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Considerations Regarding Multi-channel Sheet Hydroforming

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***Abstract*—The paper introduces a new concept in sheet metal forming, which is multichannel sheet hydroforming technology. The new concept assures an improving of the flexibility of the hydroforming technology as well as an increasing of the productivity. This concept is based on the use of a high fluid pressure that is transmitted through a number of channels to the same number of deformation cells. The experimental and numerical results validate the new technology concept.**

Keywords—*sheet hydroforming, unconventional forming, numerical simulation, sheet metal, deep drawing*

I. Introduction

In the conventional deep drawing techniques using rigid tools wrinkles, excessive material thickness or fractures are the common problems of the process [1]. In order to eliminate or at least minimize these problems, various drawing processes with using elastic forming tools have been developed. One of these processes is the sheet hydroforming [12, 15]. Different methods have been developed during the years: hydro-mechanical deep drawing [2, 3, 14], hydroforming with an elastic membrane [4-6], counter pressure drawing [7, 8], hydraulic pressure-augmented drawing [9-11, 13]. Studies of these technologies offered information about sheet formability, surface quality, dimensions accuracy, spring-back effect reduction, and part wall thickness uniformity.

The present paper introduces a new tool concept for the hydroforming process. One-channel hydroforming equipment is presented. A series of experimental results and numerical ones come to validate the new method.

II. Concept Definition

At the basis of the concept of the new hydroforming process is the law of constancy of volume, *Fig. 1*. By equalizing the volumes of blanks deformation cells (G) and of channels space (F), dimensions of the main pressure chamber (E) can be determined. The liquid volume to be transferred between the two chambers (of the pressure (E) and of the deformation (G)) must be equal to the volume of channels in the die. This is very important, because only when the two volumes will be equal, the deformation of blanks will be completed.

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To equalize the two volumes, the punch must perform a precisely determined stroke. Exceeding this stroke will cause the blank to be deformed at a greater pressure than required, and there will be a risk of its damage.

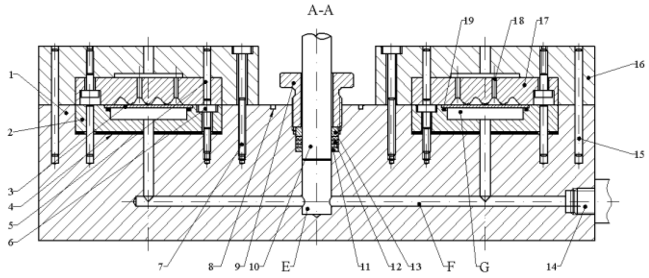


Figure 1. Principle of Multi-channel Sheet Hydroforming

According to the new concept, the multi-channel hydroforming die consists of a punch (10) which moves, through the pre-set (9), washers (11) and (13) and gaskets (12), into the central pressure chamber (E), thus creating the pressure required to deform the material.

The pressure is transmitted through channels (F) sealed with the welded plugs (14) to the deformation cells (G). These are materialized by the lower plates (2) and the upper plates (17). The lower plates (2) are assembled with the body (1) by means of screws (6) and are positioned by pins (5) and sealed against the body (1) with the metallic seals (4). The upper plates (17) give the parts geometry. They are active elements because blanks take their geometry, as a result of applying direct pressure toward them. Plates (17) are provided with the air removal holes (18) and are assembled in plates (16) attached to the body (1) of the equipment by means of screws (7) and are positioned by pins (15). The lower plates (2) have an upper O-ring (19) for securing the sealing and a positioning area of each blank (3). The channel (8) practiced in the body (1) has the role of the fluid collecting at the withdrawal of the punch from the central pressure chamber.

Deformation cells can be reconfigured by changing plates (2) and (17) to obtain other types of parts. The equipment can be used on any hydraulic press that provides the necessary force and dimensions.

III. Experimental Work

Based on the new design concept, a simplified tool for one-channel sheet hydroforming, was built. The tool, *Fig. 2* and *Fig. 3*, is placed on a 20 tones hydraulic press.

Figure 2. View of the hydroforming die

Figure 3. Upper plate of the die with active zone and screws

Fig. 2 presents the die body of the hydroforming tool. The figure shows the deformation cell, the O-ring, the positioning area of the blank and the threaded holes for upper plate mounting. The punch is mounted on the press and it is placed inside the chamber pressure of the die body.

Fig. 3 presents the upper plate. In the upper plate is manufactured the active zone which gives the part geometry. A number of screws are used for assembly the upper plate with the hydroforming die body.

For experiments circular blanks, with a diameter of 82 mm and a thickness of 0.8 mm, from DC04 steel sheets where used. The material characteristics are: tensile strength R_m = 340 MPa; yield strength R_c = 210 MPa; anisotropic coefficient r_{90} = 2.12; strain-hardening exponent n = 0.225.

For the blank deformation, the pressure chamber, the channel and the deformation cell were filled with oil. Then the blank where placed on the deformation cell and the upper plate was mounted on the die body. First, the punch was introduced on the chamber pressure and then the ram of the hydraulic press moves the punch in the chamber pressure with a stroke of 15.5 mm. This stroke assures the necessary pressure for blank deformation.

The geometry of the part is composed from two reliefs with a depth of 3 mm each. *Fig. 4* shows the image of the obtained part after the deformation.

Figure 4. Part obtained by One-channel sheet hydroforming

At this stage the equipment doesn't have the possibility for the pressure measuring. So the simulation will give us this information.

IV. Numerical Simulation

A. *Simulation model*

Numerical simulation is present throughout the conception of the product manufacturing process. In most cases the simulation is intended to identify critical areas subject to excessive stretching or compression stresses, i.e. areas that are predisposed to excessive thinness, respectively, in the occurrence of cracks or rupture of the material workpiece, and/or areas predisposed to wrinkles or in the increased thickness of the material over a required maximum limit.

Dynaform software was used for the numerical simulation. Dynaform is a simulation software solution, which allows organizations to bypass soft tooling, reducing overall tryout time, lowering costs, increasing productivity & providing complete confidence in die system design. It also allows for the evaluation of alternative and unconventional designs & materials [16].

First, the geometry of the part was created using SolidEgde Software and it is presented in *Fig. 5*.

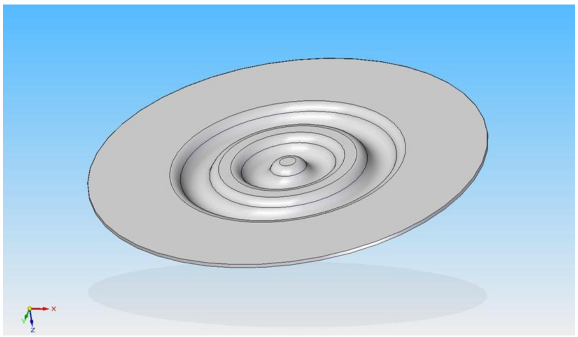


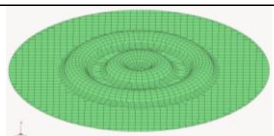
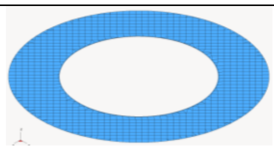
Figure 5. Geometry of the part

The part geometry defines in the simulation model the geometry of the die.

4-node Belytschko-Tsay shell elements, with five integration points through the thickness of the sheet metal, are used.

The tooling was modeled as rigid surfaces. The model elements are presented in table 1.

TABLE I Model elements

	Active elements	**Diameter (mm)**	**Finite elements**
Die		82	2679
Restraint plate		82/50.4	973

The circular blank has 1593 finite elements.

Fig. 6 presents the simulation model in the initial position.

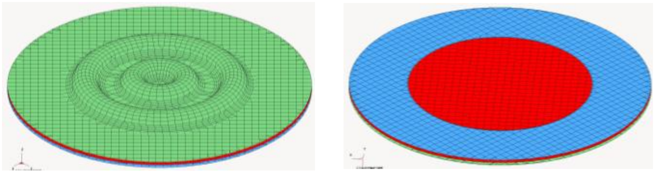


Figure 6. Simulation model: left side – upper view; right side – bottom view

The yielding of the material was modeled using a power law:

$$\sigma = K\,\varepsilon^{n}\,. \qquad (1)$$

where: K is the material characteristic; n – strain-hardening exponent. In simulation the n-value = 0.225 and K = 475 MPa. The r-value was set to r_{90} = 2.12. The Coulomb friction law was used with a friction coefficient of 0.10.

Contact Forming One Way Surface To Surface was used. Orientation is automatic in contacts specific to the deformation problems. Penalty forces are used to limit penetration. This option is recommended since the penetration of master nodes between slave nodes is considered in re-meshing the slave network.

The applied pressures were 5, 10, 20 and 30 MPa.

B. *Numerical simulations results*

The influence of the pressure toward the degree of material deformation is presented in *Figs. 7-10*.

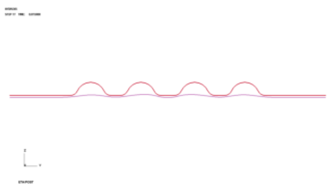


Figure 7. Pressure p=5MPa

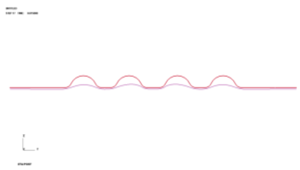


Figure 8. Pressure p=10MPa

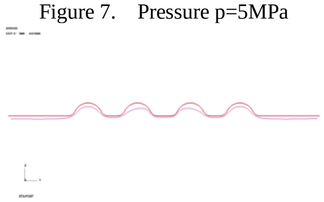


Figure 9. Pressure p=20MPa

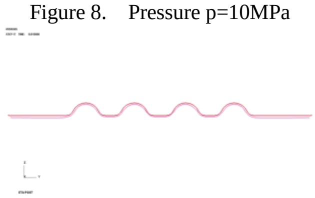


Figure 10. Pressure p=30MPa

By increasing the pressure the degree of the material deformation will increase and at the pressure of 30 MPa, the blank get the shape of the die.

The thickness of the deformed parts varies with the increasing of the pressure. *Figs. 11-14* show the qualitative images of parts thickness variations. The images show that the largest thinning occurs in the middle of the part, where due to the material flow braking a pronounced thinning occurs.

The thinning ratio is calculated as:

$$t\% = \frac{s - t}{t} * 100\,. \qquad (2)$$

where: s is the starting thickness of the sheet metal; t - the formed thickness of the part at the location of interest (in the middle of the part)

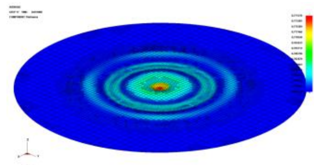


Figure 11. Pressure p=5MPa

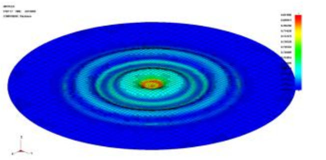


Figure 12. Pressure p=10MPa

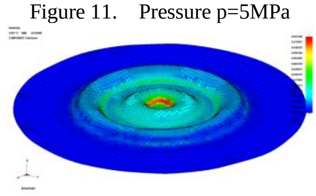


Figure 13. Pressure p=20 MPa

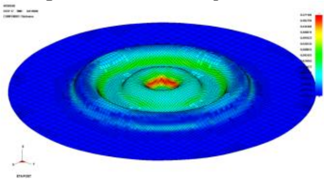


Figure 14. Pressure p=30 MPa

The minimum and maximum valus of the thickness are presented in table II.

TABLE II Thickness variation

	Maximum Thickness tmax, [mm]	Minimum Thickness tmin, [mm]
p=5 MPa	0.8	0.77
p=10 MPa	0.8	0.69
p=20 MPa	0.8	0.49
p=30 MPa	0.8	0.37

It can be seen from the table that the maximum applied pressure produces the most important material thinning. If we accepted a thinning ratio of 40%, then at pressures higher then 20 MPa, the parts will be broken.

In *Figs 15-18*, the variation of the Von Mises stress, given by the relationship (2), is presented qualitatively.

$$\bar{\sigma} = \frac{1}{\sqrt{2}}\sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_1 - \sigma_3)^2}\,. \qquad (3)$$

where: σ_1, σ_2, σ_3 are the principal stresses.

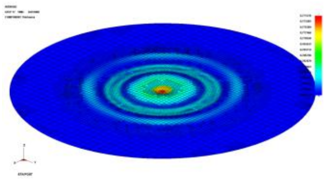


Figure 15. Pressure p=5MPa

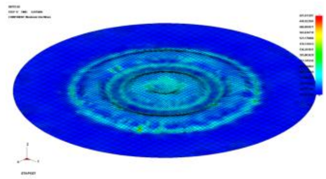


Figure 16. Pressure p=10MPa

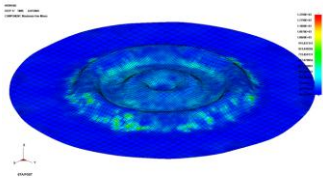


Figure 17. Pressure p=20MPa

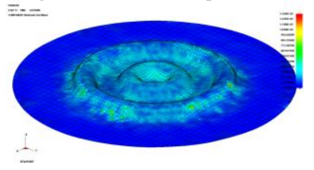


Figure 18. Pressure p=30MPa

The minimum and maximum valus of Von Mises Stresses are presented in table III.

TABLE III Von Mises stress variation

	Minimum Von Mises, [MPa]	Maximum Von Mises, [MPa]
p=5 MPa	78	485
p=10 MPa	115.21	746.85
p=20 MPa	70.65	1372
p=30 MPa	42.85	1408

Table III shows that as the pressure increases, the maximum value of the Von Mises stress increases also. The material in the deformed area is plastic deformed, but at pressures ranging from 20 MPa, the maximum value far exceeds the material constant, K = 475 MPa. As a result, breaks will appear in the part.

V. Conclusions

The paper presents a new tool concept for hydroforming method. The main advantages of this type of equipment are the improving of the process productivity.

A simplified tool with only one channel has been designed and made. A complex geometry of the part was analyzed.

The tests performed show that the equipment can be used to obtain small reliefs, 3 mm depth, on the surface of the sheet at pressures below 20 MPa.

Achieving deeper reliefs will require constructive modifications of the part so that by increasing the working pressure the greater deformation depths will be obtain.

FE simulations have been accomplished to predict the optimum forming conditions for this particular case. In numerical simulations, the working pressure has been changed.

The results from the simulation obtained showed that:

- At pressures less than 20 MPa, the deformation of the material is similar to that of the experiments, obtaining a 3 mm depth of each channel. So we can consider that this was the pressure which we experimentally obtained at the punch stroke of 15.5 mm.

- Maximum thinning is achieved in the middle area of the piece;

- Increasing pressure up to 30 MPa, results in the part fracture.

The results of the simulations lead to the conclusion that the constructive parameters of the piece will have to be modified to improve the flow conditions of the material in the tool and thus to obtain appropriate results.

Investigation of multichannel hydroforming technique is in progress. The numerical simulations and experimental work will continue in the next future in order to study the effect of different process parameters: drawing depth, number of deformation cells, geometry etc. Moreover, the new tool will be used for investigating different materials e.g. the aluminum and titanium alloys.

Finally, we can conclude that this new die concept could be used in manufacturing complex sheet metal parts, with small depth.

References

[1] S. Thiruvarudchelvan, "The potential role of flexible tools in metal forming", Journal of Materials Processing Technology, vol. 122, pp. 293-300, 2002.

[2] J. Danckert, K. B. Nielsen, "Hydromechanical Deep Drawing with Uniform Pressure on the Flange", CIRP Annals - Manufacturing Technology, vol. 49, pp. 217-220, 2000.

[3] J. Lin, S. D. Zhao, Z. Y. Zhang, Z. W. Wang, "Deep drawing using a novel hydromechanical tooling", International Journal of Machine Tools and Manufacture, vol. 49, pp. 73-80, 2009.

[4] F. Vollertsen, R. Breede, K. Lange, "Method for deep drawing with multiple elastomer membranes", CIRP Annals - Manufacturing Technology 48 (1), pp. 221-226, 1999.

[5] M. H. Parsa, P. Darbandi, "Experimental and numerical analyses of sheet hydroforming process for production of an automobile body part", Journal of Materials Processing Technology, vol. 198, pp. 381-390, 2008.

[6] T. Hama, T. Hatakeyama, M. Asakawa, H. Amino, A. Makinouchi, H. Fujimoto, H. Takuda, "Finite Element Simulation of The Elliptical Cup Deep Drawing Process by Sheet Hydroforming", Finite Elements in Analysis and Design, vol. 43, 234 – 246, 2007.

[7] N. Abedrabbo, M. A. Zampaloni, F. Pourboghrat, "Wrinkling control in aluminum sheet hydroforming", Int. J. of Mechanical Sciences, vol. 47, pp. 333-358, 2005.

[8] L. Lang, J. Danckert, K.B. Nielsen, "Investigation into hydrodynamic deep drawing assisted by radial pressure: Part I. Experimental observations of the forming process of aluminum alloy", J. of Mater. Process. Technol., 148 (1), pp. 119-131, 2004.

[9] S. Thiruvarudchelvan, M. J. Tan, "A note on fluid-pressure-assisted deep drawing processes", J. of Mater. Process. Technol., vol. 172, pp. 174-181, 2006.

[10] S. Thiruvarudchelvan, H. Wang, "Investigations into the hydraulic-pressure augmented deep drawing process", J. of Mater. Process. Technol., vol. 105, pp. 161-175, 2000.

[11] M. Ramezani, Z.M. Ripin, "Rubber-pad forming processes: technology and applications". Woodhead Publishing Ltd, ISBN-13: 978-0857090942, UK, 2012.

[12] V. Paunoiu, V. Teodor, F. Susac, "Researches regarding the hydroforming process of aluminum components", Modern Technologies in Industrial Engineering (ModTech2015), IOP Conference Series-Materials Science and Engineering 95, ISSN: 1757-898, 2015.

[13] G. Palumbo, S.H. Zhang, L. Tricarico L, C. Xu, L.X. Zhou, "Numerical/experimental investigations for enhancing the sheet hydroforming process", Int. J. of Machine Tools and Manuf., Vol. 46, pp. 1212-1221, 2006.

[14] M. Dariani, A. Fazli, "Parameter study of the axisymmetric hydromechanical deep drawing process", Proceedings of the Institute of Mechanical Engineers (IMechE), Vol. 220 Part B: J. Engineering Manufacture, pp. 1937 – 1944, 2006.

[15] J. Liu, M. Ahmetoglu, T. Altan, "Evaluation of sheet metal formability, viscous pressure forming (VPF) dome test", J. of Mater. Process. Technol, Vol. 98, pp. 1-6, 2000.

[16] Dynaform 5.9.3, Application Manual, 2015.

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