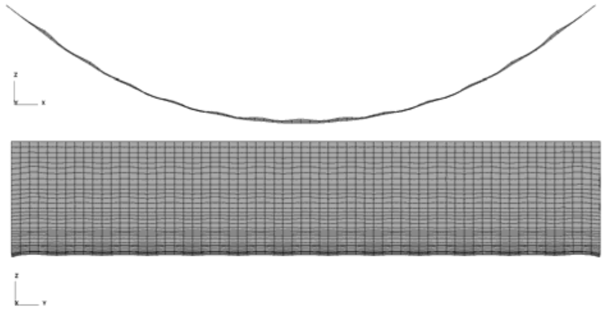

Fig. 5. Geometry and thickness variation of simulated part in RMPF

If we look after the thickness variation, we can observe, see figure 6, that the difference between the maximum and minimum value is 0.08 mm. This difference appears as a result of the local effect of the pins radius. From point of view of thickness deviation this is an acceptable value, the normal deviation being at the level of tenth of millimeter. On the other hand, if the sample is an exterior automotive body part, these deviations could not be accepted and an interpolator between the blank and the active elements of the tool must be used.

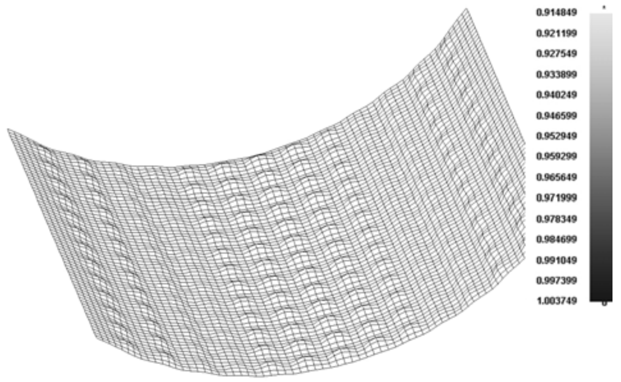

Fig. 6. Thickness variation of simulated part in RMPF

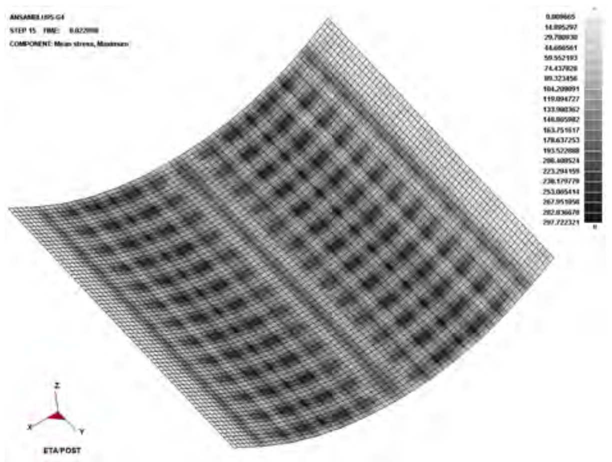

Fig. 7. Mean stress variations of simulated part in RMPF

But if we consider the stress state, the local effect of pins radius is very important, the regions of high compression stresses are intercalated with regions of small compression stresses, which could lead to fracture for thin materials (Figure 7).

Figure 8 shows an optimum case, ones could observe the same variation of the thickness along the part surface as in the case of deformation with continuous surface of die and punch. This means that the relation between punch radius, part radius and blank thickness conduct to the annulation of the local effect of pins radii.

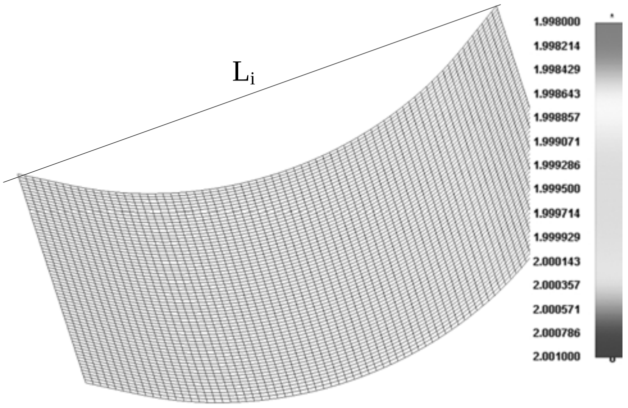

Fig. 8. Optimum geometry and thickness variation of simulated part in RMPF

Table 2. Parts widths before and after springback

g-*R* combination	Width L_i, [mm], before springback,	Width L_f, [mm], after springback,
1-80	120.526	120.465
1-85	124.617	125.596
1-90	125.828	127.204
1-95	127.696	127.438
1-100	128.877	128.596
2-80	123.594	123.711
2-85	124.777	124.754
2-90	125.642	125.768
2-95	128.725	129.103
2-100	129.016	129.005
3-80	124.725	124.729
3-85	125.934	126.134
3-90	127.045	127.149
3-95	127.736	128.354
3-100	129.132	129.216
4-80	125.039	125.241
4-85	126.500	126.829
4-90	127.821	127.946
4-95	128.645	128.816
4-100	129.462	129.607
5-80	125.094	125.289
5-85	126.889	126.885
5-90	127.975	128.117
5-95	129.147	129.321
5-100	130.148	130.205

In table 2 are presented the values of widths before and after springback, measured on simulated parts.
The springback was calculated, considering the width variation, with the relation:

$$\Delta L = [(L_f - L_i)/L_f] * 100 \qquad (8)$$

where: L_i and L_f are the part width before and after the spring back.

From table 2 we obtain the springback variation presented in figure 8 and 9. In both figures the arbitrary points are the values of 80, 58, 90, 95, 100 mm of parts radii.

Figure 9 presents the springback variation considering the case of deformation with the same thickness and different bending radius according to table 1. As we could see there's appear different types of behaviors.

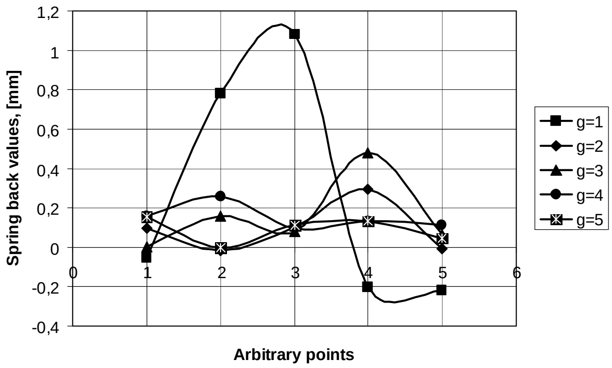

Fig. 9. Springback values for different bending radii and the same thickness in RMPF

For small thickness, in this case 1mm, appears a phenomenon of spring forward.

At a part radius of 90 mm the value of spring back is maximum.

The curves present or two maxims or one minimum and one maximum with increasing the material thickness. It is interesting to note that at parts radii of 90 and 100 mm the values of spring back are almost the same, when the material thickness is higher then 2 mm.

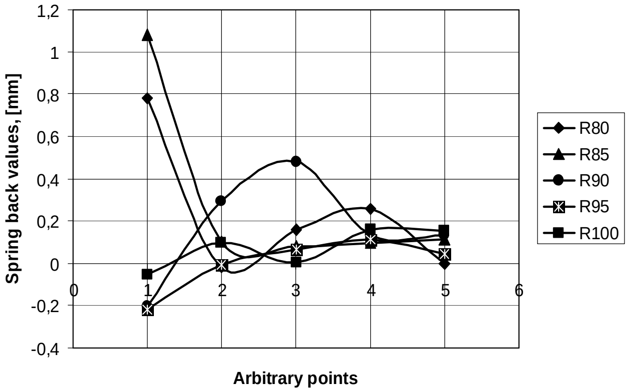

Fig. 10. Springback values for different thickness and the same bending radii in RMPF

Figure 10 is presents the springback variation considering the case of deformation with the same bending radius and different thickness according to table 1. The curves present different variations for different material thicknesses.

The force in RMPF varies from zero to a maximum value, when the punch and the die are in contact with the blank at the end of the process (Figure 11).

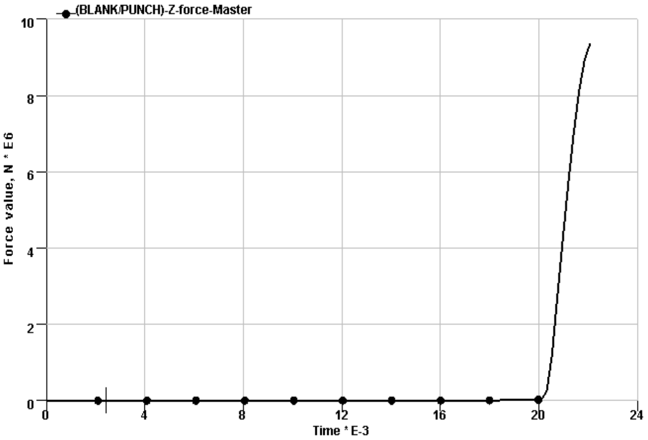

Fig. 11. Axial force curve, thickenss 4 mm, part radius 95 mm

At the beginning of forming process the values of forces are small because only a few of pins are in contact with the material. With increasing the punch travel, more and more pins get into contact with the sheet and the force increases very much. At the end of punch travel the force reaches its maximum because almost all the punches are in contact with the material. The word *almost* is very important, because in the case of small radii at the end of the process, most of the pins are in contact with the sheet. When the radii are increasing the numbers of the pins in contact with the sheet are decreasing, especially the pins from the border of the punch are losing their contact with the material.

Figure 12 presents the force variation for different thicknesses and part radii in RMPF.

The figure shows that for the same thickness, the variations of the force values, in the studied domain of the parts radii, are small. In the same time, with increasing the thickness values, the force values are increasing, also.

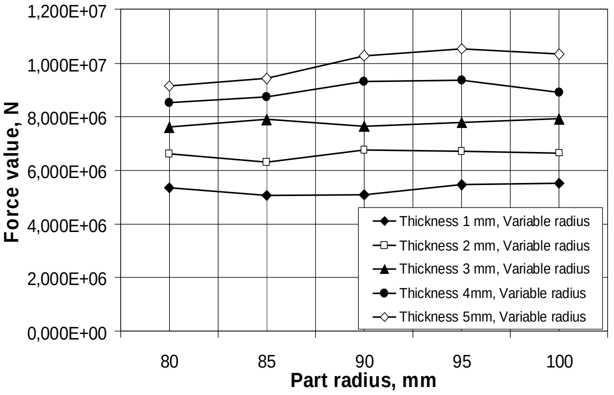

Fig. 12. Force variation for different thicknesses and radii in RMPF

5. CONCLUSIONS

In this paper, a study about the springback and dimpling phenomenon in RMF is presented, based on a numerical analysis. An algorithm for establishing the contact points between the sheet metal and the active elements in multipoint forming was developed. The phenomenon of springback is important to be quantified and is it necessary to develop methods for compensate it. The phenomenon of spring-forward is also present and it is a result of stresses variation along the part surface. The localized deformation reduced the surface quality of the part due to the presence of dimpling. The dimpling phenomenon could be avoid if an optimum combination of parameters could be found. Finally we could concluded that RMF manufacturing technology assures the production of parts variety with low costs in short time. Also a lot of expenses are saved because the manufacturing of very expensive rigid dies is replaced.

6. ACKNOWLEDGEMENTS

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