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# Comparative study on sheet metal forming processes by numerical modelling and experiment

W. Sosnowski*,

*on leave of absence from the Institute of Fundamental Technological Research, Polish Academy of Sciences, Warsaw.

E. Oñate, C. Agelet de Saracibar

International Center for Numerical Methods in Engineering, Universidad Politécnica de Cataluña, 08034 Barcelona, Spain

## Abstract

In this paper some results of a wide experimental program are presented and compared with some finite element solution of sheet metal forming problems using a viscous shell formulation.

## INTRODUCTION

The objective of this paper is to present some results of experimental tests which have been performed in the sheet stamping factory, Estampaciones Sabadell S.A. with cylindrical and prismatic dies designed and manufactured at Candemat S.A.

Tests included the deep drawing of circular and rectangular blanks with cylindrical and prismatic dies, respectively.

Different die and punch edge radios (i.e. roundings), the use of different lubricating conditions in the whole contact area and the use of different blank holding forces have been included into the experimental study.

Blank geometry i.e. draw-in values for different drawing depths, strain distribution and thickness distributions have been measured after each test.

A total of 26 successful tests have been performed. Unsuccessful tests included those with drawing depth much smaller than the value corresponding to ultimate strength or maximum displacement possible, or those in which total collapse of the blank has been reached. Only part of this work is presented in this paper.

All measured values are compared with corresponding parameters obtained from numerical simulation performed using a numerical code based on a finite element viscous shell approach developed by the authors [1-3]. The computer simulation of the experiments is under way so only part of the results was published already in [4] and in this paper. The full report [5] will be published soon.

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# 1 BRITE BENCHMARK DATA

## 1.1 Material data

Two types of material: AP04XR, serie of 17.06.1991 (material 1), for cylindrical tests and serie of 13.09.1991 (material 2) for rectagular tests have been used for the examples given in this paper.

Standard tension tests were applied using testing machine HOYTOM DI-10-CP/SV in order to establish tension characteristics for each material. In the case of circular blanks, eight test pieces presented on fig. 1 were cut off from the panel in different directions. In the case of rectangular blanks similar eight test pieces have been cut off in two directions parallel to panel sides and in two diagonal directions. Results of tension tests carried on up to collapse for each test piece are approximated by curves given in table 2 for each test.

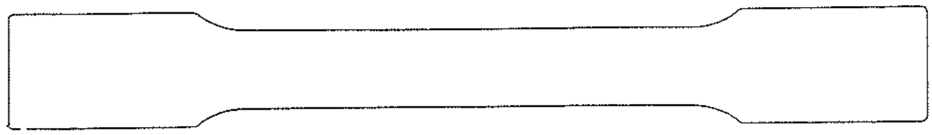

Figure 1. Specimen for material tension test

## 1.2 Blank geometry

Cylindrical blanks with radius $250mm$ and rectangular blanks $(400 * 500mm)$ have been used in experiment.

Average initial thickness measurements for some tests are given in figures 2 and 4.

It must be admitted here that the initial thickness distribution measured before experiments for some blanks shows relatively big discrepancy, up to 0.01 mm.

## 1.3 Tools geometry

Tools geometry have been introduced into the program MFP3DD as discretised rigid surfaces modelled with simple triangles. Summary of data are given in tables and in figures presented for each test.

The coordinates of all points used in order to build images of tools for all geometries consisting of die, punch and blankholder can be obtained from the authors. In this paper two following tools geometries have been used:

Cylindrical tools with edge radius (rounding) r=6mm,

Prismatical tools with edge radius (rounding) r=6mm.

### 1.4 Blankholder force

Constant blankholder (BH) force corresponding to initial contact area of the blankholder with the blank was applied:

A) for cylindrical test:

$BHForce = 19061.64kp = 186995N$

B) for prismatical test

$BHForce = 24505.5kp = 240402N$

### 1.5 Lubrication conditions:

Two different friction coefficients of 0.07 and 0.2 correspond respectively to processes with oil and without oil on tool and blank surfaces.

## 2. EXPERIMENTAL RESULTS AND NUMERICAL SIMULATION

This section contains the data summary and some results measured for two of a total of 26 tests. Thickness and/or radial strain distribution are given at measure points situated on deformed blank surface along symmetry lines. Thickness distribution is given as a function of the distance of measure points from the blank center along both two deformed symmetry lines. Fortran program calculating this distance as a function of tool roundings, drawing depth and final dimension of symmetry line is given in [5].

For prismatic test also a quarter of deformed free blank boundary is plotted. In case of cylindrical test this deformed shape was almost circular, so it was sufficient to measure and specify in table the diameter of deformed blank along both symmetry axis.

Maximum drawing depth possible before blank collapse was depending on deep drawing parameters such as blankholder pressure, friction coefficient (with or without oil), punch speed, geometry of tools and quality of blank material.

The summary of 3D finite element formulation based on the assumptions of rigid-plastic flow theory is given in [1-3]. The efficiency of this formulation in the context of axisymmetric sheet metal forming analysis has been demonstrated in many previous applications using membrane, bending and selective bending - membrane finite elements [6-8].

Starting from above approach the MFP3D numerical code was developed by the third author. This code is based on explicit predictor - implicit corrector algorithm. Mindlin 2-noded and Discrete Kirchhoff Triangular elements are incorporated. Penalty treatment of contact and friction phenomena is applied. Both Coulomb local linear/nonlinear and kinematic friction models are possible. Tools are modeled as discretized rigid surfaces with prescribed velocities. Program can be applied in all typical sheet metal forming simulations: stretch forming, deep drawing and superplastic forming.

In computer simulation some purely numerical parameters have played a significant role. Specially important were the penalty parameters for contact and friction, the discretization of blank and tools and also the type and value of convergence tolerance norms.

# CYLINDRICAL DRAWING OF CIRCULAR SHEET

| TABLE 1 GEOMETRICAL DATA | |
|---|---|
| Initial blank radius, $R_i$ | 250.0 mm |
| Punch radius, $R_p$ | 149.9 mm |
| Punch roundings, $r_p$ | 6.0 mm |
| Die radius, $R_d$ | 150.7 mm |
| Die roundings, $r_d$ | 6.0 mm |
| Initial average thickness | 0.675 mm |

| TABLE 2 MATERIAL PROPERTIES | |
|---|---|
| Material number | 1 |
| Yield function | $\overline{\sigma} = 320 - 80 * exp(-7.5 * \varepsilon * *0.97)$ |

| TABLE 3 PROCESS PARAMETERS | |
|---|---|
| Blankholder force, BF | 186995 N/quarter |
| Friction coefficient | 0.2 |
| Drawing depth, $D_d$ | 12.4 mm |
| Final diameter, $R_f$ , edge $Y = 0$ | 496.1mm |
| Final diameter, $R_f$ , edge$X = 0$ | 498.0 mm |

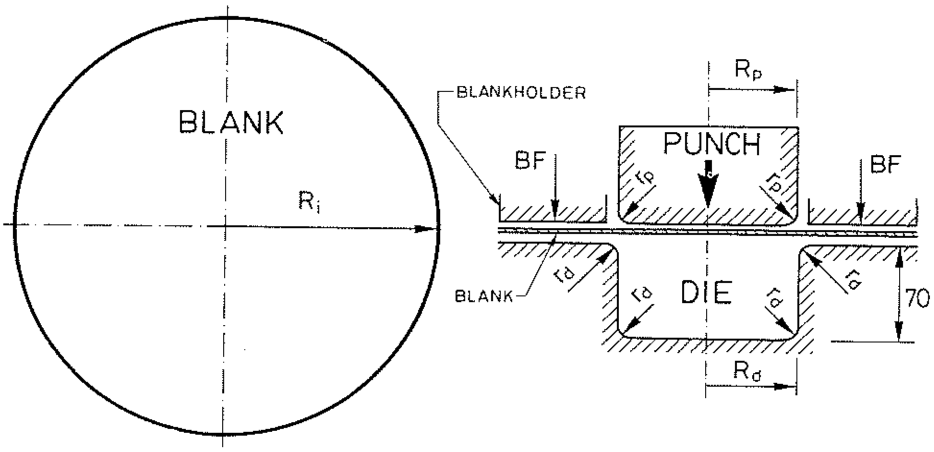


Figure 2. Geometrical and material data for cylindrical test with roundings 6 mm .

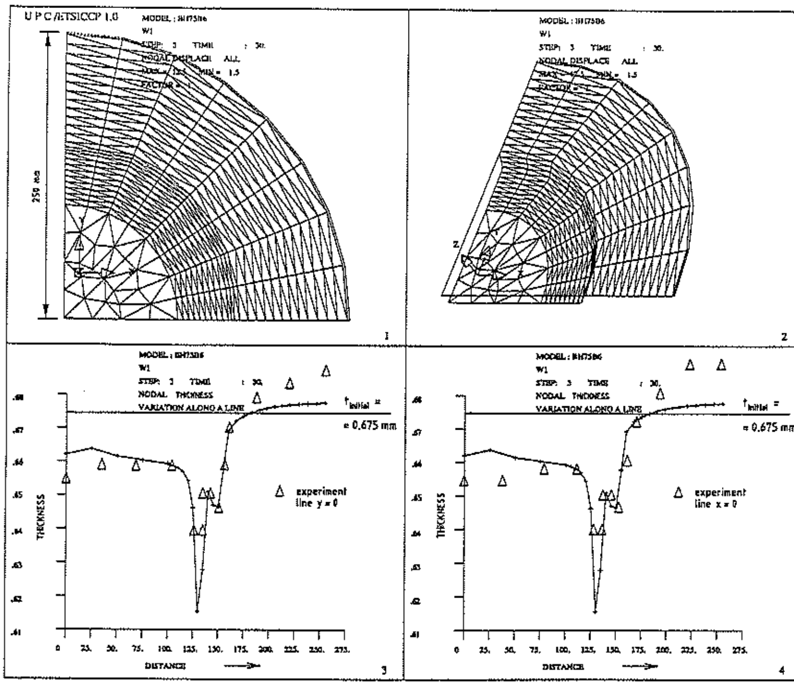

Figure 3. Comparison of experimental and numerical results. Friction coefficient assumed - 0.2.

On Figures 2-3 some results of experiments and calculations for the cylindrical test with die and punch radius=6 mm are shown for the high friction case ($\mu = 0.2$) . For this data not very big deflection was reached, due to small lubrication. Similar effect was also observed in practice.

Numerical and experimental results shown in Figure 3 are close. Differences are probably due to relatively big discrepancy of blank initial thickness distribution. Thickness measures with ultrasonic device gave errors of the order of 0.001 mm only, but discrepancy of measured initial blank thickness was up to 0.01 mm.

Others results of the experiment and calculations with prismatical tools with rounding 6 mm are presented in Figures 4 - 7. Again comparisons with experimental results have been made. Much bigger draw depths were possible in this case as oil was present on blank and tools surfaces. Some general views of deformed shapes of the blank plotted from numerical simulation have been compared with those obtained from experiments and given in Figure 7.

In summary the differences between experimental data and results of calculations are relatively small. In most cases these differences are not bigger than error of measure tools used in experiment and differences between maximum and minimum values of blank initial thickness distribution.

The computer simulation of the experiment is under way so only part of the results is available now and a full report [5] will be published soon.

# PRISMATIC DRAWING OF RECTANGULAR BLANK

| TABLE 1 GEOMETRICAL DATA | |
|---|---|
| Initial blank dimensions, | 400.0 * 500.0 mm |
| Punch dimensions, | 100.0 * 150.0 mm |
| Punch roundings, $r_p$ | 6.0 mm |
| Die dimensions, | 100.7 * 150.7 mm |
| Die roundings, $r_d$ | 6.0 mm |
| Initial average thickness | 0.7 mm |

| TABLE 2 MATERIAL PROPERTIES | |
|---|---|
| Material number | 2 |
| Yield function | $\overline{\sigma} = 320 - 195 * exp(-7.5 * \varepsilon * *0.97)$ |

| TABLE 3 PROCESS PARAMETERS | |
|---|---|
| Blankholder force, BF | 240402 N/quarter |
| Friction coefficient | 0.07 |
| Drawing depth, $D_d$ | 36.87 mm |
| Final dimension, edge $Y = 0$ | 340.0 mm |
| Final dimension, edge $X = 0$ | 444.0 mm |

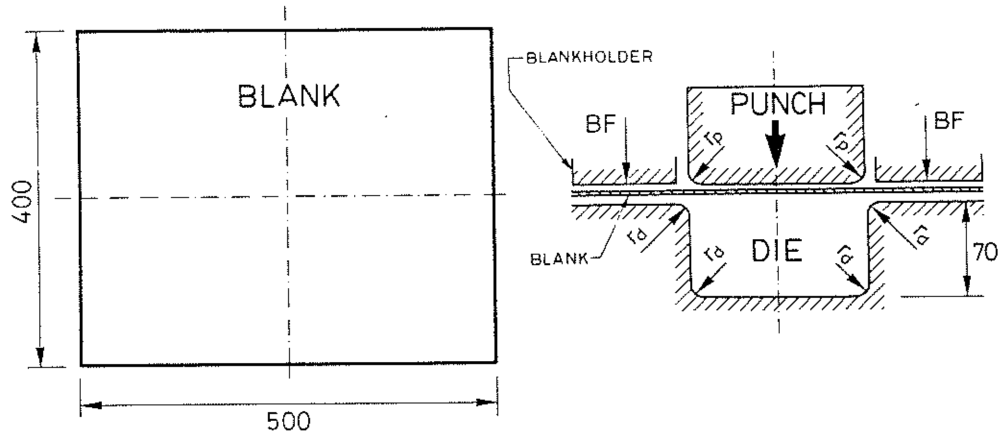


Figure 4. Geometrical and material data for prismatic test with roundings 6 mm .

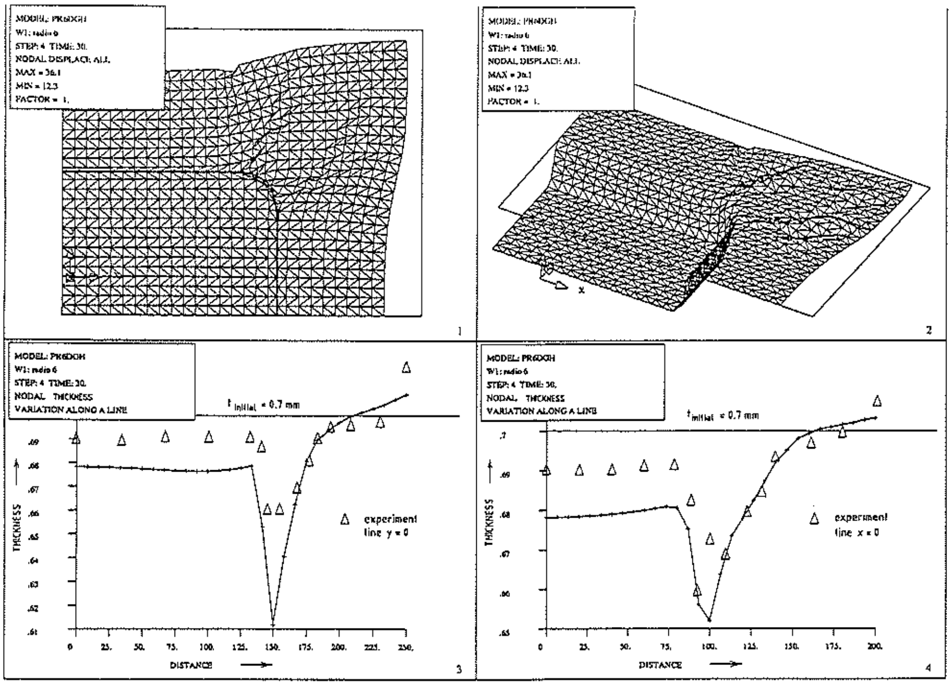


Figure 5. Comparison of experimental and numerical results. Friction coefficient assumed - 0.07

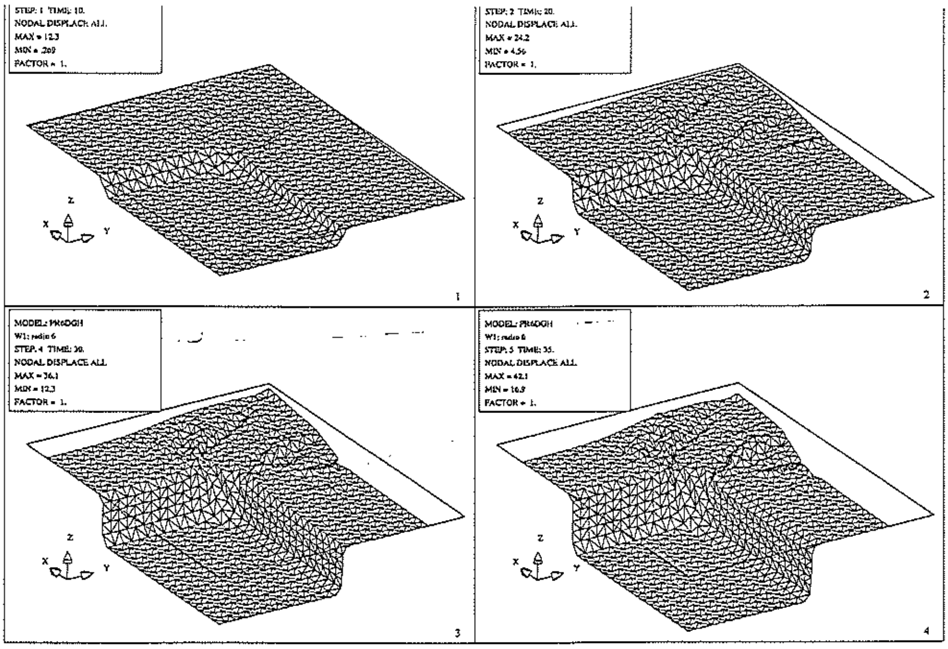

Figure 6. Deformed shapes for different punch travels.

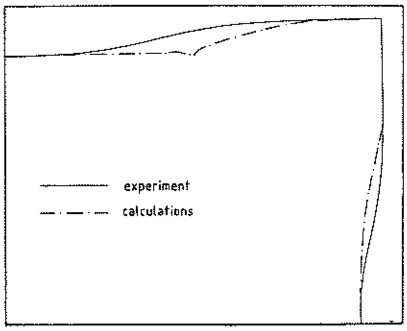


Figure 7.Deformed shapes of the blank plotted from numerical simulation and experiment.

## ACKNOWLEDGEMENT

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