

## Simulation of reverse deep drawing of cylindrical cups

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**Abstract:** *In this work was done the simulation of deep drawing process and reverse re-drawing of cylindrical cups of low carbon steel used in auto parts industries. In the simulation of process was used the finite element method with implicit formulation and yield criteria of Hill for the material. The simulation was done in two steps, first one with direct drawing followed of punch return and second with reverse re-drawing followed of punch return to identify the springback of part. Mechanical characterization of steel and anisotropic indexes of material were got experimentally and used in the finite element model. The thickness variation in the anisotropy directions were compared with experimental values for the first and second steps.*

**Keywords:** *re-drawing, simulation, finite element*

### 1. INTRODUCTION

The deep drawing operations have had an important role into mechanical industries. Automotive and auto parts industries have one special interest to these operations because many parts produced for them use sheets. In these industries the consumption of steel sheets has been growing in last years with the increase of production.

Dies to the stamping processes are expensive, so simulation of stamping processes has one important role during the development of these dies for parts each time more complexes, with less chance of mistakes and one performance that can be each time better.

These parts need processes that can produce them with minimum thickness variation to avoid problems with component life, so is necessary to design one process with correct number of steps for the product.

Stamping parts, normally, are not made in only one step, being necessary one sequence of operations up to final form. In deep drawing processes is necessary to do re-drawings and the number of re-drawings depends on the ability of material stands strains during the process before plastic instability. This ability is directly related with mechanical properties.

In cold rolling steel sheet mechanical properties are related with microstructure and anisotropy. Great values of anisotropic indexes during plastic behavior make the material supports more thickness strain, improving capacity of diameter reduce.

There are two types of re-drawings: direct, where the diameter of the product is reduced without change the side of sheet and reverse where the sheet is re-drawing and sides of sheet are changed, external side will be internal side after the process. Reverse re-drawing is used because is easier to keep correct position during the process. This process uses internal diameter for localization in the die, so is possible guarantee correct position.

Thuiller et al, (2002) describe the reverse re-drawing of cylindrical cup of anisotropic steel sheet with variation of blankholder force during the process. The process was simulated using finite element method with implicit formulation. The variation of blankholder force in the process was used to promote less sheet thickness reductions with no wrinkles after the process.

Zhao et al, (2007) describe the deep drawing process of one cylindrical cup using reverse re-drawing with hydro-mechanical blankholder force, where the force on the blankholder is controlled by pressure in opposite direction of material flow, reducing the force during the deep drawing process. This process was simulated using finite element method of explicit formulation. The thickness reductions and deep drawing force were compared among simulation results and experimental results.

In this work were done the simulation of direct deep drawing and the reverse re-drawing of a cylindrical cup of low carbon cold rolling steel sheet used in engine oil filter case.

Tensile tests in three different directions (0°, 45° and 90° in relation to the rolling direction) were done to determine mechanical properties and anisotropic indexes for the steel sheet.

Process was modeled with MSC/PATRAN software and simulated using MSC/MARC 2005. Anisotropic mathematical material model and Hill flow criteria was used in all steps.

The simulation was performed in four steps but only two made deformations. In the first step was done the direct deep drawing of the sheet, in the second step the punch return to initial position and changed strain and stresses state of the cup are changed because of springback. In third step was done the reverse re-drawing and in the fourth the punch of re-drawing return to original position showing springback effects in this step.

Sheet thickness in the three principal anisotropic directions were measured and compared with simulation results.

## 2. DIE SET

The drawings with dimensions of die set used in the process are in figure 1.

This part is made of low carbon cold rolling steel with thickness of 0,60 mm and processed in two steps. In the first one the disk with 249,0 mm of initial diameter is reduced until 151,2 mm with a punch displacement of 65,0 mm. In the second step the part is put in other die and the reverse re-drawing is done, reducing the diameter to 121,4 mm with one punch displacement of 82 mm.

For both processes were used blankholder to avoid wrinkles on the wall cup during the process.

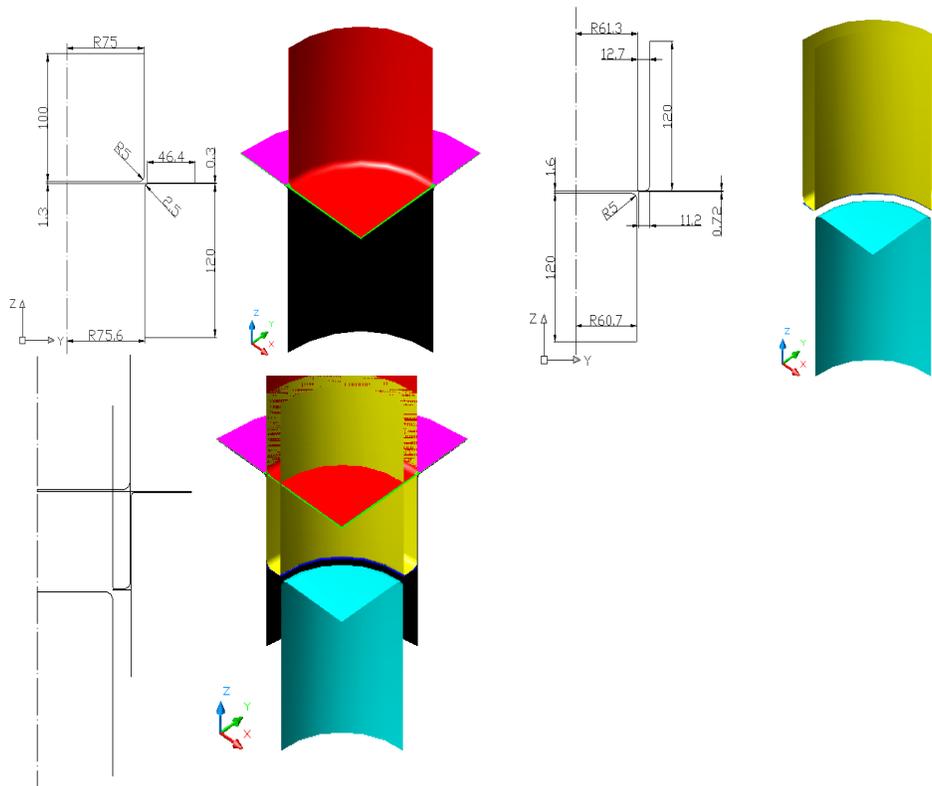


Figure 1. Dimensions of dies for first and second steps and schematic drawing of process

## 3. MATERIAL

Chemical composition of the low carbon steel used in experiments is described in table 1.

Table 1. Chemical composition of low carbon steel used % in mass.

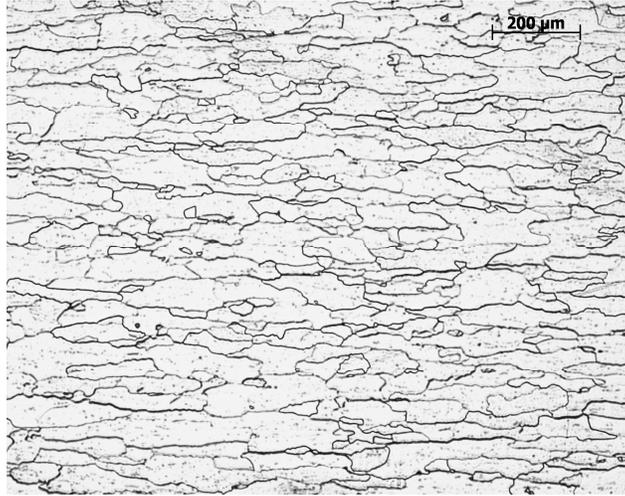
Element	C	Mn	Al	P	S
Mass (%)	0,040	0,234	0,046	0,013	0,006

Mechanical properties of the material, yield limit ( $\sigma_0$ ), strength coefficient (K), work hardening (n) and plastic strain for three directions in relation of the rolling direction are in table 2. Value is mean of 3 tests in each direction.

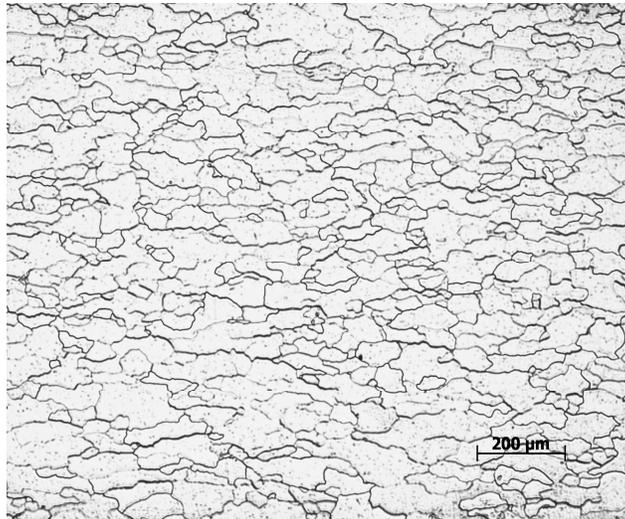
**Table 2. Mechanical properties of low carbon steel used.**

Direção	$\sigma_0$ (MPa)	K (MPa)	n	R
0°	235	498	0,21	1,98
45°	240	495	0,19	1,76
90°	242	435	0,19	1,96

In the figures 2 and 3 is the microstructure of the material. In these pictures is possible to see fine cementite inside the grains but not in grain boundaries, so this material present good characteristics for deformation processes.



**Figure 2. Microstructure of material in rolling direction (Nital 3%)**



**Figure 3. Microstructure of material in transverse rolling direction (Nital 3%)**

The grain size in microstructure is uniform that improves the uniform strain of the material.

#### 4. FINITE ELEMENT MODEL

For simulation was used one quarter of model to reduce processing computer time. In the finite element model the dies, punches and blankholders were modeled as rigid bodies of two dimensions (no thickness is necessary for this modeling) and sheet was considered a deformable body.

In rigid bodies were not defined displacement boundary conditions. To these bodies, boundary conditions are defined as velocity and rotations. For the sheet were defined boundary conditions of displacement to the nodes on side of the blank. Below the boundary conditions used on side of sheet model are listed:

Nodes in x direction:

- Displacement in x and z: free
- Displacement in y: 0
- Rotation in x and z: 0
- Rotation in y: free

Nodes in y direction:

- Displacement in y and z: free
- Displacement in x: 0
- Rotation in y and z: 0
- Rotation in x: free

Dies and blankholders in the model had velocities equal zero and the contact of rigid element with deformable body is made by boundaries of geometry. In the sheet was used a shell element with 4 nodes with 6 degrees of freedom per node, the medium size of element used was 4 mm and the contact was done in each node of 893 elements. Friction model used was Coulomb model and friction coefficient was equal to 0,08 for all elements in both steps of process.

Material model used to sheet was anisotropic in three directions and Hill yield criteria used to the sheet. In this simulation was not considered elastic anisotropy to the material and the elastic properties were:

Young's module: 203 GPa

Poisson's coefficient: 0,3.

## 5. EXPERIMENTAL AND SIMULATION RESULTS

In figure 4 is showed the thickness distribution to first step of the process after punch has returned to its original position, it means, the punch went down changing the form of the sheet and then it returned to original position, so is possible to verify springback effects when punch and parts there is no more contact.

The biggest thickness reduction in this step is over the punch radius, this region normally is stretched during deep drawing. This region presented maximum thickness reduction of 10% for 65 mm of punch displacement. This reduction was measured after punch return to initial position.

In the end of cup wall, final thickness is bigger than initial thickness. It happens due to compressive efforts that appear to reduce the sheet diameter.

Thickness distribution for second step is showing in figure 5 in same conditions of first step, it means, punch of the second step in original position after deformation.

In the second step compressive efforts that appeared by diameter reduction increased more the sheet thickness in the end of wall and some wrinkles appeared there.

After second step, regions that were near of punch radius in first step stayed in the middle of cup wall and is not possible to notice more thickness reductions (figure 5). Second step has a change of form less severe that the first step. In the figures is not possible to see, in this color scale, thickness reductions with great definition, but when separated elements were analyzed it was possible to notice this.

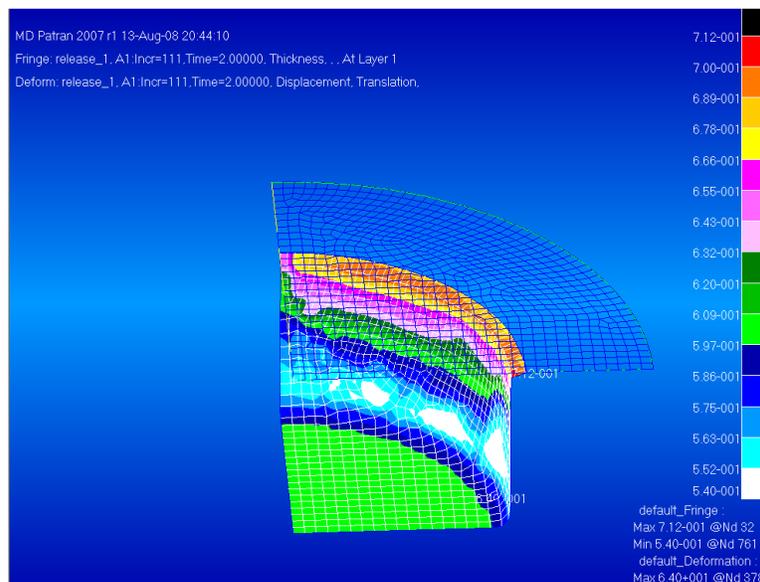


Figure 4. Thickness distribution for first step of process

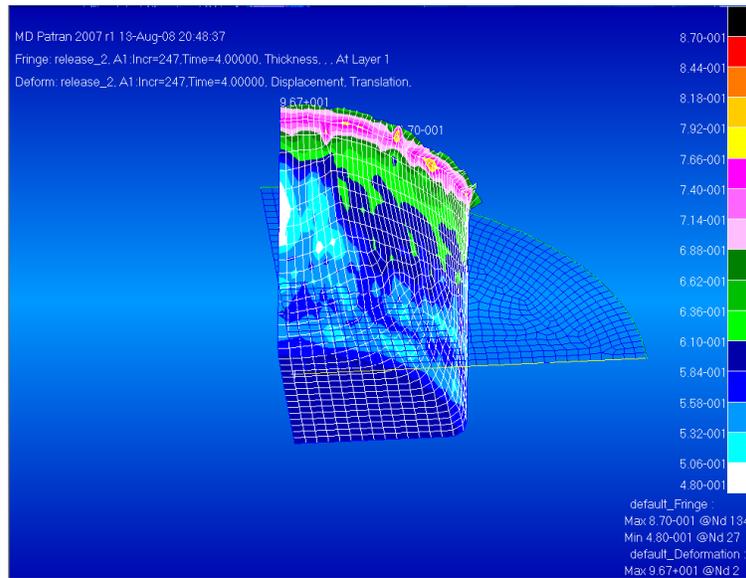


Figure 5. Thickness distribution for the second step of process

In figures 6, 7 and 8 are presented the thickness distribution of the finite element method compared with experimental values to first step of the process for directions  $0^\circ$ ,  $45^\circ$  and  $90^\circ$  in relation of rolling direction.

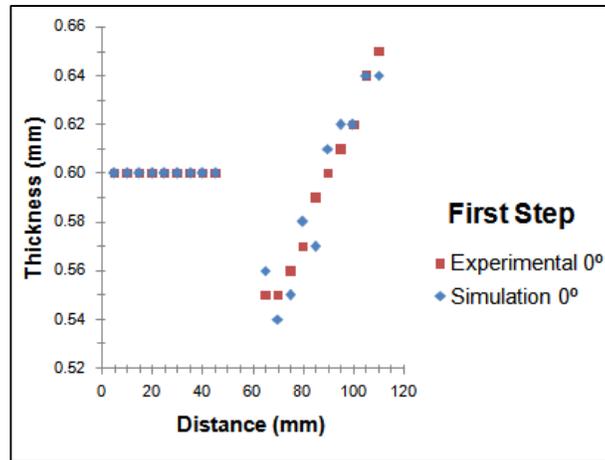


Figure 6. Thickness distribution after first step in direction  $0^\circ$

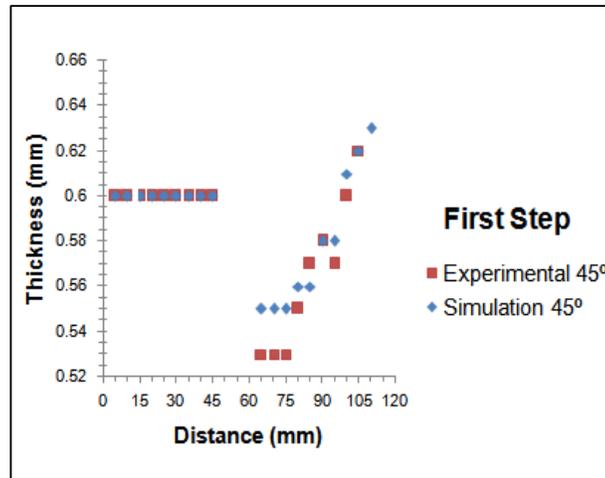


Figure 7. Thickness distribution after first step in direction  $45^\circ$

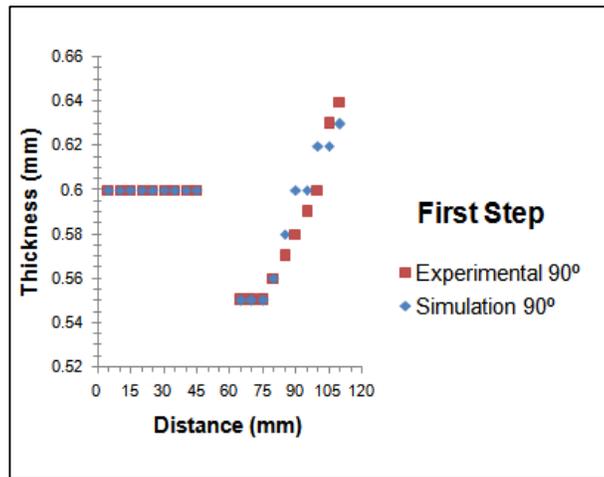


Figure 8. Thickness distribution after first step in direction 90°

Thickness variations in the experiments and the simulation have the same distribution in three directions. Bottom of the cup there is no reduction thickness, after punch radius thickness has the biggest thickness reduction like showed in figure 4 in the three directions, on the cup wall thickness increased due to compressive efforts.

Minimum values of thickness measured at 0° in relation of rolling direction is 0,55 mm, at 45° the thickness is 0,53 and at 90° was 0,55 mm, immediately after end of punch radius. Differences among experimental and simulation results for minimum thickness occurred in this area, especially in directions 0° e 45°.

Figures 9, 10 and 11 are showing thickness distribution to second step at same conditions and directions showed in the figures before.

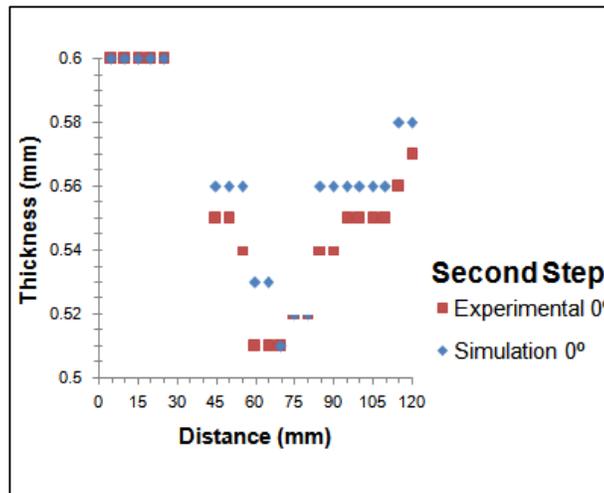


Figure 9. Thickness distribution after second step in direction 0°

Results in second step presented more differences in the distribution of experimental and simulation results than in the first step on the cup wall. These differences can be explained because of contact and friction that change during the process but in the simulation they are constant during all steps.

Minimum thickness values in the second step there is no differences among simulation and experiments for 0° and 45° but it presents a small difference in direction 90°.

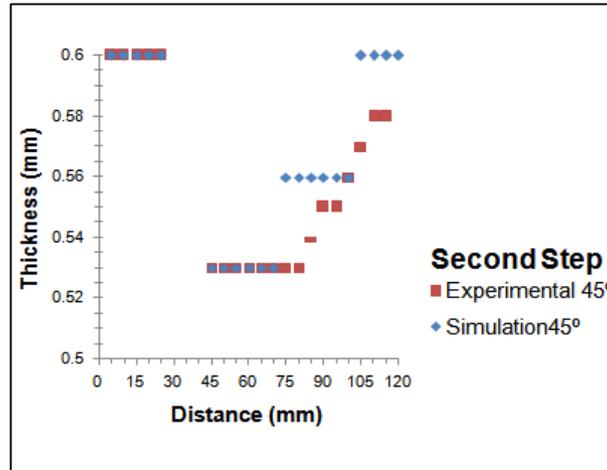


Figure 10. Thickness distribution after second step in direction 45°

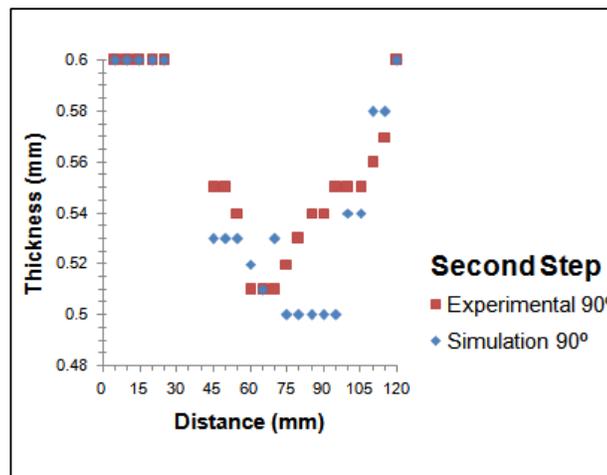


Figure 11. Thickness distribution after second step in direction 90°

## 6. CONCLUSIONS

The direct deep drawing and reverse re-drawing process were simulated using finite element method of implicit formulation with anisotropic material properties model and using Hill yield criteria.

Thickness variation in simulation and experiments were compared in the three main anisotropic directions for two steps of process. In the first step there are no significant differences among simulation and experiments in thickness minimum value and variation. In second step thickness distribution had a different distribution in the cup wall but minimum values are the same at 0° and 45°, it shows that mathematical model is accurate to simulate this process.

## 7. REFERENCES

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