Researches regarding the hydroforming process of aluminum components

V Paunoiu¹, V Teodor¹ and F Susac¹
¹Dunarea de Jos University of Galati, Department of Manufacturing Engineering, Galati, 800008, Romania
E-mail: viorel.paunoiu@ugal.ro

Abstract. The lightweighting with aluminum offers the potential for using unconventional fabrication technologies such as sheet hydroforming. Triform process is an unconventional sheet forming technology where the blank sheet is placed under a flexible rubber pad and is deformed under the action of the hydraulic pressure applied from the top of the equipment. The part shape is given by the shape of the die located at the bottom of the equipment. In the paper are presented the experimental results, regarding the influence of the fluid pressure towards the parts properties. The parts quality is evaluated in terms of springback variation. The results could lead to the implementation of the designed procedure for triform die and equipment.

1. Introduction
In the car body constructions the substitution of steel by aluminum presents most interesting lightweighting possibilities [1]. The lightweighting with aluminum is not limited to material substitution, but the different aluminum product forms offer in addition the potential for using unconventional fabrication technologies [1] one of them being sheet hydroforming.

Sheet hydroforming includes a series of manufacturing technologies which have as the main characteristic a liquid pressure medium which acts toward the blank [2, 3]. There are two mainly manufacturing methods: one consists in the action of the liquid pressure toward the blank, the pressure is created by the punch moving into the die filled with the fluid [4], the so called hydromechanical sheet forming (see figure 1) and the other one consists in the action of liquid toward the blank using a flexible rubber and no punch (see figure 2), the so called triform of flexform process [5].

In hydromechanical sheet forming the area of application of fluid pressure may be the punch-blank holder region or the die region (see figure 1) and the mode of application may be the hydrostatic pressure or hydrodynamic pressure.

Figure 1. Hydromechanical sheet forming [2].
The fluid pressure in this process can be produced by the downward movement of the punch, or be supplied by a hydraulic system, since no rubber diaphragm is used [2]. The tool device in this process is similar to that in a conventional deep drawing. A rubber seal is used to prevent the flow out of the fluid on the flange. According with figure 1, $F_p$ is the deep drawing force and $Q$ is the restraint force. Since the blank is pushed against the punch by the hydraulic pressure, the punch force is uniformly distributed over the blank, which controls the localized reduction of the thickness in the punch shoulder.

The triform process (see figure 2), is a sheet hydroforming technology where the blank sheet is placed under a flexible rubber pad and is deformed by the action of a hydraulic pressure applied from the top of the equipment.

The rubber is pressurized with hydraulic fluid, and it exerts equal pressure on each point inside the die cavity. The part shape is given by the shape of the die located at the bottom of the equipment [6]. Some advantages of the technology are [5, 7]: reduced tooling costs by 50% to 90% compared to conventional presses because is no need for a mated die to the punch (male die), as the flexible rubber acts as a universal female; due to uniform elongation of the metal, variation in blank to finished part thickness is less than 10% [8, 9]; thanks to the flexible rubber parts are produced with a smooth, uniform surface, typically requiring no additional finishing; tooling and material changes are simple and inexpensive; precise tolerances can be achieved with difficult parts configurations; a wide range of material can be formed such as: high strength steel, carbon steel, aluminum, stainless steel, precious metals, copper and brass [10, 11]. The main drawback of sheet hydroforming is its longer cycle time which causes the process to be costly at high volumes [12, 13]. Another drawback is still lack of knowledge so a lot of researches are being conducted to extend hydroforming’s capabilities.

The study of the correlation between the fluid pressure and the part dimensions is a fundamental task to improve the performances of processed parts [14]. In the paper are presented some experimental results applying the triform process to Al alloys for obtaining the above task.

2. Experimental work
A hydraulic press was used for the experimental study of the sheet hydroforming process. The hydraulic system of the press assures a maximum pressure of 25 MPa.

Figure 3 shows the die. The die profile has a radius of 141.5 mm and a diameter of 150 mm. A flexible rubber was used with a thickness of 3 mm. The vulcanized natural rubber used has a Shore A hardness of 55, Tensile strength, $R_m=35$ MPa at 200C, Elongation at brake 650% at 200C.
For the experimental work, blanks made out of aluminum, Al 99.5, with a thickness of 2 mm and Al alloy series 5000 with 1 mm thickness were used. The blanks diameters were equal with D=150 mm.

According with the dates presented in [3, 7], the material properties are:
- for Al 99.5, 2 mm thickness: density, $\rho=2.7 \text{ g/cm}^3$; Elastic module $E=70 \text{ GPa}$; Tensile strength, $R_m=130 \text{ MPa}$; Yield strength, $R_c=80 \text{ MPa}$; Poisson ratio, $\nu=0.35$.

- for Al alloy series 5000, 1 mm thickness, the material properties are: $\rho=2.7 \text{ g/cm}^3$; Elastic module $E=70 \text{ GPa}$; Tensile strength, $R_m=320 \text{ MPa}$; Yield strength, $R_c=240 \text{ MPa}$; Poisson ratio, $\nu=0.35$.

Four pressures were applied: 20, 40, 60 and 80 Bar. No lubricant was used.

**Figure 3.** CAD model of the hydroforming die.

**Figure 4.** Off-line measurement of part.  **Figure 5.** Display informations about part measurement.
The deformed parts were measured on a CM machine, see figure 4. The machine software gives automatically values of parts diameters and radii, in these cases of simple geometrical forms, see figure 5. The points were measured from the centre of the part to the bottom along the exterior surface.

3. Results and discussions
Figure 6 shows the sample parts obtained by applying the above pressures.

Figure 6. Al Sheet hydroformed parts.

Figure 7 presents the radii variations of the samples for different pressure. It could be seen that the radius of the deformed part decrease with increasing the pressure, after the springback.

Figure 7. Radius variation function of the applied pressure.
This means that the radius will be more closely to the radius of the die and the part will be more accurate. Starting with the pressure of 60 bar (6 MPa) the part radius is almost the same, insensitive to material characteristics and pressure. We could consider that the only factor which alter the part precision is the flexible rubber characteristics.

Figure 8 presents the samples diameters deviations for different pressures. It could be seen that deformed parts diameters deviations are minimum at 60 bar (6 MPa), for both materials. The deviation was calculated using the relation:

\[
\text{Deviation} = \frac{d_{\exp} - d_{\text{target}}}{d_{\text{target}}} \cdot 100\% \tag{1}
\]

where: \(d_{\exp}\) is the experimental obtained part; \(d_{\text{target}}\) – is the target part diameter, which is equal with 140 mm. At low pressure the diameter variation due to springback is almost constant. By increasing the pressure the part diameter deviation will increase, because the springback will increase. After the pressure reached a certain value, in our case 6 MPa, the diameter variations will decrease. This variation is due to the fact that any lubricant was used. So the adhesion between the blank and the rubber avoid the part to correctly springback.

![Figure 8. Part diameter deviation function of the applied pressure.](image)

The presence of the solid lubricant is important. Without this, the parts adhere from the rubber. The adherence is greater as the pressure is higher as this influence the part springback.

4. Conclusions

It was concluded that in triform process the pressure has an important role in obtaining high quality parts, but for a certain material it exists a maximum pressure which assures the optimum conditions of deformation. In our case this has the value of 6 MPa. The part dimensions are affected by the presence of the lubricant. This is particularly visible when pressure is high. We are considering that the flexible rubber which assures the uniform pressure toward the blank largely and the lubricant influence the process of deformation. For complex parts we presume that a more flexible and thinner rubber will lead to an improvement of the deformation process. Future experimental studies and numerical ones will follow the above research direction.
References

[1] The Aluminium Automotive Manual, Version 2013 © European Aluminium Association.

[2] Bakhshi-Jooybari M, Gorji A and Elyasi M Developments in Sheet Hydroforming for Complex Industrial Parts, Metal Forming – Process, Tools, Design, INTECH, http://dx.doi.org/10.5772/48142

[3] Ramezani M and Ripin Z M 2012 Rubber-pad forming processes: technology and applications. (UK: Woodhead Publishing Ltd)

[4] Paunoiu V and Nicoara D 2004 Sheet Metal Forming Technologies (Bucharest: University Book Press Bucuresti)

[5] Vollertsen F, Breede R and Lange K 1999 Method for deep drawing with multiple elastomer membranes CIRP Ann. – Manuf. Tech. 48(1) pp 221-226

[6] Information on http://www.triformpress.com; http://industry.avure.com/solutions/flexform-introduction

[7] Ramezani M, Ripin Z M and Ahmad R 2009 Computer aided modelling of friction in rubber-pad forming process J. of Mater. Process. Technol. 209(10) pp 4925-4934

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

[9] Lang L, Danckert J and Nielsen K B 2004 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

[10] Lang L, Danckert J and Nielsen K B 2005 Investigation into hydrodynamic deep drawing assisted by radial pressure: Part II. Numerical analysis of the drawing mechanism and the process parameters J. of Mater. Process. Technol. 166(1) pp 150-161

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

[12] Novotny S and Hein P 2001 Hydroforming of sheet metal pairs from aluminium alloys J. of Mater. Process. Technol. 115 pp 65-59

[13] Abedrabbo N, Zampaloni M A and Pourboghrat F 2005 Wrinkling control in Aluminum sheet hydroforming Int. J. of Mech. Sci. (47)3 pp 333-358

[14] Dariani M and Fazli A 2006 Parameter study of the axisymmetric hydromechanical deep drawing process Part B: J. Eng. Manuf. 220 pp 1937 – 1944