THE INFLUENCE OF THE PUNCH SHAPE ON THE RESIDUAL STRESSES DISTRIBUTION AND SPRINGBACK IN THE CASE OF CONICAL DRAWN PARTS

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ABSTRACT

The residual stresses that occur in drawn parts after tools removing are the main cause that generates the springback of such parts. Hence, to investigate the springback phenomenon it is needed to know at first the state of residual stresses developed in part by its cold forming. Because of the complex forming tools and parts geometry, the experimental investigation of residual stress distribution in the case of drawn parts is a difficult problem. A possible solution of the problem can be the simulation of the forming process, springback and residual stress distribution.
The present paper investigates the influence of the punch shape on springback intensity and residual stresses distribution by simulating the drawing process in the case of conical parts made from steel sheets by using the following two punch shapes: cylindrical and conical.

KEYWORDS: springback, residual stresses, deep drawing, conical parts.

1. INTRODUCTION

The residual stresses are generally developed by mechanical working processes that determine the material deforming and modify the shape of part or the properties of its material [1, 3]. In the case of metal sheets deep drawing, such stresses are generated by the incompatibility between the permanent deformations of material and occur in conditions in which some differences exist between the states of deformation of different material strata. Thus, in the case of a cave drawn part, the generation of residual stresses can has the following causes:

• in the regions of part stressed by bending combined with tensile, regions located in the zones of connection bottom – wall and wall – flange, the outer face of part, generally, passes into yielding before the inner face;

• in the moment when the applied load is removed, the zones with larger yielding will prevent the zones with smaller yielding to back in an unstressed state. In such conditions, when a difference exists between different surfaces and zones of part concerning the material yielding, the generation of residual stresses in the deformed material will be favoured [2, 4].

Springback is a phenomenon manifested by the modification of the geometric shape of formed parts.

The main springback effects and parameters can be as follows: modification of the curvature radius and angle of inclination of the part walls, difference in height etc. An important cause that generates and influences the springback phenomenon is represented by the distribution of residual stresses on the formed part. Thus, in the case of a cave drawn part in its regions stressed by bending combined with tensile and located in the zones of connection bottom – wall and wall – flange where high values of residual stresses were accumulated, in the moment when the applied load is removed the above mentioned zones will tend to relax their state of stress and will determine the part springback with a high intensity. Hence, to investigate the springback and to control its intensity it must be known the distribution of residual stresses developed in part by its cold forming. But, the experimental determination of residual stresses distribution in the case of drawn parts is a difficult problem caused by the complexity of the forming operations, forming tools construction and formed parts geometry. Hence, the investigation concerning the residual stresses can be generally performed by simulation. On the other hand, the main factors that influence the springback intensity are as follows: punch and die radii, initial clearances, lubricating conditions, blankholder force, part shape, material chemical composition and mechanical properties, sheet thickness etc. Among the above mentioned

factors, the variation of blankholder force has an important influence on the modification of the part springback parameters. Thus, the utilization of high blankholder forces in deep drawing will blocks the flow of material into the part flange and die cavity and will lead to the elimination of differences between the stress and strain states on the two faces of part, especially in the sidewall region. The reduction of the differences between the stresses or strains generated on the part faces will have like effect the reduction of springback parameters and deviations from the theoretical profile of part [5, 6].

The present paper investigates the distribution of residual stresses and its relation with springback intensity by simulating the drawing process in the case of conical parts made from steel sheets and by using two shapes of punch: cylindrical and conical.

2. INVESTIGATION RESULTS

The investigations were done for the following two forming cases of conical parts: by using conical punch and by using cylindrical punch. The analysis concerning the residual stresses distribution and springback intensity was performed by simulation using the ABAQUS-Explicit software. The parts were made from SPE 220BH steel sheets, the sheet thickness being equal to 0.8 mm. The geometry of the part used in simulation is presented in Fig. 1.
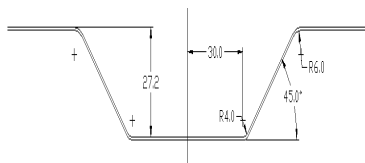

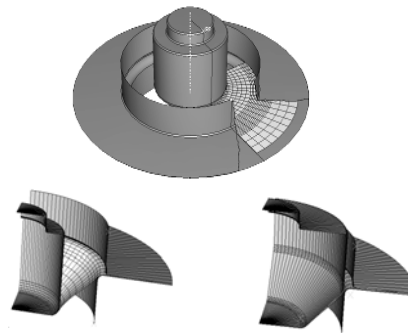Fig. 1. Geometry of the part used in simulation

A three dimensional model was used for simulation. The model was created in order to ensure the simulation of a quasi-static problem and to obtain the state of equilibrium after the forming operation. The blank-holder, punch and die were modelled as rigid surfaces. The blank was considered as deformable with a planar shell base. The models used in simulation for the above mentioned shapes of parts are presented in Fig. 2.

The integration method was Gaussian with 5 integration points through the thickness of the shell. The elements used for the blank mesh were of S4R type (4 nodes reduced integration shell).

A symbolic mass of 1 kg was attached to the blankholder and punch and an initially concentrated load of 30kN was applied to the reference node of the blankholder. Contact interactions between blank and tools were modelled by using the penalty method.

The working parameters were as follows: drawing speed = 18 mm/min, blank holding force = 50 kN, friction coefficient: $\mu = 0.1$. In simulations a quarter of part having two symmetry conditions

(symmetry of yz plane -A and symmetry of xy plane - B) was used.

cylindrical punch   conical punch
Fig. 2 Geometry of the model used in simulation

The materials elastic properties used for simulation were as follows: Young's modulus 2.1×10^5 MPa, Yield Stress $\sigma_y = 176$MPa, Yield Strength k = 472MPa, Poisson's ratio 0.3, coefficient of anisotropy 1.42, density 7800 kg /m³. In order to describe the plastic behaviour of the used material, 10 points were chosen from the material stress – strain diagram. The material was considered elastic-plastic with an isotropic hardening.

The stresses distribution was determined on the both faces of part, inner and outer, after drawing and after springback and in the main points of the part profile (Fig. 3).
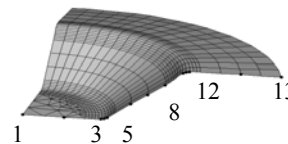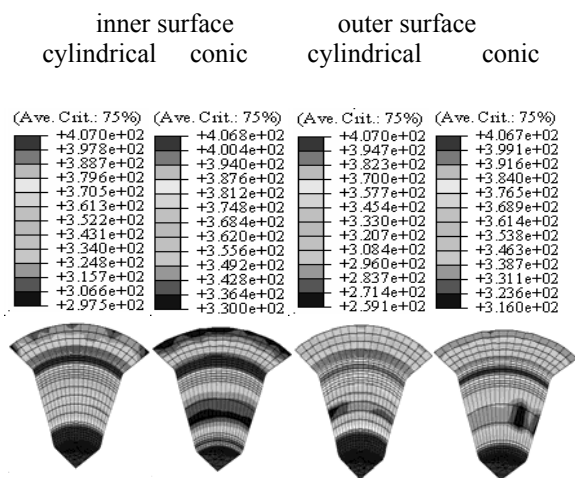

Fig. 3 Main points of part profile

The distribution of residual stresses resulted from simulation as a function of different factors is presented in Fig. 3.

inner surface   outer surface
cylindrical conic   cylindrical   conic

a.   Von Misses stresses

inner surface   outer surface
cylindrical   conic   cylindrical   conic

b.   Maximum stresses

inner surface   outer surface
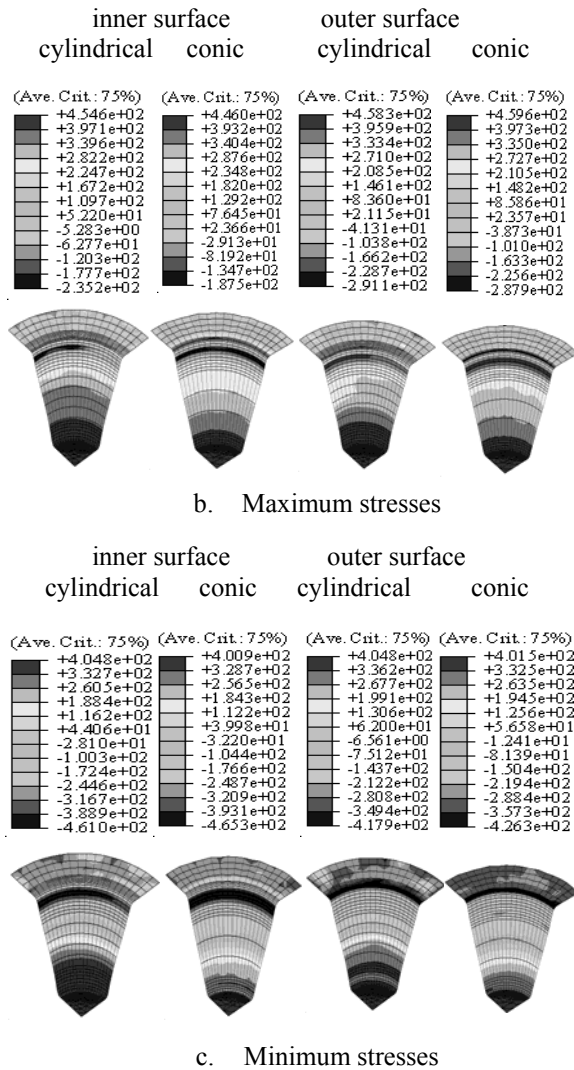cylindrical   conic   cylindrical   conic

c.   Minimum stresses
Fig. 3 Residual stresses distribution in the case of
conical drawn parts

3. RESULTS ANALYSIS

The values of residual stresses and springback parameters resulted from simulation as a function of punch shape, working conditions and parameters are given in Tables 2 and 3, respectively. From the analysis of springback parameters and residual stresses distribution on the drawn parts and by taking into account the punch shapes, the following main remarks can be made:

• the level of residual stresses is higher on the part bottom and wall in the case of cylindrical punch by comparing with the level resulted in the case of conical punch using;

• the level of residual stresses is smaller on the part flange in the case of cylindrical punch by comparing with the level resulted in the case of conical punch using;

• in the case of conical punch, the springback parameters that include the deviations from theoretical profile are higher in flange and smaller in the zone of connection wall – bottom by comparing with the values resulted in the case of cylindrical punch using.

By analysing the residual stress distribution on the drawn part, the following remarks can be done:

• an increase of residual stress values and a concentration of such stresses were registered in the regions located at the zones of connection part wall - part bottom and part wall - part flange, regions that are stressed by bending combined with tensile; minimum values of stresses were registered at the middle of the part wall;

• between the distribution and values of the residual stresses on the outer and inner surfaces of part, for the both cases of conical and cylindrical punches using a difference resulted, especially, in the zones of connection wall - bottom and wall – flange;

• the level of residual stresses was higher on the outer surface of part in the zones of bottom and wall by comparing with the level resulted on the inner surface in the same zones;

• the level of residual stresses was smaller on the outer surface of part in the zone of part flange by comparing with the level resulted on the inner surface of flange;

• the maximum stresses - that act along the part profile - have had the highest values on the part bottom and in the zones of connection wall - bottom

Table 1. von Misses stress values in the main points of the part profile

BHF = 50kN				
Punch shape	cylindrical		conical	
Part surface	Inner	Outer	Inner	Outer
Profile points	Equivalent stress after forming (von Misses) [MPa]			
1	398.7	406.3	405.9	406.3
3	406.1	406.1	389.6	405.9
4	406.4	406.4	391.3	405.9
5	406.4	406.4	403.3	406.3
8	361.9	362.7	355.0	354.5
10	381.6	363.1	406.3	379.8
11	374.4	359.5	391.5	373.4
12	344.9	322.1	345.5	344.1
13	330.3	186.9	334.6	331.5

Tab. 2 Springback parameters

BHF = 50kN	Springback values		Deviations from theoretical profile	
Punch shape	conical	cylindrical	conical	cylindrical
Flange radius [mm]	6.81	6.41	0.81	0.41
Bottom radius [mm]	4.26	4.41	0.26	0,41
Flange angle [°]	-0.53	-0.13	-0.53	-0.13

and wall - flange, on the part flange the above mentioned stresses have had very small values;

• the minimum stresses - that act along the part circumference and perpendicular to maximum stresses – presented highest positive values on the part bottom and on the zone of connection bottom - wall and negative values on the flange and zone of connection wall - flange; from the analysis of the minimum stresses variation along the part circumference – on the zone of connection wall - flange - it was observed that after forming such stresses presented only negative values the highest being obtained on the outer face of part.

The variation of the springback parameters and hence the deviations from the theoretical profile of part presented also the following aspects: in zones where the material was compressed in flange and bended over die and punch profile radii, the increase of the flange angle and the decrease of the curvature radii over the die and punch radii were registered in the both cases of conical and cylindrical punches using.

4. CONCLUSIONS

Some differences resulted between the distributions of residual stresses obtained in the case of drawn parts made by using cylindrical and conical punches; such differences can be caused and influenced, among other causes or factors, by the differences that exist between the friction conditions that are created by the punch shape on the part wall; thus, in the zone of part wall, the friction between material and punch exists only in the case of conical punch and is absent in the case of cylindrical punch using. Hence:

• in the case of conical punch, the friction between punch and part wall will determine a uniform and smaller material yielding on part wall and hence the residual stresses on the wall and in the zone of connection wall - bottom will have smaller values than in the case of cylindrical punch using; in the case of cylindrical punch, when it not exists friction between punch and part wall the material yielding will be intensive and hence the residual stresses on the wall and in the zone of connection wall - bottom will have higher values;

• the restrictions created by friction in the material flow between punch and part wall will influence the residual stresses values in the zones of flange and bottom where such stresses will have higher values than in the case of cylindrical punch using.

Like in the case of residual stresses distribution, the differences in springback intensity in both cases of cylindrical and conical punches using can be also influenced by the differences that exist concerning the friction conditions between punch and material as a function of punch shape. Thus:

• in the case of conical punch, the friction between punch and part wall will determine a smaller yielding of wall material and will influence the springback in the zone of connection wall - bottom by determining smaller values of springback parameters in this zone in comparison with the case of cylindrical punch using;

• because in the case of cylindrical punch using the material yielding is more intensive on part wall by comparing with other zones of part, the springback parameters in the zone of flange or in the zone of connection wall – flange will have smaller values by comparing with the case of conical punch using.

Concerning the connection between residual stresses distribution and springback intensity, the following conclusions can be formulated:

• in the both cases of conical and cylindrical punches using, the differences resulted between the residual stresses on the outer and inner faces of part and on sheet thickness can be the main cause of springback and influence its intensity, especially in zones of connection wall – bottom and wall - flange;

• the variation and values of the major components of residual stresses - that act along the part profile - can influence the springback intensity.

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