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ANALYSIS BY SIMULATION OF THE STRESS DISTRIBUTION IN DIFFERENT STAGES OF THE DRAWING PROCESS OF CONICAL PARTS MADE FROM METAL SHEETS

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Abstract: *The stresses generated in the stamped parts before and after the removing of the tools are the main cause that determines the springback of the draw parts made from metal sheets. Hence, to investigate the springback phenomenon it must be known the state of stresses developed in the drawn part by the cold plastic forming. The experimental investigation of the stresses distribution in the case of drawn parts is a difficult problem because of the forming operations and parts geometry complexity. An optimum solution to solve the problem can be the simulation of the forming process and stress distribution. The present paper investigates the distribution of the stresses by simulating the drawing process using ABAQUS software in the case of conical parts made from steel sheets.*

Key words: *loading stresses, residual stresses, deep drawing.*

1. INTRODUCTION

The total stresses (s_{ij}^{TS}) that act on the material during the mechanical processes of its transformation into a finished part (Fig. 1) are given by summing the loading stresses (s_{ij}^{LS}) with residual stresses (s_{ij}^{RS}).

The *loading stresses* are the stresses generated by the action of the external loads on the material in order to create the shape and dimensions of the part; such stresses become equal to zero when the external loads will finish their action on the material.

The *residual stresses* are the stresses generated by the working process in a manufactured part, which remain in material after the external load will stop its action on the part. Such stresses, which are contained in part before its entering in the operating stage, have variable sizes and senses as a function of different factors, like: type of the working process, material properties, working parameters etc. [1] The mechanical generated residual stresses occur in the conditions in which some differences occur between the states of deformation of the outer and inner material strata and have as main cause the incompatibility between the permanent deformations of the material; such kind of stresses can be developed by the majority of the mechanical working processes that suppose the material deforming and that modify the shape of the part or the properties of its material. The residual stresses combined with that determined by the servicing loads can have an important effect on the behaviour of the material or part. [2] In the case of metal sheets stamping, the residual stresses that occur in parts after the tools removing are the main cause that generates the springback and influences its intensity. [3] Springback is not only manifested by the modification of the state of stress/strains in the formed material but also by the modification of the geometric shape of the formed parts. 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. The residual stresses generated by the drawing processes are caused by the facts that some differences occur between the states of deformation of the outer and inner strata of material and also because between the permanent deformations of the material there is an incompatibility. The consideration of the effects and levels of the residual stresses is imposed not only by the damage of the material integrity destruction but also by the factors of stability or accuracy concerning the dimensions and shape of the worked part. [4]

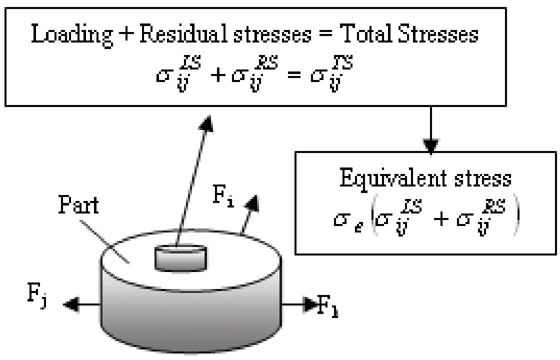


Fig. 1. Total stresses that act on a worked part.

The present paper presents the results of investigations concerning the distributions of loading and residual stresses by simulating the drawing process in the case of conical drawn parts.

2. CONDITIONS OF SIMULATION

The study concerning the stresses distribution on the conical draw parts included the analysis of the loading

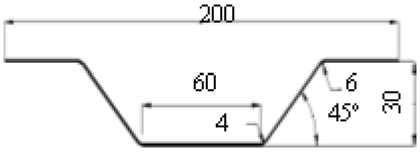


Fig. 2. Geometry of the part.

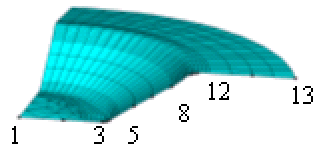


Fig.3 Main points of part profile.

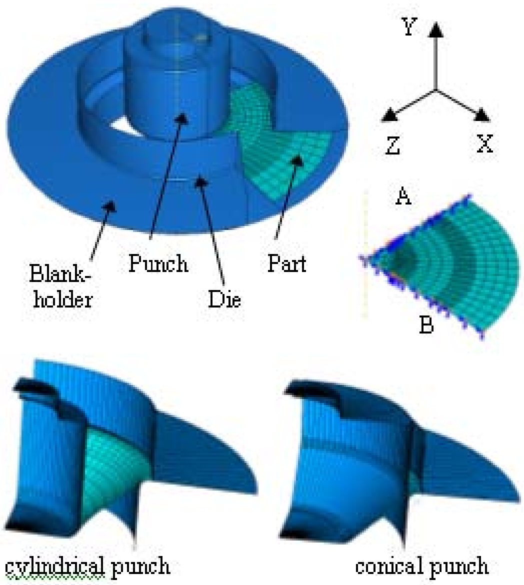


Fig. 4. Geometry of the model used in simulation.

stresses and residual stresses as a function of different factors of influence. The analysis was performed by simulation using the ABAQUS-Explicit software for the following two forming cases of drawing: with conical punch and with cylindrical punch. The geometry of the conical part analysed by simulation is presented in Fig. 2. The stresses distribution was determined on both faces of part, inner and outer, after drawing and after springback and in the main points of the part profile (Fig. 3).

In simulation a three dimensional model was used (Fig. 4); it was created in order to ensure the simulation of the quasi-static problem and to obtain the state of equilibrium after the forming operation. A quarter of part having two symmetry conditions (symmetry of *yz* plane – *A* and symmetry of *xy* plane – *B*) was used in simulations.

The blank was considered as deformable with a planar shell base. 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). The blank-holder, punch and die were modelled as rigid surfaces. A symbolic mass of 1 kg was attached to the blankholder and punch and an initially concentrated load of 30 kN was applied to the reference node of the blankholder. Contact interactions between blank and tools were modelled using penalty method. The simulation was performed for the parts made from SPE 220BH steel sheets. In order to describe the plastic behaviour of the used material, 10 points were chosen from the stress – strain diagram. The material was considered elastic-plastic with an isotropic hardening. The materials elastic properties used for simulation were as follows: Young's modulus 2.1×10^5 MPa, Poisson's ratio 0.3, density 7800 kg/m^3. The sheet thickness was equal to 0.8 mm and the blank radius was equal to 105 mm. The working parameters were as follows: drawing speed = 18 mm/min, blank holding force = 20 …50 kN, friction coefficient: f = 0.1 and 0.05.

3. INVESTIGATION CONCERNING THE STRESSES DISTRIBUTION

The simulation concerning the distribution of loading stresses was performed for the case of a BHF = 35 kN – at the beginning and before the end of the forming process; the obtained results are presented in Table 1 and 2 for the cases of cylindrical and conical punches, respectively. The variations of the stresses generated by the forming load at the beginning and before the end of the forming process are presented in Fig. 5a and b respectively.

Concerning the distribution and variation of stresses generated by the forming loads, the following aspects were remarked:

• the values of the loading stresses on the outer face were much higher than on the inner face; between the loading stresses generated in the cases of cylindrical punch and conical ones there were not great differences;

Table 1

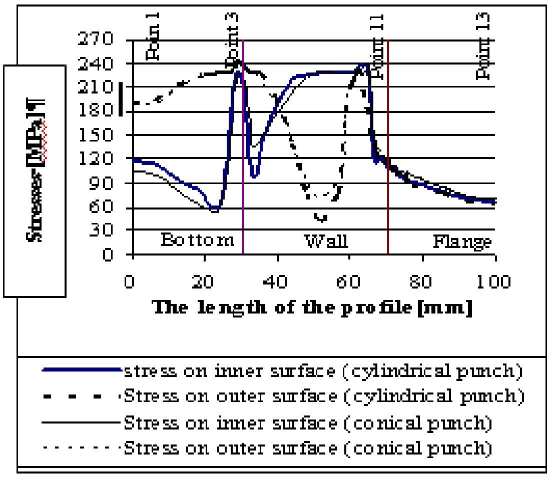
Stresses [MPa] generated by forming load in the main points of part profile - cylindrical punch

Profile points	Inner face	Outer face	Inner face	Outer face
	After forming start		Before forming end	
1	118.6	189.1	407.0	407.0
2	114.4	193.2	407.0	407.0
4	227.5	239.7	402.4	406.9
6	228.1	244.6	334.1	329.6
8	134.4	227.3	351.9	350.4
10	116.1	133.2	400.6	367.1
12	80.3	78.7	325.3	337.0
13	65.71	64.6	312.5	314.3

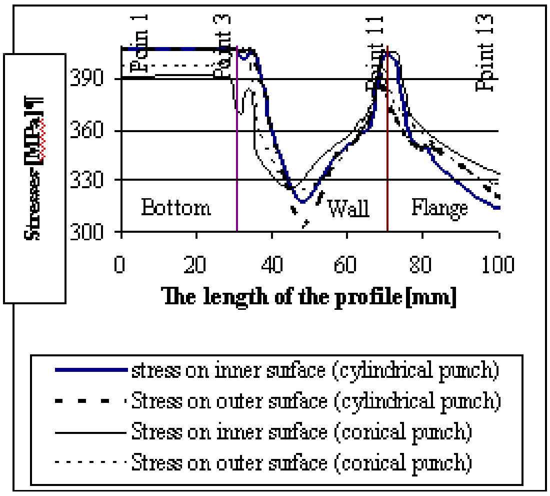
Table 2

Stresses [MPa] generated by forming load in the main points of part profile - conical punch

Profile points	Inner face	Outer face	Inner face	Outer face
	After forming start		Before forming end	
1	105.0	185.3	392.3	398.0
2	73.4	216.0	392.0	398.1
4	226.6	237.2	369.2	406.9
6	188.0	167.2	326.2	324.8
8	227.5	97.7	359.3	352.7
10	124.4	122.6	404.7	373.0
12	82.9	83.0	343.2	335.4
13	69.3	69.41	330.6	326.5



a. after the beginning of the forming process



b. before the end of the forming process

Fig. 5. Distribution of the stresses determined by the forming load in the case of a BHF = 35 kN.

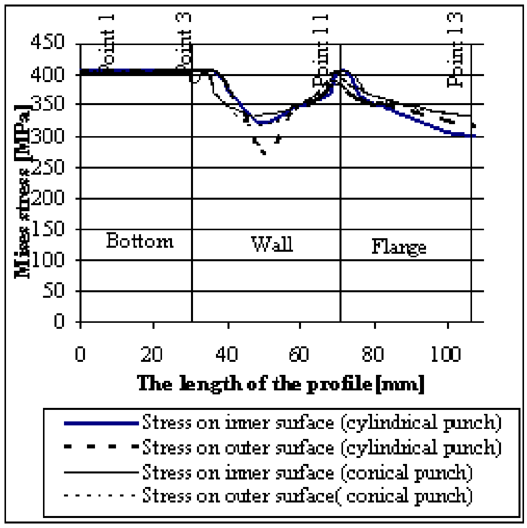
generally, the loading stresses that resulted before the forming end have had much higher values than in the case of the forming start;

•just after forming start the highest values of the loading stresses were located in the zones of connection between bottom - wall and wall – flange; between the above mentioned zones, on the part wall, the loading stress distribution have had a minimum in the middle of the wall profile; in the zone of the flange border the loading stresses were two or three times smaller than in the case of bottom centre; in the zones of connection bottom - wall and bottom - flange the loading stresses were two or three times greater than in the case of bottom centre and flange border;

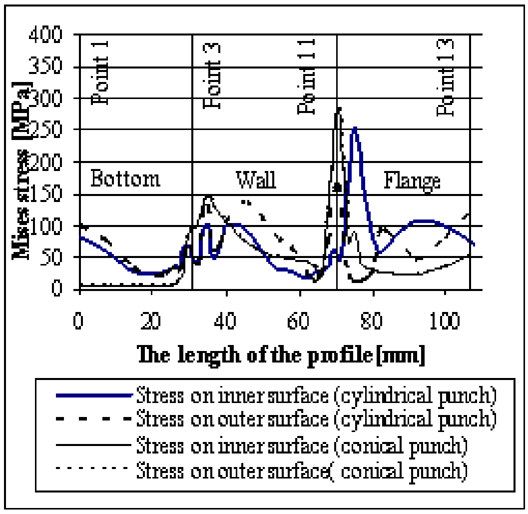
• before the forming end the highest values of the loading stresses were located on the part bottom and in the zones of connection bottom - wall and wall – flange; between the above mentioned zones, on the part wall, the loading stress distribution has had a minimum in the middle of the part wall;

• the values of the loading stresses on the outer face were approximately the same like on the inner face; the differences between the loading stresses located in the bottom centre and flange border were not too great.

The variations of the residual stresses - expressed by the von Mises equivalent stresses – on the drawn parts for a blankholder force equal to 35 kN and a friction coefficient equal to 0.1 are presented in Fig. 6 a and b; the values of residual stresses in the main points of the part profile are given in Tables 3 and 4 for the cases of cylindrical and conical punches, respectively.



a. after drawing



barter springback

Fig. 6. Variation of the equivalent stresses in different points along the part profile.

Table 3

Equivalent stresses [MPa] determined in the main points along the part profile – cylindrical punch

Profile points	**Inner surface**	**Outer surface**	**Inner surface**	**Outer surface**
	After forming		**After springback**	
1	406.9	406.1	83.2	100.5
2	406.6	406.8	30.0	35.7
4	406.2	406.5	45.6	38.9
6	374.2	373.0	96.8	100.4
8	352.8	351.4	19.9	27.8
10	399.9	368.2	182.2	20.9
12	326.2	339.3	107.3	46.7
13	299.2	315.8	69.1	126.2

Table 4

Equivalent stresses [MPa] determined in the main points along the part profile – conical punch

Profile points	Inner surface	Outer surface	Inner surface	Outer surface
	After forming		After springback	
1	402.6	403.7	5.01	5.0
2	403.3	403.2	6.25	5.7
4	388.3	406.2	116.9	94.4
6	334.3	320.4	75.2	77.1
8	357.2	356.7	52.10	43.54
10	402.7	378.2	176.2	77.6
12	347.6	342.8	79.6	21.4
13	334.4	331.5	109.5	53.05

By analyzing the residual stresses variation on the conical draw parts and in different points along the part profile the following general aspects were remarked: after drawing, a concentration of the residual stresses was observed on the part bottom and in the zones of connection wall – bottom and wall – flange, zones that are stressed by bending; minimum values of the 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 – it also existed a difference, especially, in the zones of connection wall - bottom and wall – flange. After springback a relaxation of the stresses will take place. Thus, in the case of cylindrical punch, in the zone of connection bottom - wall the equivalent stresses decreased nine times on the inner face and ten times on the outer face; in the zone of connection – wall – flange the equivalent stresses decreased two times on the inner face and nineteen times on the outer face. In the case of conical punch, in the same zones the equivalent stresses decreased three times on the inner face and four times on the outer face, and 2 times on the inner face and five times on the outer face, respectively.

5. CONCLUSIONS

The differences in the states of loading stresses resulted between the outer and inner strata of material will generate differences in the state of deformation between the same strata. Such differences can be main cause that generates the residual stresses.

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 - it also existed a difference, especially, in the zones of connection wall – bottom and wall – flange. The differences resulted between the states of residual stresses on the outer and inner faces of part, especially in the zones of connection wall – bottom and wall – flange, can be the main cause of springback. The variation of residual stresses on the drawn part can be explained as follows:

• in the regions of part stressed by bending combined with tensile – regions located over die and punch radii - 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 a unstressed state and hence the generating of residual stresses will take place;

• in the region of blank comprised between the die plate and blankholder - where it takes place a radial tensile of material - will be marked by the increase of the sheet thickness and hence by the generating of higher compressive residual stresses in material.

After springback, a relaxation of the residual stresses will take place. In spite of this fact, the level of residual stresses that remain in material after springback is high especially on the zones of connection bottom – wall and wall – flange. In the operating stage of the part, such residual stresses combined with the stresses generated by the operating loads can have an important effect on the material or part behaviour. If the residual stresses will act in an opposite sense to the stresses generated by the operating loads applied on the part it can be expected that such stresses to be reduced to zero before to occur undesirable effects determined by the increase of the combined stresses. If the residual stresses will act in the same sense with the stresses generated by the operating loads, than a small load applied on the part can generate undesirable effects compared with a part having zero initial stresses.

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