Parametric Influences in Hydro Mechanical Deep Drawing: A Review

Bhavesh Gadkari[a*], Chandrakant Bhatia[b], Chintan Barelwala[c]

[a] PG Research Scholar, Mechanical (CAD/CAM), Gandhinagar Institute of Technology, Gandhinagar, Gujarat, India.
[b,c]Assistant Professor, Gandhinagar Institute of Technology, Gandhinagar, Gujarat, India.

Abstract

Hydro-mechanical deep drawing (HMDD) is a new sheet metal forming technology originating from hydroforming technology to manufactured automobile parts, beverage cans and cookware of high strength and light weight. Various process and geometrical parameter influence the quality produced by hydro mechanical deep drawing. This paper is highlighting recent research work and results in HMDD. HMDD operations are executed to produce a high strength, low density and light weight. These requirements will rise the failure defects in the product. Parameters like Pre bulging pressure, Chamber Pressure, Coefficient of friction, Blank holder pressure, Drawing ratio, Punch speed and punch velocity, punch radius, die corner radius and springback affect HMDD. Understanding of process is required to produce product with minimum defects. This review paper has given the attention to collect latest progress, development and research work in the area of HMDD.

Keywords: Hydro-mechanical Deep Drawing, Pre bulging, Blank Holding Force, Friction, Drawing Ratio.

1. Introduction

Products made of sheet metals are all around us. They contain an extensive range of consumer and industrial products, such as beverage cans, metal desks, appliances, cookware, car bodies, trailers, and aircraft fuselages. Sheet metal is any metal that has a thickness in between 0.5 to 6 mm. In sheet-metal working, there is no need for additional machining as required for casting and forging works. It is the production of closed bottom cylindrical or rectangular containers from thin metal sheets. This process is sometimes called shell drawing, because one of the earliest applications of this process was the production of artillery shells and cartridge cases. When the ratio of depth of the product to its diameter (or the smallest dimension of its opening) is greater than 1, the process is known as deep drawing, whereas when the ratio is less than 1, it is considered as shallow drawing.

HMDD is a sheet metal forming technology creating from hydroforming technology. It consociates the features of both conventional deep-drawing process and hydroforming technology. The bottom of the sheet is supported with a bed of pressurized viscous fluid during forming process.

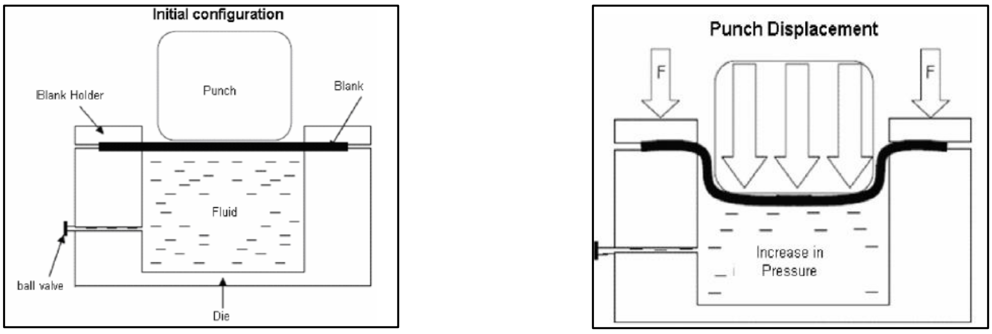

Fig 1. Hydro Mechanical Deep Drawing Process (a) Initial configuration (b) Punch Displacement

The punch deforms the sheet to its finishing shape by moving against a controlled pressurized fluid. The purpose is to form deep drawn cups without any kind of forming instability such as wrinkling, buckling, or bursting. The HMDD process comprises 2 steps: firstly, Pre-bulging step, in which blank is bulged by initial pressure and secondly drawing step with applied controlled pressure. In this step, a punch draws the blank into a chamber that has been filled by a controlled fluid medium (usually oil) as the female die. The fluid pressure used in the HMDD process mainly so that friction can be significantly reduced and so that clamping (or friction holding effect) between punch and blank can prevent the fracture of the blank at the punch corner, thus enabling the LDR value to be increased.

---

* Bhavesh Gadkari
E-mail address: bhaveshgadkari@gmail.com

There are many benefits of HMDD, over traditional metal forming processes, such as increased drawing ratio, forming of complex shapes, better surface quality, cost-effective parts and lower tool costs. The female die in the traditional; deep drawing process is replaced by a cavity filled with a fluid in the HMDD process. The final form of the part is determined by the punch. The usage of the fluid make possible to decrease the friction and to prevent metal-to-metal contact at the blank-die interface which improve the possibilities of obtaining a better geometry of the final products.

The factors affect the Hydro mechanical deep drawing process may be categorized into two categories. (1) Process parameters (2) Geometrical Parameters. Process parameters include pre bulging pressure, chamber pressure, coefficient of friction, blank holder force, drawing ratio. Geometrical parameters include Punch radius, die corner radius, clearance and springback.

2. Literature Review

The Hydro mechanical deep drawing has been a most important area of research for the forming of the sheet metals. The various parameter influencing the HMDD are

1. Pre bulging pressure
2. Chamber pressure
3. Coefficient of friction,
4. Blank holder force,
5. Drawing ratio,
6. Punch speed and punch velocity
7. Punch radius,
8. Die corner radius
9. Clearance
10. Springback

2.1 Pre Bulging Pressure

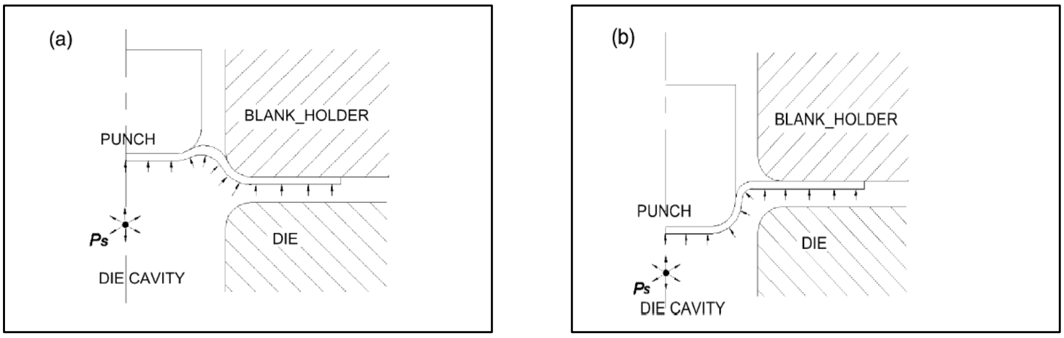

Fig 2. Pre-bulging methods (a) Plus pre-bulging method (PPB), (b) Minus pre-bulging method (MPB)

Pre-bulging height is the distance between the punch and blank before forming process. Pre bulging method incorporates 2 types (a) plus pre-bulging method (PPB) (b) Minus pre-bulging method (MPB). Pre bulging influence the uniformity of the product. Many process parameters such as the sheet thickness, the blank holder entrance radius, the die entrance radius, the clearance between the punch and the blank holder and the material properties of the sheet will impact the effects of pre-bulging. Generally, pre-bulging has two functions: building the pressure at the initial stage of forming, and pre-forming the sheet to interaction with the punch nose radius for stopping the fracture. The pre-bulging method has 2 parameters including pre-bulging pressure and pre-bulging height. F. Rahmani (2021) has investigated the effect of pre bulging pressure in HMDD process for square parts. HMDD for square parts was studied using FEA and Abaqus software has used for simulation. An experimental study has been also carried out to verify FEA result. Different simulations had carried out to conclude the influence of pre-bulging pressure on a maximum thinning by keeping fixed space between blank and punch. The blank can't reach to punch at lower pressure and it doesn't bulge and therefore the thinning increased. On the other hand, the blank is subjected to further extension at higher pre-bulging pressure. Minimum thinning is optimized by set a parameter of pre-bulging pressure Between 20 to 35 Bar. S. Yagohubi (2020) has presented an investigation on the effects of the process parameters of HMDD on manufacturing high-quality bimetallic spherical-conical cups. The bimetallic cup consists blank of aluminum and steel sheets. Two criterions has been selected to evaluate the effects on quality of the final product are thickness variation and thickness strain. The most substantial effect of the pre-bulge pressure was observed at the wall of the composite cup, where the separation of the layers was nearly prevented and, so the total thickness variation of the product was improved. The quality of the final product was improved by means of reduction of thinning with increasing the fluid pressure up to 15Mpa. Maximum thickness strain and thickness variation in the study were gained to be 57% and 68%, respectively, in comparison with the conventional deep drawing process. L. Lang (2003) has Investigation of the effect of pre-bulging for HMDD with uniform pressure on blank. The pre-bulging consist 2 factors: pre-bulging pressure and pre-bulging height. The pre-bulging have greater impact on the initial forming stage as well as initial middle forming stage final formed cups but has no affect the final stage of forming cups. Around the punch nose the sheet will harden significantly by the bending and unbending effect, which will be very useful in stopping the occurrence of fracture. The pre-bulging height will be useful to prevent fracture here because of friction reduction between the blank and the punch. However, if using too-high pre-bulging height, fracture initiated due to heavy bending and unbending. At the starting of the forming stage, the pre bulging will affect the liquid pressure variation considerably.

2.2 Chamber Pressure

F. Rahmani (2021) submitted their work Thickness Distribution in HMDD Process for Square Parts. In this paper, different parameters like chamber pressure, bulging pressure and friction coefficient were investigated on thinning. Various simulations were carried out in different final chamber pressure to determine the effect of chamber pressure on the maximum of thinning. In all states, pre-bulging pressure (Pi) was considered 20 Bar. It can stated that from study, for 2 different LDR, the maximum of thinning increased at higher pressure, but wrinkling was decreased by increasing the chamber pressure in the flange zone. Wrinkling is generally shown in the flange area. Thinning was lower at the bottom side than the other areas and Thinning observed in the wall area is high. S. Yaghoubi (2020) has presented HMDD for manufacturing high-quality bimetallic spherical-conical cups and investigate on the effects of the process parameters on thickness distribution. Both the quality and uniformity of the final double-layer product was improved by optimizing a chamber pressure and by this study it has conclude that the optimize pressure is 15Mpa. Tensile stresses and the bending at the punch tip were uniformly distributed in HMMD comparison with conventional deep drawing so can say that the level of thinning was noticeably reduced. H. Ballikaya (2019) has studied the LDR in HMDD method in which die shape is angled. Taguchi experimental design method is used for investigating the effect of the different parameters on LDR. ANOVA which is a statistical formula used to analyze the data statically for evaluate the effect of different parameters on LDR. LDR increases with chamber pressure at some extent and after that it started decreasing. At 8MPa.The chamber pressure gave the optimum LDR When the chamber pressure was increased up to 8MPa, it was determined that the LDR increased up to 2.6 and decreased after this value.

2.3 Coefficient of Friction

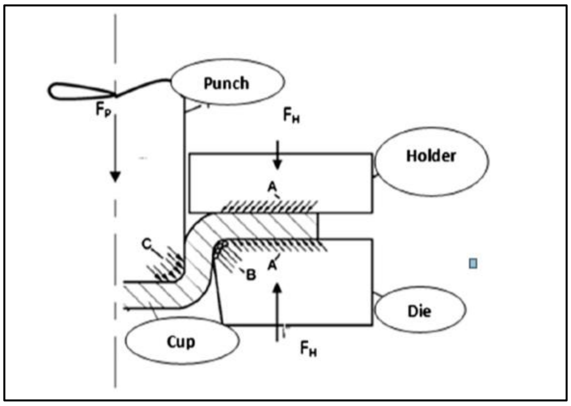

Fig. 3. Friction area when deep drawn a cup (A) Friction area between sheet metal blank and holder and sheet metal blank die; (B) friction area between sheet metal blank and the die radius and (C) friction area between sheet metal blank and punch edges; F_P - total drawing force; F_H, blank holder force.

The coefficient of friction, μ, is a measure of the amount of friction existing between two surfaces. A low value of coefficient of friction point out that the force required for sliding to take place is less than the force required when the coefficient of friction is high. K. There is generally 3 friction area considered when deep drawn a cup which shown in figure. A indicate a friction area between sheet metal blank and blank holder. B indicates friction area between sheet metal blank and the die radius and C indicates friction area between sheet metal blank and punch edges. The friction influences the energy which is desirable to deform a sheet material. Friction also affect the stresses and strains in the work piece material and, hence, the quality of the product. Therefore, it is important to control the friction between the tools and the work piece. Wiratchakul studied on Effect of Friction Coefficient in Hydro mechanical Deep Drawing Process on Part Quality for Parabolic Part. FE analysis has done by LS-DYNA program. AISI 1008 used in this work. This research examined the effect of friction coefficients: binder/blank ($\mu_{S\,(B/B)}$) and punch/blank ($\mu_{S\,(P/B)}$) on the wrinkle and thinning defect in the HMDD by FEM. Friction coefficients of $\mu_{S\,(B/B)}$ and $\mu_{S\,(P/B)}$ defined in range of 0.00-0.15 and 0.00-0.25, consequently. To analyze effect of friction coefficient on part quality for parabolic parts, least square regression method was selected to apply. Study indicates that thinning is affected by $\mu_{S\,(B/B)}$ and $\mu_{S\,(P/B)}$ and wrinkle is affected by $\mu_{S\,(B/B)}$ and interaction of $\mu_{S\,(P/B)}$ and $\mu_{S\,(B/B)}$. So, $\mu_{S\,(B/B)}$ is very crucial because it affect both of the wrinkle and thinning defect for the HMDD. Thus, it should be considered firstly. Form the analysis, the proper friction coefficient of $\mu_{S\,(B/B)} = 0.06$ is chosen to avoid wrinkles from occurring on the part. Then, the thinning quality can be improved by increment of $\mu_{S\,(P/B)}$. H. Zein (2014) presented Thinning and spring back prediction of sheet metal in the deep drawing process. The blank is made of MS. A FE model was developed for the numerical simulation of the deep drawing process with help of ABAQUS software. For validation, the FE results has compared with experimental results. The developed model predicts the thinning, the thickness distribution and spring back of the blank which is affected by punch force, the blank holder force and the lubrication. The fluid lubricant with (μ_p = 0.25), is more appropriate for the punch/blank interface to decrease the thinning and the springback in the cup. The fluid lubricant with (μ_h = 0.125–0.2), is appropriate for the holder/blank. Interface, (μ_h) should be around 0.18 to reduction of thinning and the springback in the cup. The fluid lubricant with (μ_d = 0.125–0.2), is appropriate for die/blank interface. (μ_d) is recommended to be about 0.16 to decrease the thinning and the max residual stresses within the cup wall. Wen-yu MA (2015) has investigated Effect of friction coefficient in deep drawing of AA6111 sheet at elevated temperatures. In this study, the effect of the friction coefficient ranging from 0 to 0.30 is evaluated. Results show that the friction coefficient and lubrication position considerably impact the minimum thickness, the thickness deviation and the failure mode of the formed parts. In terms of formability, the optimal value of friction coefficient determined in this study is 0.15. Thinning occurs near corner of the cup. The crack occurred at the center of cup bottom is the ductile fracture, while in ductile and brittle mixed fracture, the crack occurred near the cup corner. Q. Liu (2012) has investigated cushion conditions optimization for micro multi point sheet forming. The effect of material of cushion and friction coefficient on the sheet thickness distribution had investigated. Because of Good lubrication condition, Better thickness distribution and surface quality and can be obtained. It has found that friction influence the relative thickness distribution and surface quality in micro MPF. A lesser friction coefficient produces a superior surface quality and makes the thickness variation of the formed sheet higher. F. Vollertsen (2008) has studied Determination of size dependent friction functions in sheet metal forming w.r.t. the contact pressure distribution. In ABAQUS software, friction can be applied to realize size dependent FEA simulation. Applying the new friction features in ABAQUS, the virtual punch pressure vs. punch journey curves definite a higher settlement with the experimental curve. J.Hol (2015) investigated Multi-scale friction modeling for sheet metal forming with the boundary lubrication system. Outcomes display that friction coefficients range in space and time, and rely upon condition such as plastic strain and nominal contact pressure in sheet material. Friction model is confirmed through 2 small-scale forming processes, proving the improved predictive abilities of FE simulations. The slight growth in FE computation time, as compared to the use of a Coulomb primarily based totally friction version, demonstrates the efficiency of the proposed friction model. However, the outline of the material behavior itself will become increasingly. D. Karupannasamy(2012) has investigated Modelling blended lubrication for deep drawing processes. The coefficient of friction decreases because of hydrodynamic results and additionally will increase because of the have an effect on of stress. Further, the nominal pressure, stress and sliding velocity have been taken from FE simulation of a cup and used within side the mixed lubrication model to calculate the coefficient of friction. The coefficient of friction was shown for cup drawing at 3 distinctive drawing depths.

2.4 Blank Holder Force

Blank holder force (BHF) is important parameter in HMDD process and it influence wrinkle formation. In complex parts, Deep drawn cup can't manufactured by using constant BHF, so variable BHF is also used. The-Thanh Luyen (2021) has presented a deep drawing process using the graphical method and simulation as well as experimental study have been carried out. Firstly, Flow stress curve has evaluated by conducting experimental tests and for this uniaxial tensile specimens was used. Secondly, by using maximum force criterion (MMFC), the fracture point at plain strain, biaxial strain and biaxial tensile strain has calculated. After that, Forming limit curve (FLC) estimated with use of graphical method. Fracture height was determined by FEA and it compared with experiments. The study showed a good agreement between simulated and measured fracture height with a highest of 3.6 % deviation. BHF of 7.5 to 17.5kN is selected for study. The fracture height of the cylinder cup during process reduces by increasing BHF. There is no fracture at low BHF and BHF mostly occurs in the flange area because of insufficient compressive force. Also, there is no wrinkle on wall side. H. Ballikaya (2019) has investigated the LDR in die angled HMDD method. In this study, the experimental set-up of die angled HMDD was designed and established for conducting the tests. In the sub chamber of die, Hydro Oil Aw 46 was used as a forming fluid. The effects of the parameters on the LDR were numerically examined and compared experimentally using ANSYS packaged software. From this study, it can say that the optimum value of BHF parameter was 5882.72N and at this BHF LDR increases up to 2.6 and after that LDR decreases. H. Zein (2014) has developed experimental set up to calculate the Thinning and spring back prediction of the deep drawing process. A FE model was developed for the numerical simulation of the deep drawing process with help of ABAQUS. For validation, the FE results has compared with experimental results. The developed model predicts the thinning, the thickness distribution and spring back of the blank which is affected by punch force, the blank holder force and the lubrication. It has been shown from study that BHF increases over 0.5 tons, cup collapsed due to thinning. The strain over the punch face will greater at the high BHF. BHF also influences the springback percentage. With increasing the BHF up to 5 tons springback percentage is stable and after that value springback percentage increases. L. Lăzărescu (2015) has investigated Evaluation of thickness distribution and drawing force in the deep drawing process with variable blank holding force. The objective of this work was to examine the consequence of BHF on the wall thickness distribution and drawing force for cylindrical and square cups made from AA 6016-T4 aluminum alloy in deep drawing process. Drawing forces increases with blank holding forces. Drawing force is influenced by the amount of Blank holding force. The wall thinning in the punch shoulder part cannot be influenced by the constant or variable BHF considered in this study. The constant or variable BHF can't affect the wall thinning in the punch shoulder part. The thickening at the side wall of cups can be influenced by variable and constant BHF. Ultimately, it was shown that the increasing in BHF leads to a reduction of thickening of the side wall cups. S. Tommerup (2012) studied Experimental verification for adaptive blank holder pressure distribution of a deep drawing tool system. 8 different cavity pressure schemes are applied during the punch stroke and its effects are documented by way of process data and 3D coordinate measurements of the formed parts establishing that both the thickness distribution and the geometric shape in the formed parts can be affected by the shimming system.

2.5 Drawing ratio

Deep drawability generally is expressed by the limiting drawing ratio (LDR) as LDR = Maximum blank diameter/punch diameter. LDR can limited by thickening at the flange. The flange portion is subjected to compressive load (circumferential) and tensile load (radial). Flange thickness increases due to circumferential load. Biaxial tensile loading at cylindrical portion affecting the thinning of sheet. And at the blank and tool interface affecting a fracture at the interface correspondingly. So thickening and thinning at flange portion and blank-tool interface correspondingly can controlled by BHF. S. Yaghoubi (2020) has an investigation on the effects of the process parameters of HMDD on bimetallic spherical-conical cups. This paper study analytically, numerically and experimentally study the HMDD process of bimetallic specimens. In this research work, double-layer blanks was used which consist 2 sheets, St13 and 1200 Al sheets The drawing depth, one of important parameters in various deep drawing processes, is defined in the present research work as: DD = H/d where H and d represent the final depth and the product diameter, respectively. The max. Thickness strain of the final product was determined for Al/St and St/Al layer sequences at various drawing depths to validate the results of the numerical simulations of the HMDD process. The HMDD operation was performed for 2 drawing depths of 0.40 and 0.55 with the purpose of investigate the effects of process parameters. With a maximum pressure of 30MPa at a drawing depth of 0.55, the experimental and numerical simulation has done for composite cups for sheet order of Al/St and St/Al layer. The workpiece was subjected to stretching and bending at the contact area with the punch tip. This condition could exaggerate the thinning at workpiece and contact area of the punch tip in comparison with the other areas of the spherical conical cup. The Thanh Luyen has studied on the deep drawing process for SPCC sheet using the graphical method. Simulation and experimental study has also carried out to investigate the effect of different parameters. Uniaxial tensile specimens is prepared and experimental tests were conducted to conclude the flow stress curves. In this study, ABAQUS software is used to analysis the deep drawing of cylindrical cup. A high drawing ratio ensures a constant contact area between blank holder and blank with the purpose of increase the capability of deformed sheet metals in the deep drawing. But, thinning and tearing take place with large drawing ratio. The calculation of the fracture points at plane strain, uniaxial tensile strain, and biaxial tensile strain was presented using the modified maximum force criterion (MMFC). The influence of drawing ratio on the fracture height is examined. Generally, the drawing ratio range is between 1.6 and 2.2 for most metals. A high drawing ratio is expected in the deep drawing process of sheet metals because a higher drawing ratio ensures a stable contact area between blank holder and blank with the intention of increase the ability of deformed sheet metals in the deep drawing. Though, large drawing ratio can cause unwarranted thinning and tearing of the metals. The drawing ratio is selected from 2.1 to 2.4 in this investigation. The punch corner radius and the blank holder force are set to 4 mm and 10kN respectively. It can be seen that with increasing drawing ratio, the fracture height gradually decreases. The deviation % of fracture height shows that the estimated and measured results are well matched with a max. Error of below 4%. I. Irthiea (2020) has investigated the Effect of process parameters on micro flexible deep drawing for SS304 cups utilizing floating ring. The floating ring is used to reduce minor wrinkles that normally occur at the flange, while the flexible die is used to complete the forming stroke. In this study, the consequence of choosing different initial sheet thickness, punch corner radius, drawing ratio and rubber height is investigate through simulations and experiments. This article presents a micro deep drawing in which consist of a floating ring (primary rigid die), and with a rubber pad (main flexible die) is engaged for forming cups. The function of the floating ring is to reduction of wrinkles that commonly occur at flange, while the flexible die is used to complete the forming stroke. For FEA, ABAQUS software is used. Several experiments are carried out using a special setup to validate the numerical results. The LDR obtained at the three scale factors adopted in this study are 2.63, at and $\lambda = 0.5$ and 1 where the blank diameters are 5.25 and 2.75 mm, respectively, and 2.5 at $\lambda = 2$ where the dia. is 10 mm. A Reddy has studied deep drawing of circular cups for calculate limiting drawing ratio and for that experimental study and simulation has carried out and compared both result. The AA6111 aluminum alloy of different sizes sheet blanks were drawn using optimum forming conditions which established through Taguchi experimental method. The LDR found for AA6111 was 1.8325 in this study. The critical diameter was found 146.6 mm in the study.

2.6 Punch Speed and Punch Velocity

Y. Dewang (2020) has studied effect of the velocity of the punch on Deformation Behaviour in Deep Drawing of Aluminum Alloy. The material is used for this investigation is AA-1100-O. FE simulation of the deep drawing was by the ABAQUS/6.14. With increase in punch velocity from 150 to 350 mm/s, Effective stress improved by nearly 56%. Equivalent plastic strain increased by 5 times on increase in punch velocity from 150 to 350 mm/s. At flange radii region (die corner) and at all velocities of punch, Von Mises stress and equivalent plastic strain found to be maximum. The wrinkling was found to be noticeable with rise in velocity of the punch after unloading of the punch. For prevention of wrinkling tendency, the punch velocity should be less than 200 mm/s. F. Vollertsen has investigated Analysis of velocity of punch in micro deep drawing. Using the material Al99.5 blank in thickness of 0.02 mm a LDR of 1.8 was selected for micro deep drawing independent from punch velocities from 1 to 100 mm/s. The allowable upper limit initial BHF increases with increasing velocity of punch. The permissible upper limit for initial BHF can be theoretically calculated. The calculation agrees well with the experimental process. The increment of the height of the process window is due to the decrease of the coefficients of friction. The investigation in this work shows that the velocity dependent friction coefficients are Liable for the difference in process windows under different velocities of punch.

M. Jabbar (2021) has studied Numerical and Experimental of the Elastic Recovery by means of springback in Deep Drawing. 2 types of material, low carbon (AISI 1008) and galvanized steel sheets, of 110 mm dia circular blanks at 1.2 and 0.9 mm thickness are formed by process. Conical dies of 70°, 72°, and 74 were used to execute the experimental work and numerical calculation in which the punch velocities were 100, 150, and 200 mm/min. ABAQUS 6.14 was used for Numerical simulation. Increasing the velocity of punch causes an increase in the springback factor by around 0.002 to 0.003 and by 0.002 to 0.004. The numerical simulation results show same tendency and high agreement with experimental results with a maximum inconsistency of 4 percentage. M. Kardan (2017) has investigated Experimental and FE Results in Deep Drawing Process for Optimization of Punch Force and Thickness Distribution. By experimental investigation, the effects of 8 process parameters including punch velocity, lubrication conditions, die corner and punch radius, blank thickness, and Blank holder force on cylindrical deep drawing process have been studied, concurrently. Thickness distribution and punch force are considered as process outputs in this study. From the study, it is found that addition to blank thickness, die corner radius, punch radius and Blank Holder Force are correspondingly 3 main parameters which have uppermost influence on the punch force. It can be determined that initial blank thickness and die radius are 2 most significant parameters should be set up properly to accomplish the uniform thickness distribution and minimum punch force at the same time. Furthermore, uniformity of thickness distribution be increased the punch force will be decreased for higher die radius.

2.7 Punch Radius

The selection of punch nose radius is a crucial in the sheet metal forming process. The-Thanh Luyen (2021) has investigated the effect of Punch corner radius, drawing ratio and blank holder force on the fracture height of cylinder cup. A simulation and experimental study on the deep drawing for SPCC sheet by graphical Method. It has found that from simulation and experimental results, punch corner radius varying from between 4 mm to 8 mm affect the fracture height. The BHF is kept constant at 10kN. With the increasing punch corner radius, fracture height will increase. So small punch radius often results in a large drawing force for same cup height. This is due to increasing punch radius reduces the degree of bending deformation of the blank around the punch. SO using a punch with large corner radius, the metal flow in the die can smooth. When the detailed fracture height values and its deviation percentages between simulation and measured value with varying the punch corner radius, it shows a good agreement between simulation and experiment with below 3.67 % of the difference. H. Ballikaya (2019) has studied the effects of the parameters on LDR in die angled HMDD. The process were numerically examined and compared experimentally using ANSYS and for that Taguchi experimental design method is used, Also, ANOVA is used for the statically analysis of data in order to calculate the effect of various parameters such as punch radius, die radius and die angle. When the punch radius was increased up to 10 mm, it was witnessed that the LDR increased and after that the ratio decrease. The parameter of punch radius 10mm gave the best LDR and it is 2.6. H. Zein (2014) has studied Thinning and spring back prediction of sheet metal within the deep drawing. Thickness distribution and thinning of sheet metal blank within the deep drawing processes are influences by the geometry of punch. FE model is developed for the 3-D numerical simulation for deep drawing (Parametric Analysis) via ABAQUS/ with the anisotropic material property and simplify the boundary conditions. For validation finite element result compared with experimental results. Afterward The developed model predicts the spring back, the thickness distribution and thinning of the blank as tormented by the die design geometrical parameters and physical parameters. The blank is made of M.S. The material is demonstrated as an elastic–plastic material with isotropic elasticity by the Hill anisotropic yield criterion for the plasticity to term the anisotropic characteristics of the sheet metal. If a punch nose radius is less than 3 x blank thickness, the cup fails because of thinning, whilst for punch nose radius > 3t, thinning will fairly stable. The punch geometry influences the spring back of blank in the deep drawing. From this study it can be say that if a punch nose radius $r_p > 6t$, the cup have small values for the springback %, while for $(r_p) < 4t$, the spring back % is increasing. That's why the r_p is recommended to be > 4t. I. Irthiea (2020) has examined the Effect of process parameters on micro flexible deep drawing of SS 304 cups using floating ring: Simulation and experiments have also carried out to investigate the influence of punch corner radius, drawing ratio, initial sheet thickness, and rubber height on the thickness distribution in terms of max. Thickening, thinning and relatively large aspect ratio. System consist 2 dies: floating ring (primary die) and rubber pad (main flexible die). 3 size scales are selected to investigation. ABAQUS is used for finite element model and then number of experiments are carried out to verify the result. At every scale factor, forming processes are carried out using punches with several nose radius and blanks with different initial thicknesses. It is witnessed that using 50mm sheet thickness results in successful cups at $\lambda = 0.5, 1$, while wrinkled cups at $\lambda = 2$ for radius of 0.1 to 0.3 mm ranges are attained. The results showed that the possibility of failure by wrinkling increases as the scale factor increases for a particular range of punch nose radius.

2.8 Die corner radius

H. Ballikaya (2019) has investigate the effects of the several parameters on LDR in die angled HMDD. The process were numerically examined and compared experimentally using ANSYS and for that Taguchi experimental design method is used, Also, ANOVA is used for the statically analysis of data with the purpose of calculate the effect of various parameters such as die radius, punch radius, BHF, chamber pressure and die angle on the LDR. Up to 8mm die radius, it is witnessed that the LDR increased and after that the LDR decrease. It was determined that the LDR increased up to 2.6 and then decrease. It was concluded that in this die angled HMDD, when optimum parameters were choose, the LDR increased up to 2.6 value.

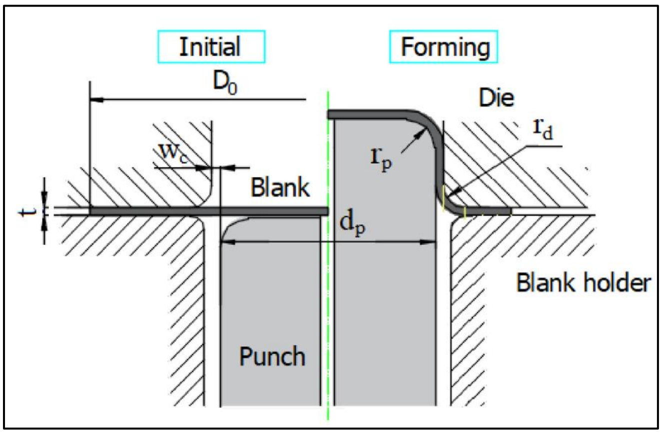

Fig. 4. Geometry of deep drawing assembly; r_p – Punch radius; r_d – die corner radius;
W_c – Clearance between punch and die

H. Zein (2014) has studied spring back prediction and Thinning of sheet metal in the deep drawing. Thinning and Thickness distribution of sheet metal blank within the deep drawing processes are impacts by the geometry of punch. The blank is made of M.S. The material is demonstrated as an elastic–plastic material with isotropic elasticity by the Hill anisotropic yield criterion for the plasticity to term the anisotropic characteristics of the sheet metal. Finite Element model is developed for the numerical simulation for deep drawing via ABAQUS/ with the anisotropic material property and shorten the boundary conditions. For validation, the Fe result compared with experimental results. Afterward the developed model predicts the thickness distribution, thinning and spring back of the blank as tormented by the die design geometrical parameters and physical parameters. Results show that the cup fails due to thinning increased while the die shoulder radius (r_d) < thickness of the blank (t), whilst for r_d>10t, thinning is stable. So, from result it conclude that the r_d should be 10 x sheet thickness. Also, the spring back of sheet metal blank in the deep drawing processes affected by geometry of die. These results indicate that for the r_d < 6 x thickness of the blank (t), the cup has a large spring back %, whilst for $r_d \geq 10t$, the spring back % have smaller values. So, it is recommended that r_d should be 10 times sheet thickness. S Yaghoubi (2020) has studied Optimization of the geometrical parameters of HMDD process of 2024 aluminum alloy at elevated temprature. A Group Method of Data Handling (GMDH) process used to train a neural network with the aim of study of the process behaviour. Based on the uniformity of the final product and maximum reduction in sheet thickness, an objective function was created. To achieve the optimal values for process variables, The Bees Algorithm (BA) was used. The die corner radius is chief parameter and its excessive increase reason of the wrinkling at the sheet periphery and decreases the homogeneity of the final part. It is clear from study that if the die corner radius increasing from 4 to 8 mm, the max thickness reduction and the thickness variation of the product are reduced by 2.0% and increased by 10.0%, correspondingly. As the increase of this parameter has a direct effect on the sheet wrinkling and therefore on the product quality, it is predictable that the effect of the die corner radius on the uniformity of the final cup would be greater compared with its influence on the sheet rupture.

2.9 Clearance

P. Arora (2021) did A Survey on Formability of Material and its Effects during Deep Drawing Process. The choice of the punch-to-die clearance depends on the requirements of the drawn part and on the work metal. Because there's a decrease and so a gradual increase inside the thickness of metallic as it's miles drawn over the die radius, clearance in step with facet of seven to fifteen percentage extra than stock thickness allows prevents burnishing of the aspect wall and punching out of the cup bottom. Clearance between the punch and die for a rectangular shell, at the side walls and on the ends is identical as within the round cup. Radius on the nook could also be the maximum amount 50% greater than stock thickness to avoid ironing in those areas. H. Zein (2014) has examined Thinning and spring back prediction of sheet metal in the deep drawing process. Thinning and Thickness distribution of deep drawing processes are impacts by the geometry of punch. The blank is made of M.S. FE model is developed for the numerical simulation for deep drawing via ABAQUS/ with the anisotropic material property and shorten the boundary conditions. For validation, the Fe result compared with experimental results. Axial clearance is the difference between die radius and punch radius (WC = DR–PR) and it's an significant parameter. It is shown that with the reducing the radial clearance (WC), the distribution in sheet metal thickness is increaes. In addition, for the WC < blank thickness (t), the cup fails due to thinning. Whilst for the radial clearance WC > t, thinning is stable. The radial clearance which is less than 0.5t is not suitable because the % of reduction in thickness is more than 45%, while the maxallowable % of reduction in thickness is 45%. From the variation of the springback % with the radial clearance (WC), it is shown that the springback % is reduced with increasing the radial clearance (WC). Moreover, If the radial clearance (WC) that is less than the blank thickness (t), the cup fails due to increased thinning.

S Yaghoubi (2020) has examined the Optimization of the geometrical parameters of HMDD process of 2024 aluminum alloy at elevated temperature. A Group Method of Data Handling (GMDH) process used to train a neural network with the purpose of study to the process behaviour. Based on the maximum reduction in sheet thickness and uniformity of the final product, the objective function was created. To achieve the optimal values for process variables, The Bees Algorithm was used. With an increase in the gap between the punch and die, resulting in a certain decrease in the essential forming force. The main problem faced by a high clearance is the increase in the thickness variation due to the existence of a large gap so it means of reduction in the final product quality. Clearance should be minimized because the product uniformity is more important than the required forming force in sheet metal forming operations. The amount of max thickness reduction and thickness variation of the final product for clearances of 2.2 mm to 2.4 mm. It shows that with the clearance rise from 2.2 to 2.4, the thickness variation and the max thickness reduction of the final product increased by 10.4%, reduced by 1.3% and respectively.

2.10 Springback

Springback prediction is one of the major challenges in sheet metal forming to produce dimensional accuracy parts. The springback behaviour is determined by angle of springback. To meet the requirements for dimensional accuracy of a sheet metal part, the springback must be compensated and the deep drawing process has to be designed accordingly. During forming, elastic energy is stored in the product. When removing a part from the deep-drawing tool, the resultant residual stresses with an elastic component reason of the unwanted changes of the part`s geometry in forming. Specially sheet materials with low elastic modulus and high yield strength tend to an incremental springback. Among other things, these materials comprise aluminium alloys of the 7000 series. Thus, a fundamental understanding of the material behaviour of these materials is related for designing a sheet metal forming process.

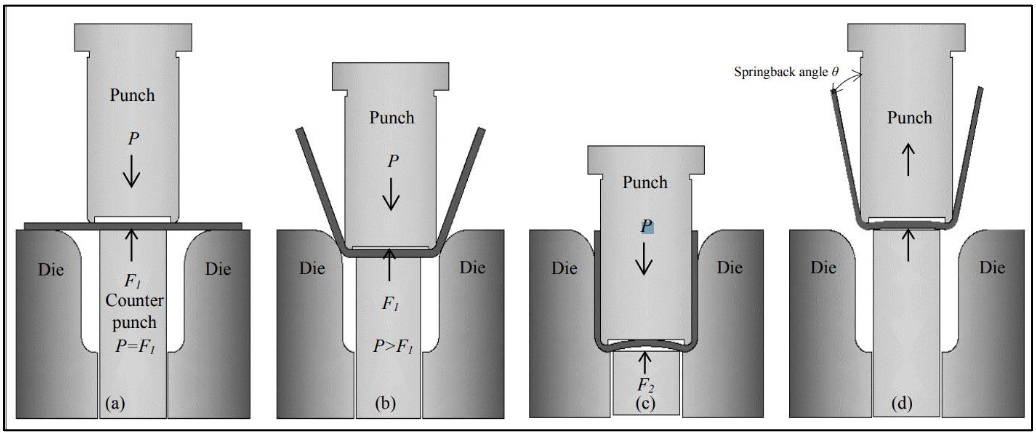

Fig 5. Schematic illustrations of U-bending with bottom pushing-up

A. Takalkar (2018) has a review on effect of thinning, wrinkling and spring-back on deep drawing process. The Taylor’s theory for elastic–plastic media with aspects of Sach’s theory will be used for spring-back prediction with low cost and less time. The spring-back angle in valley region is decreased with an increment of punch radius and punch angle. The prediction of spring-back may be done using multi-cyclic stress-strain curves generated from FE simulation and gas forming process simulation. The surface roughness and variation in material properties affect the spring-back action just in case of the micro deep drawing of a cup. P. Hetz (2020) has Investigation of the Springback Behaviour of High-strength Aluminium Alloys Based on the Cross Profile Deep Drawing Tests. AA7020-T6 and AA7075-T6 material are used for investigation of springback. Within this contribution, cross profiles are formed in a deep drawing tool and after that it digitized. A rise in the tool radius of punch and die as well as die diameter tends to higher springback for both materials. But, the BHF has no significant influence on the springback. The springback angles for AA7075-T6 are greater than for AA7020-T6 because of the higher yield strength level. The results for AA7075 have also demonstrated that this material is barely limitedly formable at room temperature and small radius. R. Lal (2018) has investigated the Study of factors affecting Springback in Sheet Metal Forming and Deep Drawing Process. The springback is affected by the several parameters such as BHF, ratio of die corner radius to blank thickness and blank thickness, etc. These parameters were investigated. Spring back % in deep drawing process was studied numerically (using FEA software). The numerical results gotten shows that springback can be reduced by the increasing the value of the initial blank thickness. Also, the spring back will be decreased with the increasing BHF, and if BHF is too high then it may cause tearing of sheet. The spring back was also increases, with the increasing of punch nose radius. E Ouakdi (2012) has studied Calculation of springback under the effect of die radius and holding force in a stretch bending test. Springback decreases non-linear with stretching height. With An increase in BHF, sliding of the sheet between the blank holder and the die reduces springback by increasing the tension. The bigger the entrance radius of the die, the lesser the concluding springback.

3. Research gap

The research survey was reflected different types of research on thinning, thickness distribution, LDR and spring back in metal forming. It was reflected on different kind of research paper regarding Pre bulging pressure, Chamber pressure, coefficient of friction, Blank holder force, Drawing ratio, Punch speed and punch velocity, Punch Radius, Die corner radius, clearance and spring back effect in metal forming. There is possibility of work in Coefficient of friction, Drawing ratio, Punch radius, die corner radius, clearance and spring back effect in metal forming and optimization process for effective output from changing punch design, die design, blank holding force and punch velocity.

4. Problem statement

Oil drain cup material is EDD 513 of 1.5mm sheet thickness. In oil drain cup, crack occurs during deep drawing process. Crack is the major defect of the part. The part wall thinning is used in industry to indicate probability of fracture. Therefore, the maximum wall thinning was selected as a fracture criteria. The Fracture occurs at contact location between the oil drain cup and punch corner. At that point, there exists the highest strain that causes the largest thinning and due to large thinning at that location, the fracture occurs. The fracture is due to wall thinning at bottom radius. As the punch increments, the crack and thinning enhances.

5. Objectives

To improve uniformity of the sheet thickness of oil drain cup by reducing the sheet thinning. Maximum sheet thinning is the cause of fracture (Crack). FEA simulation and experimental development of oil drain cup will be carried out. FEA simulation will be carried out in Altair inspire form software. To improve LDR ratio, optimize the various geometrical and process parameters.

References

1. Farzad Rahmani, Seyed Jalal Hashemi, 2021, Numerical and Experimental Investigation of Thickness Distribution in Hydromechanical Deep Drawing Process of Square Parts, Journal of Modern Processes in Manufacturing and Production, Volume 10, No. 2, Spring.
2. S. Yaghoubi, F. Fereshteh-Saniee, 2020, An investigation on the effects of the process parameters of hydro-mechanical deep drawing on manufacturing high-quality bimetallic spherical-conical cups, The International Journal of Advanced Manufacturing Technology.
3. Lihui Lang, Joachim Danckert, Karl Brian Nielsen, 2003, Investigation into the effect of pre-bulging during hydromechanical deep drawing with uniform pressure onto the blank, International Journal of Machine Tools & Manufacture, 44, p. 649–657.
4. Hasan Ballikaya, Vedat Savas, Cetin Ozay, 2019, The limit drawing ratio in die angled hydromechanical deep drawing method, The International Journal of Advanced Manufacturing Technology.
5. Kotchakorn Wiratchakul, Thanasan Intarakumthornchai, Effect of Friction Coefficient on Part Quality for Parabolic Part in Hydromechanical Deep Drawing Process, 7th International Conference on Tribology in Manufacturing Processes.
6. H. Zein, M. El Sherbiny, M. Abd-Rabou, M. El shazly, 2014, Thinning and spring back prediction of sheet metal in the deep drawing process, Materials and Design, 53, p. 797–808.
7. Wen-yu MA, Bao-yu WANG, Lei FU, Jing ZHOU, Ming-dong HUANG, 2015, Effect of friction coefficient in deep drawing of AA6111 sheet at elevated temperatures, Trans. Nonferrous Met. Soc. China 25, p. 2342-2351.
8. The-Thanh Luyen, Van-Canh Tong, Duc-Toan Nguyen, 2021, A simulation and experimental study on the deep drawing process of SPCC sheet using the graphical method, Alexandria Engineering Journal.
9. Ihsan Irthiea, Zaid Mahmood, 2020, Effect of process parameters on micro flexible deep drawing of stainless steel 304 cups utilizing floating ring: Simulation and experiments, Proc IMechE Part B: J Engineering Manufacture 1–10, IMechE.
10. Yogesh Dewang . Vipin Sharma . Yash Batham, 2020, Influence of Punch Velocity on Deformation Behavior in Deep Drawing of Aluminum Alloy, J Fail. Anal. and Preven.
11. Frank Vollertsen, Zhenyu Hu, 2010, Analysis of punch velocity dependent process window in micro deep drawing, Prod. Eng. Res. Devel. 4:553–559.
12. Masoud Kardan, Ali Parvizi, Ali Askari, 2017, Experimental and Finite Element Results for Optimization of Punch Force and Thickness Distribution in Deep Drawing Process, Arab J Sci Eng.
13. Mohammed S Jabbar, Muhsin J Jweeg, Adnan I mohammed, 2021, Numerical and Experimental Study of Elastic Recovery in Deep Drawing of Low Carbon and Galvanized Steel Sheet Conical Products, IOP Conf. Series: Materials Science and Engineering 1094, 012155.
14. S Yaghoubi, F Fereshteh-Saniee, 2020, Optimization of the geometrical parameters for elevated temperature hydro-mechanical deep drawing process of 2024 aluminum alloy, Proc IMechE Part E:J Process Mechanical Engineering 0(0) 1–11, IMechE.
15. Prince Arora, Dharmendra Tyagi, 2021, A Survey on Formability of Material and Effects during Deep Drawing Process, International Journal of Engineering Research in Current Trends (IJERCT) ISSN: 2582-5488, Volume-3 Issue-4.
16. Takalkar Atul S, M C Lenin Babu, 2018, A review on effect of thinning, wrinkling and spring-back on deep drawing process, Proc IMechE Part B:J Engineering Manufacture, p. 1–26, IMechE.

17. Peter Hetza, Sebastian Suttnera, Marion Merkleina, 2020, Investigation of the Springback Behaviour of High-strength Aluminium Alloys Based on Cross Profile Deep Drawing Tests, 23rd International Conference on Material Forming.
18. Radha Krishna Lal, Vikas Kumar Choubey, J. P. Dwivedi, Shravan Kumar, 2018, Study of factors affecting Springback in Sheet Metal Forming and Deep Drawing Process, Materials Today: Proceedings 5, p. 4353–4358.
19. Komgrit Lawanwomga, Hiroshi Hamasakib, Ryutaro Hinob, Fusahito Yoshida, 2014,A novel technology to eliminate U-bending springback of high strength steel sheet by using additional bending with counter punch, Procedia Engineering 81, p. 957 – 962.
20. Qiqian Liua, Cheng Lu, Wenzhi Fu, Kiet Tieu, Mingzhe Li, Xuepeng Gong, 2012, Optimization of cushion conditions in micro multi-point sheet forming, Journal of Materials Processing Technology 212, p. 672– 677.
21. Frank Vollertsen, Zhenyu Hu, 2008, Determination of size-dependent friction functions in sheet metal forming with respect to the distribution of the contact pressure, Prod. Eng. Res. Devel. 2, p. 345–350.
22. J. Hol, V.T. Meinders, M.B. de Rooij, A.H. van den Boogaard, 2015, Multi-scale friction modeling for sheet metal forming: The boundary lubrication regime, Tribology International 81, p. 112–128.
23. D.K. Karupannasamy, J. Hol, M.B. de Rooij, T. Meinders, D.J. Schipper, 2012, Modelling mixed lubrication for deep drawing processes, Wear, p. 294–304.
24. Lucian Lazarescu, Ioan Nicodim, Dorel Banabic, Evaluation of Drawing Force and Thickness Distribution in the Deep-Drawing Process with Variable Blank-Holding.
25. Søren Tommerup, Benny Endelt, 2012, Experimental verification of a deep drawing tool system for adaptive blank holder pressure distribution, Journal of Materials Processing Technology 212, p. 2529– 2540.
26. E.H. Ouakdi, R. Louahdi, D. Khirani, L. Tabourot, 2012, Evaluation of springback under the effect of holding force and die radius in a stretch bending test.
27. Araveeti C S Reddy, Mahender Thotakuri, experimental and simulation study in deep drawing of circular cups for determination of LDR.

Acknowledgements

The authors would like to acknowledge Dept. of Mechanical Engineering, Gandhinagar Institute of Technology for their kind support for prepare a review paper.