# EXPERIMENTAL INVESTIGATIONS AND NUMERICAL SIMULATION OF THE SEMISPHERICAL PUNCH PROCESS

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**Keywords:** semispherical punch process, numerical simulation, criteria of plasticity, speed of deep drawing.

**Abstract:** The simulation of the deep drawing process allows us to know even from the designing phase whether a piece with a certain configuration can be obtained through the deep drawing process or not by taking into account the three factors which influence the process: characteristics of blank, shape of tools, deep drawing conditions. This paper presents studies regarding the evolution of the deep drawing force determined through simulation and experiments in the case of semispherical punch process of blanks made of steel A5 STAS 10318-80. In order to do so the speed of deep drawing, the width of specimen and the criterion of plasticity used were varied.

## 1. INTRODUCTION

Sheet metal forming is an important manufacturing process widely used to produce complex stamped parts from flat blank sheets in sectors such as the automotive, food and domestic appliances industries.

Within the plastic deformation processes an important place is held by blank forming. In case the pieces which have to be obtained from blank are big or have a complex shape (components for car bodies) they can be obtained only through deep drawing.

Obtaining a deep drawn piece with defects depends mainly on three factors: characteristics of blank (material, thickness); shape of tools (radii connecting the die and the punch); deep drawing conditions (pressure of the blank holder, braking edges, lubricating). The three factors depend on each other: when a material has low deformability, a thorough study of the die and good lubricating allow removing the difficulties which appear in the deep drawing process. Therefore, simple modifications (increase of the die radii, changing the thickness of the blank, changing the pressure of the blank holder) may lead to the possibility of obtaining a piece without defects through deep drawing.

By simulating the semispherical punch process, using the finite element method, the difficulties which appear in the process may be highlighted. Therefore, by simulating the semispherical punch process, there were studied: the influence of material anisotropy and of tool-material friction on the distribution of deformations [6], the influence of rheological and tribological parameters on the distribution of deformations [3], distribution of main deformations in the case of steel with a low content of carbon [7], variation of the thickness of the deep drawn piece [5].

The paper presents the influence of the speed of deep drawing and the stress applied on the specimen at maximum speed in the case of semispherical punch process. The process was simulated to point out the importance of the criterion of plasticity used to define the material. The simulation was performed with the programme Abaqus/Cae. The results obtained through simulation were compared to the experimental ones.

## 2. EXPERIMENTAL PROCEDURE

### 2.1 MATERIAL

In this study, A5 STAS 10318-80 sheet steel of deep drawing quality, 1 mm thick, supplied by Mittal Steel, Galati, Romania is used. The chemical composition is given in Table 1.

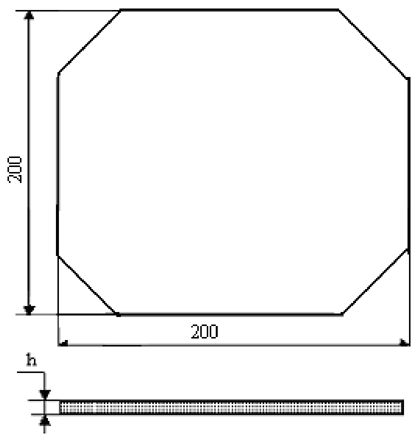
**Table 1. Chemical composition (weight percentage)**

| Element content | C | Mn | Si | P | S |
|---|---|---|---|---|---|
| % | 0.08 | 0.40 | 0.10 | 0.025 | 0.03 |

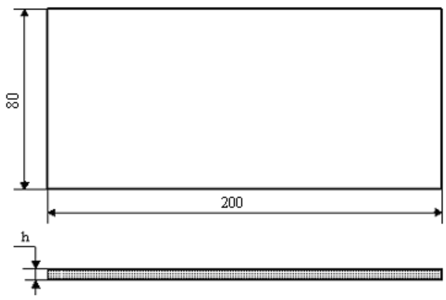
### 2.2 SPECIMENS AND EXPERIMENTAL EQUIPMENT

For the semispherical punch process, square, fig. 1a, and rectangular, fig. 1b, specimens were used in order to obtain two states of deformation.

The traction machine used for the deep drawing process is a Zwick machine with a maximum force of 200 KN (20tf). In order to achieve the deep drawing test the machine was equipped with the deep drawing modulus, fig. 2.a. During the deep drawing the punch is fixed, the active plate and the blank holder are mobile. The shape and dimensions of the punch used are presented in fig. 2b.

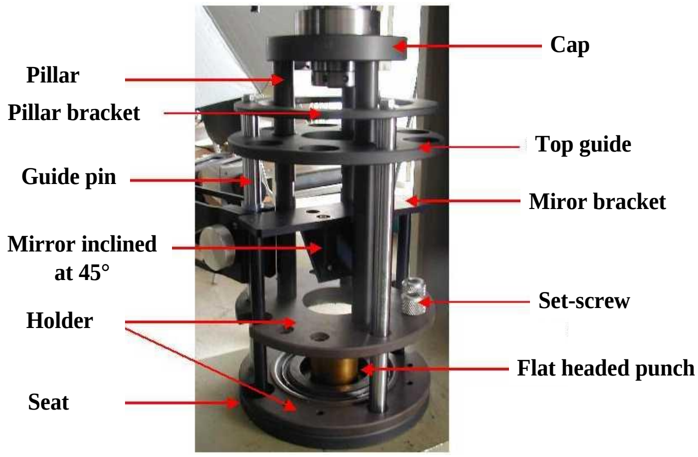



*a*




*b*

***Fig. 1 Specimens used***

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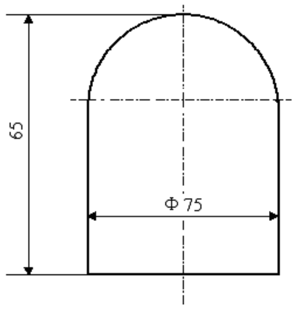



*b*

***Fig. 2 Experimental equipment***
***a)-deep drawing manner***
***b- punch***

## 3. NUMERICAL PROCEDURE

### 3.1 DEFINING THE MATERIAL

In Abaqus the material to be deep drawn is described with the Vumat subroutine using a criterion of plasticity. The general shape of the criterion of plasticity used is [2]:

$$(1-k)^{m/6} g^{-m}(\theta,\alpha) = [F(\theta)]^{m/6} + 2a\sin\theta\cos^{2n-1}\theta + b\sin^{2p}\theta\cos^{2q}2\alpha \qquad (3.1)$$

where: $g(\theta, \alpha)$ is the polar radius;
$\theta$, the polar angle.
Function $g(\theta)$ is defined through relation:

$$(1-k)g(\theta)^{-6} = F(\theta) = (\cos^2\theta + A\sin^2\theta)^3 - k\cos^2\theta\cdot(\cos^2\theta - B\sin^2\theta)^2 \qquad (3.2)$$

Therefore, by modifying the values of coefficients k, m, n, p, q, a, b, A, B the expressions of different criteria of plasticity are obtained.

The material was defined with Von Mises criterion of plasticity and then with Hill criterion of plasticity with normal anisotropy. The difference between the two criteria is that Von Mises does not take into account the anisotropy of the material, it takes into account the anisotropy coefficient R = 1 and coefficient A=3. The coefficients used for the simulations are presented in table 2.

**Table 2. Coefficients of the criteria of plasticity**

| Coefficient | A | B | k | m | n | p | q |
|---|---|---|---|---|---|---|---|
| Von Mises | 3 | 9 | 0 | 2 | 1 | 1 | 1 |
| Hill anis. norm. | 4.14 | 9 | 0 | 2 | 1 | 1 | 1 |

The plastic behaviour of the material is defined with Swift's law [1]:

$$\sigma = k(\varepsilon_0 + \varepsilon)^n \qquad (3.3)$$

where: k, $\varepsilon_0$, represent material constants;
n, hardening coefficient of the material.
The coefficients of Swift's law were determined using the results of the traction test:

$$\sigma = 536(0.0061 + \varepsilon)^{0.228} \qquad (3.4)$$

The elastic behaviour of the material is defined with the help of the longitudinal elasticity modulus, E=200 Gpa, and Poisson's coefficient, v = 0.29.

### 3.2 GEOMETRY USED

The geometry used to simulate the deep drawing process corresponds to the experimental stand and is presented in fig. 3.

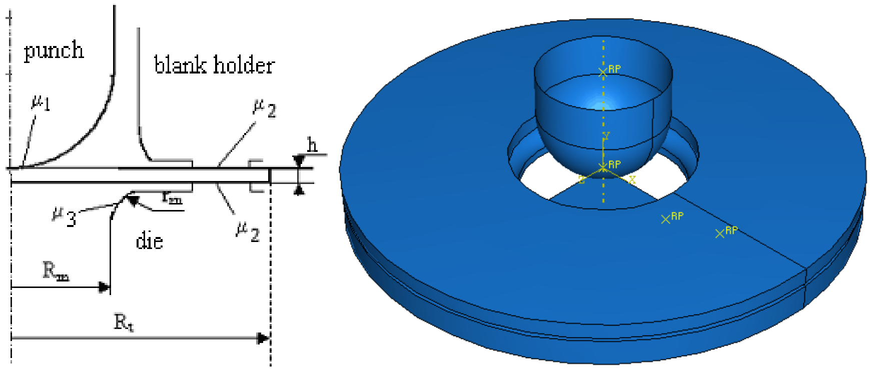



*Fig. 3 Geometry used for the simulation*

The geometry used for the simulation is defined by the following parameters: punch radius $R_p$=37.5mm, inner radius of the die $R_m$=50 mm, radius connecting the die $r_m$=10 mm, radius connecting the pressure plate $r_s$= 10 mm, initial radius of the blank $R_t$ = 100 mm, initial thickness of the blank h = 1 mm.

Between the surfaces there are established a Coulomb type of friction contact and the value of the friction coefficient. 3 friction coefficients are defined according to the friction existing between real surfaces, fig. 1:

- specimen-punch friction coefficient, $\mu_1$= 0.05 and $\mu_1$=0.2;
- specimen-active plate and specimen-blank holder friction coefficients, $\mu_2$= 1;
- friction coefficient between the specimen and radius connecting the active plate, $\mu_3$= 0.15.

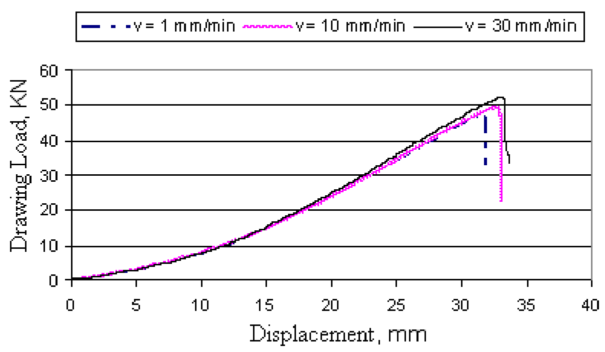
Simulating the deep drawing is achieved in 2 stages. During the first stage, a force of 200 KN is applied to the blank holder and then, during the second stage, the punch moves with a speed of 10mm/min. The time required depends on each test and corresponds to the deep drawing experimental time.

## 4. RESULTS OBTAINED

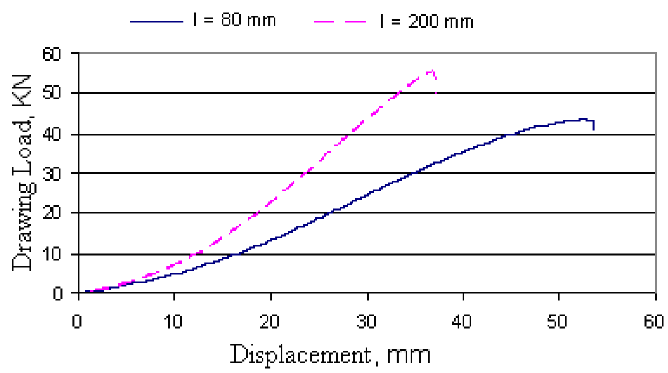
### 4.1 EXPERIMENTALLY

During the semispherical punch process we aimed to determine the influence of the speed of deep drawing and the stress applied to the material on the force and depth of deep drawing. The deep drawing tests are presented in tables 3 and 4.

The influence of the speed of deep drawing and of the stress applied on the force and depth of deep drawing is presented in fig. 4.




**a**




**b**

***Fig. 4 Evolution of the force of deep drawing for different speeds of deformation (a) and different types of stress (b)***

**Table 3. Results obtained at the variation of depth of deep drawing**

| No | Specimen width in mm | Friction coefficient | Speed of deep drawing, in mm/min | Maximum force of deep drawing, in KN | Maximum depth of deep drawing |
|---|---|---|---|---|---|
| 1 | 200 | 0.2 | 1 | 47.26 | 31.65 |
| 2 | 200 | 0.2 | 30 | 52.44 | 34.7 |
| 3 | 200 | 0.2 | 10 | 49.4 | 34.0 |

**Table 4. Results obtained at the variation of stress**

| Number of tests | Specimen width, in mm | Friction coefficient | Speed of deep drawing, in mm/min | Maximum force of deep drawing, in KN | Maximum depth of deep drawing |
|---|---|---|---|---|---|
| 1 | 80 | 0.05 | 10 | 43.3 | 52.5 |
| 2 | 200 | 0.05 | 10 | 55.4 | 36.41 |

## 4.2 NUMERICAL SIMULATION

By simulating the semispherical punch process we aimed to determine the influence of the punch-specimen friction, the influence of the criterion of plasticity used and of the stress applied on the deep drawing force. The models achieved for the semispherical punch process are synthetized in table 5.

**Table 5. Results obtained at the variation of the criterion of plasticity used and of the stress applied on the specimen**

| No. | Specimen width, mm | Punch specimen friction coefficient | Criterion of plasticity used | Maximum force, KN | | Error obtained % |
|---|---|---|---|---|---|---|
| | | | | abaqus | exp | |
| 1 | 200 | 0.2 | Hill | 49.80 | 49.4 | 0.8 |
| 2 | 200 | 0.2 | Von Misses | 48.31 | 49.4 | 2.26 |
| 3 | 80 | 0.2 | Hill | 39.71 | 37.13 | 6.4 |

Different types of stress were obtained by using different widths of the specimen. Therefore, in the case of specimens 200 mm wide stress is biaxial stretching and in the case of specimens 80 mm wide stress is uniaxial traction.
The influence of the criterion of plasticity used to describe the material on the force and depth of deep drawing is presented in fig. 5 for l = 200mm, μ = 0.2 and in fig. 6 for l= 200 mm and l=80mm, Hill criterion.

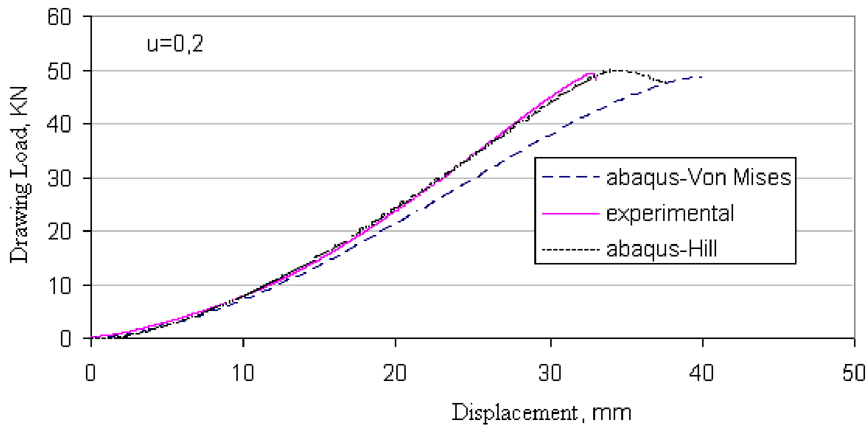



***Fig. 5 Evolution of the force of deep drawing obtained through simulation and experimentally***

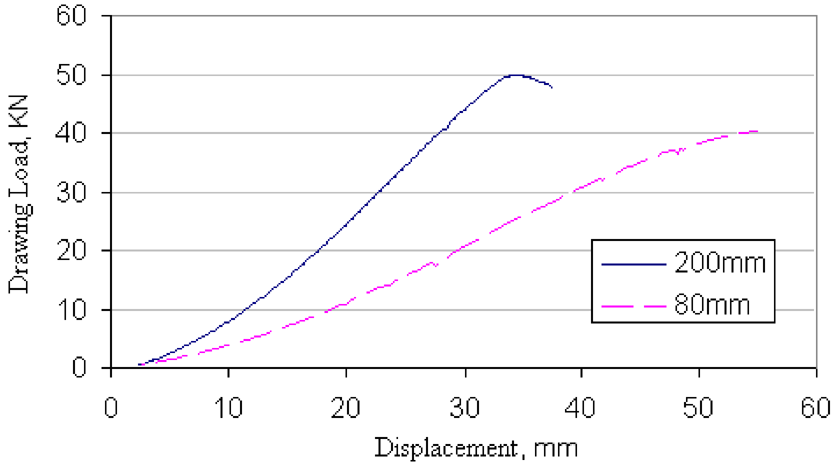



*Fig. 6 Evolution of the force of deep drawing for different types of stress*

## CONCLUSIONS

From the results obtained the following conclusions can be drawn:
- the speed does not influence significantly the force and depth of deep drawing;
- the force required by the deep drawing is higher in the case of biaxial stretching stress;
- the maximum deep drawing force obtained through simulation has values close to the experimental ones;
- the evolution of the force obtained through simulation, in case Hill criterion is used, is very close to the one obtained experimentally.

It resulted that simulation leads to obtaining data close to reality and allows establishing from the designing phase whether a given piece, with a certain geometry, can be obtained through deep drawing without any risks.

## ACKNOWLEDGMENTS

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