# AN ANALYSIS OF THE RESTRAINT FORCE IN DEEP DRAWING OF THE RECTANGULAR PARTS

**Paunoiu Viorel**

*Dunarea de Jos University of Galati, Faculty of Mechanics,*
*Manufacturing Engineering Department*
*Domneasca Street no. 111, 800201, Galati, Romania*
*viorel.paunoiu@ugal.ro*

**Abstract:** *In deep drawing the binder provides the restraint force necessary to avoid wrinkling, tearing or excessive thickening of the blank. For complex parts such rectangular ones, different schemes for applied the restraint force are applyed. In the paper the scheme of segmented BH is compared with the conventional one. The numerical study based on FEM is applied to investigate the part quality in terms of thickness, force and springback variation in both cases. The simulation results are then compared with the experimetal ones when a conventional binder is used. Finally for this study conditions the segmented BH scheme emphasizes the improvements in the part formability.*

**Keywords:** *Segmented BH, Deep drawing; Sheet metal forming; Finite element analysis; BHF*

## 1. Introduction

The quality of a deep drawn part is influenced by a number of variables. These include material properties, die design, and process parameters such as the drawing ratio, friction conditions as well as the blank-holder force, BHF [5]. In particular, the force exerted by the blank-holder (BH) on the sheet supplies a restraining pressure which controls the metal flow into the die cavity [2]. This restraining action is largely applied through friction. Excessive flow may lead to wrinkles within the part, while an insufficient flow can result in tearing [6].

Various BH restraining techniques had been studied [3, 4, 7] for improving the sheet metal formability such as the segmented BH scheme

Individual segments of the BH are controlled independently of the each others [8]. The method also enables holding with locally different BHF on each segment. Segmented BH solves very effectively the problem of holding the blank flange of parts with various thicknesses.

The disadvantage of tools with segmented BH is that they still are very expensive because of their particular design.

Figure 1 presents a first application of the segmented BH scheme, available for forming cylindrical parts.

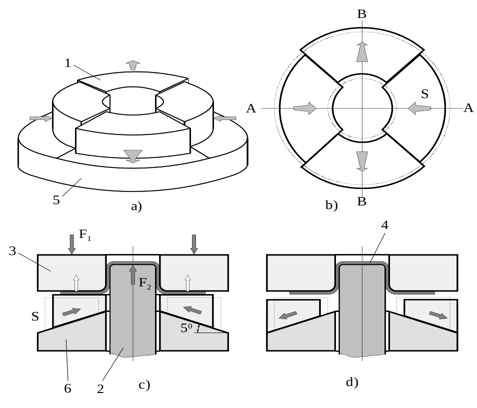



**Figure 1:** *Die with segmented blank-holder, cylindrical parts application [13]*

Another application of this technique is in the rectangular panel forming (figure 2).

The four corners of the rectangular panel remain the critical deformation areas (figure 3). The deformation in the corners creates a large volume of material trying to be compressed and stuffed over a die radius with a much smaller circumference compared to the original dimensions [1, 3].

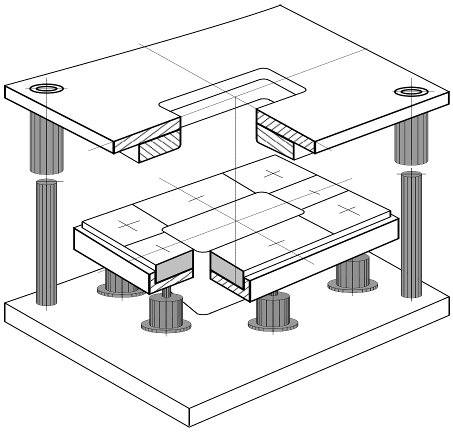


**Figure 2:** *Die with segmented blank-holder, [12] rectagular parts application*

The stresses state at the flange is basically tensile stress in the radial direction and strongly compressive stress in the circumferential direction [11]. As a result tears or fracture may appear in the four locations coinciding with the corners of the blank.

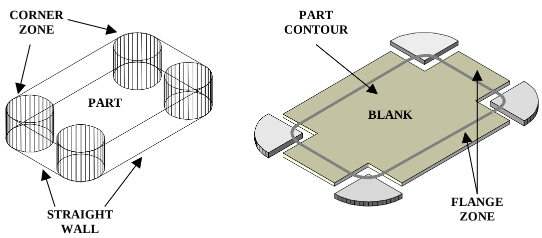



**Figure 3:** *The geometry of a rectangular part and corresponding blank, [2]*

In the paper a study based on FEM is used to investigate the rectangular part quality in terms of thickness, force and springback variation when a constant BH force and a variable one is applied through a segmented BH scheme. The simulation results are compared with the experimental ones when a conventional binder is used.

## 2. Numerical Work

There are two primary goals for the use of Finite Element Method (FEM) in analysis of a sheet metal forming process [10]. First, the analysis aims to reduce the trial and error in tooling and process design, and thereby reduce the material waste and lead times to produce a new part. Second, the analysis aims to influence the design of the desired part for ease of manufacture.

As it follows the FEM method will be applied for the deformation of a blank (figure 4) used in obtaining a rectangular panel (figure 5). The blank is composed from to straight opposite lines connected with two arcs. The width is 98 mm and length is 124 mm.

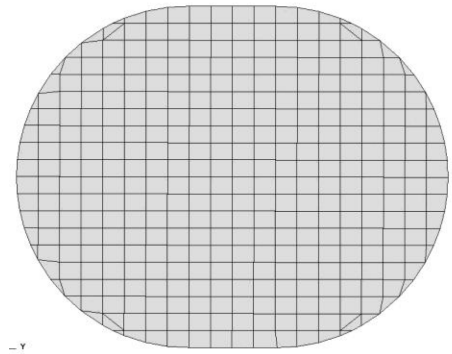


**Figure 4:** *The blank shape used in FEM simulation*

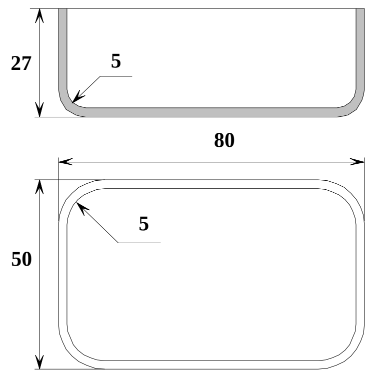



**Figure 5:** *Sketch of the rectangular part*

An explicit finite element program DYNAFORM was used for simulation. Figure 5 presents the FEM model.

The tooling was modeled as rigid surfaces. The BH is composed from 8 sectors, each of them could have his moving and different loads could be applied on each of them. A friction coefficient of 0.125 was used. The die had a radius at corners of 3 mm and the punch had a radius of 5 mm.

The material used in experiments was mild steel, with a thickness of 0.8 mm. The mean tensile properties of the material were: the yield stress of 180 MPa; the ultimate tensile stress of 303 MPa.

The material was assumed to be anisotropic. The constitutive material model is:

$$\sigma = K\,\varepsilon^{n}\,. \qquad (1)$$

where: *n*-value of 0.22 and *K* of 640 MPa. The average *R*-value was 1.705.

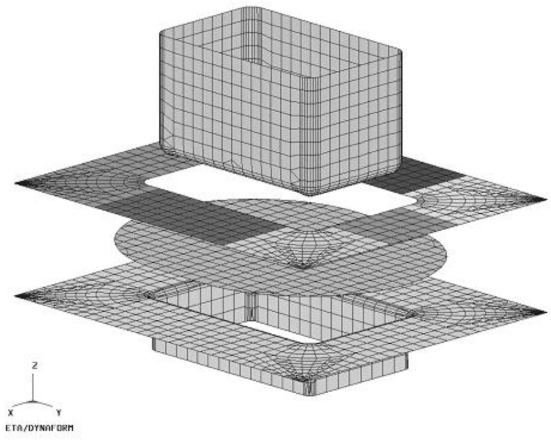



**Figure 5:** *The tooling used in FEM simulation*

The punch speed was 10 mm/second. The maximum forming depths was set at 40 mm.

BH forces were set according Table 1. These are the six models considered in analysis.

**Table 1:** *The values of binder forces, [N]*

| | | | | | | |
|---|---|---|---|---|---|---|
| Corner zones | 1000 | 1000 | 1000 | 1000 | 1000 | 13000 |
| Lateral zones | 1000 | 3000 | 5000 | 70000 | 9000 | 17000 |

### 3. Numerical Results Analysis

During the deformation process the material is displaced from the blank edge into the die. According to the blank geometry, the edge movement will be higher in the lateral zones than in the corners zones.

For a constant BH force of 1000 N, the intermediate stages of deformation when the part was drawn 13.5 mm, is presented in figure 6.

From figure 6 it can observe the displacement of the material mainly from the lateral walls parallel with the length direction. Also the radii from the left and right sides of the blank become linear.

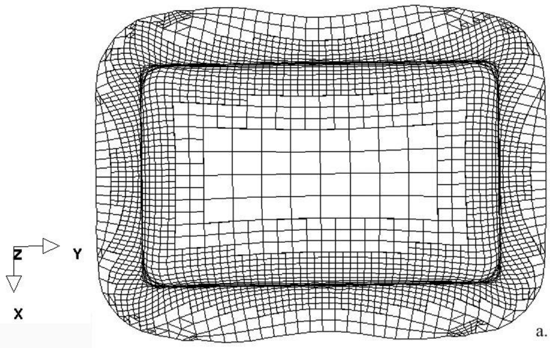



**Figure 6:** *The intermediate shape of the blank in FEM simulation, constant force*

Figure 7 presents the final shapes of the blank. Important ears appear in the corners of the part. The heights of these are about 6 mm, measured on simulation model.

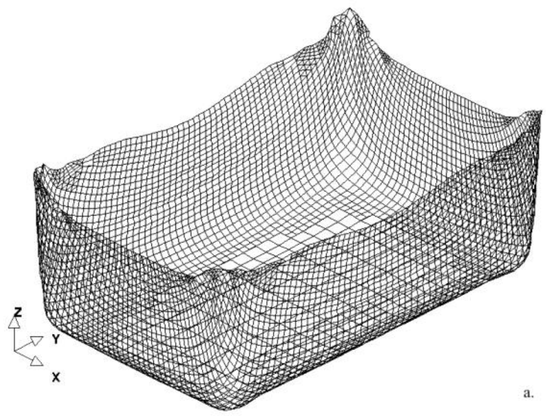



**Figure 7:** *The final shape of the blank, for a binder force of 1000 N*

To compensate for the unequal material flow, a compose binder force using a segmented BH it will be using.

As it is presented in table 2, the use of this technique could change the material displacement in an important manner.

**Table 2:** *Edge movements function of binder forces*

| Corner zones/ Lateral zones | 1000/ 1000 [N] | 1000/ 3000 [N] | 1000/ 5000 [N] | 1000/ 7000 [N] | 1000/ 9000 [N] | 13000/ 17000 [N] |
|---|---|---|---|---|---|---|
| Width [mm] | 19,72 | 19,64 | 19,59 | 19,47 | 19,44 | 18,98 |
| Length [mm] | 18,31 | 17,87 | 17,37 | 16,93 | 16,49 | 15,65 |

The values presented in table 2 are available at an intermediate stage. By increasing the values of binder forces in the lateral zones, the values of displacement will be smaller and this will affect the material distribution both in height and in thickness, the final geometry of the part and the process force.

The displacement in the smaller lateral zone (in width) is bigger then in the longer lateral zone.

The form of the part front line at the end of the deformation process is changing also depending of the BHF values.

Figure 8 presents the form of the part front line in the smaller lateral zone of the part. For an uniform pressure, differences between the maximum point on the line profile and the minimum one are bigger in comparison with the case when a variable pressures are applied.


**Figure 8:** *Edge height in the smaller lateral zone*

Figure 9 presents the form of the part front line in the longer lateral zone (inlenght) of the part. The same observation could be made as above.


**Figure 9:** *Edge height in the longer lateral zone*

Increasing and applying a compose binder force will change the form of the part front line increasing the height of the part in this zone (see the figures 10 and 11).

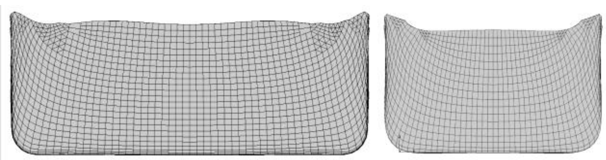
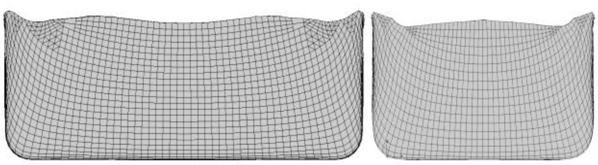


**Figure 10:** *Edge form of the part for a constant binder force of 1000 N*



**Figures 11:** *Edge form of the part for a compose binder force of 13000/17000 N*

The thickness variations in the smaller and longer lateral walls, measured in the middle of the walls, are presented in figures 12 and 13. In both figures variable pressures will lead to a more variation of the thickness.

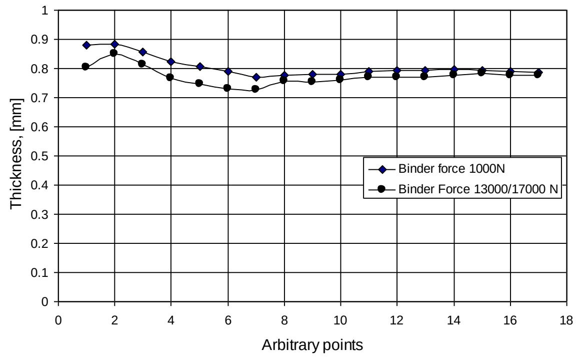



**Figure 12***:* *Thickness variation in the smaller lateral zone*

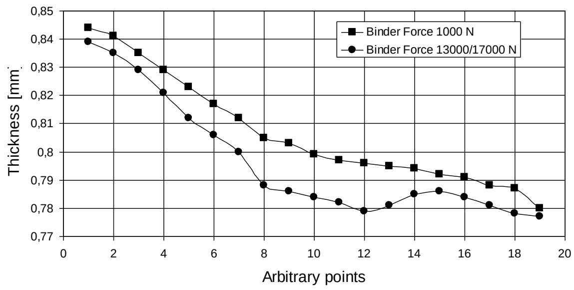



**Figure 13:** *Thickness variation in the longer lateral zone*

According to figures 12 and 13 by increasing the binder force, the phenomenous of thinning is more pronounced.

The axial force variations function of the applied binder forces are presented in figure 14. With the increasing of the binder force, the axial force will also increase.

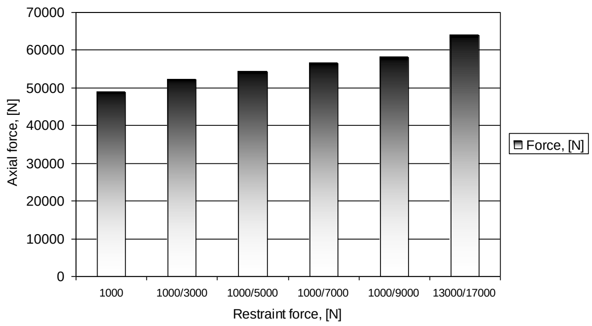



**Figure 14:** *Axial force variation in rectangular panel deep drawing*

Springback is another parameter which is affected by the values of binder forces. Figures 15 and 16 present the springback variation in case of applying a constant binder force and a compose binder force. The springback was measured on the panel width. In the case of a constant binder force the maximum value of sprinback measured in orizontal direction at the edge of the panel was 0.483. For the compose binder force the maximum value of sprinback measured in orizontal direction at the edge of the panel was 1.540. It results that for the considered panel the value of springback increasing with increasing the value of binder forces.

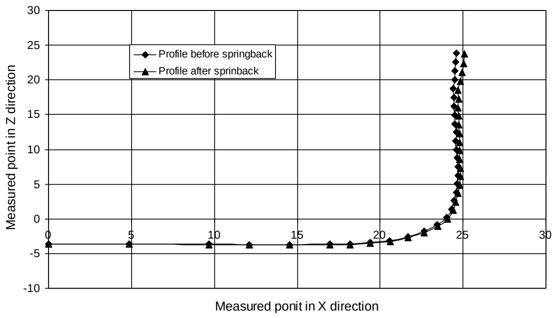



**Figure 15:** *Panel springback for a binder force of 1000 N*

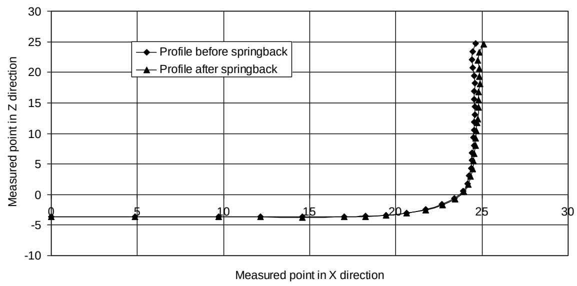



**Figure 16:** *Panel springback for a compose binder force of 13000/17000 N*

## 4. Experimental Work

Using the same material and process parameters as in simulation, were performed a series of experimental tests.

In figure 17 is presented the shape of the blank having the width of 80 mm and length of 150 mm.

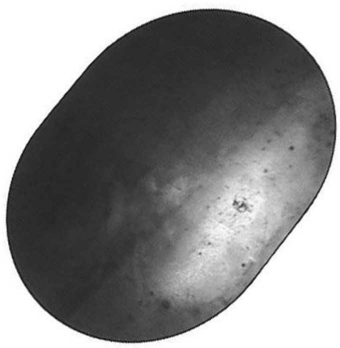


**Figure 17:** *The shape of the blank*

The part obtained after the process of deformation is presented in figure 18.

**Figure 18:** *The shape of the rectangular part for a binder force of 1000 N*

The experimental results show the influence of the form blank toward the quality of the rectangular part. As it results from figure 18 in the corners of the parts excessive ears appear as the result of the strains and stresses in these regions. The height of these ears is about 6 mm, like in simulation. This form, see also the figure 7, was predicted using the simulation with the DYNAFORM program.

## 5. Conclusions

The complex state of deformation in the case of rectangular parts forming need a control of the binder force during the process of deformation.

A numerical study was made for analysing the effect of the compose forces applied with the help of a segmented blank-holder toward the part quality.

Using such type of BH and process all the parameters and part characteristics are modified. A better control of the forces on each segmented blank-holder could lead to process improvements and also to a material economy by redesign the blank geometry.

The results of the numerical study in the case of appying an uniform pressure toward the blank have been validating by physical experiments.

Future investigations are necessary.

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