EXPERIMENTAL AND THEORETICAL INVESTIGATION OF THE CUP DRAWING PROCESS OF ANISOTROPIC STEEL SHEETS

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Abstract: In order to obtain flawless pieces during the deep drawing process it is important to control the value of the blank holder force. An important value of the blank holder force limits the gliding of the steel sheet and develops its radial elongation. On the other hand, if it is not too big, the steel sheet can easily glide and the compressing stress which appears can cause the steel sheet's folding. The article presents the influence of the blank holder force on the variation of the cupped specimen's thickness in the case of cup drawing process. The results obtained through this simulation are compared to the experimental results. The simulation was performed by using the ABAQUS/Explicit v6.5 program.

Keywords: cup drawing, blank holder force, anisotropic steel sheet, simulation

1. INTRODUCTION

At the moment the deep drawing process is used on a large scale in industry. During the cup drawing process the steel sheet is kept between die and blank holder. The punch curves the steel sheet to a certain depth. In order to avoid the folding tendency, the blank holder presses the sheet with a certain force which leads to a force of friction. The power of the friction force determines the deep drawing process by the influencing both, the indirect stress and the crippling of the material which is being bent, and also the degree of bending. The area at the superior part of the cupped piece is being thickened, thus, it results a strain on normal direction, and the circular area near the joining with the lateral side of the piece thins. This variation of the cupped specimen's thickness is influenced by several factors, such as: the blank holder force, the friction coefficient between the steel sheet and the die and the bending degree of the material.

In order to reduce the experimentation periods which can be long and expensive many researches have been made concerning the simulation of the deep drawing process through the method of the finite element. The simulation of the deep drawing process allows one to know even from the designing phase whether a piece with a certain configuration can be obtained through the deep drawing process or not, taking into account all the factors that influence this process. Simulation progressed considerably in the past twenty years, due to the development of the capacity of accounting and stockage of the computer associated with graphic interfaces are in hand to the CAO users. As a simulation method one uses the method of the finite element which due to the solid algorithms can treat the non-linear problems introduced by the material's behavior, the piece's geometry and friction. The simulation programs dispose of graphic interfaces which allow the analysis and visualization of the results. As a conclusion, simulation is a useful tool for analyzing the causes of the eventual flaws of cupped pieces.

The article presents the influence of the blank holder force on the variation of the cupped specimen's thickness during the cup drawing process. The results obtained through this simulation are compared to the experimental results. The simulation was performed by using the ABAQUS/Explicit v6.5 program.

2. EXPERIMENTAL AND NUMERICAL PROCEDURE

2.1 Material and experimental conditions

In this study, A5 STAS 10318 sheet steel of deep drawing quality, 0.73 mm thick, is used. The chemical composition is given in table 1.

Chemical composition (weight percent) - Table 1

Element	C	Mn	Si	P	S
content	0,08	0,40	0,10	0,025	0,03

The cup drawings were performed with a specific device. The punch diameter is equal to 30 mm and the circular blanks have a diameter of 66 mm, giving a drawing ratio of 2,2. Therefore, the process parameters were as follows: drawing depth - 30 mm; drawing speed – 15 mm/min; blank-holding force – 10…75 KN, with lubrication.

2.2 Numerical procedure

The geometry used at the simulation is presented in figure 1 and corresponds to the experimental equipment. The geometry adopted at the simulation is defined by the following parameters:

- the punch's radius, R_p=15 mm;
- the die's punch, R_m=16,25mm;
- the radius of joining of the die, r_m=5mm;
- the radius of joining of the punch, r_p=6mm;
- the initial radius of the steel sheet, R_t = 33mm.
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The specimen was meshed with 3780 elements, S3D8R type, of ABAUS, meaning right-angled solid elements with four nodes, figure 2.

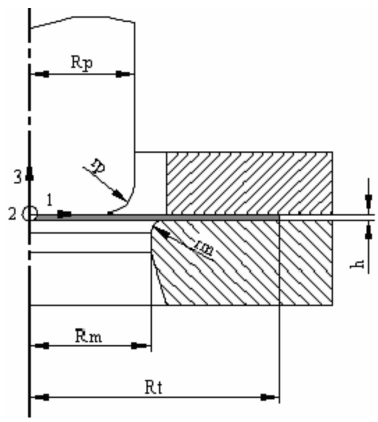


Fig.1 The geometry used at the simulation

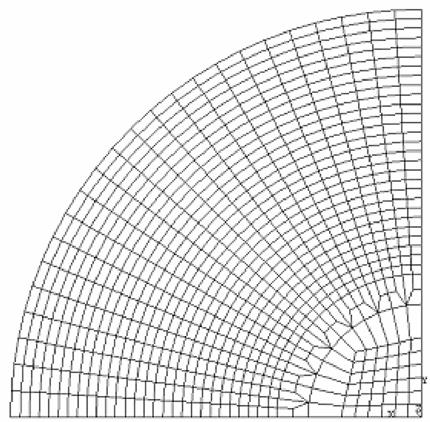


Fig.2 The specimen's mesh

The simulation is also done in two stages. The main conditions imposed in the first stage are: the die and the punch are fixed (moving and rotating on all directions are null), a force on direction 3 is applied to the blank holder, moving and rotating on the other directions are null.

2.3 The specifications of the material

The tools are rigid elements defined with the option "analytical rigid". In ABAQUS the specimen's material is described by the VUMAT (User MATerial) subroutine using the plasticity criterion developed by Ferron and others [1]. This pattern consists in a parametrical representation of the yield surface (f=0). The yield surface is traced in the plan of the main stress σ_1, σ_2, figure 3. For a material with transversal isotropy Ferron and others (1994) expressed the polar line *g (θ)* with the help of the expression:

$$(1-k)g(\theta)=\left(\cos^2\theta+A\sin^2\theta\right)^3-k\cos^2\theta\left(\cos^2\theta-B\sin^2\theta\right)^2 \quad (1)$$

where A and B are positive dimensionless constancies and k a real constancy.

This expression forms an expression of Drücker's criterion (1949) for whom the values of constancies A and B are equal with 3 and respectively 9.

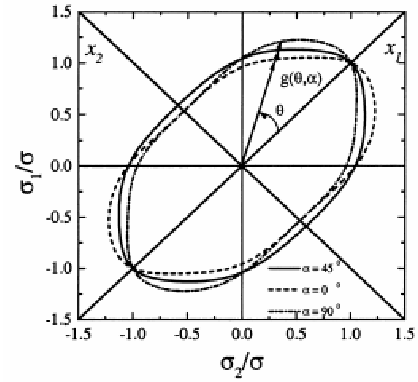


Fig. 3 The yield surface

The polar line g (θ, α,) used by Ferron and others [1] in order to define the bearing surface of a material with transversal anisotropy is an extension of the expression (1) and is written under the form:

$$g(\theta,\alpha)^{-m}=g(\theta)^{-m}+2a\sin\theta\cos^{2n-1}\theta\cos2\alpha+b\sin^{2p}\theta\cos^{2q}2\alpha \quad (2)$$

where *m, n, p* and *q* are positive constancies and *a* and *b* are dimensionless coefficients. Coefficients *a* and *b* characterize the material's anisotropy.

The values of the coefficients A, B, a, b of the plasticity criteria are calculated with the help of the coefficients of anisotropy (R_0=1.70, R_{45}=1.07 and R_{90}=1.98), table 2.

The coefficients of Ferron plasticity criterion - Table 2

A	**B**	**k**	**m**	**n**	**p**	**q**	**a**	**b**
3,125	9,375	0,07	2	2	2	1	-0,0466	0,7734

The plastic behavior of the material is defined with Swift's law:

$$\sigma=k(\varepsilon_0+\varepsilon)^n \quad (3)$$

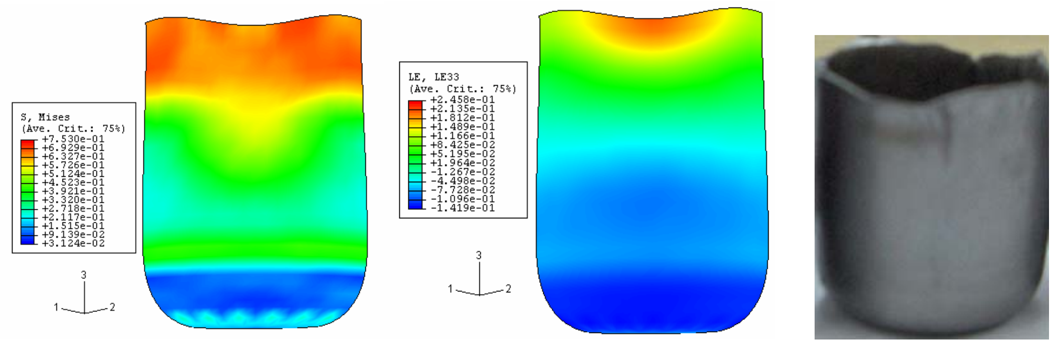
in which: k, ε_0, represent material constants
n, strain-hardening exponent.

The coefficients of Swift's law were determined by using the results of the traction test: $\sigma=529{,}4(0{,}0073+\varepsilon)^{0.236}$
The elastic behavior of the material is defined with the help of the longitudinal modulus of elasticity E=200000MPa and of Poisson's coefficient, ν = 0,29.

3. EVALUATION THEORETICAL AND EXPERIMENTAL RESULTS

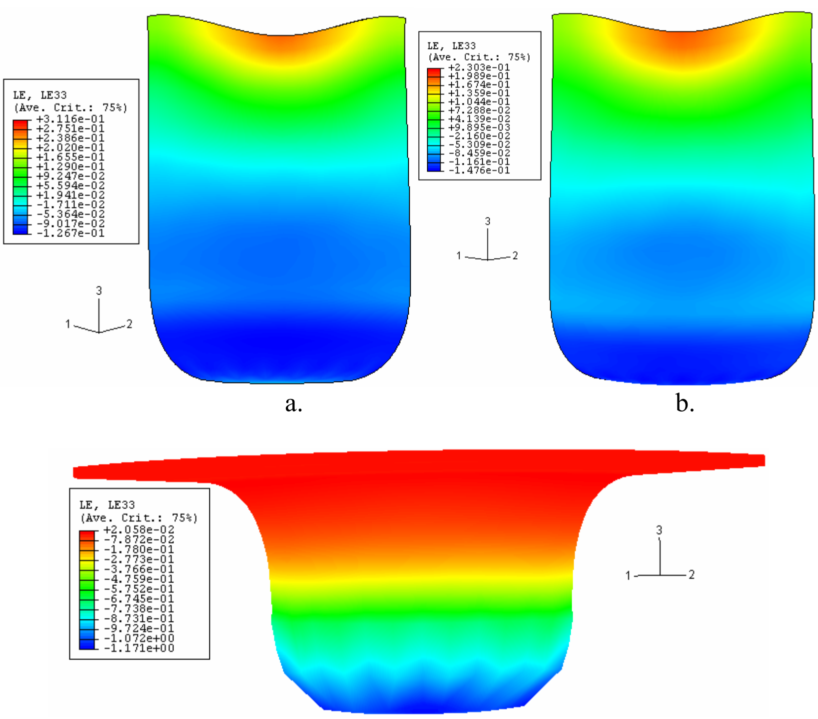
In order to analyze the influence of the blank holder force on the variation of the cupped specimen's thickness there have been taken into consideration the forces of the blank holder in the interval 10…75 KN. The cupped specimens are presented in figure 4 and the results obtained through the simulation in figure 5 and 6.

Fig. 4 Experimental results



a. b. c.

Fig. 5 With the application of 50 KN blank holder forces (a) stress distribution (b) differences in thickness and experimental results(c)



a. b.

c.

Fig. 6 Theoretical results for different blank holder forces: 25 KN(a), 60 KN(b) and 75 KN(c)

It was observed that for force values between 25KN and 65KN the obtained cupped specimens are without wrinkles and cracks. Due to the anisotropy of the steel sheet the cupped piece has an irregular height irrespective of the blank holder force. The maximum and minimum heights of the pieces obtained experimentally and through simulation are presented in table 3.

Depth drawing results - Table 3

Blank holder force, KN	10		25		50		60	
	exp	abq	exp	abq	exp	abq	exp	abq
Minimum depth	29,3	28,2106	29,72	28,8756	28,92	29,4183	29,58	29,7989
Maximum depth	31,76	31,4708	31,5	31,3394	32,05	31,8276	33,06	32,2269

The variation of the cupped specimen's thickness for different values of the blank holder force is presented in figure 7. The results obtained through simulation are comparable to experimental results.

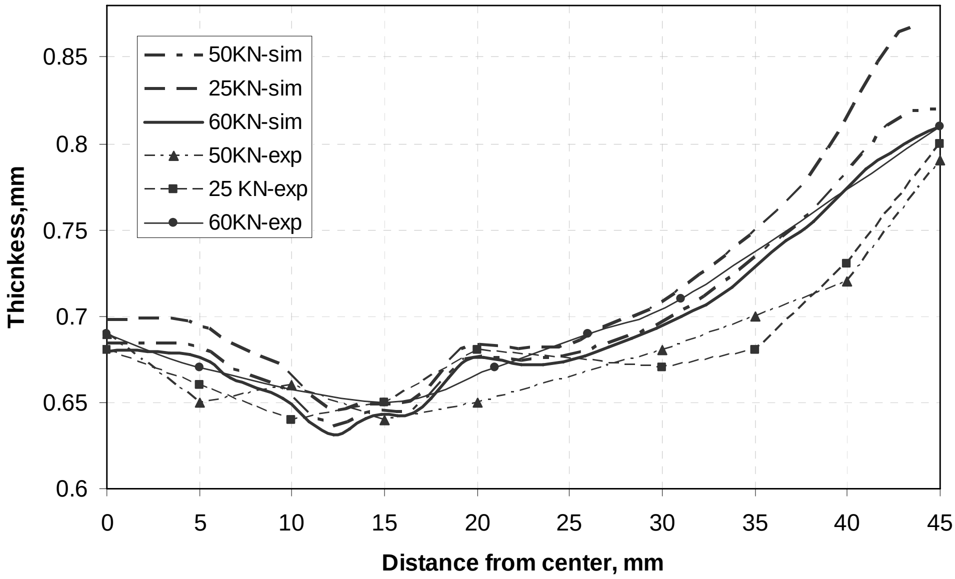


Fig. 7 Experimental and theoretical thickness distribution

The maximum and minimum thickness of the cupped specimens - Table 4

The blank holder force, KN	The maximum thickness, mm		The minimum thickness, mm	
	exp.	abq	exp.	abq
25	0.81	0.869	0.64	0.645
50	0.80	0.819	0.63	0.635
60	0.79	0.809	0.63	0.630

In the case of simulation for a force of 25KN of the blank holder the specimen's material thins with almost 12%, with 13% for a force of 50KN and with 14% for a force of 60KN.

4. CONCLUSIONS

When the cup drawing process is applied to an A5 STAS 10318-80 material, being 0.73 thick, the material folds at holding forces lower than 25 KN and at holding forces higher than 65KN the material cracks.
The piece's thickness in the central area varies very little, in the joining area the piece thins and in the superior area it thickens due to the folding of the material.

As the blank holder force increases, the attenuation of the piece, which appears predominantly in the area of the joining radius at the bottom of the specimen, is more stressed; the specimen's thickness in the superior area of the cupped specimen grows as the blank holder force diminishes.

Due to the steel sheet's anisotropy, irrespective of the degree of the force the cupped specimen has an uneven height.

The results obtained through simulation are comparable to experimental results, the Ferron criterion describing well the material's anisotropy. By doing the simulation of the deep drawing process in the designing stage one can choose the blank holder force, thus, reducing the experimentation periods which can be long and expensive.

5. REFERENCES

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