MEASUREMENT AND VERIFICATION OF DEEP DRAWING FORCE IN CASE OF NON-SYMMETRIC PARTS

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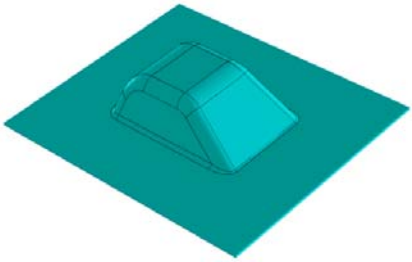
ABSTRACT
Deep drawing of complex, non-symmetric shapes is often related with problems with wrinkling and excessive thinning. Draw beads can be useful addition to drawing tool in such situations but its shape and positions are difficult to determine in advance. In this paper we describe experimental procedure of deep drawing force measurement in order to verify numerical simulation of deep drawing process of non-symmetric part using draw beads. Forces obtained by numerical simulations are compared with the ones obtained by specially developed resistance strain gage force sensors. We have analysed results and gave some recommendations.
Keywords: deep drawing, drawbeads, finite element model, restraining force.

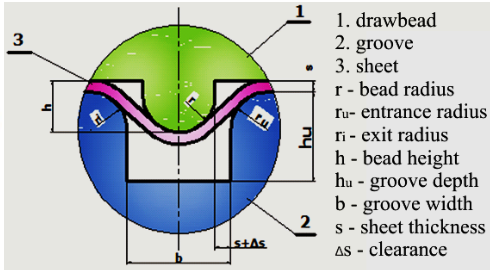
1. INTRODUCTION
For the axially non-symmetric part (proportionally scaled wheelbarrow box in our case) we performed series of numerical simulations in order to determine appropriate geometric parameters of drawbeads. With respect to its depth, such parts belongs to intermediate deep drawing class and it is made of standard deep drawing steel DC03 according to EN10130 specifications, with sheet thickness of 0.8 mm. From experiences for such products and tool design, it is known that, frequently, there are problems in deep drawing process related to wrinkling, thinning or tearing in the flange of the part. By utilisation of drawbeads those problems can be reduced or eliminated but deep drawing tool design with drawbeads is much more complicated and its costs are much higher. In order to reduce tool design time and number of tool corrections, we use series of numerical simulations to detect possible problems in advance, with iterative improvements, proceeding to optimal deep drawing tool design.

2. PARAMETERS USED IN NUMERICAL SIMULATIONS
We start with definition of 3D CAD model of working part, according to original documentation, shown in Figure 1 (a). The basic geometric parameters of drawbeads are shown in figure 1(b). Shape and size of drawbeads are defined by those parameters. We performed simulations with different drawbeads shapes and positions. The parameters that were varied are:

- bead height (we use this parameter in the range of 3,4,5,and 6 mm)
- bead radius (this parameter was varied with values of 2, 2.5 and 4 mm
- entrance radius (the same values as bead radius)
- exit radius (the same values as for entrance radius)

- clearance (this value is related with sheet thickness and for s=0.8 mm we use Δs = 0,3 mm)
- groove width (this parameter is related with some of previous parameters and its value is automatically determined.





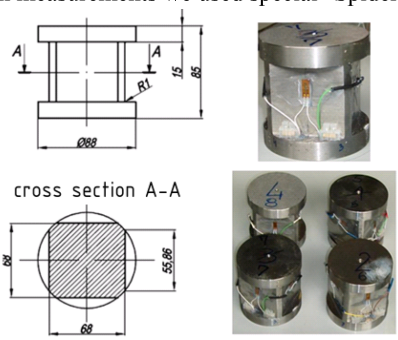
a. *b.*

Figure 1. 3D part model (a) and drawbead model used in simulation (b)

By appropriate FEM software and simulation plans we have obtained optimal shape, positions and dimensions of drawbeads necessary to obtain good final shape of given working part. It appears that only one row of cylindrical drawbeads with bead radius of 2.5 mm, bead height of 3 mm and position of longitudinal axes at distance of 11.5 mm from drawing ring entrance edge is the best solution.

3. REALIZATION OF EXPERIMENT

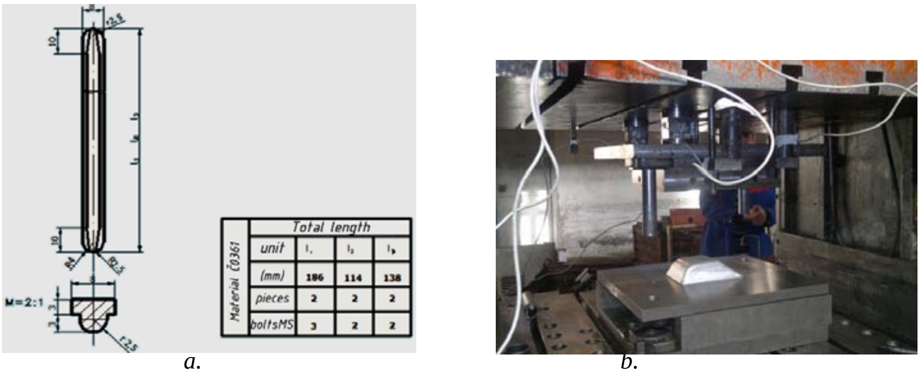
As a part of research, appropriate number of experiments on testing tool was performed. The experiments main goal was verification of results obtained by numerical simulations. The test tools for the axially non-symmetric part were specially developed for this research and they possess possibility for easy change of drawbeads shapes and positions. The most important effects that can be compared between numerical and experimental models are drawing forces and change of sheet thickness. In this paper we present results of drawing forces comparisons. For the purpose of total drawing force and blank holder force (binder force) measurements, we developed special dynamometers based on resistance strain gauges. The measuring equipment consists of four force sensors for total drawing force measuring, Figure 2 and four sensors for binder force measurements. We have used resistance strain gauges HBM 10/120 LY11 with strain factor K_t=2. Two strain gauges were parallel and other two were normal to dynamometer's axis. All four gauges were connected to Wheatstone's bridge in order to measure only vertical component of force and to include temperature compensations. For strain measurements we used special "Spider 8" device shown in Figure 2 (b).



a. *b.*

Figure 2. Total drawing force dynamometer (a) and "Spider 8" amplifying device (b)

As we used fixed proportion (scale) between real drawing tool and testing tool (geometry proportion factor n=3.6), the test tool was produced with following geometric parameters: bead radius r=2.5 mm, bead height h=3 mm, with three different length. Actual drawbead geometry is shown in Figure 3. (a). The distance between bead axis and outer edge of drawing ring was 11.5 mm for the first row and 10 mm between axis of drawbeads in first and second row. The final test tool assembly is shown in Figure 3. (b).



a. b.

Figure 3. Actual drawbead shape (a) and test drawing tool assembly (b)

In all experiments we use cold rolled deep drawing steel DC03 according EN101130 specifications. Sheet thickness was 0.8 mm. Mechanical properties of this material are obtained by laboratory measurements and are given in Table 1.

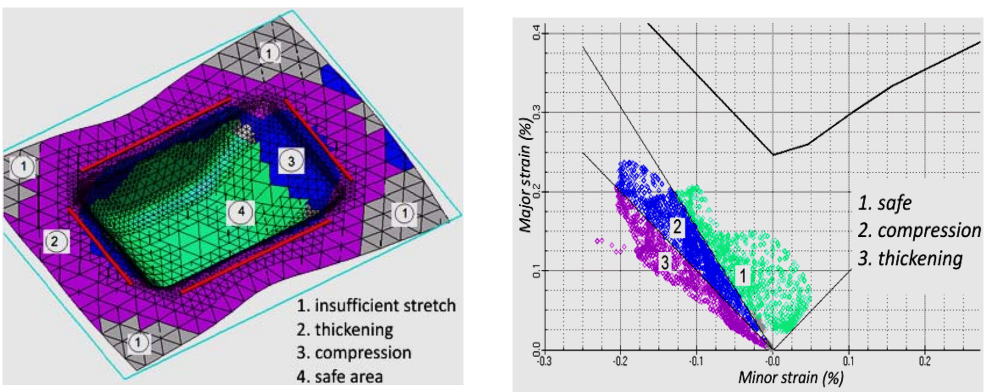
Table 1. Mechanical properties of deep drawing steel DC03

σ_{x1}	σ_M	□$_M$	□$_{tM}$	σ_B	□$_B$	□$_{tB}$	b	h	A_0
N/mm^2	N/mm^2	%	%	N/mm^2	%	%	mm	mm	mm^2
299	330	25	25	147	38	38	20	0,8	16

Parameters in Table 1: □$_{x1}$- stress at elongation of 10 %; □$_M$-ultimate stress, □$_M$ -ultimate dilatation, □$_B$ - breaking stress, □$_B$ -breaking dilatation, b, h, Ao – specimen width, height and cross section respectively.

4. COMPARISONS OF NUMERICAL AND EXPERIMENTAL RESULTS

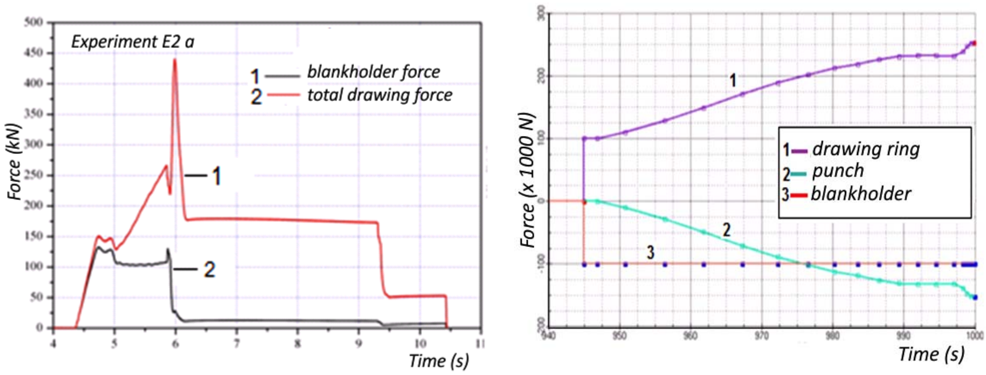
By numerical simulations, as optimal solutions we obtained configuration with single row of drawbeads at distance of 11.5 mm from outer drawing ring edge, with bead radius of 2.5 mm and 3 mm height. Distribution of formability and forming limit diagram are shown in Figures 4. (a) and (b).



a. b.

Figure 4. Distribution of formability parameters (a) and forming limit diagram (b)

Forces obtained from previously described numerical model were compared with forces measured at test tool with the same geometry, material parameters and drawbeads dimensions, shape and positions. The change of total drawing force with respect to time, measured on test tool is shown in Figure 5 (a). It starts at 125 kN and rising up to peak value of 440 kN. Numerical simulation predicts force in the range between 100 and 275 kN, Figure 5 (b). The high maximum value of measured force was registered at the end of tool movement and it was due to hard contact between upper (movable) and lower (fixed) parts of tool.



a. *b.*

Figure 5.Total drawing force obtained by experiment (a) and numerical simulation (b)

From diagram above, it is easy to see that measured value of total drawing force just before the end of stroke is about 260 kN and it is in good agreement with numerically predicted value of 275 kN. Relative error is approximately 5.7 %. The blankholder force (binder force) was set to 100 kN and its main part (80 kN) is cancelled with vertical component of drawbead force. The blank was held only by remaining force of 20 kN. Beside of such low value of blankholder force, generation of wrinkles at corners and lateral parts of working part was eliminated due to additional drawbeads restraining forces.

5. CONCLUSION

For the given working part geometry, optimal drawbead shape, dimensions and positions can be effectively determined by numerical simulation based on finite element method. In order to obtain numerical results or predictions of possible formability problems, it is necessary to build precise CAD models of working part and all drawing tools parts and to perform geometrically and materially nonlinear finite element analysis. In case of wheelbarrow box that we have investigated, for the total drawing force we obtained numerical results with relative error of 5.7 % with respect to actual force obtained by measurement. It can be regarded as good agreement. It is generally known that all parameters in deep drawing process have standard deviations of at least 5-10 %. Therefore, we can conclude that shape, dimensions and positions of drawbeads defined in these models can be used as recommendations for the actual deep drawing tool design. Due to reduced number of corrections, such drawing tool can be designed and set in use for the very short time.

5. REFERENCES

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