The effect of friction coefficient on punch load and thickness reduction in deep drawing process

Sadık Olguner, A. Tolga Bozdana

***Abstract*—**This paper presents a numerical study for the determination of the effect of friction coefficient on punch load and thickness reduction in cylindrical cup deep drawing process. The effects of friction have been investigated by Finite Element Method (FEM). Finite element simulations have been carried out with material model of AISI 1006 cold rolled steel for deep drawing by using DEFORM-3D software. It was seen that the required punch load increases significantly with the increase of coefficient of friction between forming tools and sheet blank. Additionally, in order to see how limiting drawing ratio (LDR) is influenced by the friction, thickness reduction of sheet blank at flange and wall regions of drawn cup is evaluated for a specified drawing ratio under the influence of different friction conditions. Reduction of thickness was found to be more pronounced under a higher friction effect.

***Keywords*—**Deep drawing process, limiting drawing ratio (LDR), finite element method (FEM), coefficient of friction.

I. INTRODUCTION

SHEET metal forming covers a significant part of manufacturing industry providing wide range of products for everyday life [1]. Deep drawing is one of the most important sheet metal forming processes and widely used in industry to produce cup-shaped components such as kitchen utensils, beverage cans and car body parts.

Throughout many years, the strong demand for improvement of products has lead researchers to dig deep into the deep drawing process [1]. However, there are still some difficulties in deep drawing of specific materials with specific thicknesses due to the fact that formability of such materials may not permit required degree of deformation at such thicknesses. Due to the strong dependence of formability on the friction conditions between tools and blank as well as the resistance of material against deformation, reducing such friction and resistance becomes an important research topic to improve the processing.

At present, many researchers have studied the friction models and effect of friction on deep drawing process. Ma et al. [2] have investigated the effect of friction coefficient in deep drawing of aluminum alloy AA6111 sheets at elevated temperatures based on finite element analyses and experimental approach. It is concluded that the formability of the aluminum alloy is influenced significantly by the friction coefficient.

Jayahari et al. [3] suggested a methodology in order to evaluate the friction coefficient between sheet blank and tools using finite element analyses and experimental results. Also, punch loads for forming were calculated at different temperatures. It was noticed that there was a considerable improvement in formability by increasing temperature.

Trzepiecinski et al. [4] determined the coefficient of friction experimentally in deep drawing process for drawing steels that are commonly preferred in automobile industry. As a result, it is shown that the friction coefficient is the function of metal surface roughness, lubricant condition and sheet orientation.

Başpınar and Akkök [5] introduced a combined friction model by integrating the Khonsari's and Wilson's models. It is resulted that Khonsari's frictional model gives more accurate results below a specified film thickness ratio and Wilson's model gives better results above the same film thickness ratio.

Tamai et al. [6] developed a nonlinear friction coefficient model which considers contact pressure, sliding velocity and sliding length in order to improve the accuracy of predictions of the formability of steel sheets. The results of cup drawing experiments and finite element analysis using the developed friction model revealed that the model improves the accuracy of predictions of the formability of steel sheets.

In addition to studies that investigate the effect of friction in deep drawing operations, there are many studies including different techniques to weaken the influence of friction in deep drawing process. Use of electromagnetic, hydromechanic or servo controlled forming systems, placing the lap-sheets on the both side of the plate to be drawn, application of variable blank holding force and the use of ultrasonic vibrations on the forming tools are some of these techniques. Application of ultrasonic vibrations was found to provide one of the most effective results among these applications for reducing the frictional effect. Pasierb and Wojnar [7] investigated the effects of ultrasonic vibrations in drawing of thin-walled products. The preliminary theoretical friction model was given in their study. The main contribution was that the decrease in deformation force was caused by utilization of active friction force in defined portion of vibration period.

This work is supported by The Scientific and Technological Research Council of Turkey (TUBITAK) with the project under the grant number of 315M300 and by University of Gaziantep Scientific Research Project Administration Unit (BAP) under the grant number of RM.15.01.

Sadık Olguner is with the Department of Mechanical Engineering,University of Gaziantep, 27310, Gaziantep, TURKEY (phone: +90-342-3172529; fax: +90-342-3601104; e-mail: olguner@gantep.edu.tr).

A. Tolga Bozdana is with the Department of Mechanical Engineering, University of Gaziantep, 27310, Gaziantep, TURKEY (e-mail: bozdana@gantep.edu.tr).

Jimma et al. [8] summarized various methods of applying oscillations of vibrations in deep drawing operations. They constructed an experimental apparatus with vibrating blank-holder or die plate in the radial mode. The effects of two frequency oscillations (i.e. 20 kHz and 28 kHz) were investigated on LDR of cold rolled steel and 304 stainless steel. Results of experimental trials indicated that the application of ultrasonic oscillation increases LDR of 0.5 mm thick sheets from 2.68 to 3.01, from 2.58 to 2.94, and from 2.38 to 2.77. In addition, the maximum punch load was reduced by 15% due to such vibrations.

Siegert and Ulmer [9] discussed the possibility of influencing the friction in deep drawing process by superimposing ultrasonic waves. Reduction of the frictional force was detected with dies oscillating at ultrasonic frequencies in the range of 20-22 kHz parallel to the drawing direction. The reduction in friction force was found to be a function of ultrasonic amplitude and drawing velocity. It was emphasized that such reduction was less with increasing drawing velocity.

Ashida and Aoyama [10] mentioned that the reduction of friction force in drawing process was essential for high quality products, and hence they proposed the utilization of high frequency vibrations to reduce friction. Finite element method was used for analyzing the vibration modes of metal, and the validation of analyses were confirmed in comparison with theoretical and experimental results. In addition, the results of numerical simulation of process were presented. It was indicated that the coefficient of friction between blank and die without lubricant was approximately 0.5 whereas that with ultrasonic vibration was approximately 0.15. The coefficient of friction between blank and die together with lubricant and ultrasonic vibration was approximately 0.1.

Wen et al. [11] examined the effects of quasi-ultrasonic vibrations on deep drawing of AZ31 magnesium alloy sheets at room temperature. From the geometry of drawn cups and the observation of microstructure within large deformation area, it was indicated that high frequency vibrations had great influence on formability, forming load and failure mode of AZ31 due to volume effect as well as surface effect.

Kim and Lee [12] constructed an experimental setup by installing ultrasonic equipments onto die and investigated the influence of superimposed high frequency vibrations on producing cylindrical cups from cold rolled steel sheet. Conventional and vibration assisted drawing tests were carried out at various drawing ratios. In order to evaluate the contribution of ultrasonic vibration to the reduction of friction between tools and blank, finite element analyses were carried out. As a result, it was emphasized that application of ultrasonic vibrations effectively improves LDR by reducing the friction between tools and blank.

Huang et al. [13] performed micro deep drawing process combined with ultrasonic vibration on 304 stainless steel foils of different thicknesses to determine the influence of ultrasonic vibrations on micro-cup formability and LDR. The experimental results showed that using ultrasonic vibrations increased LDR from 1.67 to 1.83, from 1.75 to 1.92, from 1.83 to 2.0 for sheet thicknesses of 50, 75, 100 μm, respectively. It was also revealed that the reduction of forming force was more obvious with applying ultrasonic vibration when compared with using soybean oil for lubrication.

Kriechenbauer et al. [14] investigated the effects of superimposed low-frequency vibrations of 10-50 Hz at cushion and press ram. Wrinkles were reduced, and the drawing ratio was increased from 2.1 to 2.4 by the effect of low frequency vibrations.

As discussed above, there are many studies attempts to reduce frictional effect between forming tools and sheet blank in deep drawing process. In this study, effects of friction coefficient alteration on the required punch load for forming and thickness reduction of sheet metal to be drawn for a specified limiting ratio have been investigated.

II. DEEP DRAWING PROCESS

Deep drawing is a sheet metal working process in which a sheet metal blank is drawn into a forming die by the mechanical action of a punch [15], as illustrated in *Fig. 1*. In this process, sheet metal blank is held between die and blank holder. The blank holder is loaded by uniform or varying force to prevent wrinkling and control the flow of sheet metal. The punch is pushed down into die cavity, simultaneously transferring the specific shape of punch and die to the sheet metal blank, and hence forming a cup.

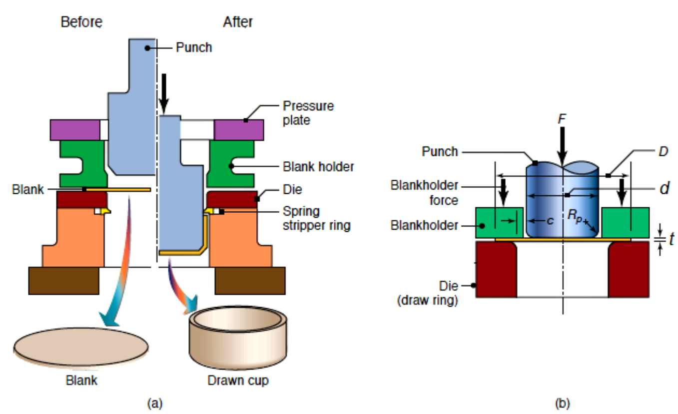

Fig.1. Deep drawing process [16], (a) drawing a cup, (b) process variables.

There are a number of distinctive features of deep drawing process: friction condition between forming tools (i.e. punch / die / blank holder) and blank material, forces acting on punch and blank holder, clearance between punch and die, fillet radii of punch and die, Limiting Drawing Ratio (LDR) that shows the maximum extent of drawing in one step without wrinkling and tearing, number of drawings to attain the final shape of deep drawn cup, and speed of forming.

One of the most important parameters in deep drawing process is LDR and it is directly related to thickness reduction of sheet metal during drawing. LDR depends upon properties of the blank material as well as diameter of the punch, friction condition between tools and blank, fillet radius of punch, and lubricant used to reduce friction coefficient [17]. LDR (β) can be expressed as:

$$LDR = \beta = \left(\frac{D}{d}\right) \approx e^{\eta} \tag{1}$$

In this equation, D and d refer to the diameters of sheet metal blank and punch, respectively. η is an efficiency term to account for frictional losses. For an ideal case where there is no friction between tools and blank material, $\eta=1$ and β is approximately equal to 2.7. Theoretically, it is not possible to completely eliminate the frictional condition. Thus, in practical applications, η is assumed to be 0.7 and β is approximately equal to 2. For the products to be drawn at an extent of above LDR, the process is to be accomplished in multiple steps. In such case, drawing ratios are expressed as $\beta_1 = D/d_1$, $\beta_2 = d_1/d_2$, $\beta_3 = d_2/d_3$, … $\beta_n = d_{n-1}/d_n$ where d_1, d_2, d_3,…d_n refer to the punch diameters in first, second, third, and n steps, respectively.

Another important parameter in deep drawing process is punch load since it is directly related to energy consumption. The punch force required to produce the cup is the summation of ideal force of deformation, frictional forces, force required to produce ironing. The following equation gives approximate calculation of drawing force [18]:

$$P = \left[\pi dt\left(1.1\bar{\sigma}\right)\ln\frac{D}{d} + \mu\left(2H\frac{d}{D}\right)\right]e^{\left(\mu\pi/2\right)} + B \tag{2}$$

where P is the total punch load; t is the sheet thickness; $\bar{\sigma}$ is the mean flow stress; H is the blank holding force (BHF); B is the force required for bending; μ is the coefficient of friction between tool and blank.

As discussed above, determination of the thickness reduction and punch load is fairly critical for deep drawing operations. However, thickness reduction and punch load are difficult to calculate analytically since it is not possible to determine efficiency and friction terms exactly. Therefore, numerical techniques such as finite element method are widely used for the calculation of punch load and LDR in deep drawing operations.

III. Finite Element Method

Finite element method has recently become a significant tool for studying the mechanics of sheet metal forming processes, which provides accurate and realistic simulations. Such analyses are going to be employed in the aspects of minimizing production costs of die and punch, reducing the number of trials in experimental study, improving the environmental protection, manufacturing the products with desired quality and shortening the time of production.

In this study, a three dimensional finite element method is adopted. All finite element analyses are carried out by DEFORM-3D commercial finite element analysis package. As shown in *Fig. 2*, a 30º section of the sheet blank is analyzed using symmetric plane boundary conditions instead of modeling the whole geometry in order to shorten simulation time. Punch, die and blank holder assumed to be rigid and sheet blank has elasto-plastic material model. Hill's quadratic yield criterion is used with kinematic hardening. Blanks for deep drawing analyses are AISI 1006 cold rolled steel for deep drawing with a thickness of 1 mm. Tetrahedral 4-noded three dimensional elements are used to mesh solid structure of the sheet blank. The total number of elements is 15064 with 3680 nodes.

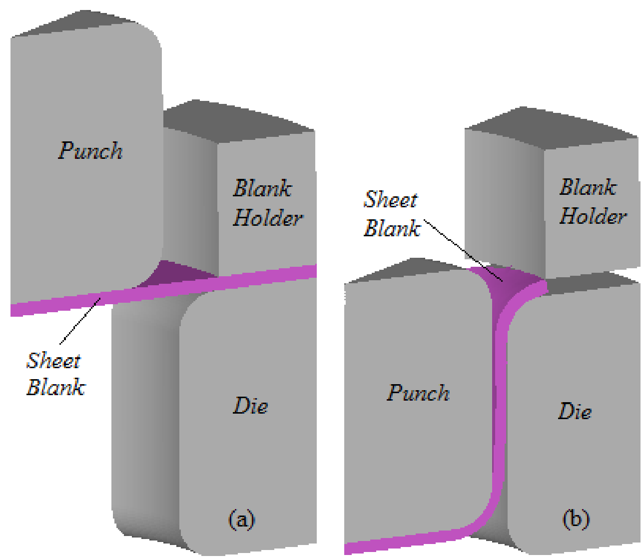

Fig. 2. Finite element model of cylindrical cup, (a) before deformation, (b) after deformation.

The diameter of the punch and die hole is 25 mm and 27.6 mm, respectively and radius of each corner is 3 mm. Initial diameters of the sheet metal are 50 mm and the diameters of the drawn cups are 25 mm. Thus, drawing ratios in all analyses are equal to 2. 18.75 mm drawing depth is completed in 200 steps with 0.09375 mm constant punch displacement in each step. In order to prevent wrinkling of the sheet material, a constant 2400 N blank holder force applied to blank holder. The forming speed is set to 3 mm/s and all analyses are carried out in cold drawing conditions. Totally 6 different analyses are performed by adopting shear friction model with 0, 0.05, 0.10, 0.15, 0.20, 0.25 coefficients of friction between forming tools and sheet material.

IV. Analyses And Results

Finite element analyses have been performed for 6 different shear friction coefficients. The variations of punch load during forming and required minimum punch load to accomplish operations have been determined. Thickness reductions of the sheet blanks at flange and wall regions have also been investigated. The thickness reduction at wall region is found to be more critical for that specific application. Full view of the cylindrical drawn cup is shown in *Fig. 3*.

Fig. 3. Full view of the deep drawn cup.

A. Punch Load

Punch load variations for different friction coefficients are shown in *Fig. 4*. It is seen from the figure that the increase of friction coefficient significantly increases the required punch load. Required forming load is 27.48 kN for the theoretical condition without friction (μ=0). It increases to 27.84 kN for μ=0.05, 31.2 kN for μ=0.1, 32.76 kN for μ=0.15, 34.92 kN for μ=0.20 and 36.12 kN for μ=0.25. It is observed that the increase of coefficient of friction from 0 to 0.25, causes increase of punch load more than 30%.

B. Thickness Reduction

Blank thicknesses of sheet material after forming operation are illustrated in *Fig. 5*. It is seen from the figure that the increase of friction coefficient reduces blank thickness at wall region considerably. Material thickness of 1 mm is decreased to 0.871 mm for theoretical condition without friction. It is reduced to 0.815 for μ=0.05, 0.796 for μ=0.1, and 0.748 for μ=0.15. Necking and tearing are observed on the blank sheets for μ=0.20 and μ=0.25, respectively. Thickness reduction of the blank sheet is 12.9% even if the friction is assumed to be 0. It is 18.5% for μ=0.05, 20.4% for μ=0.1 and 25.2% for μ=0.15. Further increase of friction coefficient caused the deterioration of the drawn cup due to excessive reduction of material thickness.

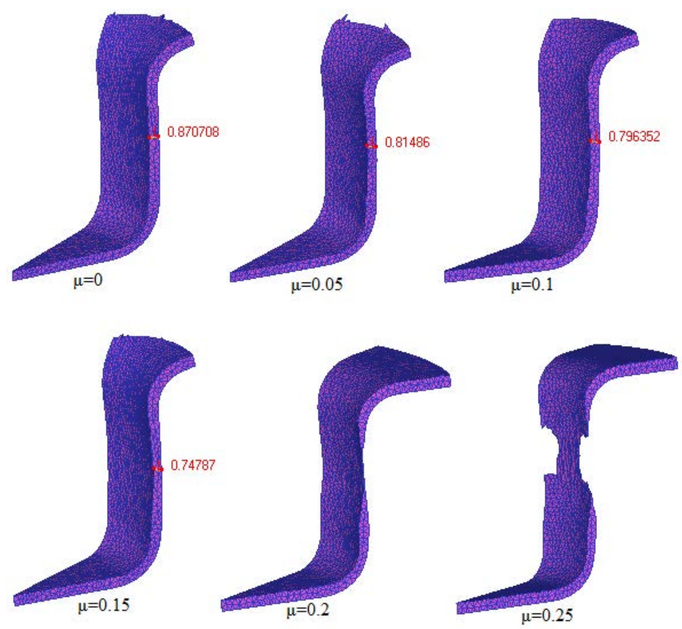

Fig. 5. Blank thicknesses of sheet material after forming operations.

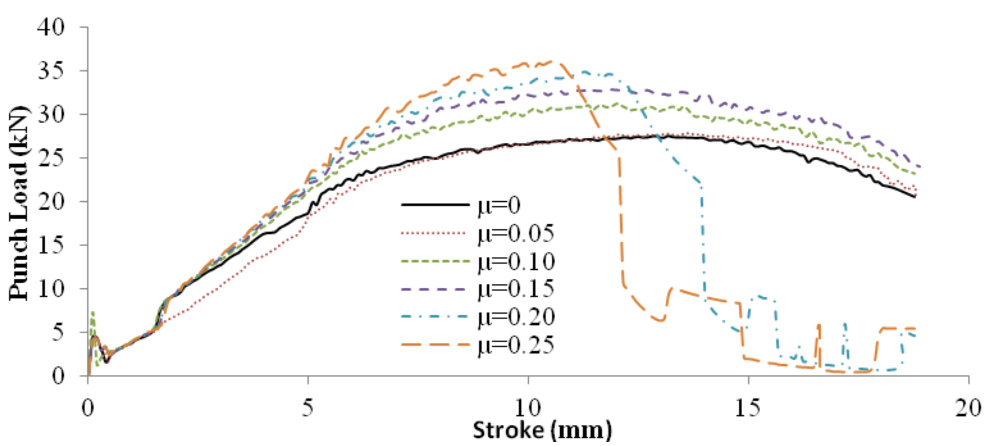

Fig. 4. Punch load variation during forming for different friction coefficients.

V. Conclusion

Required punch load for deep drawing of a cylindrical cup and thickness reduction of the sheet material are studied by using a numerical approach. A finite element model is generated and 6 different analyses are carried out by changing the coefficient of friction between forming tools and blank sheet. Elasto-plastic finite element analyses have been performed in DEFORM-3D. It has been observed that the increase of friction coefficient from 0 to 0.25 results an increase in punch load 30% approximately. Also, it is clear from the analyses that increasing of the friction coefficient between tools and blank sheet reduces final thickness of the sheet metal significantly. Thickness reduction of the sheet is increased from 12.9% to 25.2% while the coefficient of friction is increased from 0 to 0.15. Further increase in coefficient of friction results the deterioration of the drawn cup.

References

[1] H. H. Gharib, “Analysis of the cup drawing process and optimization of the blank holder force”, MSc. Thesis, 2004.

[2] W. Ma, B. Wang, L. Fu, J. Zhou, M. Huang, “Effect of friction coefficient in deep drawing of AA6111 sheet at elevated temperatures”, Transactions of Nonferrous Metals Society of China, vol. 25, issue. 7, pp. 2342-2351, 2015.

[3] L. Jayahari, P. V. Sasidhar, P. P. Reddy, B. BaluNaik, A. K. Gupta, S. K. Singh, “Formability studies of ASS 304 and evaluation of friction for Al in deep drawing setup at elevated temperatures using LS-DYNA”, *Journal of King Saud University-Engineering Sciences*, vol. 26, issue 1, pp. 21-31, 2014.

[4] T. Trzepiecinski, A. Bazan, H. G. Lemu, “Frictional characteristic of steel sheetsused in automobile industry”, *International Journal of Automotive Technology*, vol. 16, issue 5, pp. 849-863, 2015.

[5] M. Baspinar, M. Akkok, “Modeling and simulation of friction in deep drawing”, Journal of Tribology, vol. 138, issue 2, 2015.

[6] Y. Tamai, T. Inazumi, K. Manabe, “FE forming analysis with nonlinear friction coefficient model considering contact pressure, sliding velocity and sliding length”, Journal of Materials Processing Technology, vol. 227, pp. 161-168, 2016.

[7] A. Pasierb, A. Wojnar, “An experimental investigation of deep drawing and drawing processes of thin walled products with utilization of ultrasonic vibrations”, Journal of Materials Processing Technology, vol. 34, pp. 489-494, 1992.

[8] T. Jimma, Y. Kasuga, N. Iwaki, O. Miyazawa, E. Mori, K. Ito, H. Hatano, “An application of ultrasonic vibration to the deep drawing process”, Journal of Materials Processing Technology, vol. 80-81, pp. 406-412, 1998.

[9] K. Siegert, J. Ulmer, “Influencing the friction in metal forming processes by superimposing ultrasonic waves”, CIRP Annals - Manufacturing Technology, vol. 50, pp. 195-200, 2001.

[10] Y. Ashida, H. Aoyama, “Press forming using ultrasonic vibration”, Journal of Materials Processing Technology, vol. 187-188, pp. 118-122, 2007.

[11] T. Wen, R. Gao, X. Chen, “Influence of high frequency vibration on deep drawing process of AZ31 sheet at room temperature”, *Journal of* Shanghai Jiaotong University, vol. 17, pp. 456-460, 2012.

[12] S. W. Kim, Y. S. Lee, “Investigations on the effect of ultrasonic vibration in cylindrical cup drawing processes”, Key Engineering Materials, vol. 622-623, pp. 1152-1157, 2014.

[13] Y. M. Huang, Y. S. Wu, J. Y. Huang, “The influence of ultrasonic vibration-assisted micro-deep drawing process”, *International Journal of Advanced Manufacturing Technology*, vol. 71, pp. 1455-1461, 2014.

[14] S. Kriechenbauer, R. Mauermann, P. Muller, “Deep drawing with superimposed low-frequency vibrations on servo-screw presses”, *Procedia Engineering*, vol. 81, pp. 905-913, 2014.

[15] DIN 8584-3, “Manufacturing processes forming under combination of tensile and compressive conditions-Part 3: Deep drawing; classification, subdivision, terms and definitions”, 2003.

[16] S. Kalpakjian, S. R. Schmid, “Manufacturing Processes for Engineering Materials”, 5th edition, Pearson Education, 2008.

[17] Schuler, “Metal Forming Handbook”, Berlin: Springer-Verlag, 1998.

[18] J. Schey, “Introduction to Manufacturing Processes”, McGraw-Hill Publication, 1987.