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THE HYDRO-MULTIPOINT FORMING PROCESS OF COMPLEX SHEET METAL PARTS

The paper presents the concept of a new tool for the sheet metal blanks deformation which is based on the hydro-multipoint method. In this method the upper die with pins is replaced with a hydraulic pressure chamber. The blank sheet is placed between two flexible interpolators and it is deformed under the action of the pressure applied from the hydraulic chamber until it takes the shape of the multipoint die located at the bottom of the equipment. A critical review of the main hydroforming and multipoint forming methods is done. Then, a simulation model for the new hydro-multipoint forming tool is developed. Material thickness, stresses and part dimensions are analysed. A mechanical hydro-multipoint forming tool which was designed and manufactured based on the new concept is presented. Using this tool a number of experiments are done. The real parts are evaluated in terms of surface quality and parts dimensions. The experimental results come to validate the numerical ones. Finally, it was concluded that this new die concept could be used in manufacturing complex sheet metal parts.

1. INTRODUCTION

The sheet hydroforming and the sheet multipoint forming are two cold plastic deformation technologies which are largely used in industry for prototyping and low-volume production, mainly in the aerospace and automotive industry.

Figure 1 presents the main sheet hydroforming methods which consist in the action of the liquid toward the blank. Figure 1a presents the sheet hydroforming with punch, or hydromechanical deep drawing, where the female die used in conventional deep drawing is replaced by a pressure chamber [1],[2]. The sheet is deformed over the punch surface due to a counter pressure generated by a pressurized fluid in the pressure chamber. Figure 1b presents the sheet hydroforming with die, where the sheet is formed in the die by the hydraulic pressure of the fluid [3],[4]. Figure 1c presents the so called triform process or flexforming where a flexible rubber and a chamber with oil replace the solid punch. Due to the flexibility of the rubber pad, parts with undercuts and sharp contours can be formed, even with sheets of different initial thicknesses [5],[6].

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Table 1 depicts the main multipoint forming processes, which take place when a pin network exerts pressure towards the blank with the network materializing the upper or down geometry of the part. Multipoint forming or Digitized-die forming is an engineering concept developed more than fifty years ago, designed for sheet metal forming. The concept means that the working surface of the die is made up of hemispherical ends of individual active elements (called pins), where each pin can be independently, vertically displaced [7],[8].

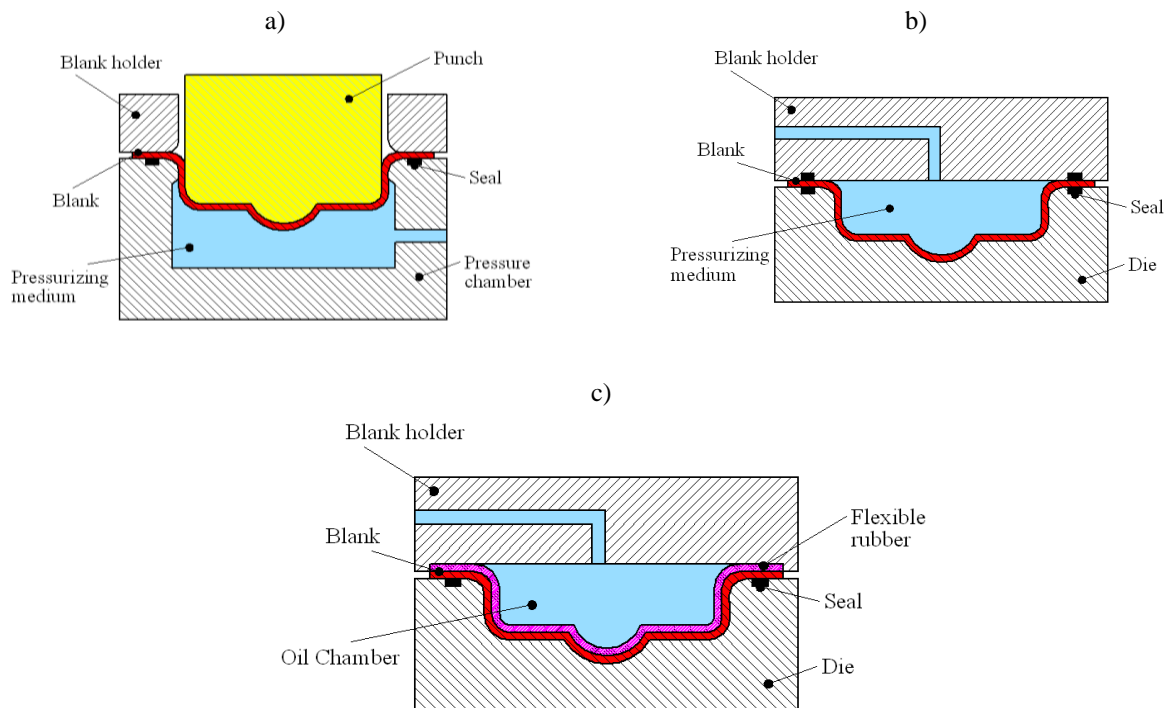


Fig. 1. The main sheet hydroforming methods: a) sheet hydroforming with punch [1], b) sheet hydroforming with die [2], c) flexforming process [3]

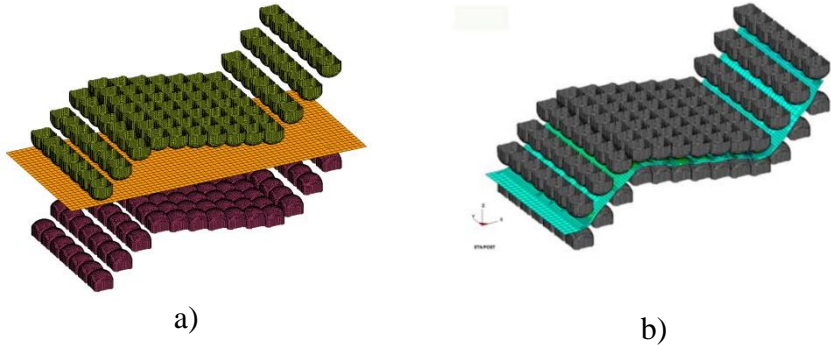
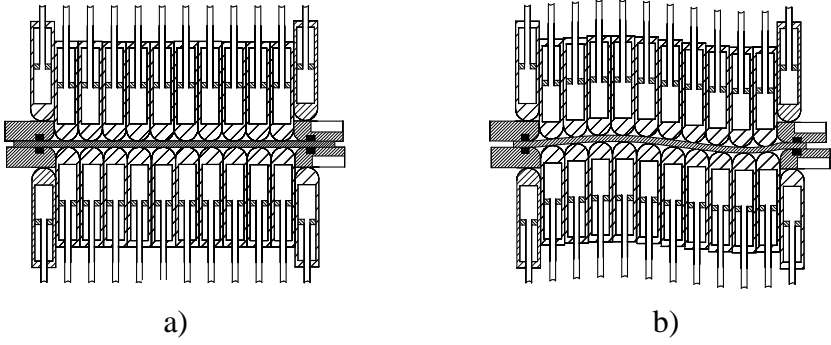
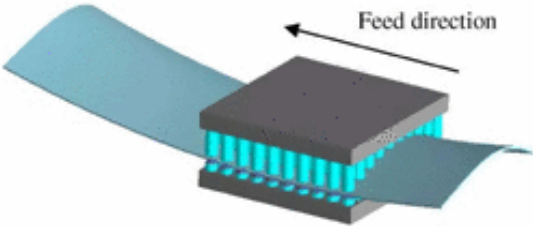
The function of pins' position towards the blank is being discussed taking into account three different configurations, namely:

In the fixed configuration, the multipoint die is configured from the beginning to the end of the process using mechanical, hydraulic or electrical devices. In order to increase the number of contact points between the die and the blank and for technological reasons, a square network of pins is used irrespective of type of configurations [9],[10]. An offline adaptive control could be applied to decrease the configuration time. The method is the most commonly used [11].

In the active configuration, the die geometry configuration is changeable, pins are vertically moved during the process of deformation, accordingly to a forming path, to finally obtain the desired geometry of the part. The forming path depends on the degree of stresses and strains in material. Electrical, hydraulic or electro-mechanical devices are used to control the pins' positions during the deformations. An online adaptive control of the process [12],[13] is necessary. The method is still in the research stage.

In the sectional configuration, the part is obtained by deforming the blank section-by-section. It is used to obtain parts of large sizes using small multipoint dies. During the process of deformation three regions coexist: the deformed region, the undeformed region and the transition region. The transition regions are the superimposing area between the deformed regions in previous forming steps and the forming region in the current step and play an important role in the quality of the final part [14],[15].

Table 1. Multipoint forming - Process classification

No.	Type of configuration	Configurations examples
1	Fixed [12]	 <p>a) initial state; b) final state</p>
2	Active [13]	 <p>a) initial state; b) final state</p>
	Sectional [14]	

These technological methods have the following disadvantages:

- In multipoint forming the deformed part surface is of a low quality because of the dimpling phenomenon, which is more pronounced when thin sheets are used;
- The equipment for multipoint forming is complex and expensive due to the multitude of components;
- The setup of pins, axial moving and fastening, is a difficult operation;

- The cost of maintenance in multipoint forming is relatively high;
- In sheet hydroforming the active elements (punch/die) could not be reconfigured. Parts that are obtained are dependent on the geometry of the forming punch/die;
- The sheet hydroforming is a process characterised by relatively long cycle time;
- A more pronounced thinning phenomenon may appear during the liquid pressure, in the contact area between the punch and the blank, which affects the quality of the part.
- Higher capital investment due to the fact that the methods need presses of higher capacity, comparing to stamping, in order to obtain the necessary pressure;
- High pressure is required to form sharp corners in the part. This pressure depends on the sheet material, thickness and the dimensions of the corner radius in the die geometry;
- Lower dimensional accuracy in complex geometries.

The paper presents a way of overcoming the aforementioned shortcomings through a new type of tool which has major advantages, both from technological and economical point of view. The numerical and experimental results, based on the new concept tool, come to validate some advantages of the patented equipment.

2. HYDRO-MULTIPOINT FORMING CONCEPT TOOL

The idea of using an elastic medium in the multipoint forming process appeared for the first time in [16]. The authors propose a method for hydro-mechanical deep drawing with the punch composed from an array of pins, which are independently shifted in vertical direction, accordingly with the piece profile.

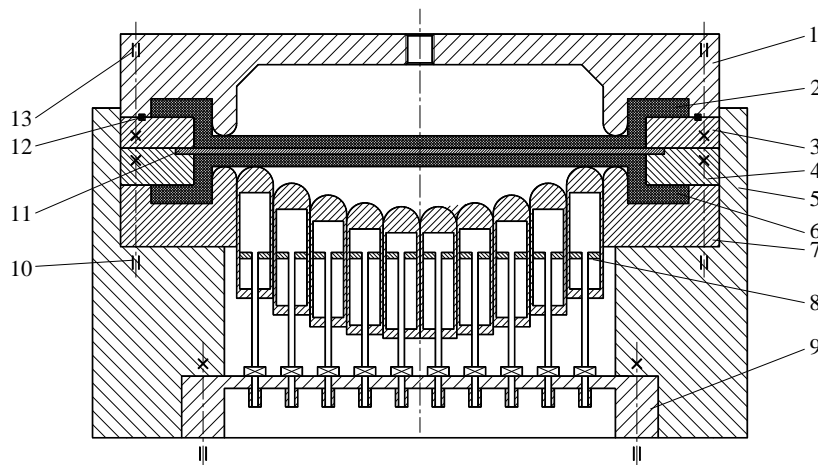


Fig. 2. Hydro-multipoint die concept : 1- superior body ; 2, 6- elastic interpolator; 3, 4 - fastening plate; 5 - inferior body; 7 - profiled plate; 8 - reconfigurable die; 9 - support plate; 10, 13 - screw; 11 – blank; 12 – sealing ring

In [17], the authors used a rubber pad and an interpolator instead of the superior subassembly of a conventional multipoint forming die. Recently, in [18], simulation

researches in this field have been presented. They make use of a hydraulic pressure and two types of interpolators: a rubber pad and a metallic.

The concept of the patented hydro-multipoint forming tool is presented in Fig. 2 [19]. The solution, Fig. 2, simplifies the construction of the multipoint tools with pins by replacing the upper die with a hydraulic/pneumatic pressure chamber and also combines advantages of hydroforming and multipoint forming. The blank sheet is placed between two flexible membranes and is deformed under the action of the hydraulic/pneumatic pressure applied from the top of the equipment. The part shape is given by the shape of the multipoint, reconfigurable die located at the bottom of the equipment.

The equipment consists of a superior subassembly provided with an elastic interpolator (2), a lower subassembly also provided with an elastic interpolator (6) and a reconfigurable die (8) consisting of a number of hydraulic cylinders in a network. The blank (11) is deformed accordingly to the geometrical part shape of the die. The geometrical shape of the die could be digitally controlled, allowing for the material flow during the deformation process. Figure 2 depicts the tool in the initial position. Figure 3 shows the tool in the final position.

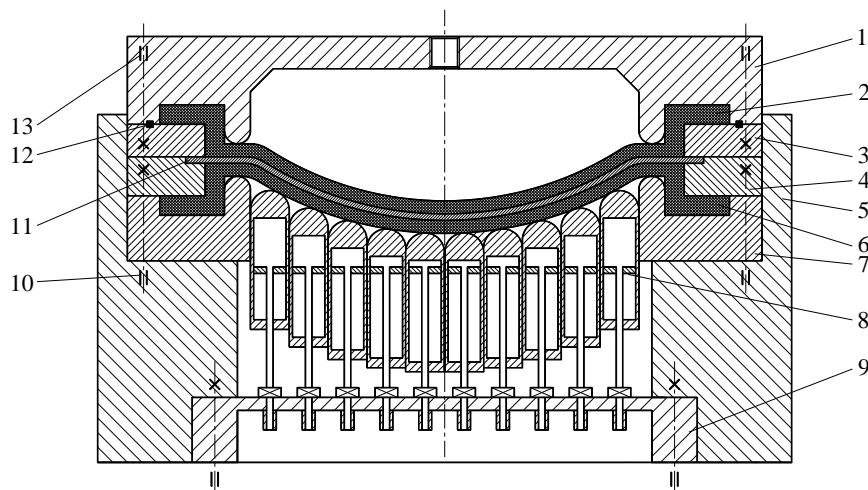


Fig. 3. Final position of hydro-multipoint forming tool

Based on this new concept of hydro-multipoint forming tool, the following advantages are obtained:

- Reduction of the setup time in half, in comparison to the conventional digitized dies;
- The construction is relatively simple due to the absence of the upper pins network;
- Expansion of the range of deformed parts shapes due to easy configuration of the die;
- The degree of deformation could be obtained from data files provided on-line from a simulation program or from a database created on the basis of real or simulated tests of the process, resulting in the control of springback phenomenon;
- The dimpling is avoided because of the presence of the elastic interpolator between the die and the blank;

- The device provides a uniform pressure towards the blank surface due to the presence of the two elastic interpolators;
- The pressure provides the material deformation with large limits, which expands the range of deformed parts shapes.

3. HYDRO-MULTIPOINT FORMING SIMULATION

The numerical simulations by FEM are very effective to test new ideas which may be necessary when designing tools for forming complex parts. Simulation also provided detailed quantitative information about the expected cracks, wrinkles, and weaknesses of the final pieces. Numerous finite element programmes have been developed for sheet metal forming simulation. One of the most used is Dynaform [20],[21].

Figure 4 presents the deformation model. The model includes the die and the blank. In this paper the simulations are made without an interpolator between the blank and the die.

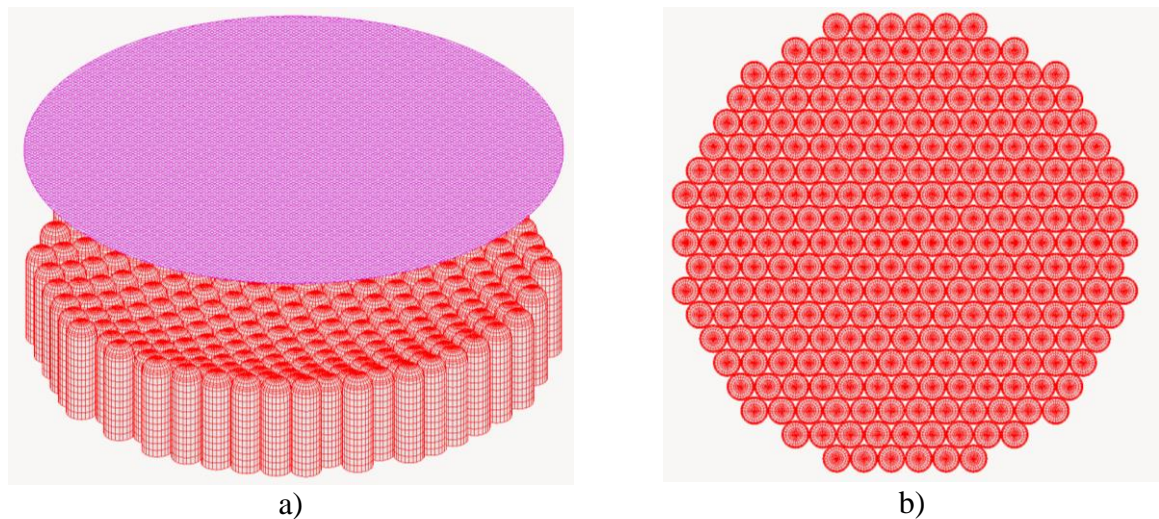


Fig. 4. FEM model of the tool: a) – blank and die; b) – die top view

The dynamic explicit finite element method is used. A 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 die consists of a total 253 pins. Figure 4a. presents the tool configuration in initial position, and Fig. 4b presents the die top view. The number of finite elements for the die was 112456.

A Surface_to_Surface contact was used. Both, the slave (blank) and master (die) side are defined by segments. This is a symmetric contact, i.e. both slave and master nodes are checked for penetration. A Coulomb friction law was used with a friction coefficient of 0.125.

The blank was a circular plate with the diameter of 140 mm. The number of finite elements for the blank was 15481. The pressure applied was of 4 MPa.

The blank material used in experiments was mild steel, 1 mm thick. The yielding of the material was modelled using a power law, as in:

$$\sigma = K \varepsilon^n \tag{1}$$

According to the material properties, for simulation, the n -value = 0.21 and $K = 540.7$ MPa are used. The R -values were set to: $R_{00} - 1.66$; $R_{45} - 1.22$; $R_{90} - 2.10$.

Figure 5 presents the tool and the blank in final position. The dimpling phenomenon and the material wrinkling on the region around the blank contour could be observed. The simulated part diameter is about 137 mm, measured along the middle of the part, and the simulated height is 13.699, measured in the part center.

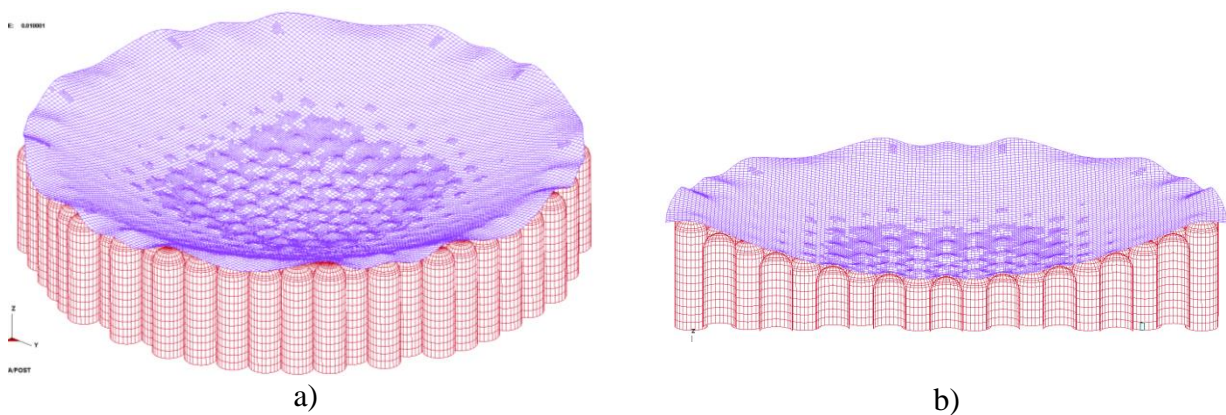


Fig. 5. FEM model of the tool in final position:
a) - general view; b) - middle section

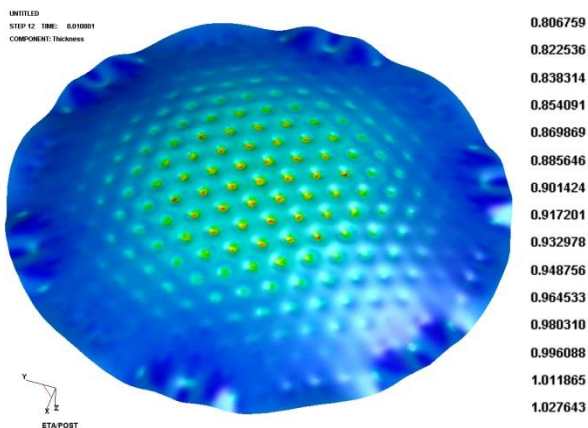


Fig. 6. Thickness variation in hydro-multipoint deformation

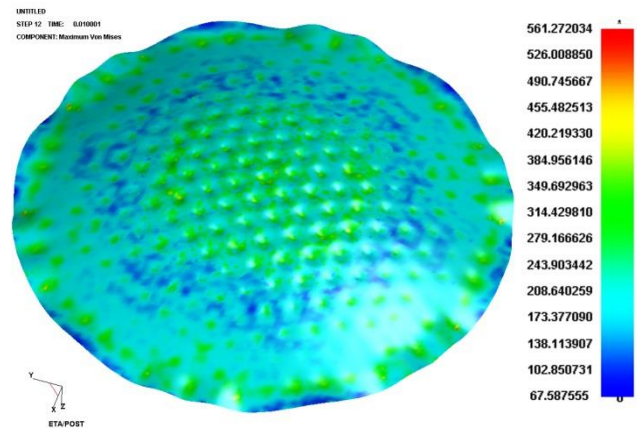


Fig. 7. Von Mises stress variation in hydro-multipoint deformation

Figure 6 shows the qualitative variation of the blank thickness. It can be observed that in the region around contour a material thickening (1.02 mm) appears and in the middle of the sheet the material is thinner, the lower value (0.81) being in the dimpling zones.

Von Mises stresses are given by:

$$\sqrt{2}\sigma_c = \sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2} \quad (2)$$

where: σ_1 , σ_2 , σ_3 are the normal, principal stresses and are a measure of the level of the flow stress in material.

The Von Mises contour plots presented in Fig. 7 show that the stress level reached 561.27 MPa which confirms that the forming process occurred within the plastic region.

4. HYDRO-MULTIPOINT FORMING EXPERIMENTAL RESULTS

Based on the hydro-multipoint die concept presented above, a hydro-multipoint mechanical actuated tool was designed. Figure 8.a depicts the reconfigurable subassembly of the die. The die is shaped using the piece profile. For this, each pin from the network is vertically displaced due to its own threaded area. Figure 8.b shows the pressure chamber of the die. The pressure chamber is coupled with a hydraulic system which assures a maximum pressure of 25 MPa. The pressure is transmitted to the blank using an elastic membrane.

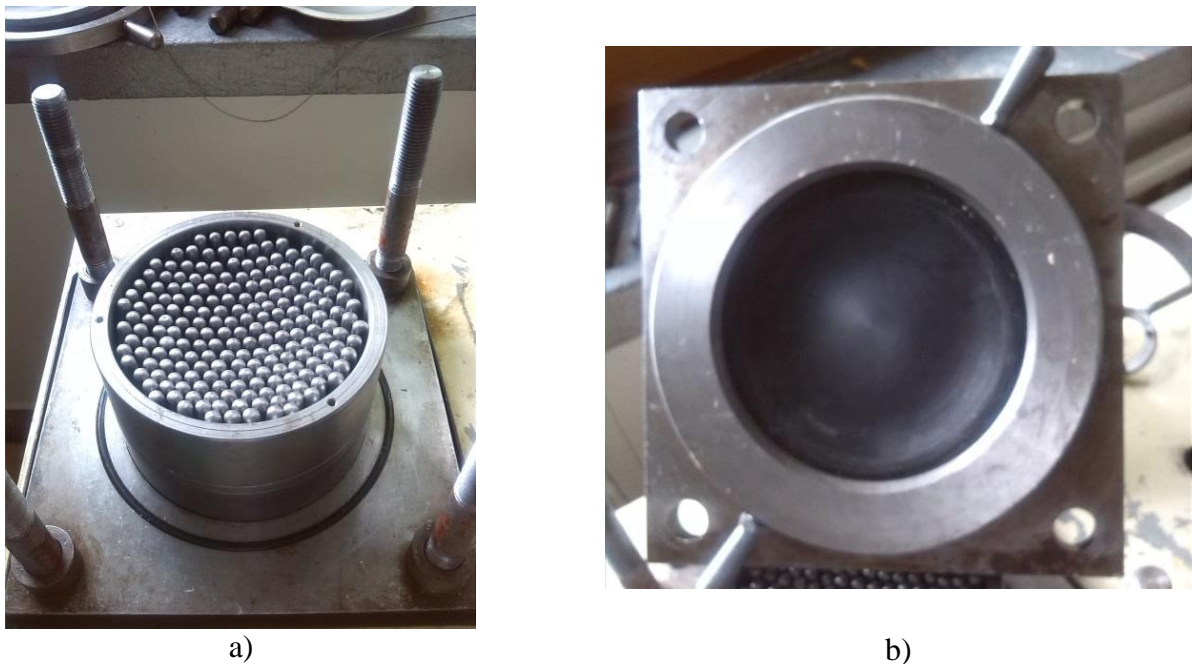


Fig. 8. Subassembly of the hydro-multipoint forming die a) - inferior, b) - superior

A circular blank, having a diameter of 140 mm, made of mild steel sheet and similar to the one in simulation, was used. The properties of material were: yielding strength – 268.8 MPa; ultimate tensile strength – 389.6 MPa and hardening exponent – 0.21. The part is a spherical sector with a radius of 141.5 mm and a depth of 14 mm.

A number of experiments were done without any interpolator between the blank and pins (Fig. 9a). The part surface is affected by pins ends profiles which produced dimples. The part contour is highly affected because the outer contour of the pins network is not uniform. Both the dimpling and wrinkles appear. The deformation was made at a pressure of 4 MPa. The image is similar to the one obtained in simulation. The experimental part diameter is about 136.7 mm, measured along the middle of the part, and the experimental height is 13.5, measured in the part center.

Next, a number of experiments were conducted using a metallic interpolator between the blank and pins, at the same pressure of 4 MPa (Fig. 9b). A 2 mm thick Al sheet was used as interpolator. Most of the part surface is of a good quality. The part contour is also affected by the non uniformity of the pins network. The part has the same dimensions as the first one.



Fig. 9. Hydro-multipoint forming part deformed: a) - without interpolator, b) - with interpolator

5. CONCLUSION

The paper presents a new tool concept for hydro-multipoint forming method. The main advantages of this type of equipment are the reduction of the setup process time in half, in comparison with the conventional digitized dies, and the combining of hydroforming and multipoint forming advantages.

Based on this concept, a simulation model and an experimental mechanical tool were designed. Both the numerical simulations and the experimental results are in accordance.

In numerical simulations, for a fixed configuration of the hydro-multipoint deformation tool without interpolator, the effect of localized deformation is important and depends on the contact points positions. The quality of the part is poor because of dimpling.

The experimental results validated the new type of deformation and highlighted the importance of the interpolator to the parts quality. For complex parts we presume that a harder interpolator will lead to an improvement of the deformation process.

A binder will be needed to avoid dimpling and wrinkling phenomena because the pressure at the outer contour is not uniform due to irregular pins network in this region.

The numerical simulations and experimental work will continue in the next future in order to study the effect of interpolators on the quality of the parts. Moreover, the new tool will be used for investigating different materials e.g. the aluminum and titanium alloys and different process parameters, such as pressure, binder force, number of pins, pins diameters, etc.

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

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