Journal of Applied and Computational Sciences in Mechanics, Vol. 28, No. 2, 2017.

Experimental Study and Simulation of Tube Hydroforming Process of Bi-layered Aluminum-Copper with Axial Feeding

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1. Introduction

Tube hydroforming is a process in which tubular sections of different geometries are produced from base circular tubes. At recent years, the use of hydroforming products in aircraft and automotive industries have been increased due to their advantages over products of conventional processes. Advantages of this process include an integrated product, reduced weight, high toughness and structural strength, lower-cost tools, less demand of additional treatment, and high dimensional precision. Tube hydroforming can be defined as a process which is started by a straight or bended tube. Then tube ends are isolated and the tube is formed into the die-cavity as a result of the internal fluid pressure (Fig.1). Water is usually used with an anti-corrosion complementary for applying an internal pressure.

The main success of the hydroforming process is mostly dependent on material characteristics of the tube. Properties such as composition, type of the weld, tensile strength, yield extreme, flexibility, and anisotropy should be determined before the process. In this work, aluminum according to the A1050ASTM standard for the outer wall and copper according to the 11000 ASTMC Standard for the inner wall were chosen. increasing the friction coefficient, which is dependent on material of the external tube and die wall, results in local decrease of the tube wall thickness at the corner areas of hydroformed parts which in turn leads to early choking. Therefore, measurements performed during the friction moderation cause an improved operable and reliable extension of the process.

2. Process Simulation

In order to acquire a proper loading curve for deforming the dual aluminum-copper tube, it is needed to assess the tube deformation at the time of applying forming forces. By observing the created deformation in the tube, loading curves are varied such that a perfect part is produced. Since it's difficult to analytically achieve this aim, a finite element method was used. Tube hydroforming is classified as the metal plate forming. It is suggested in ABAQUS manual that if the thickness to the whole structure index ratio is less than 0.1, the object can be modeled as a cortex. Since multi-task elements are suitable for modelling large membrane strains in the cortex, element S4R as one of the multi-task elements was chosen for modeling the plate.

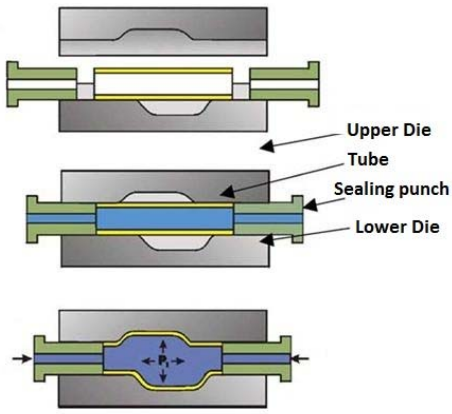

Fig. 1. Schematic of tube hydroforming process

3. Loading Curves

In linear loading curve, the final pressure is increased without using the axial feeding until die corners become totally full. After identifying of the required pressure for filling the die corners, different values of axial feeding were employed simultaneously with applying pressure in order to lessen the thinning (fig.2).

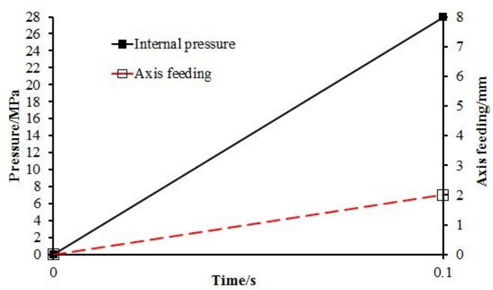

Fig. 2. Linear loading curve.

In stepwise loading, axial feeding is not applied at the beginning of the process. At the end of process when the calibration pressure is used for filling the corners, the effect of axial feeding is insignificant and its value does not changed.

4. Experimental Setup

Tube hydroforming machine was designed and developed with the capability of utilizing different

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loading curves (fig.3). An insignificant leakage at tube ends will cause dropping the internal pressure and, process failure. Isolating tube ends is provided via rings of polyurethane. Internal pressure of 700 (bar) is introduced by the manual pump. The internal pressure of the forming container is displayed by the barometer installed on the manual pump. The axial feeding levels and simultaneous progress of punches are controlled by the hydrolic circuit. Ohmic rules installed on each punch will detect their displacements and the values are compared to each other by the electronic board which controlled by LABVIEW.

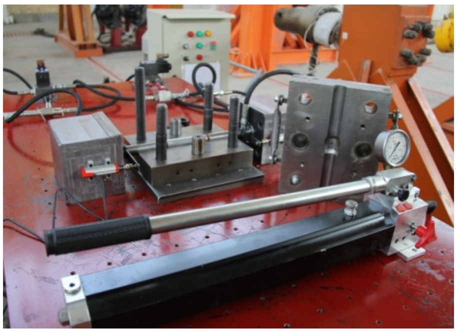

Fig. 3. General view of the tube hydroforming machine.

5. Results and Discussions

In this section, simulation results of the dual-layer hydroforming process are analyzed and compared at different loading curves. Single-layer and dual-layer hydroforming are also compared. Likewise, simulation results will be benchmarked with experimental data.

5.1. Linear loading curve

In this case and without applying any axial feeding, the maximal thinning of the aluminum tube is equal to 57.1% and 49.25% for the copper tube. It is evident that due to the fast thinning, the tube fills the die by a less pressure compared to when the axial feeding impedes the fast thinning. To reduce the thinning, axial feeding curves are equally introduced to the tube ends. However, since the axial feeding prevents the fast thinning, the required pressure for filling the die at each axial feeding value will be different.

6. Conclusion

In this paper, aluminum-copper tube hydroforming was studied by a finite element simulation. Also tube hydroforming in various loading paths was performed using a setup designed for this process. Concluded remarks of this simulation and experimental study are as follow

1- The linear loading curve with axial feeding of 6 mm and final pressure of 28 (MPa) leads to the maximum thinning of 9.3% and 7.5% for aluminum and copper tubes, respectively. While increasing the axial feeding up to 3 mm and decreasing the thinning, the required pressure for filling the die corners are raised.

2- The minimum thinning among the loading curves is associated with the stepwise loading curve (5.6% and 7% for the aluminum and copper tubes, respectively) but there is a high fluctuation in the middle thickness of tube. Also the eliminated wrinkles at the calibration stage play a key role in the tube thinning.

3- Results show that the pressure calculated from analytical relations are much higher than the required pressure for forming the corners so that the calibration pressure was found as 140 (MPa) based on analytical relations, but the needed pressure in measurements was 28 (MPa) (fig.4).

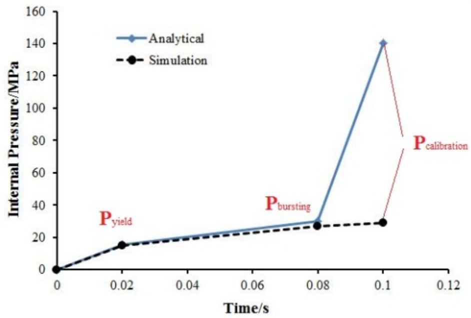

Fig 4. Stepwise loading curve.

4- The perfect sample in experiments was provided by using the linear loading curve. Axial feeding of 5.5 mm was applied at both sides of tubes and the maximum internal pressure of 280 (bar) was exerted on two tubes. The maximal thinning in the simulation for aluminum and copper tubes was 11.5% and 9%, respectively. Also the sample results are presented in Table 1. The discrepancy between experimental results and simulations was 4.3% which is an acceptable level.

Table 1. Comparison of experimental and simulation results.

The maximum difference between experimental results at a given point (mm)	-0.747
The measured thickness at that point (mm)	1.72
The maximum error of the simulated process with respect to the experiments (%)	4.3

5- Experimental results show that the most important reason for tube bursting is the lack of applying a proper axial feeding at the internal pressure introduced to the part as well as not following the loading curve.