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Investigation of Effective Parameters of the Two-Layer Sheet Hydroforming Process for Hollow Parts Having Complex Geometry

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Abstract: Hydroforming process is a deep stretching process with a difference that a fluid is used instead of the mandrel. This paper investigates the hydroforming process of non-cylindrical and non-spherical geometries using finite element analysis software to calculate the influences of effective process parameters such as the coefficient of friction between the surfaces and the pressure applied during the process. The results indicate that decreasing the friction between surfaces, with an optimum lubrication, can decrease the changes in thickness which is related to sheet heightening and leads to a final product with more uniform thickness and more appropriate strength. On the other hand, it is observed that with a pressure change, there are very slight changes in the thickness for this geometry which can be neglected. The geometry of the mold also showed a great influence on the final quality of the formed sheet.

Keywords: Sheet hydroforming, Complex geometry, Finite element analysis, Friction, Multistage pressure

1. Introduction

Hydroforming technology is now well known and its development in applications for the automotive industry, especially in Germany and the United States of America is impressive. Hydroforming of pair metal sheets is still in pre-industrial stage. Hydroforming is mainly used for the production of tubular-shaped pieces but the use of pair of metal sheets as semi-finished products has led to an expansion in hydroforming field towards a new range of geometries which can be produced with this technique. Pair sheet metal hydroforming process for producing hollow bodies has been introduced by various authors. [1-3]. Assempour and Emami [4] provide a way in which counter pressure on the outer surface of the sheet is applied to compensate for the different behaviors of two forming sheets and thus the whole potential formability of the materials could be used. Geiger et al. [5] have studied two main parameters which are the clamping force and the liquid pressure for deformation of two discreet sheets with liquid. Tang et al. [6] investigated the effects of temperature on mechanical properties and the tubular extension of aluminum-magnesium 61 Alloy by uniaxial tensile tests at different temperatures. Tolazzi [7] studied pipe hydroforming and plat hydroforming, showing the gradual development of both technologies by using research and development projects results, prototypes or successive parts production. Wei et al. [8] analyzed hydroforming process of one pair of metal sheet. Xin, et al. [9] used hydroforming for evaluating the ductility with the aim of high ejection ratio, low dimensional accuracy and low fatigue durability for aluminum alloy parts with complex shapes and doubly curved surface which are formed by a conventional trickle molding and deep drawing operation. Wei et al. [10] surveyed hollow bones like component with a bent axle and complex geometry of cross section as their target.

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The objective of this paper is to study complex geometry i.e. geometries other than spherical, cylindrical, and cubic cross section. Axisymmetric geometry and cubic asymmetric geometry are the ones studied in this research. For the cube-shaped parts, geometry is like a car oil cartel and another sheet forms on the top of the original sheet into a mold with a cylinder and cube simple geometry. In this way we can do a comparison between simple and complex cross section and validate modeling by comparing the achieved results with available results for simple geometries. Accordingly, the study of the effect of friction and fluid pressure exerting path on thinning and thickness distribution will be considered. In this situation, friction parameters must be changed to investigate the effect of pressure on the process, which can be evaluated by changing the slope of the pressure line and using multistage pressure, in order to change the direction of the exerting pressure.

2. Hydroforming Process

Hydroforming process is a deep stretching process with a difference that a fluid is used instead of the mandrel. Therefore, results and methods of deep stretching could be used in order to study the hydroforming process with a good approximation. The considered part is suitable for stretching when it can provide the necessary depth. Due to combination of tension, walls flux and metal bending during rectangular seamless container stretching, determination of the diameter is a problem in this process. The diameter of these molds can be obtained from the following equation [11]:

$$R_e = \sqrt{2Rh + R^2 + 1.41Rr} \tag{1}$$

In which R is the radius of the container corners, h refers to the height of the container and r is the radius of the bottom of the container.

To determine the number of required stretching for the container production and to calculate the original part dimensions, it is necessary to calculate the size ratio of original part dimensions to container dimensions. It should be noted that stretching height and container corner radius in the rectangular containers have ratios that are presented in Table 1.

Table 1. the ratio of the stretching height and the container corner radius in rectangular containers [11].

Container corner radius (inches)	Stretching height (inches)
$2/3 - 2/16$	1
$3/16 - 8/8$	1
$8/8 - 1/2$	2
$1/2 - 8/4$	3

According to Fig. 1, different condition of hydroforming of pair metal sheets is shown. Due to the liquid pressure and sheet stuck force in leakage area, the deep stretching with sheet moving under the sheet stuck force and also stretching without sheet moving has been shown. Moreover, dominant relations in this condition are shown in the same figure.

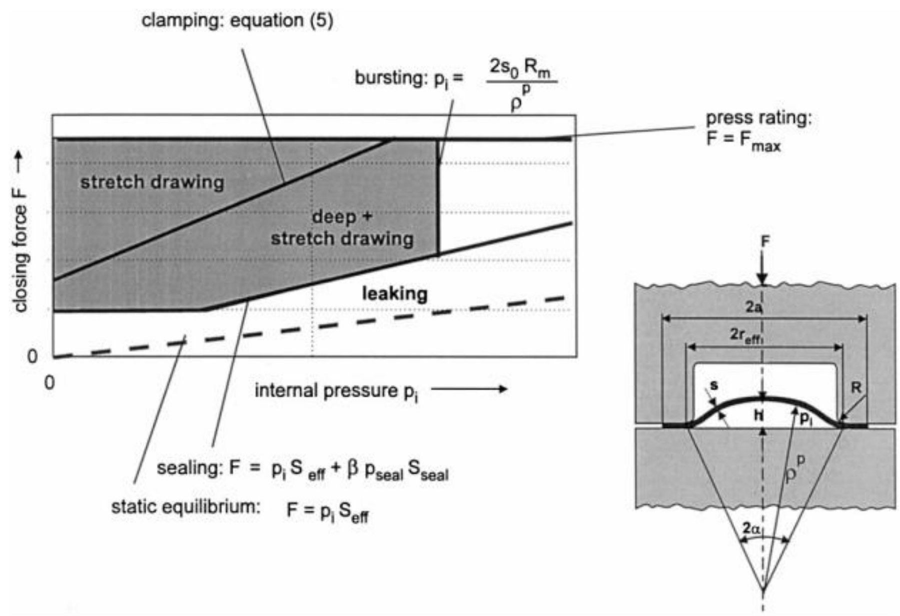


Fig. 1. Various states of deep stretching according to sheet stuck force and pressure [11].

3. The Simulation Method

Hydroforming with complex geometry is modeled and analyzed in finite element software *(Abaqus).* A sheet of DDQ graded steel with below inhomogeneous properties and strain hardening equation has investigated. The plastic properties of the material were incorporated in the software using Eq. (2), while other properties were as mentioned in Table 2."

$$\bar{\sigma} = 525.6(0.0043 + \bar{\varepsilon})^{0.197} \tag{2}$$

$R_0=2.16$, $R_{45}=1.61$, $R_{90}=2.67$ (3)

Table 2. Properties of the used material

Poisson's ratio	Young's modulus (GPa)	Density (kg/cubic meter)
0.3	207	7850

Since this process is axisymmetric in order to reduce the solution time and computation time, only half of the geometry is modeled. In the present simulation, molds have intended rigid shell and two ductile sheet's with a thickness of one millimeter and the mentioned elastic-plastic material properties are used. Molds are constrained in a manner that there is no motion. On the other hand, sheets have been limited with axisymmetric constraints such that they are able to move in both vertical and horizontal directions. Contact between sheets and molds are considered to allow sheets shaping in the process. The loads which were required to perform the hydroforming process, were imposed on the sheets. Moreover, in this study regular meshing in the finite element software is used to reduce errors. It should be mentioned that sheets are parts to be investigated and thus molds precision meshing does not matter. Depending on the friction and sheet pressure, about 2 to 5 seconds is taken to solve the simulation and every time the software is run, finite element software needs about 1 to 3 hours to get the results. Considering friction coefficients of 0.05 and 0.1, analysis was done for pressures of 10 and 100 MPa.

4. Results and Discussion

4.1. Validation

Compares the results of this research modeling with the experimental results of Assempour and Emami [4]. The figure shows the values of peak thickness versus peak height and a very good agreement is seen between the present results and those obtained in ref. [4].

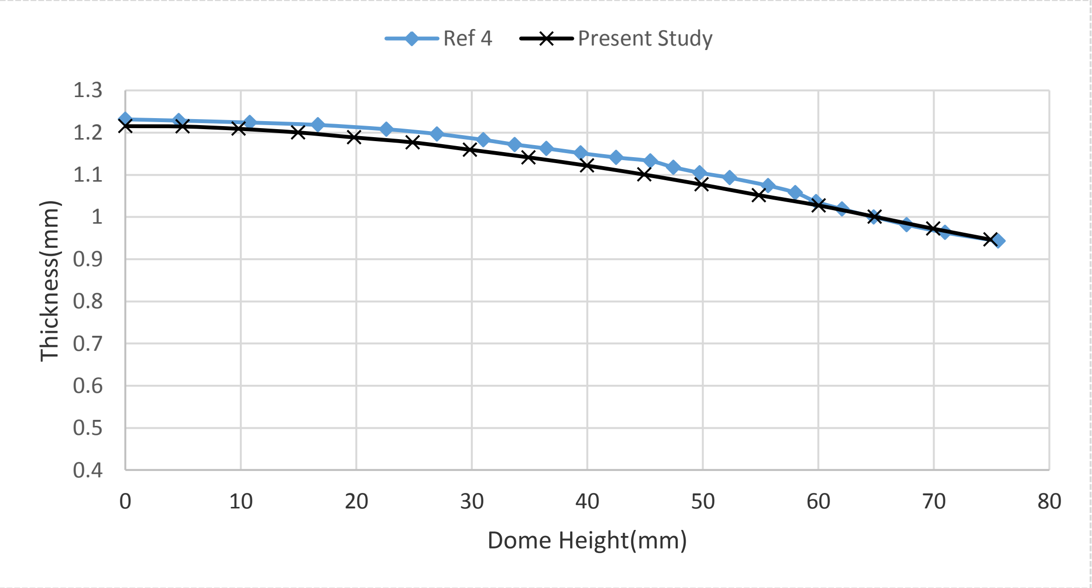


Fig. 2. Comparison of results with reference [4].

4.2. Friction Effect Analysis

The effect of friction between contacting surfaces of molds and sheets are investigated. Values of 0.1 and 0.05 are considered for coefficient of friction between surfaces. In this case, the effect of variations in sheet thickness as a function of sheet height changes is studied. A fluid pressure of 100 MPa was considered on the sheet. Figures 3 and 4 show results for the lower and upper sheet, respectively.

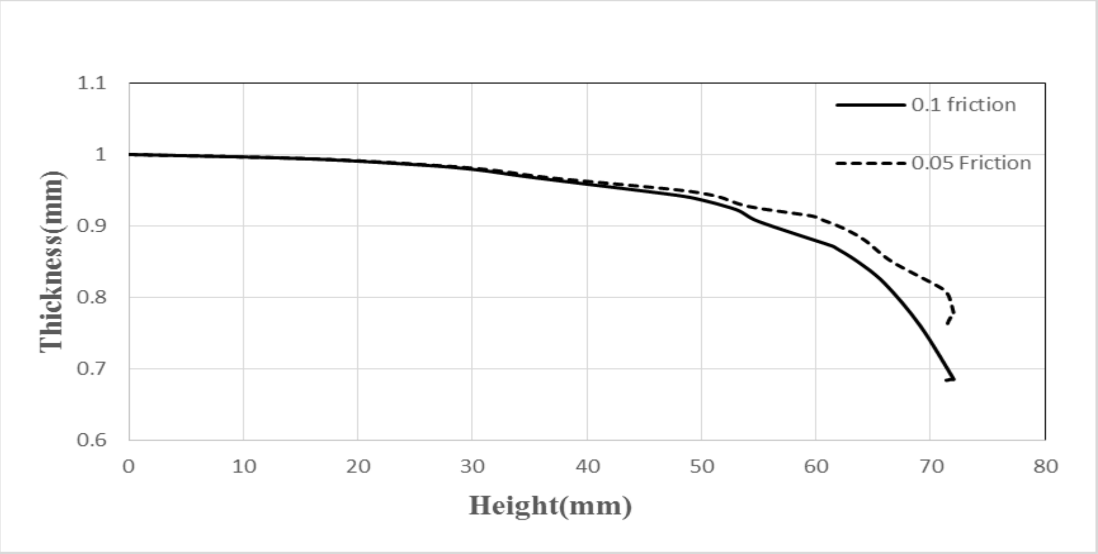


Fig. 3. The effect of friction on the bottom sheet thickness variation.

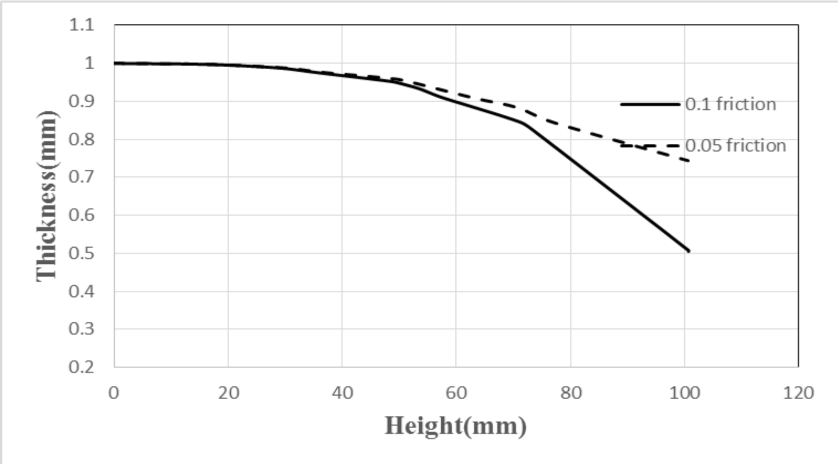


Fig. 4. The effect of friction on the upper sheet thickness variation.

As the figures depict, with decreasing the coefficient of friction, the bottom sheet moves easier between mold surfaces and indicates less thickness variation for completion of hydroforming process. However, the friction in the upper sheet has a considerable effect on thickness variations. When the friction is 0.1, the thickness changes a lot by continuing the process and its amount reduced to a half, but in the next state, with the coefficient of friction of 0.05, the thickness maximally reaches under 0.8.

Due to Poisson's ratio, it can be found that the side strain is inversely proportional to axial strain and increasing length lead to the decrease in the thickness

The lower friction coefficient between sheet and mold lead to the lower changes of vertical strain of sheet and also lower the decreasing of sheet thickness.

The study of friction in the upper and lower sheets indicated that decreasing the friction can reduce the changes in thickness so that the friction of 0.1 is considered in lower sheet and about %30 of thickness has decreased. When the friction coefficient is changed to 0.05, about %20 of thickness has reduced. Moreover, the friction of 0.1 in upper sheet caused %50 change in thickness which is %25 in lower sheet.

4.3. Effect of Pressure Analysis

The variations in fluid pressure on the two sheets are evaluated during hydroforming process. to investigate the effect of fluid pressure on the upper and lower sheets thickness variations in this type of geometry, two values of 100 and 10 MPa pressures with the constant friction coefficient of 0.1 are considered. Figures 5 and 6 respectively show the effect on the upper and lower sheets.

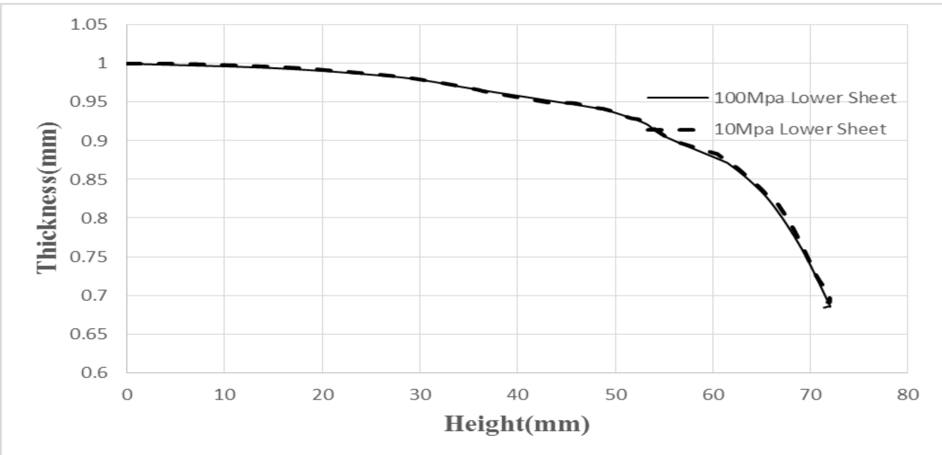


Fig. 5. Graphs of the pressure effect on the thickness variations for the bottom sheet.

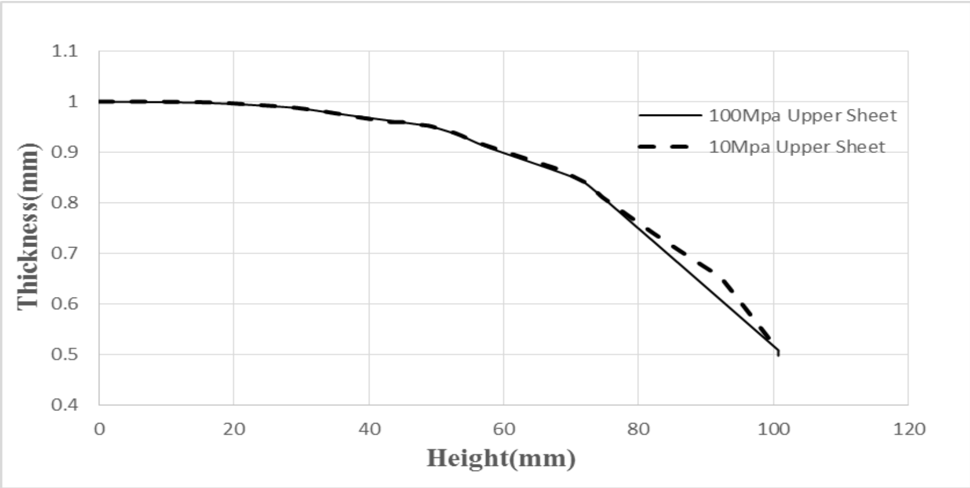


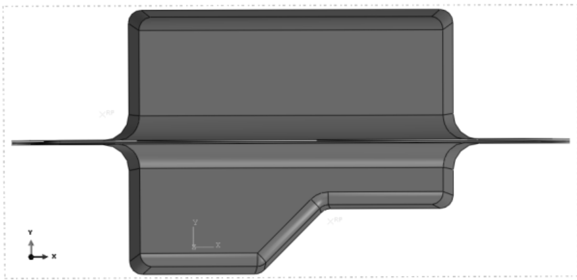
Fig. 6. Graphs of the pressure effect on the thickness variations for the upper sheet.

The above diagrams show that the pressure variations have no great influence on sheet thickness, although few minor changes in thickness increasing observed by pressure increasing.

4.4. Effects of Molds Geometry

Comparison of two sheets in the state of the same loading and the same coefficient of friction between all surfaces is discussed and the effect of the molds geometry on the thickness variations during sheets heightening in hydroforming process is reviewed as follows.

As seen in molds, it is expected that different thickness change the sheets under same loading and conditions after the process.



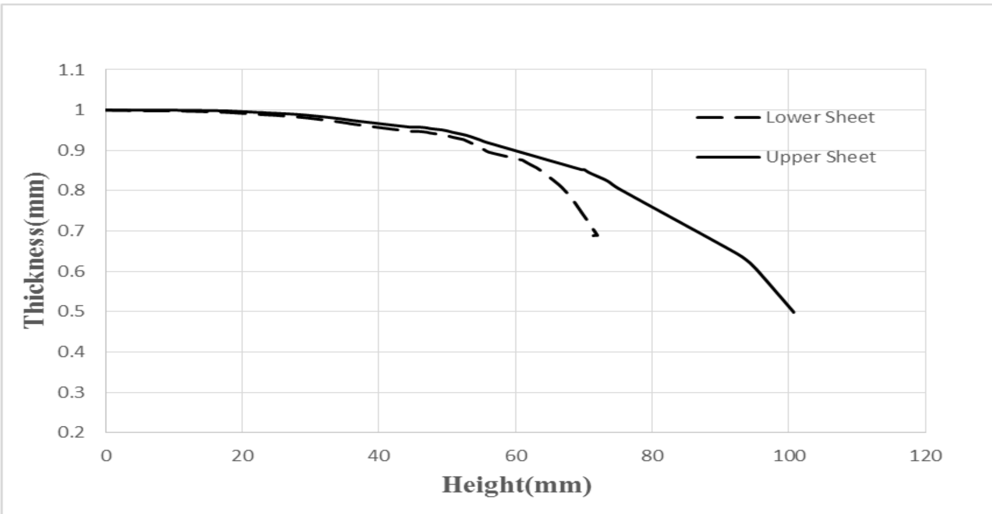


Fig. 7. Diagram of thickness variations of two sheets with a 100 MPa loading and friction coefficient of 0.1 by heightening the sheet.

The considered element goes up in the middle of the upper sheet to the end of the mold, but the selected element of the bottom sheet comes down to the mold sloping surface. Molds dimensions have a significant effect on final results so that if the mold width is small and consequently the sheet width is smaller, after hydroforming process, some part of the sheet is drawn inside and in addition to the unsuccessful operation ends, the end of the sheet wrinkles and doesn't give desirable results. In Fig. 8, some of these defects are exposed.

Length and width of mold can determine the contacting surfaces of molds and sheets which cause a friction. If the mold width is small and consequently the sheet width is smaller in this case, some parts of the sheet are drawn inside and in addition to the unsuccessful operation ends, the end of the sheet wrinkles as well.

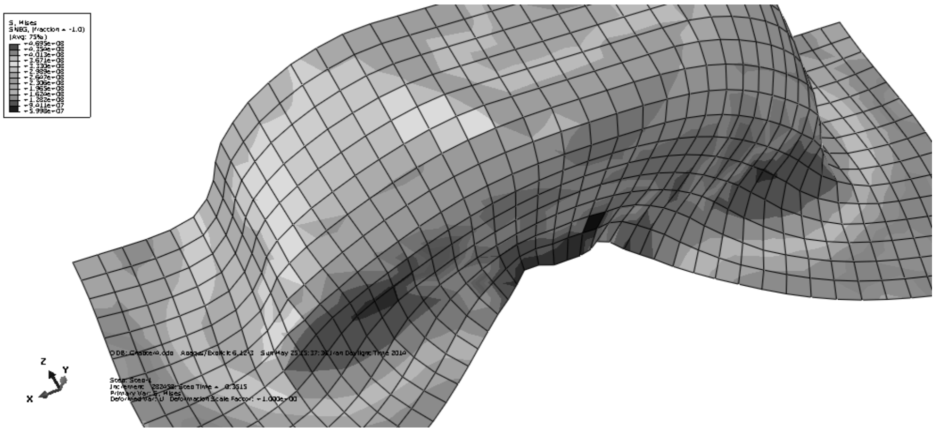


Fig. 8. Schematic of wrinkles caused due to the shortness of the mold.

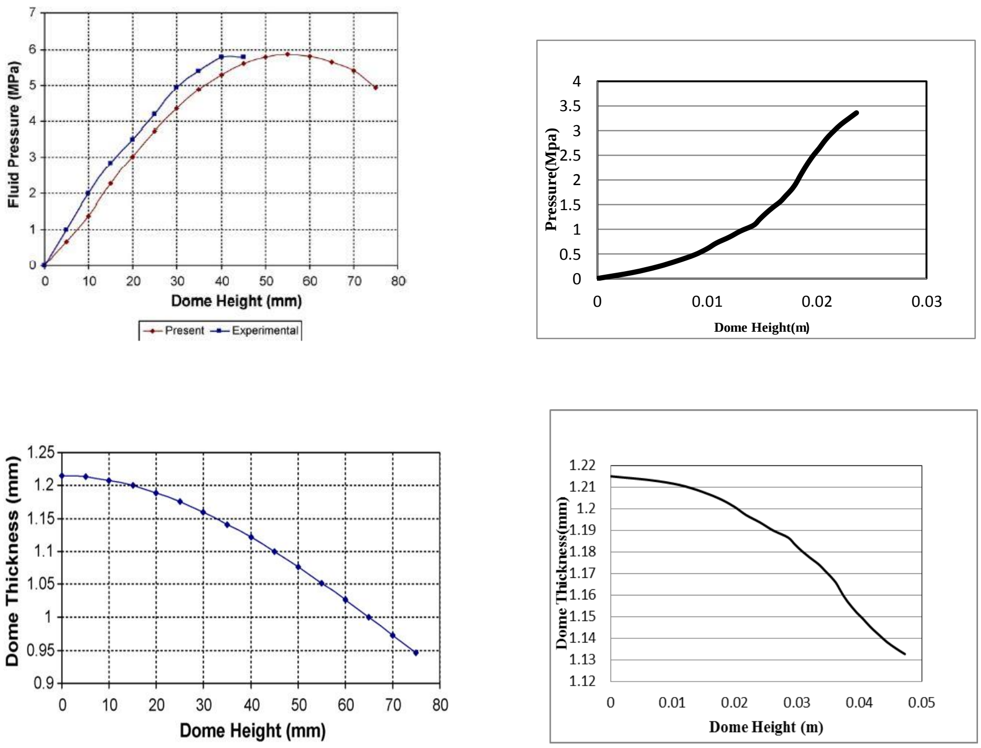


Fig. 9. Comparison and validation of the results (left; [4] and right; present work).

This study was compared to that of Assempour and Emami. Based on the figures, the thickness in peak is drawn based on the height of it (Fig. 9). After comparing the results, good agreement was evident.

5. Conclusion

The hydroforming process of hollow parts with complex geometry was investigated and the main findings are as follows:

- By reducing friction, less thickness changes during the process was observed.
- Pressure variation does not create considerable thickness changes in sheets.
- If the time is not a part of the basic aspects of production, preferably less pressure can be used and thus, create more uniform thickness along the sheet.
- Molds geometry considerably affects the thickness changes during the process.

6. References

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