Increasing the Limiting Drawing Ratio of AA 5754 Aluminum Sheet by Hydromechanical Deep Drawing Process

M. Halkaci[1)], M. Turkoz[2)*], M. Dilmec[3)], S. Halkaci[3)], B. Daghan[3)]

[1)] Technical Sciences Vocational School of Higher Education, Selcuk University, Konya, Turkey; [2)] Department of Seydisehir Mechanical Engineering, Selcuk University, Konya, Turkey; [3)] Department of Mechanical Engineering, Selcuk University, Konya, Turkey

* Corresponding author: E-mail address: mevlutturkoz@selcuk.edu.tr; Tel.: +90 332 223 3051

Abstract

Formability of sheet metals can be increased by Hydromechanical Deep Drawing (HDD) process. Formability of the deep drawn cups is generally assessed by Limiting Drawing Ratio (LDR) which is the ratio of the blank diameter to punch diameter. In order to increase LDR by HDD, process parameters of the HDD should be arranged properly. Generally to obtain a successfully formed part in HDD, the main parameters which are fluid pressure and blank holder force, must be changed according to punch stroke. Arranging the fluid pressure and blank holder force vs. punch stroke curve conveniently by the method of trials and errors is a hard duty. So these parameters should be arranged by using FEA. In order to obtain the maximum LDR, the appropriate fluid pressure and blank holder force curves were investigated in this study. Finally LDR of the hydromechanical deep drawn AA 5754 cup was determined both numerically and experimentally.

Keywords: Hydromechanical deep drawing, HDD, LDR

Introduction

The demand for manufacturing lightweight structures induces the use of aluminium alloys (Lang et al. 2009). One of the most used aluminum alloy is AA 5754 which has very good corrosion resistance, good weldability and moderate strength. With these properties it is usually used in vehicle industry.

Many sheet metal parts in industry are produced by deep drawing process. Formability of the deep drawn cups is generally assessed by Limiting Drawing Ratio (LDR) which is the ratio of the blank diameter to punch diameter. LDR values of the deep drawn cups are limited around 2.0. Because aluminium alloys have poor formability; their formability can be improved by Hydromechanical Deep Drawing (HDD) process. With this method LDR values of 2.7 can be achieved in some materials and the parts having good surface quality, higher dimensional accuracy and complicated parts can be manufactured (Lin et al. 2009). HDD process is a kind of soft tool technology which was originated from hydroforming. In HDD a pressurized fluid is taken as a female die and the punch being a rigid body. As the punch forms the sheet, pressurized fluid assists the sheet against the punch and spins it on the punch (Zhang and Danckert 1998). In HDD process firstly the sheet is compressed at a definite blank holder force in such a manner that there is no fluid leakage neither is there wrinkling on the sheet as the sheet is deformed. Then the sheet is bulged by a given pre-bulging pressure towards the punch while the punch is fixed at a definite position below the sheet **(Fig. 1a)**.Then the punch progresses and forms the sheet at a given forming pressure (Yossifon and Tirosh 1988)**(Fig. 1b)**. Pre-bulging has two functions in the process. The first building pressure at the beginning of the forming stage and the second is hardening the material near the punch radius and increasing its strength against a fracture (Lang et al. 2004).

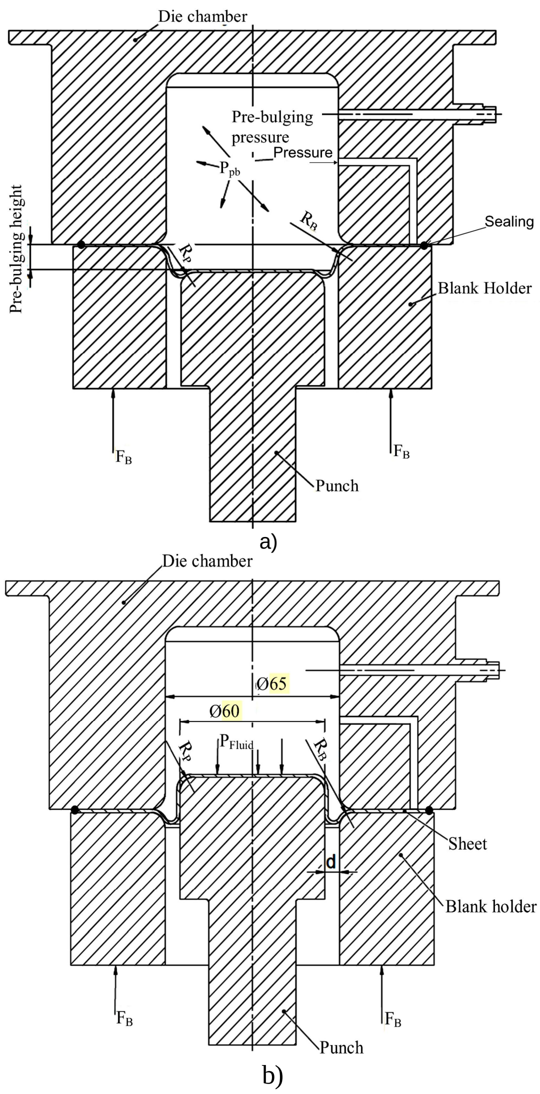

Figure 1. The experimental setup of HDD process, a) pre-bulging step, b) forming step

The process parameters that can affect possession of a successfully formed cup are fluid pressure, blank holder force, friction between the sheet and the punch; the sheet and the blank holder, the radius of the punch, the gap between the punch and die, the pre-bulging pressure and height (Zhang et al. 2000). As the HDD is a complicated process, it needs the use of Finite Element Method (FEM) to determine the correct parameter values. So that many failures in the sheet such as fracture, thinning and wrinkling can be analyzed and predicted without any expensive experimental repetitions.

In this study convenient fluid pressure versus punch stroke curves are obtained by analysis. By using this curve and blank holder force versus punch stroke curve, AA 5754 cylindrical cups were deep drawn with HDD process and the Limiting Drawing Ratio of the process for the material was obtained.

Finite Element Modelling of the HDD

In this study HDD process was simulated with Abaqus FEM software. Forming process was modeled as axisymmetric as shown in **Fig.2**. Continuum, axial symmetric and four node elements (CAX4R) were used for the sheet. Die chamber, blank holder and punch were modeled as analytical rigid parts.

The material was used in annealed form. Modeling of the material was conducted with stress-strain curve of the AA 5754 by tensile test. The properties of the material were given in **Table 1**. The true stress-strain curve of the AA 5754-O is shown in **Fig. 3** (Turkoz et al. 2010). As the elongations in biaxial stretching are too much in comparison to uniaxial stretching, the stress strain curve was extrapolated by the power law hardening rule of the material. Then extrapolated data was used in the analysis

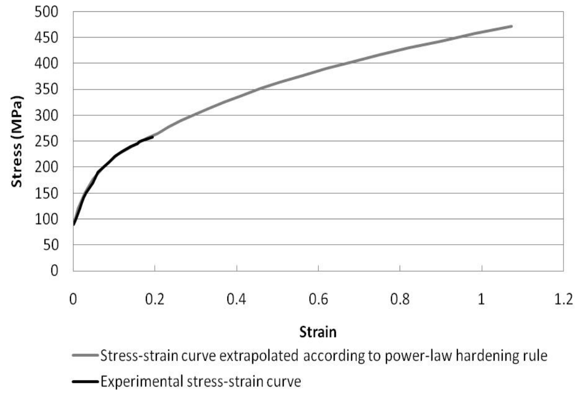

Figure 3. True stress-strain curve of the AA 5754-O material (Turkoz et al 2010)

(Fig3). Calculations in the analysis were made according to von-Mises material model.

The analysis of the forming process was performed in explicit mode in three steps. In the first step, the sheet which has a definite diameter is compressed between die chamber and blank holder at a certain force. In the second step pre-bulging is applied. In this step the punch is fixed at a definite distance below the sheet. The distance is called pre-bulging height. Then the sheet bulges against the punch at a definite pressure. In the third step the punch progresses. The blank holder force and fluid pressure parameters are arranged according to the position of the punch.

The friction coefficients between the sheet and the punch, the die chamber and the blank holder are assumed as in **Table 2**. These coefficients were estimated by performing many simulations and evaluating the simulation results that are the best compatible with experiments. The penalty friction formulation was used to define contact between the sheet and the other tools.

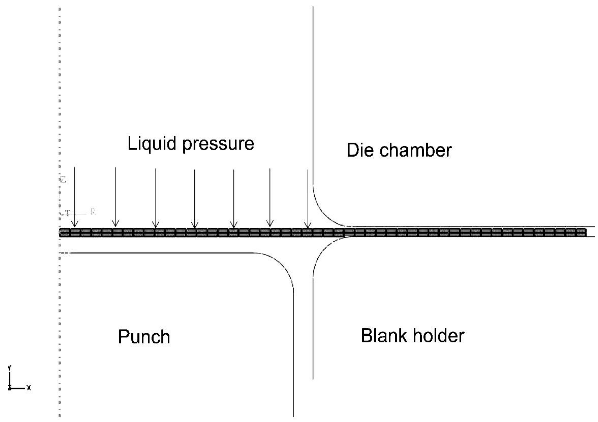

Figure 2. The FEM model of the HDD process

Table 1. The mechanical properties of the AA 5754-O

Direction*	RD	DD	TD
Yield Strength (MPa)	90	91	93
Tensile Strength (MPa)	212	209	208
Young Modulus E (GPa)	65	63	42.3
Total Elongation (%)	22.05	27	25.27
Strain hardening index n	0.338	0,335	0.341
Strength Coefficient K (MPa)	470	448	456

*RD, DD and TD designate Rolling, diagonal and tranverse direction respectively.

Table 2. The parameters used in modeling of the HDD process in FEA

Poisson's ratio	0.3
Young's modulus, E (MPa)	70000
Density (kg/m^3)	2700
Strength coefficient, K (MPa)	726
Hardening index, n	0,21
Punch diameter, D (mm)	60
Punch profile radius, R_p (mm)	5
Diameter of die chamber (mm)	65
Blank holder profile radius (mm)	5
Gap between punch and die, d (mm)	5
Friction coefficient (blank and die)	0.05
Friction coefficient (blank and punch)	0.25
Friction coefficient (blank and blank holder)	0.08
Pre bulging height (mm)	2
Pre bulging pressure (bar)	25
Blank holder force (kN)	30

The parameters and their values used in modeling of the HDD process by FEA are listed in **Table 2**. As these parameters are held constant, fluid pressure is varied with the punch stroke. The LDR of the material was calculated from the maximum sheet diameter of the successfully drawn part using the most convenient curve. Although 20 kN blank holder force was used in the simulations, it was arranged as variable in the experiments in order to compensate for the force created by fluid pressure on the sheet. The fluid pressure curve is very important for successful deep drawing. The most convenient fluid pressure curve was investigated by making many analyses. Also the other process and geometrical parameters given in **Table 2** were determined by analyses. In the analysis in order to determine whether the material attained the forming limit, a failure criterion was assumed. This failure criterion is the thinning of the material by 20%. When the unappropriate values of the parameters are used, the analysis was aborted as shown in **Fig. 4.** The highest drawing ratio of 2.33 was obtained on the curve shown in **Fig. 5**. An analysis result belonging to a successfully deep drawn cup is shown in **Fig. 6.**

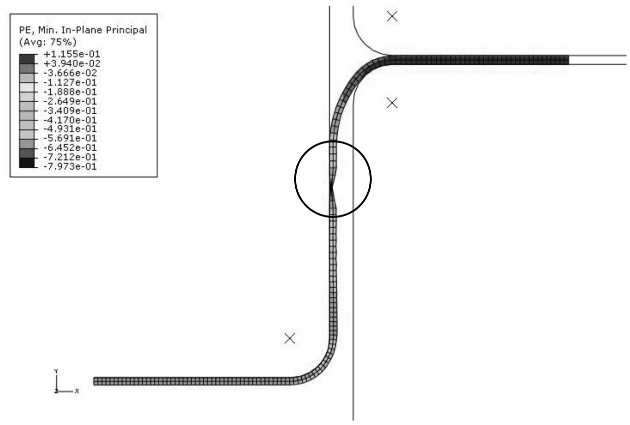

Figure 4. The analysis result of using unappropriate parameter values

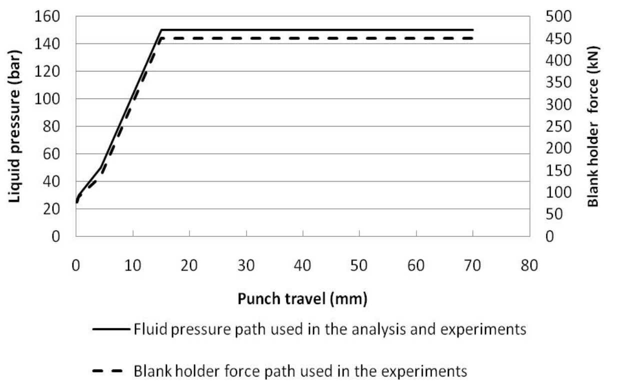

Figure 5. Fluid pressures and blank holder force paths used in the analysis and the experiments

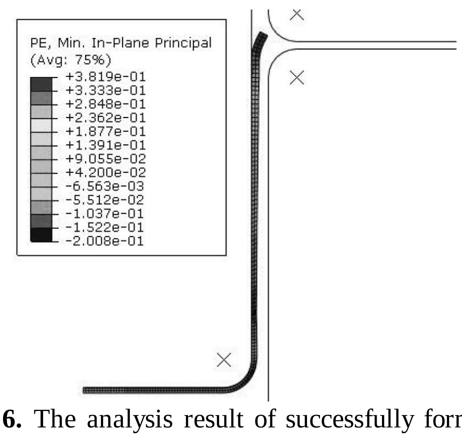

Figure 6. The analysis result of successfully formed cup by the HDD process

Experimental Results

The procedure of the HDD process is as following.

1. The sheet is lubricated by a polyethylene film except the area in contact with the punch.
2. The sheet is placed on the blank holder in the manner that it is centred with the other tools.
3. The blank holder force is applied to hold the sheet.
4. The punch is positioned below the sheet at pre-bulging height as in **Fig.1 a**.
5. The die chamber is filled with the fluid and pressurized up to pre-bulging pressure. So the sheet bulges towards the punch.
6. The punch progresses to forming the sheet. As the punch progresses, the fluid pressure and the blank holder force are adjusted according to the punch position as in **Fig.1 b**. In order to simplify flowing of the sheet a radial fluid pressure is applied around the sheet.

Cylindrical cups were deep drawn with designated procedure.

The experiments were carried out on a hydroforming press. The press has qualifications of 60 ton punch force, 80 ton blank holder force and 1000 bar fluid pressure.

Figure 7. The successfully deep drawn cups formed by HDD process

These parameters and punch position can be arranged and actual values of the parameters can be recorded during the process.

The pressure path obtained in the simulations was used in the experiments. While a constant blank holder force was applied in the simulations, the force applied in the experiments was variable. The arrangement of the blank holder force was done by multiplying the fluid pressure with the area affected from fluid pressure and adding the result with 30 kN as shown in **Fig. 5**. So the effect of the fluid pressure on the blank holder was compensated.

In conclusion with using the parameters given, the cups could be deep drawn successfully as shown in **Fig. 7.**

Figure 8. Examples of the failured specimens.

Otherwise the failures were encountered as shown in **Fig. 8**. The positions of the failures are in good agreement with the analysis.

Results and Discussion

By using mentioned parameters in the experiments a limiting drawing ratio of 2.27 was obtained. When the classical deep drawing process was conducted, the LDR of the material was obtained as 2.0. So an increase in the LDR value was gained by HDD process. This difference can be more noticeable if looked from the photographs of the drawn cups by classical deep drawing and hydromechanical deep drawing as shown in **Fig. 9**. The obtained LDR value by HDD process for AA 5754-O is given in Serhat's study (2008) as 2.4. But there are some differences between the two studies in material properties, geometrical and process parameters. While the yield strengths and tensile strains are nearly the same, the tensile strength of the material in Serhat's study is twice that

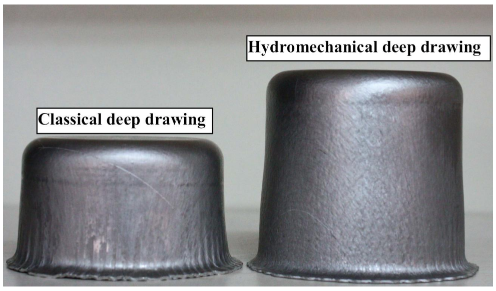

Figure 9. The deep drawn cups formed by classical deep drawing and HDD process

obtained in this process. In order to increase the obtained LDR value of the material, the followings need to be improved.

- There was an uncertainty in arranging the blank holder force. Due to the fact that leakage of the fluid causes changes in the pressurized area, and as a results preventing a certain value that holds the blank from not being arranged exactly. In order to provide the sealing, new die designs should be made.
- Other process and geometrical parameters like pre-bulging height, the radii of the punch, blank holder and die chamber as well as the gap between the punch and the die can be selected much appropriately. In order to arrange these parameters more accurately, the values of the parameters and their effects to the LDR must be investigated by multi-level experiments using design of the experiment method.
- The friction between the sheet and the blank holder can be reduced by using different lubricants.
- Effort was made to keep the net blank holder force (blank holder force minus the force coming from the liquid pressure) constant in the study. This can be arranged to be variable according to punch stroke.

The obtained LDR values by analyses and experiments are near each other. The difference between the analysis and the experiment are reasonable with respect to the assumptions made about material model and friction coefficients in the analyses. The HDD process could be conducted successfully by the aid of the analysis.

Conclusion

In order to increase the LDR value of AA 5754-O material, an investigation on optimum fluid pressure path in HDD process was conducted. The optimum fluid pressure path, blank holder force and other process and geometrical parameters were investigated by the aid of simulations in order to reduce the number of trial and error. The HDD experiments were performed by using the determined parameter values from the simulations. Consequently as the LDR of the material obtained in classical deep drawing was 2.0, a LDR value of 2.27 was attained in the experiments. So the formability of the AA 5754 material could be increased by HDD process.

For future works, the increasing of the LDR can be improved by arranging the process parameters, changing the net blank holder force according to the punch stroke etc.

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