

EXPERIMENTAL AND NUMERICAL ANALYSIS OF MULTISTAGE DEEP DRAWING

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ABSTRACT

The paper presents an analysis of the multistage deep drawing process considering the two deformation schemes namely direct and reverse redrawing. The analysis is based on numerical simulation using the finite element method, a powerful tool for analyzing complex three dimensional sheet metal forming problems. The results of numerical simulation are experimental validated. Finally it is concluded the importance of the material load pattern in the redrawing process toward the parts quality and forces level.

KEYWORDS: Finite element simulations, deep-drawing, redrawing, sheet metal

1. INTRODUCTION

The deep drawing could be performed in a single operation, or in a number of stages. The number of stages depends on the degree of deformation in each step, which is influenced by the piece geometry, by the material properties and by the technological conditions and could be evaluated by the drawing ratio defined as $\beta = D_o/d_o$ (where D_o is the blank diameter and d_o the punch diameter). For a certain blank with a certain thickness and material characteristics, it could be defined a limit drawing ratio β_{lim} . If the current drawing ratio is smaller than the limit drawing ratio than the part will be produced in more than one operation.

In direct redrawing the punch (the die) moves in the same direction with the material flow. The bending participation is greater than stretching and allowed drawing ratio must be reduced. In direct redrawing, exists triple bending: 1. bending in direction of motion; 2. bending in the opposite direction; 3. straightening [2]. The first method of direct redrawing (figure 1, a.) is the commonly used method. The second method (figure 1, b.) is used in lines production, because the part could be easily manipulated without any rotation.

In reverse redrawing (figure 2) the material flows in the opposite direction to the punch stroke and the outside of the part during the first stage becomes the inside part in the second stage. As there are four bending stages: 1. bending in direction of motion; 2. straightening; 3. bending in direction of motion; 4. straightening [2].

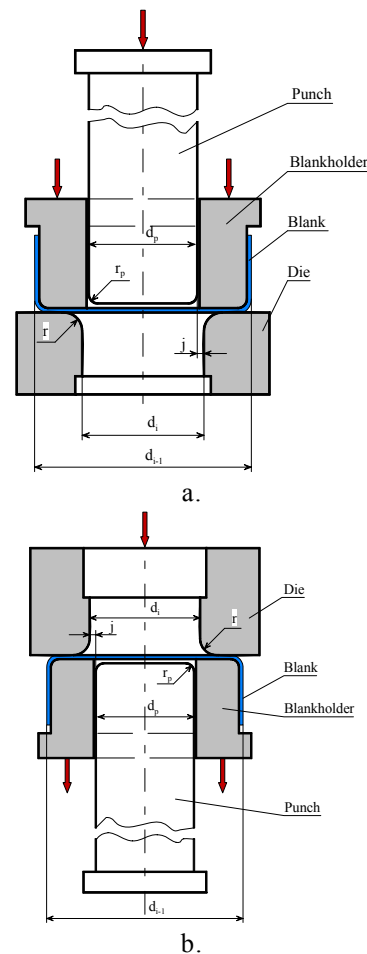


Fig. 1. Schemes of direct redrawing

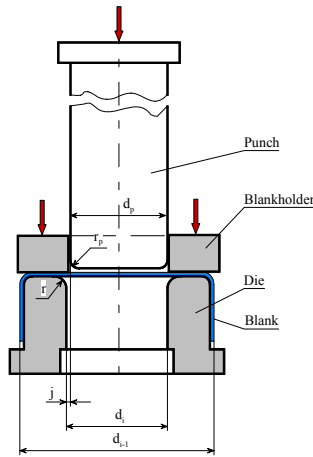


Fig. 2. Scheme of reverse redrawing

When considering multi-stage drawing, the task is even more difficult because the stress and thickness distribution resulting from the first stage will influence the subsequent behavior [3].

Because of the bending differences between the direct and the reverse redrawing, there is also differences in the level of stresses and strains that appears in material.

That is why stresses and strains should be estimated and the paper proposed for this an analysis using finite element method.

2. EXPERIMENTAL WORK

The experiments were made in the Department of Manufacturing Science, robotics and Welding from Dunarea de Jos University of Galati.

The experimental tool for the first deep-drawing operation is presented in figure 3.

The blank is a circular plate having a diameter of 80 mm. The resulted part has a diameter of 52 mm.

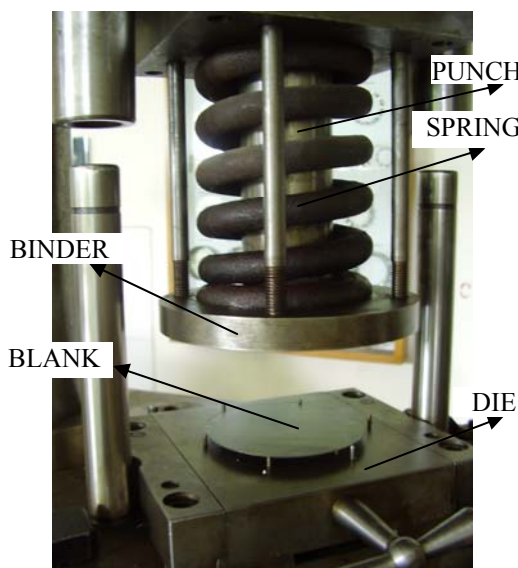


Fig. 3. Tool for the first deep-drawing operation

For the second stage of deformation it were used the tools presented in figures 4 and 5.

Figure 4 presents the tool for direct redrawing. The blank is the cylindrical ones obtained in the first stage of deformation. The blank is placed in a plate for centering. The binder applies the restraint force and it is placed in the clearance between the blank and the punch. The final piece has a diameter of 38.5 mm.

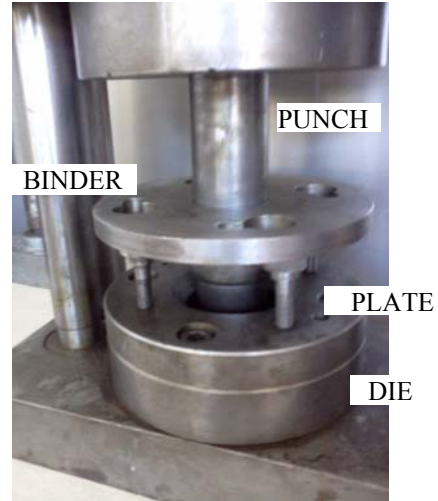


Fig. 4. Tool for the direct deep-drawing operation

Figure 5 presents the tool for reverse redrawing. The die has two functions: at the exterior plays the role of blank positioning and in the inside, the role of activ element. The blank dimensions are similar with those from the direct redrawing. The final piece has also a diameter of 38.5 mm.

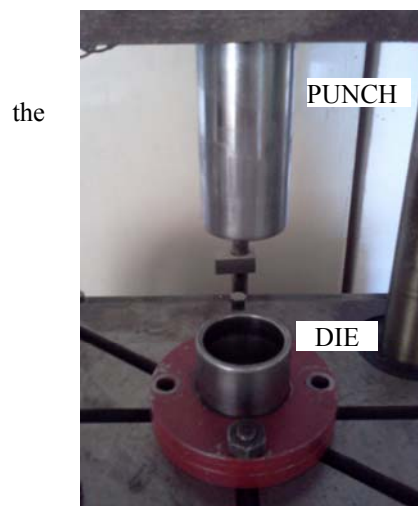


Fig. 5. Tool for the reverse deep-drawing operation

A hydraulic press with a maximum force of 20 tons was used in experiments.

The material used was A3K steel grade, with a thickness of 0.8 mm, produced by ARCELOR

MITTAL STEEL. Tables 1 shows the properties of this metal sheet.

Table 1. Mechanical properties of A3K sheet steel

Material	$R_{po,2}$, [MPa]	R_m , [MPa]	A_{50} , [%]
A3K	184.7	342.5	Min. 34

The anisotropy coefficients, R_{00} , R_{45} , R_{90} are presented in table 2.

Table 2. Anisotropy coefficients of A3K sheet steel

Material	R_{00}	R_{45}	R_{90}
A3K	1.503	1.743	1.400

2. FINITE ELEMENT MODELS

Finite Element Analysis (FEA) is a powerful simulation tool for analyzing complex three dimensional sheet metal forming problems related to potential forming defects such as tearing, wrinkling and spring back. It can be used during the die design stage or as a troubleshooting tool in the production mode. The DYNIFORM-PC solution package was used to study the issues stated above.

The blank material used in the experiments was mild steel, with 0.8 mm thickness, similar as mechanical properties with the experimental ones.

The constitutive material model is considered the power law, as follows:

$$\sigma = K \varepsilon^n \tag{1}$$

where: K is the material characteristic; n – hardening exponent. In simulation the values for n and K are 0.24 and 648 MPa. Hill’48 yield criterion is used and the anisotropic values are as follows: $R_{00} - 1.503$; $R_{45} - 1.743$; $R_{90} - 1.400$.

The blank 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 Coulomb friction law was used with a friction coefficient of 0.125. The punch speed was 100 mm/second. The tools were modelled as rigid surfaces.

For metal forming processes, the “forming-one-way” type contact interface is recommended. In this case, CONTACT FORMING ONE WAY SURFACE TO SURFACE was used. The penalty-based contact interfaces are recommended for most metal forming simulations. The penalty stiffness scale factor for all interfaces was 0.1

Some control keywords were used to change defaults or to avoid abnormal behaviour or instabilities in the simulation.

Using CONTROL_HOURGLASS keyword simulation instabilities and other problems in calculation were reduced considerably.

CONTROL_TIMESTEP was used to decrease simulation time, values between 1E-04 and 1E-06 are highly recommended and results are not considerably affected. 1E-05 was utilized in the simulation.

In the simulation assembly for the first draw, figure 6, the circular blank is placed over a die and the blank is held in place with a binder which applies the restraint force for preventing the folds formation.

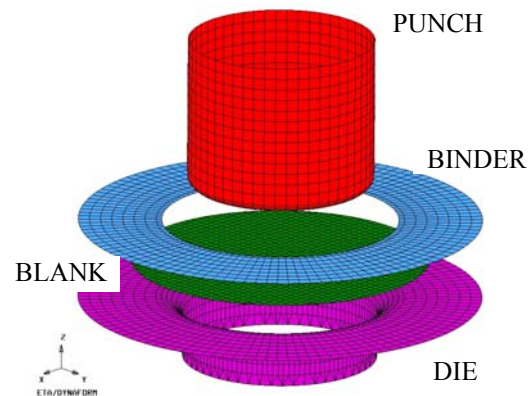


Fig. 6. Simulation model for the first draw

For direct redrawing the finite element model is composed from die, punch, binder, plate and blank.

The simulation assembly for direct redrawing is presented in figure 7. The cylindrical blank is placed over a die and the blank is held in place with a cylindrical binder which applies the restraint force.

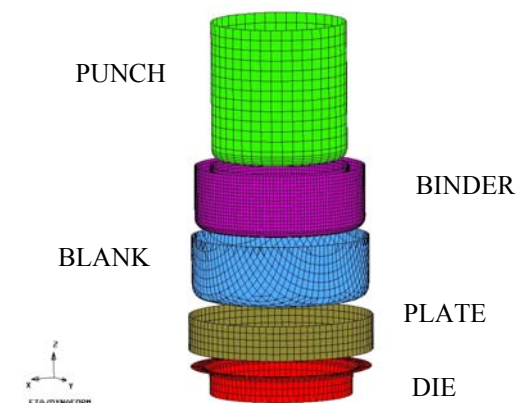


Fig. 7. Simulation model for direct redrawing

The blank is that obtained in the first stage of the simulation. It was trimmed at the end because of the ears. The FEM program imports the dates like

stresses and strains from the first simulation to the second one.

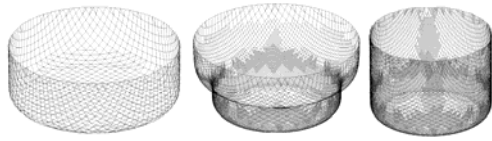


Fig. 8. Deformation stages in direct redrawing

Figure 8 presents different stages of material deformation during simulation in direct redrawing.

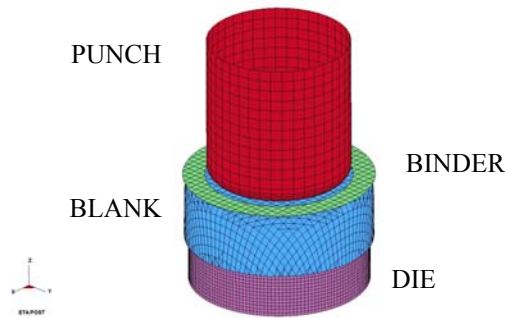


Fig. 9. Simulation model for reverse redrawing

For reverse redrawing the finite element model is composed from die, punch and blank. The simulation assembly for reverse redrawing is presented in figure 9. The cylindrical blank is placed over a die and the blank is held in place with a circular binder which applies the restraint force. A difference appears here in comparison with the experimental work. This consists in the presence of the circular binder.

Figure 10 presents different stages of material deformation during simulation in reverse redrawing.



Fig. 10. Deformation stages in reverse redrawing

3. FEM MODELS VALIDATION

The objective of this part was to validate the results of the numerical simulations with the ones obtained in the experimental conditions.

In table 2 are presented the values of pieces heights as they results from simulation and experiments. The comparison is made between the results obtained in simulation of the first and second deep- drawing operations.

Table 2. Pieces heights in deep drawing operations

Height	First stage	
	Numerical	Experimental
20		20.5
Height	Second stage – direct redrawing	
	Numerical	Experimental
33		34.5

Figure 11 shows the thickness variation for experimental and numerical simulations, considering the case of direct redrawing. In figure the height position is arbitrary and represents the measured points on the parts height. The thickness variation at the parts bottom presents a minimum because of the presence of the radius in the first stage. A similar variation could be observed also in reverse deep-drawing.

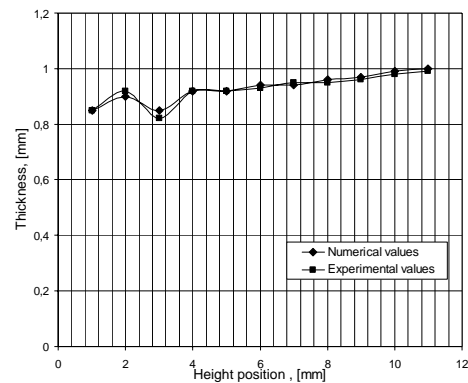


Fig. 11. Thickness variation of deep drawn parts: experimental and numerical results

The results of numerical simulation are in accordance with the experimental ones.

4. DISCUSSIONS

The two cases of redrawing were analysed in terms of strains, thickness and axial force variations.

The principal strains variations are presented in figure 12.

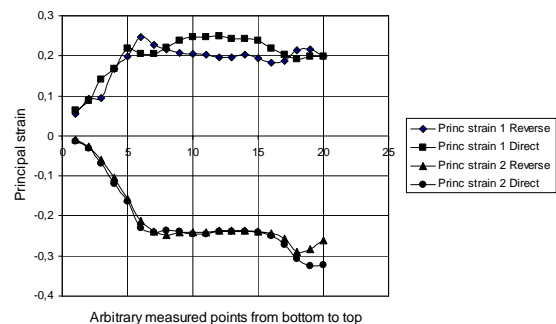


Fig. 12. Principal strains variations

For direct redrawing the principal strains after the first direction are increasing along the height direction, being maximum in the middle of the piece height. For inverse redrawing the principal strains after the first direction reach the maximum, then are almost constant in the height. The principal strains after the second direction are the same for both cases. It results, a more uniform deformation in thickness direction in the wall region for the case of reverse redrawing.

In direct redrawing, the direction of the material load is the same, both in the first deep drawing and in the second one.

In reverse redrawing, the pattern of the material load is changing after the first deep drawing operation. As a result, appears a material softening and a delayed hardening in comparison with direct redrawing.

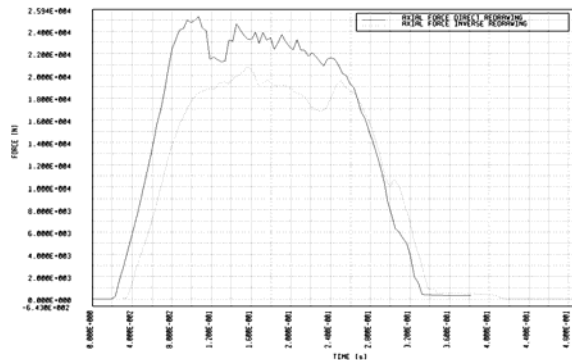


Fig. 13. Force variation in direct and reverse redrawing

The difference in the moment of hardening appearance, will determine different material resistance that causes a different reactive force to the deformation. The final effect is that the force for reverse redrawing is smaller (figure 13) than the direct redrawing force. The forces have first a maximum, then a constant zone corresponding to the material flow in the die and in the end the force becomes zero.

The form errors are presented in figures 14 and 15.



Fig. 14. Form variation in direct redrawing



Fig. 15. Form variation in reverse redrawing

The presence of wrinkles is more marked in the case of direct redrawing

The thickness variations are presented in figures 16 and 17.

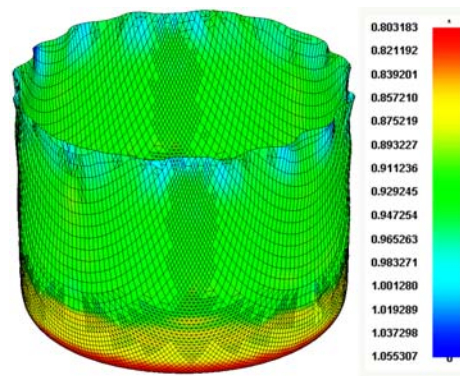


Fig. 16. Thickness variation in direct redrawing

The material is thinner at the bottom of the part, the value being 0.80, and is thicker at the end, the value being 1.05 for direct redrawing and 1.14 for reverse redrawing. The variation is linear and is increasing from the bottom to the end.

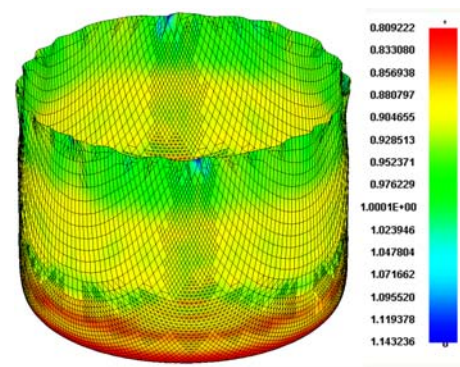


Fig. 17. Thickness variation in reverse redrawing

5. CONCLUSION

Using the finite element method the redrawing process was analysed. Moreover, the results of the finite element analysis was validated within the experimental work.

The importance of the material load pattern in the redrawing process towards the process and forces level was pointed out.

The quality of parts, in terms of form errors, obtained in reverse deep-drawing is better in comparison with that obtained in direct redrawing.

The thinning is more accentuate in the case of reverse deep-drawing.

Acknowledgements

The first author gratefully acknowledge the financial support of the Romanian Ministry of Education and Research through grant PN_II_ID_1761/2008.

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