The Effect of Step Pressure Path in Forming Cylindrical Cups in Hydrodynamic Deep Drawing with Radial Pressure

Ali Taghizadeh Armeki[*1], Jafar Bazrafshan[2]

[1]Sama Technical and Vocational Training College, Islamic Azad University, Ayatollah Amoli Branch, Iran

[2]Department of Mechanical Engineering, Islamic Azad University, Ayatollah Amoli Branch, Iran

[*1]taghizadeh_ali@yahoo.com; [2]j.bazrafshan@iauamol.ac.ir

***Abstract*- In recent years, hydroforming process has been applied in different industries such as aerospace, automotive industry and military industry due to its advantages, like high dimensional accuracy, capability of forming complicated-shaped parts and high drawing ratio. Hydrodynamic deep drawing with radial pressure is one of the hydroforming processes. In this paper, forming of cylindrical cups in hydrodynamic deep drawing with radial pressure was investigated and the effects of pressure path on the cup thickness distribution and punch force were studied. In this study two pressure paths (liner pressure with maximum pressure or step pressure) were used and their thickness distributions were compared. The results of this study showed that by choosing the step pressure path, the quality of the formed cup increases and more uniform thickness distribution will be obtained.**

Keywords- Deep drawing; Sheet hydro forming; Thickness distribution; Cylindrical cup

I. INTRODUCTION

Sheet hydroforming technology has been developed since pre-World War II. In the 1980s, this technology was applied to the small batch production of automotive panels and aircraft skins [1]. In recent years, hydroforming process has been taken into consideration as a convenient alternative for forming complex sheet parts. The parts produced by hydroforming in comparison to the ones produced through conventional deep drawing have more considerable advantages [1, 2].

Many materials can be used in this process, such as low carbon steel, stainless steel, high strength steel, magnesium alloy, aluminium alloy, copper, titanium and composites [1, 3]. In recent years, hydroforming technology has gained an increasing interest in automotive, aircraft and household applications [2]. Researchers have proposed different methods for sheet hydroforming such as Rubber diaphragm hydroforming [1, 4], hydro-mechanical deep drawing [1], hydrodynamic deep drawing [1], hydro-rim deep drawing [4], sheet hydroforming with movable die [1], hydrodynamic deep drawing with radial pressure [5, 6], etc. Among the sheet hydroforming processes, hydrodynamic deep drawing with radial pressure has been used to form complex shape that has a good drawing ratio.

Some studies have been done in cylindrical cups hydroforming. Ozek and Bal [7] have studied the effect of various radii of the die and punch and the angles of die/blank holder on the drawing ratio in conventional deep drawing. They found that the drawing ratio increases with increasing punch corner radius and die profile radius. Increasing the die/blank holder angle has a strong effect on the drawing ratio, too. They found that the optimal drawing ratio for die/blank holder angle is 12.5. If this angle exceeds 12.5 then the drawing ratio will decrease. Liu et al. [8] studied the effect of loading paths on the formability of cylindrical cups with hemispherical bottom in hydrodynamic deep drawing with independent radial pressure by numerical simulation. They also discussed the wall thickness distribution under the combination of chamber pressure with independent radial hydraulic pressure. They found that the independent radial pressure has a great effect on the formability and thickness distribution of cups; by increasing the radial pressure the thickness reduction in critical areas decreases. Wang et al. [9] studied the forming of cylindrical cups experimentally and numerically using hydrodynamic deep drawing with independent radial pressure. They also studied the effects of radial pressure on the wall thickness distribution, punch force and compressive stress in the blank flange, and came to conclusion that the higher radial pressure, the lower thinning ratio and punch force will be, but the compressive stress and the tendency to wrinkling on the flange will increase. They investigated the effect of radial pressure on the drawing ratio, too. This studies showed that a radial pressure higher than the cavity pressure must be applied to form a cup with a drawing ratio higher than 2.5. Lang et al. [10, 11] investigated the effect of pre-bulging height and pressure on the forming of cylindrical cups, drawing ratio and the geometrical precision of parts, and concluded that the higher drawing ratio, the better roundness at the same measured height will be gained, and the variation of the pressure in the die cavity does not affect this tendency significantly. Also when the pre-bulging is higher, the roundness is worse. The study proved that lower pre-bulging can improve the accuracy of the formed parts.

The most important parameter affecting the forming sheet metal in hydroforming is the applied pressure path, which has been studied in other papers. In this paper, forming of pure copper cylindrical cups through hydrodynamic deep drawing assisted by radial pressure was studied through using finite element simulations and experiments, to find the effects of two pressure paths, liner pressure path and step pressure path, on the thickness distribution.

II. EXPERIMENTAL PROCEDURE

All experiments were performed using a DMG (Denison Mayes Group) universal testing machine with a 600 KN capacity. All movements of the machine were controlled by a computer. Fig. 1 shows the schematic diagram of hydrodynamic deep drawing assisted by radial pressure (HDDRP) die set and Fig. 2 shows the geometry of the formed parts in this study. The components of the die are shown in Fig. 3.

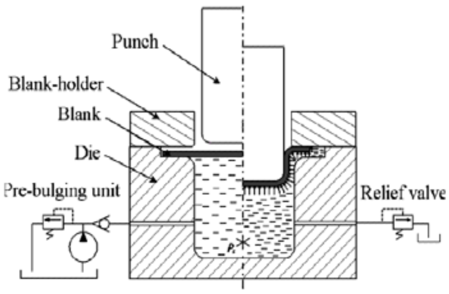


Fig. 1 The schematic diagram of the hydroforming die set

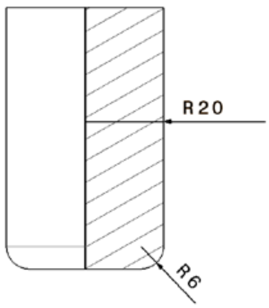


Fig. 2 Punches that were used in experiments and their geometrical dimensions in millimetre

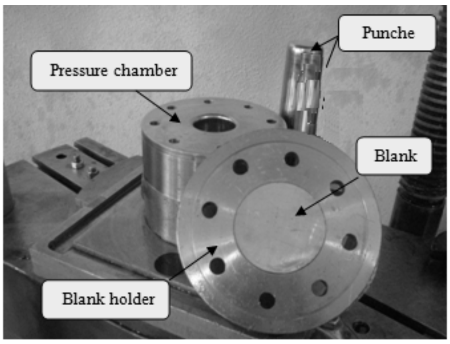


Fig. 3 The components of the die

In this study, pure copper (99.99%) sheet with a diameter of 80 mm and a thickness of 1 mm was used. The mechanical and physical properties of pure copper sheet, such as flow stress, Young's modulus, Poisson's ratio and density, are shown in Table 1. The true stress-strain curve of the copper sheet is shown in Fig. 4. Since there is little difference between curves in 0, 90 and 45 degree directions, the copper sheet was assumed to be isotropic and the experimental results validated this assumption.

TABLE 1 PHYSICAL AND MECHANICAL PROPERTIES OF THE COPPER SHEET

Flow stress [MPa]	$\sigma = 531\varepsilon^{0.44}$
Density [kg/m3]	$\rho = 8940$
Young’s modulus [GPa]	E = 117
Poisson’s ratio	$\nu = 0.32$

The two typical pressure paths used in the experiments are shown in Fig. 5. Fig. 5a shows the liner pressure path, where OA is the initial pre-bulging pressure applied to the bottom of the blank before the punch’s movement; AB is the linear pressure path that the slope changes with the punch velocity, work piece shape and thickness of the blank; BC is a constant maximum pressure that the liquid outflows from control valve by applying this pressure. Fig. 5b shows the step pressure path. In the initial stage, certain amount of pressure was used to pre-bulge the blank between the blank-holder and the punch, and when the punch started moving down, the pressure decreased. After remaining to a certain course, the pressure re-increased to a definite amount to re-bulge the work piece. This process was repeated till the final work piece formed. The punch velocity was 200 mm/min in the experiments. The fluid used in the experiments was SAE10 hydraulic oil.

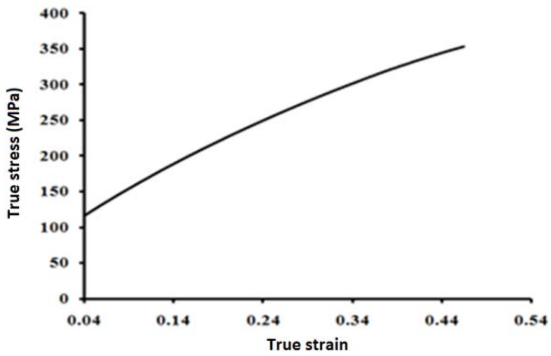


Fig. 4 True stress-strain curve of copper sheet

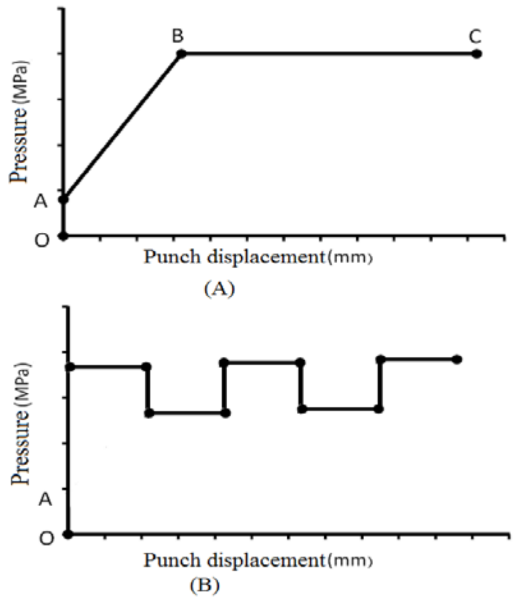


Fig. 5 Typical pressure paths used in experiments and simulations (A) liner pressure path (B) step pressure path

III. FINITE ELEMENT SIMULATION

The commercial software, ABAQUS 6.9/Explicit was used for the finite element (FE) simulation. The material behavior was assumed to be isotropic as the experimental results have verified this assumption. Due to axial symmetry, 2D models were used for the simulation of blank and die set. FE model of the die set is shown in Fig. 6. The blank was modeled as a 2D deformable axisymmetric with CAX4R four-node element. The die was modeled in a 2D axisymmetric analytical rigid element, and because of the type of selected element, the die was not meshed and analyzed. The punch velocity was considered to be 200 mm/min. The friction coefficient on the blank and the punch interface was considered to be 0.14 in the simulations, and on the other surfaces it was considered 0.04 [12].

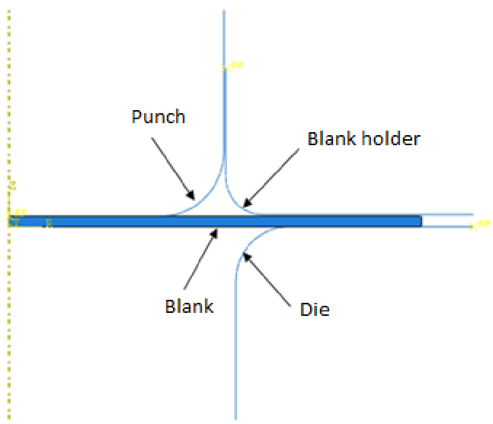


Fig. 6 Finite element model of the die set

The pressure was applied to the bottom and also the rim of the blank. Since there was no O-ring between the blank holder and the die, the fluid would leak from this space. In this study, because of the low space between the die and blank holder and thus very low leakage of fluid and also for simplification of simulations, the liquid pressure under the blank flange was uniform as the liquid pressure in the die cavity [6].

IV. RESULTS AND DISCUSSIONS

Since pressure path plays an important role in hydroforming process, the effects of the two different pressure paths on the quality of produced parts were studied. In the liner pressure path, the maximum pressure has effect on the thickness distribution. The liner pressure paths with different maximum pressures used in this research are shown in Fig. 7. In order to study the thickness distribution more carefully, the cylindrical cup was divided into different parts as shown in Fig. 8.

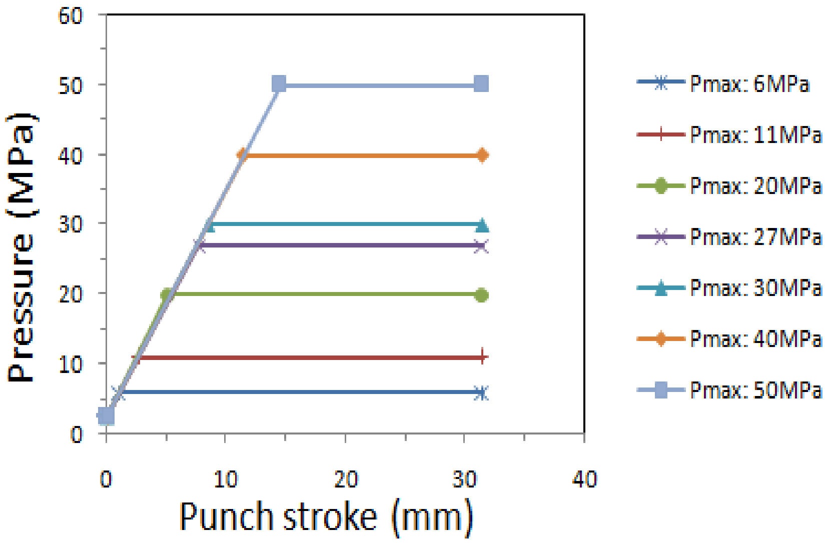


Fig. 7 Liner Pressure paths used in experiments and simulations punch with flat bottom

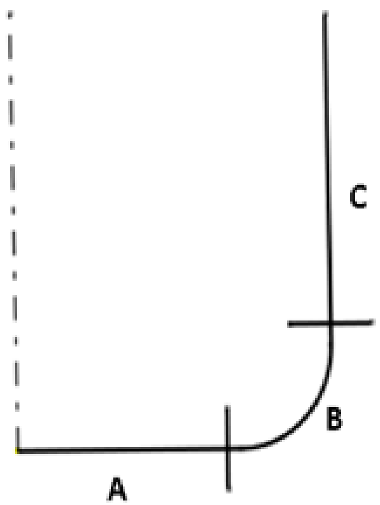
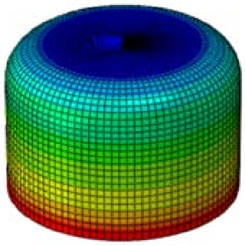


Fig. 8 Different regions on the formed parts

Fig. 9 shows a part of the cylindrical cup formed with maximum pressure of 20 MPa along with its simulation results. The initial pressure of 2 MPa was applied to the bottom of the blank. Then, the downward gradual movement of the punch increased the pressure to the maximum value (20 MPa). At this moment, the pressure control valve opened and the process continued with the constant pressure. Fig. 10 shows the thickness distribution curves for the cylindrical part with the maximum pressure of 20 MPa. As it is seen in the figure, there is a good correlation between the results of the experiment and the simulation. The thickness reduction at the bottom of the cup (region A) is small due to the tensile stresses. The most thickness reduction occurred at the corner radius of the cup (region B) because of the bending occurrence. Because of compressive stresses in the flange area, at the end of the cup wall, the thickness is increased.

A



B

Fig. 9 Deformed work piece corresponds to maximum pressure 20 MPa (A) Experiment (B) Simulation

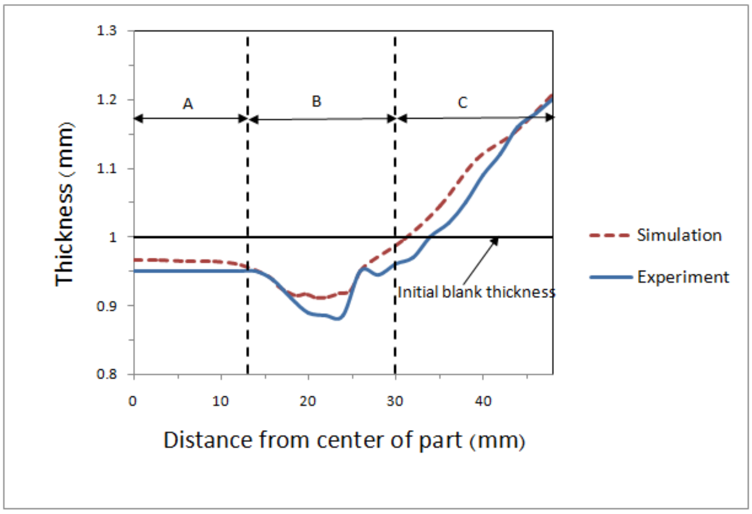


Fig. 10 Thickness distribution of cylindrical cup corresponds to maximum pressure 20 MPa

The thickness distribution curves of liner pressure path with different maximum pressure for cylindrical cup are displayed in Fig. 11. As it can be seen in the figure, the maximum pressure has a great effect on the thickness of region A and B. In order to obtain the best forming pressure path, the maximum thickness reduction curves in regions A and B was investigated. Fig. 12 shows the thickness reduction in regions A and B corresponding to liner pressure paths with different maximum fluid pressures. The maximum thickness reduction in these two regions happens when there is no pressure under the blank. As the figure shows, by increasing the maximum pressure to 27 MPa, thickness reduction in region A decreases sharply. A maximum pressure higher than 27 MPa does not have any significant effects on the thickness reduction in region A. On the other hand, by increasing the maximum pressure, the thickness reduction in region B decreases with a lower slope in comparison to region A and from the maximum pressure of 20 Mpa, the pressure does not have any positive effects on the thickness of this region. Thus, maximum pressure greater than 27MPa does not have any effect on the thickness of regions A and B. In hydroforming process, the liquid pressure pushes the blank to the surface of the punch and causes a large surface contact between the punch and the sheet. This causes more friction force between the punch and the blank and prevents the sheet slipping. Therefore, by increasing the pressure, the thickness reduction in critical areas decreases.

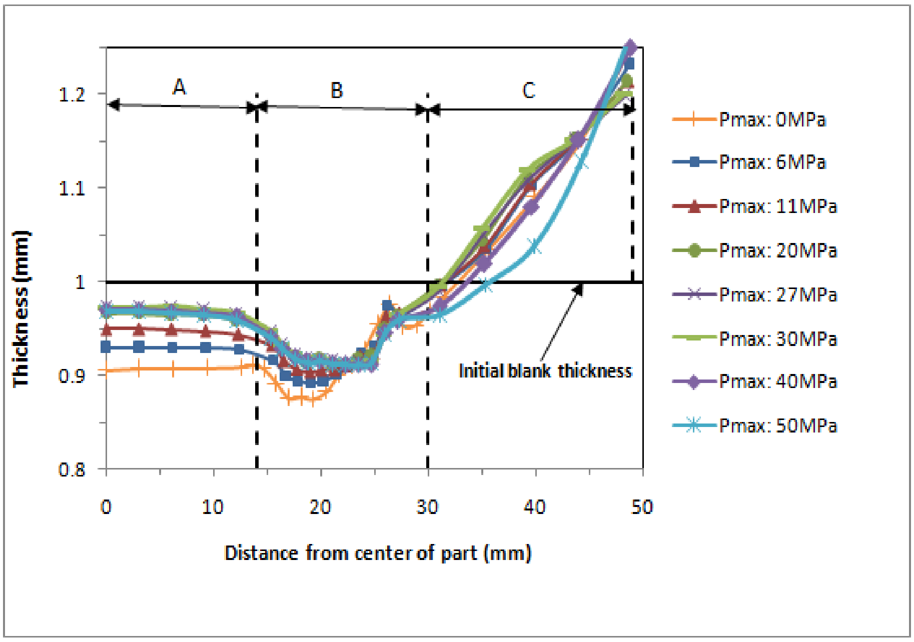
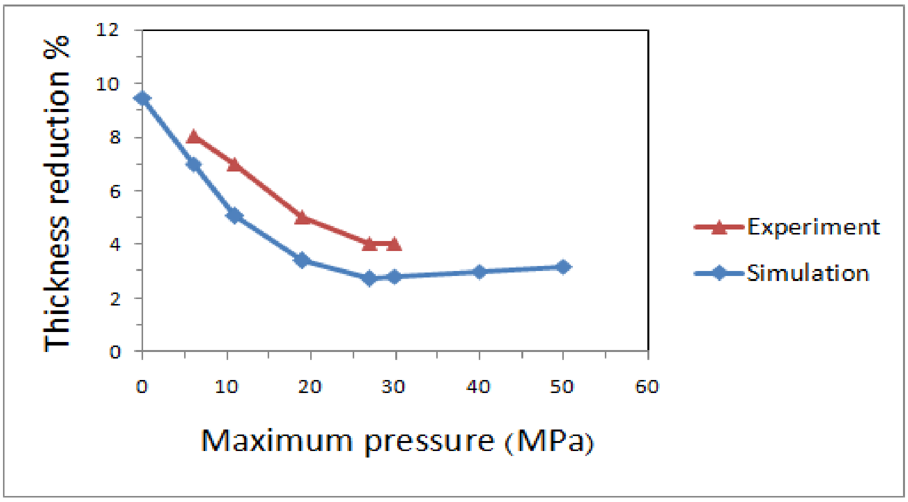
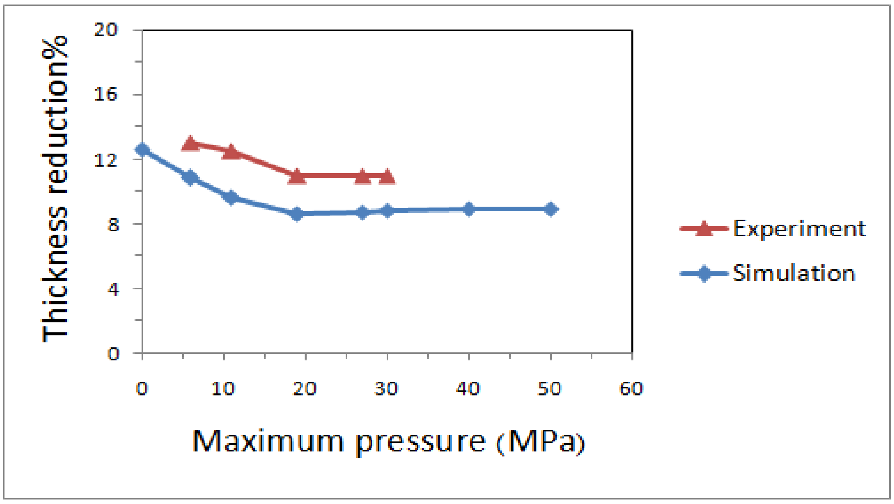


Fig. 11 Thickness distribution curves of different pressure paths for cylindrical cup with flat bottom obtained from simulation



A



B

Fig. 12 Thickness reduction versus maximum pressure (A) region A (B) region B

Fig. 13 shows the step pressure path. With the step pressure path, as can be seen in Fig. 14, in initial stage, the blank between the blank-holder and the punch is pre-bulged with increasing pressure. The pressure decreases to a certain amount so the blank moves into die cavity easier, then with increasing the pressure again which moves (bulged) the blank between the blank and the blank-holder and the these steps are continued to form the final work piece.

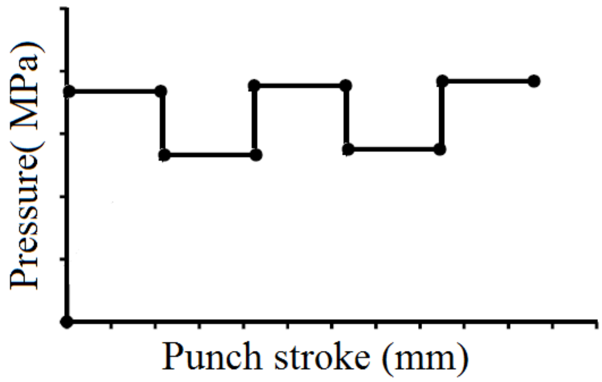


Fig. 13 Step Pressure path

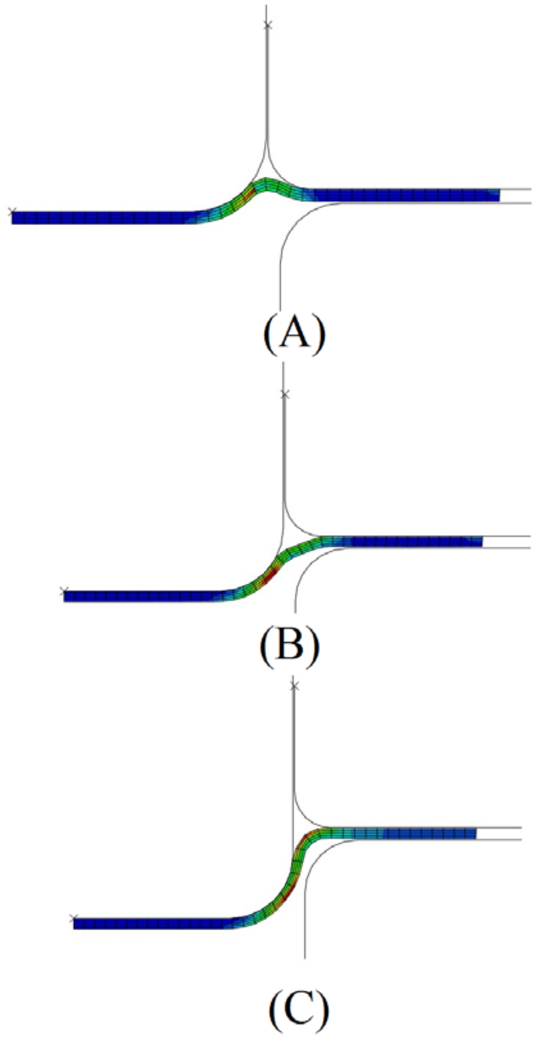


Fig. 14 Forming process by step pressure path (A) pre-bulging (B) decreased pressure (C) Bulging again

Fig. 15 shows the step pressure path used in this study. The initial pressure in this pressure path is 20 MPa to pre-bulge the blank between the blank-holder and the punch, and then the pressure decreases to 15MPa when the punch starts to move down. After 2mm moving down, the pressure re-increases to 20 MPa and the blank bulges consequently. This process was repeated till the final workpice formed. It can be seen in the figure that in 5 mm displacement, the pressure amount increased because the deeper the depth, the more pressure is needed for bulging the blank.

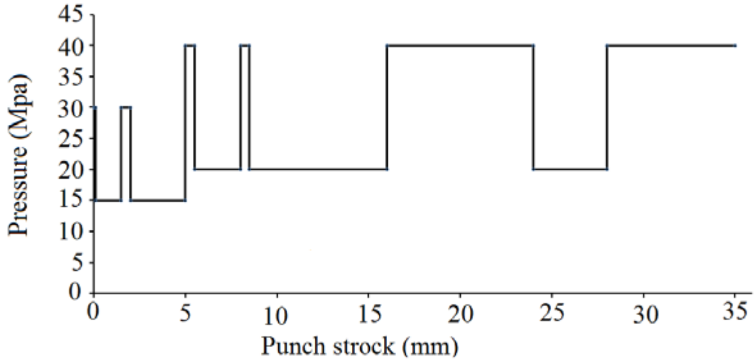


Fig. 15 Step pressure path used in this study

Fig. 16 shows the thickness distribution of cylindrical part with the step pressure path. As it can be observed, thickness reduction at the cup bottom (region A) is very small, near the initial thickness of the blank. The thickness reduction at the corner radius of the cup (region B) is smooth.

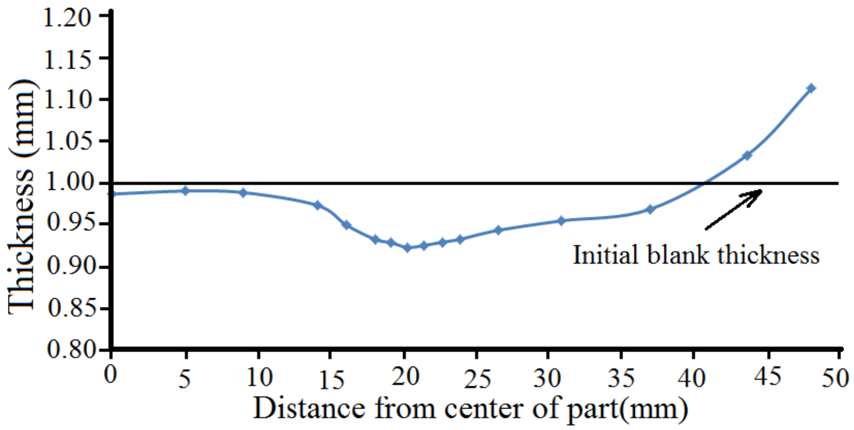


Fig. 16 Thickness distribution curves of step pressure path for cylindrical cup with flat bottom

Fig. 17 compares the thickness distributions of the cylindrical cups by using linear pressure path with maximum pressure of 50 MPa and by using step pressure paths. It is shown in the figure that by using step pressure path, the thickness distribution will be better. Thickness reductions at the bottom of the cup (region A) and at the corner radius of the cup (region B) are not very much and in region C thickness is close to the initial blank thickness. For using step pressure path, professional valves are needed.

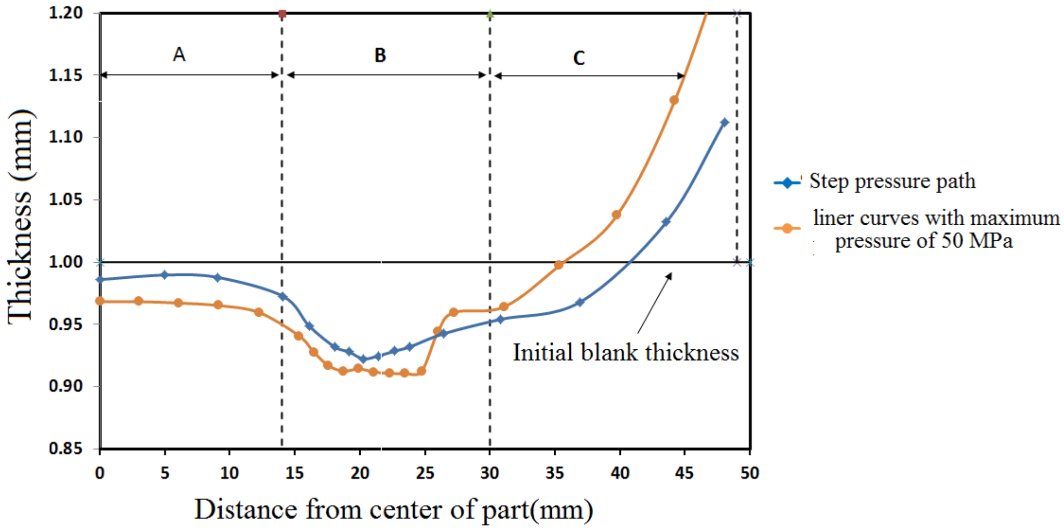


Fig. 17 Thickness distribution curves by linear pressure path with maximum pressure of 50 MPa and step pressure paths for cylindrical cup

As it can be figured out, using step pressure path in the forming of cylindrical workpiece results in better thickness distribution in comparison to using linear pressure. In regions A and B, the thickness reductions are less, and in region C it is approximately the initial thickness. The main problem of the step pressure is the application of the pressure, which needs professional valves controlled by computers, whereas the application of linear pressure path is easier through the punch movement.

V. CONCLUSIONS

In this research, for investigating the pressure path effects on the thickness distribution in the forming of cylindrical workpieces, two different pressure paths, linear pressure and step pressure paths, were investigated by practice and simulation. The results showed that in linear pressure path, the maximum pressure had great effect on the formability; pressure increase to a certain amount caused thickness reduction, but pressure greater than this amount had no influence on the thickness distribution of the workpiece.

It was also observed that by using linear pressure path, smoother thickness distribution could be obtained. However, using this method requires some special equipment, whereas linear pressure path with maximum pressure can be created very easily through punch movement.

REFERENCES

[1] S. Zhang, Z. Wang, Y. Xu, Z. Wang, and L. Zhou, “Recent developments in sheet hydroforming technology,” *Journal of Materials Processing Technology*, vol. 151, pp. 237-241, 2004.

[2] S.-H. Zhang, “Developments in hydroforming,” *Journal of Materials Processing Technology*, vol. 91, pp. 236-244, 1999.

[3] L. Lang, Z. Wang, D. Kang, S. Yuan, S.-H. Zhang, J. Danckert, et al., “Hydroforming highlights: sheet hydroforming and tube hydroforming,” *Journal of Materials Processing Technology*, vol. 151, pp. 165-177, 2004.

[4] S. Thiruvarudchelvan and F. Travis, “Hydraulic-pressure-enhanced cup-drawing processes—an appraisal,” *Journal of Materials Processing Technology*, vol. 140, pp. 70-75, 2003.

[5] L. Lang, J. Danckert, and K. B. Nielsen, “Investigation into hydrodynamic deep drawing assisted by radial pressure: Part I. Experimental observations of the forming process of aluminium alloy,” *Journal of Materials Processing Technology*, vol. 148, pp. 119-131, 2004.

[6] L. Lang, J. Danckert, and K. B. Nielsen, “Investigation into hydrodynamic deep drawing assisted by radial pressure: Part II. Numerical analysis of the drawing mechanism and the process parameters,” *Journal of materials processing technology*, vol. 166, pp. 150-161, 2005.

[7] C. Özek and M. Bal, “The effect of die/blank holder and punch radiuses on limit drawing ratio in angular deep-drawing dies,” *The International Journal of Advanced Manufacturing Technology*, vol. 40, pp. 1077-1083, 2009.

[8] X. Liu, Y. Xu, and S. Yuan, “Effects of loading paths on hydrodynamic deep drawing with independent radial hydraulic pressure of aluminum alloy based on numerical simulation,” *Journal of Materials Science and Technology*, vol. 24, pp. 395-399, 2008.

[9] H. Wang, L. Gao, and M. Chen, “Hydrodynamic deep drawing process assisted by radial pressure with inward flowing liquid,” *International Journal of Mechanical Sciences*, vol. 53, pp. 793-799, 2011.

[10] L. Lang, T. Li, X. Zhou, J. Danckert, and K. B. Nielsen, “The effect of the key process parameters in the innovative hydroforming on the formed parts,” *Journal of materials processing technology*, vol. 187, pp. 304-308, 2007.

[11] L. Lang, J. Danckert, and K. B. Nielsen, “Investigation into the effect of pre-bulging during hydromechanical deep drawing with uniform pressure onto the blank,” *International Journal of Machine Tools and Manufacture*, vol. 44, pp. 649-657, 2004.

[12] A. Gorji, H. Alavi-Hashemi, M. Bakhshi-jooybari, S. Nourouzi, and S. J. Hosseinipour, “Investigation of hydrodynamic deep drawing for conical–cylindrical cups,” *The International Journal of Advanced Manufacturing Technology*, vol. 56, pp. 915-927, 2011.

[13] Baosheng Liu, Lihui Lang, Yuansong zeng, and Jianguo Lin, “Froming characteristic of sheet hydroforming under the influence of through-thickness normal stress,” *Journal of Materials Processing Technology*, vol. 212, pp. 1875-1884, 2012.