NUMERICAL AND EXPERIMENTAL FORMING OF AXISYMMETRIC PRODUCTS USING FLOW FORMING METHOD FOR HARD-TO-DEFORM MATERIAL

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Abstract

This article is devoted to the problem of forming of axisymmetric elements of hard-to-deform material. The first stage was the deep drawing process of metal discs. Then the blanks were formed by the method of flow forming. The use of modern computer technology has become an integral part of the development of innovative flow forming technologies. The use of software tools in the forming of numerical analysis systems based on the finite element method speeds up the design and optimization of processes.

Keywords: Flow forming, FEM modeling, hard-to-deform material

1. INTRODUCTION

This article is an extension of the numerical analysis presented in the paper [1], where the simplified material model without anisotropy was used. Research up to date, allowed for a more convergent performance between numerical and experimental results. However, to increase the accuracy, the material model with anisotropy was used in this research. This modification allows for more accurate results in material thickness distribution. In the last years, in the technology of sheet metal forming has undergone a number of innovative changes such as new forming technique [2] and application of advanced computer technology such as numerical modeling. An increasingly important aspect in numerical analysis is calculation efficiency while maintaining their very good accuracy [3,4].

2. NUMERICAL MODELING FOR DEEP DRAWING AND FLOW FORMING PROCESS

Numerical modeling was divided into two successive operations. The first was deep drawing process, while the second flow forming process. Main parts of the tool set for first stage, i.e.: punch, binder, die and blank with FEM-mesh model are presented in **Fig. 1a**. **Fig. 1b** shows finite elements discretization, as well as the positioning of the working tools and their resulting relation for the second stage - flow forming process. The initial blank thickness was 2.0 mm.

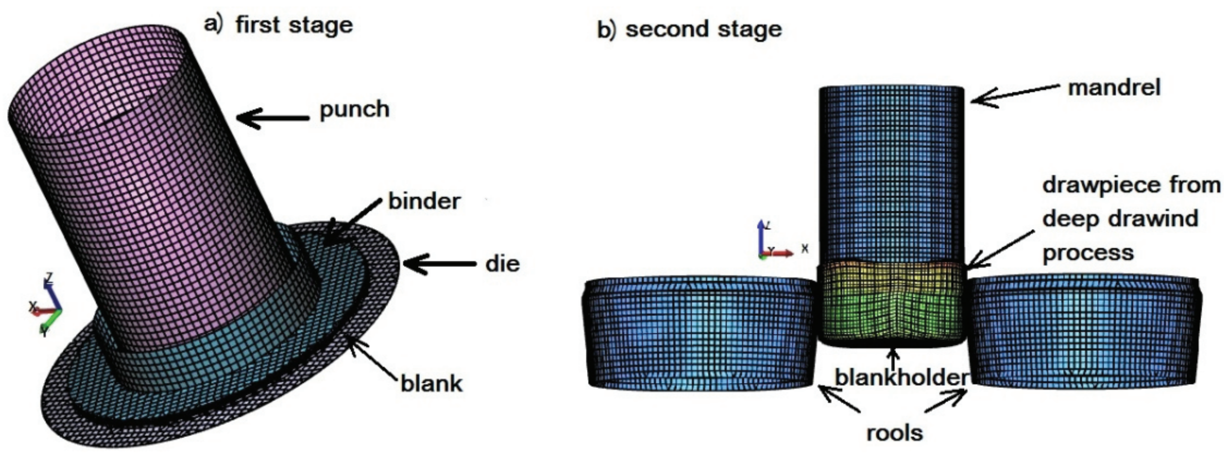

Fig. 1 FEM model of tools: a) deep drawing process b) flow forming process

This results from the stamping operation performed prior to the flow forming process. The mandrel rotates around its axis and, at the same time, it is a drive of cylindrical drawpiece giving it a rotational speed of 500 rpm. The forming rolls also rotate around their axes and additionally move along them.

In the second stage, flow forming process, the compressibility of the material was modelled with the use of penalty for deflection from stiffness. The adopted value of penalty coefficient responsible for the stiffness had value of 10^5. It means that we allow for small penetrations between the surfaces being in contact. A contact pressure, proportional to the penetration distance, was applied to keep the bodies separated. This assumption results in release of contact at the interface between the material and tools (**Fig. 2**). Compared to constraint based methods, where the surfaces (potentially) can be in perfect contact without any overlaps, there are both advantages, such as: easier to maintain energy balance, easier to handle complex contact situations and to incorporate friction, computationally much faster (no equation systems need to be solved) and disadvantages and disadvantages: contact surfaces do not match exactly, a high penalty stiffness will drive down the critical time step size.

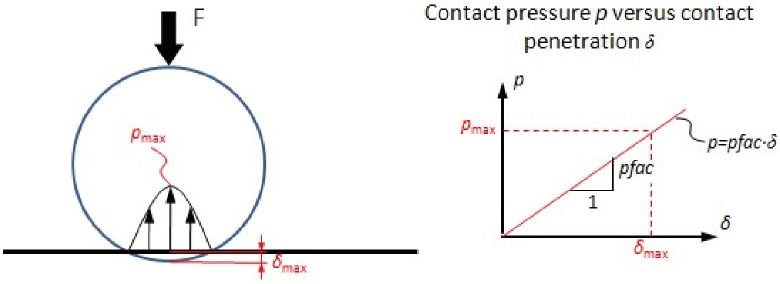

Fig. 2 Penalty stiffness based method

In numerical analysis, both for the deep drawing and flow forming, material model with anisotropy were used. This is a plasticity model where kinematical hardening and Lankford parameters can be defined as constants or as functions of the effective plastic strain. A von Mises yield criterion is combined with a non-assiciated flow rule. The non-associated flow rule is defined to satisfy the given Lankford parameters.

The effective stress is defined as:

$$\sigma_{eff} = \sqrt{\frac{3}{2}\left[b_1\hat{\sigma}_{11}^2 + b_2\hat{\sigma}_{22}^2 + b_3\hat{\sigma}_{33}^2 + 2b_0(\hat{\sigma}_{12}^2 + \hat{\sigma}_{23}^2 + \hat{\sigma}_{31}^2)\right]} \tag{1}$$

where,

$$\hat{\sigma} = \mathbf{Q}\left[\sigma_{dev} - \sigma^*\right]\mathbf{Q}^t \tag{2}$$

σ_{dev} is the deviatoric stress, σ^* is the back stress due to kinematical hardening and Q is a tensor that transforms the stress tensor to principal strain directions. b_1, b_2 and b_3 are parameters that control the difference in flow stress in different principal strain directions

3. METHODOLOGY OF STUDIES

The tests were conducted in order to verify the possibility of plastic forming of Hastelloy C-276 through a process of stamping followed by elongative flow forming. The tests were conducted on a PYE-250 hydraulic press and an MZH-400 numerically controlled flow former at a research unit at the Metal Forming Institute in Poznan. More information about methodology of studies and experimental results could be find in [1].

Table 1 Chemical composition of the Hastelloy C-276 alloy

Ni	Mo	Cr	Fe	W	Mn	Co	C	S
57.1	16.2	16.1	6.05	3.40	0.5	0.5	0.003	0.002

4. EXAMPLE RESULTS

4.1 Deep drawing process

The results of tests of the stamping process for 2-mm-thick products of the material Hastelloy C-276 are presented in **Table 2**. More result for the material model without anisotropy are presented in [1].

Table 2 Dimensions of stamped products after the process of shaping (experimental and numerical results)

Stamped product dimensions							
Numerical analysis - model with anisotropy				Experimental work			
Outside diameter [mm]	Inside diameter [mm]	Average wall thickness [mm]	Height [mm]	Outside diameter [mm]	Inside diameter [mm]	Average wall thickness [mm]	Height [mm]
126.1 - 126.5	120.7 - 121.5	1.98 - 2.03	55.7 - 58.1	124.6-125.1	120.06-120.3	1.97-2.02	57.2-59.2

Results of numerical and experimental results are presented in **Fig. 3**. The thickness distribution form numerical analysis and experimental work are convergent. **Fig. 3c** shows numerical analysis for model with anisotropy and this results are the results are closer to experiment (**Fig. 3a**) than for the model without anisotropy (**Fig. 3b**).

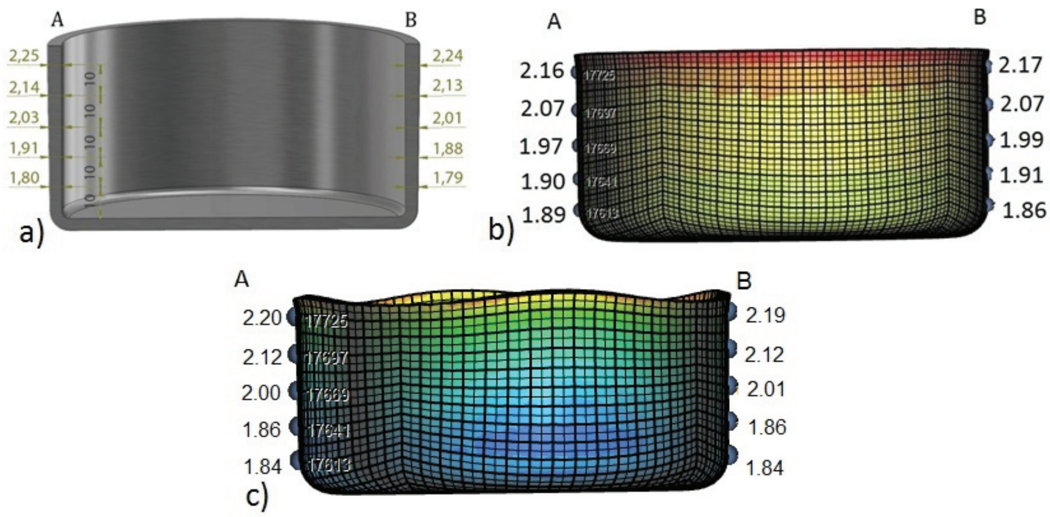

Fig. 3 Wall's thickness distribution from a) experiment - scheme b) numerical analysis - model without anisotropy, c) numerical analysis - model with anisotropy
A, B - opposite sides of the product

4.2 Flow forming process

The next stage of the investigation concerned numerical and experimental testing of flow forming process. The results of measurement of drawpiece subjected to the flow forming for two material model (without anisotropy and with anisotropy) are presented in **Table 3**. **Fig. 4** shows thickness distribution for numerical model with anisotropy for selected nodes and **Fig. 5** presents the distribution of side wall thicknesses of selected products graphically.

Table 3 Results of measurements of after the first lengthening flow forming operation

	Deformation in the direction of the wall's thickness [%]		Average wall thickness [mm]
	planned	actual	
Experimental work	30	30.5 - 31	**1.38 - 1.39**
Numerical analysis - model without anisotropy	30	27-30.5	**1.41 - 1.46**
Numerical analysis - model with anisotropy	**30**	**27 - 30**	**1.40 - 1.46**

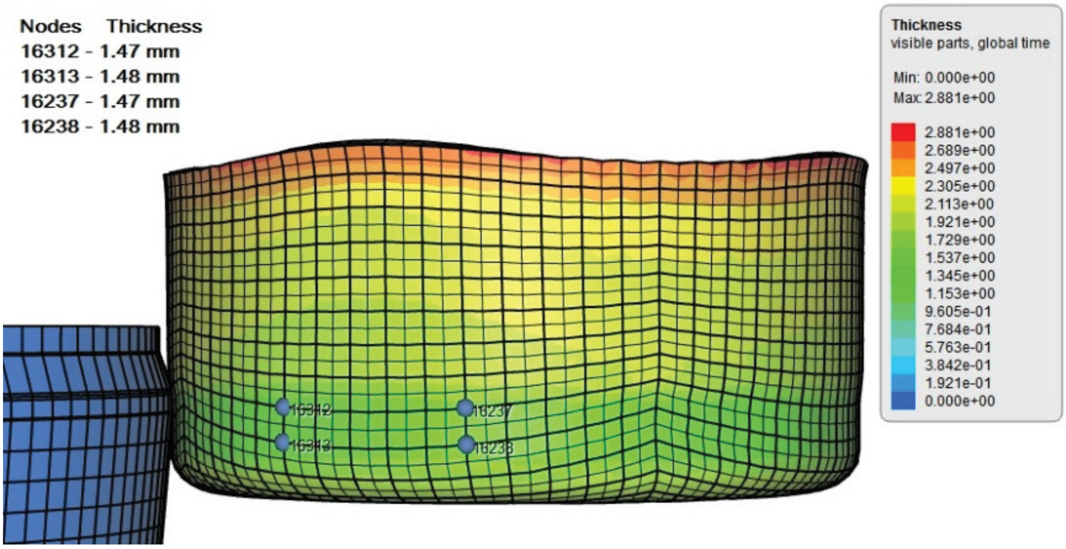

Fig. 4 Thickness distribution from numerical analysis for selected nodes at the beginning of the process

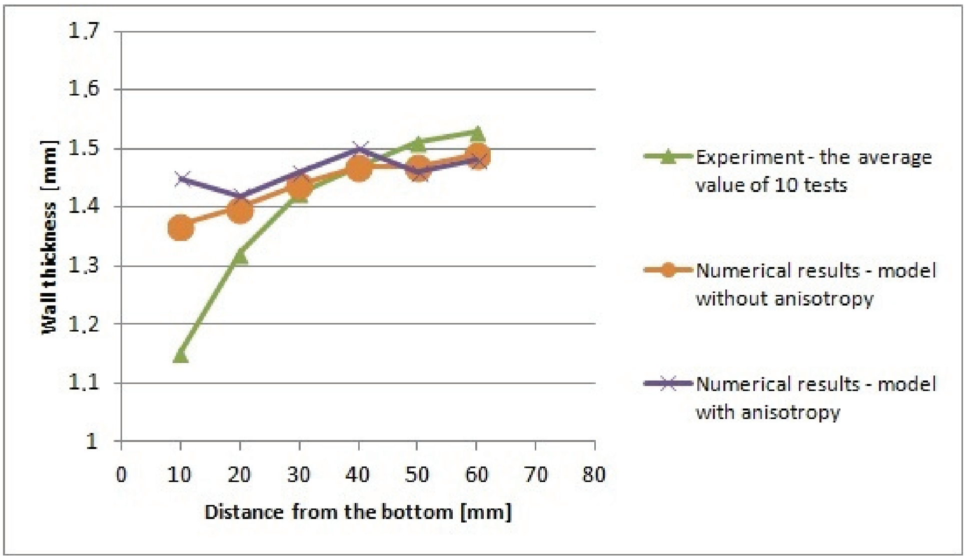

Fig. 5 Graphical presentation of the distribution of wall thicknesses of drawpiece

The small differences in thickness obtained from simulation for model with anisotropy and experiment for the points at the bottom of the product result from one of the assumption of numerical model. The tools used for simulation process were rigid and trajectory of rolls were perfect linear, whilst during experimental studies they were subjected to deformation. Therefore, maintaining the linear movement of the rollers for the experiment were very difficult. The thickness for the other measuring points at the height of drawpiece is consistent for numerical analysis and experiment. **Fig. 6a** shows thickness distribution during flow forming process and **Fig. 6b** shows thickness reduction for selected nodes.

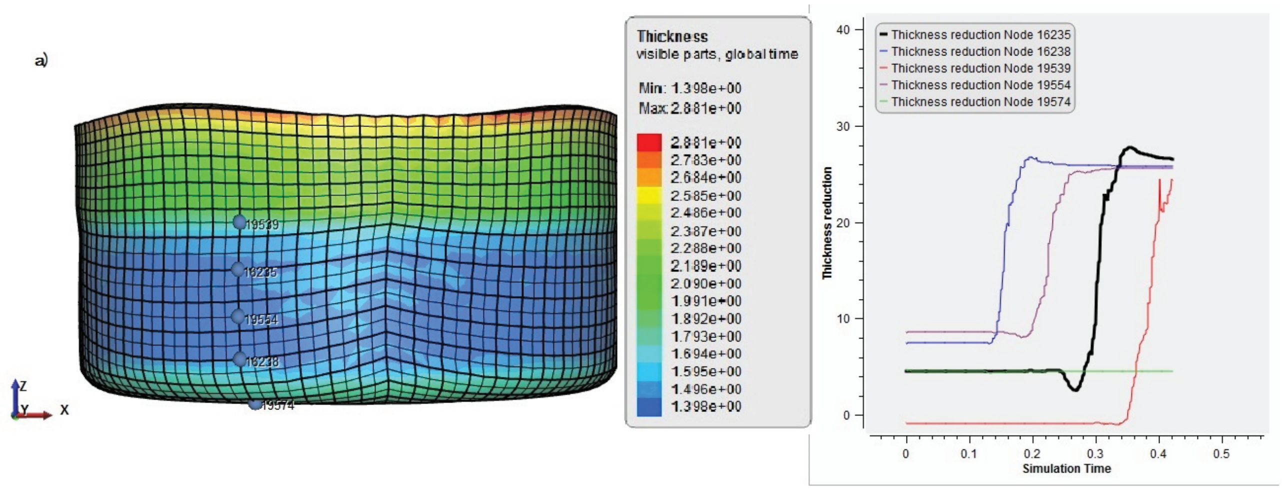

Fig. 6 Thickness distribution from numerical analysis (a) with the thickness reduction for selected nodes (b)

5. CONCLUSION

In this article example results of numerical simulation and experimental work for axisymmetric product was presented. In the numerical analysis the material model with anisotropy was used and the curve of the yield stress - true strain has been determined on the basis of solver database. The compressibility of the material was modelled with the use of penalty for deflection from stiffness. The adopted value of penalty coefficient responsible for the stiffness had value of 10^5. Compared to constraint based methods, where the surfaces (potentially) can be in perfect contact without any overlaps, there are both advantages, such as: easier to maintain energy balance and easier to handle complex contact situations.

Material model with anisotropy which was used in numerical analysis, has enabled more accurate results than the model without anisotropy, the results of which were presented in another article [1]. The recognition investigation of the processes of stamping and incremental rotary forming of drawpieces made performed by the Metal Forming Institute in Poznan, have rendered positive results. In the future work is necessary to use a real stress-strain curve for the numerical model to allow to obtain more accurate results.

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