A Review of Deep Drawing Process and Interdependency of Its Parameters

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***Abstract*— Deep Drawing is a widely used sheet metal shape transformation process with material retention. From Automobile components to plumbing and sanitary ware, this process is used for mass production of industrial and domestic artifacts with the depth greater than corresponding diameter. Deep drawing process using a die-punch pair on a press induces radial stresses on flange region and compressive stresses on the center of a blank to provide a permanent shape change. The production quality and cost associated depend upon obtained thickness distribution and an accurate prediction of formability. This demands a coherent set of correlations between various parameters associated with deep drawing. This study reviews various theoretical and experimental attempts made to connect punching force, blank holding force, dome height, thickness of blank etc. with thickness distribution on final products. The focus is also drawn onto various modes of failures for different shapes of products and associated problems including creasing and wrinkling, crushing and cracking of sheet metal parts. Conclusions are drawn to suggest impact of isolated deviation of one or more parameters on the resulted product.**

***Key words*—Deep Drawing, Punch force, Blank holding force, Formability**

I. INTRODUCTION

One of the important processes of forming of sheet metal parts is Deep drawing. Vita use of deep drawing process is in production of hollow shapes in the packing industry, automotive industry etc. According to the definition in DIN 8584, deep drawing is the tensile compressive forming of a sheet blank (or, depending on the material, also of foils or plates) to a hollow body open on one side or the forming of a pre-drawn hollow shape into another with a smaller cross-section without an intentional change in the sheet thickness. The condition for the completing process is transmitting the force into the forming zone [19].

Figure 1 shows the different parts of deep drawing assembly and forces applied at various components. Deformation in the flange occurs due to the tangential compressive stress and radial tensile stress, when the sheet blank with diameter Do is drawn through the die to a cup with the punch diameter do. The blank holder force F_N prevents the formation of folds. Blank holder pressure is small compared to the radial and tangential stresses.

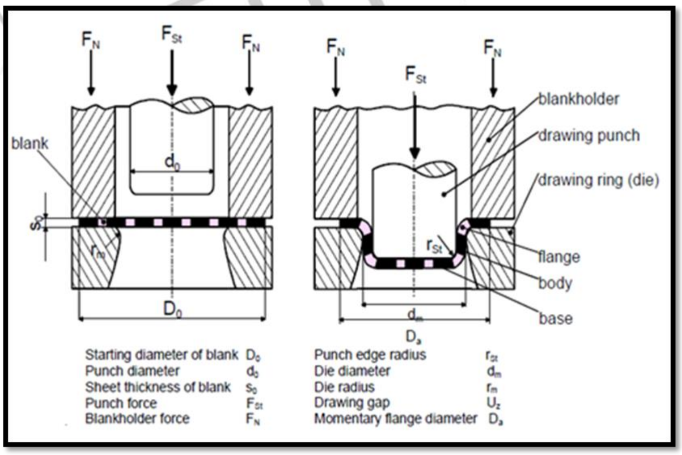

Fig.1 Deep Drawing Process

For forming, drawing force is transmitted from the punch to the work-piece base and from there to the forming zone in the flange. The resulting limiting deformation in the force application zone has nothing to do with the depletion of the forming capacity of the material in the forming zone. The limits of the process are when the largest applied drawing force cannot be transmitted to the forming zone in the flange. It can be stated that, from this condition, one can derive the characteristic behavior of deep annealing step. Subdividing the whole process is into a number of drawing steps. The advantage it has, that the tensile force acting at the force application zone can be less.

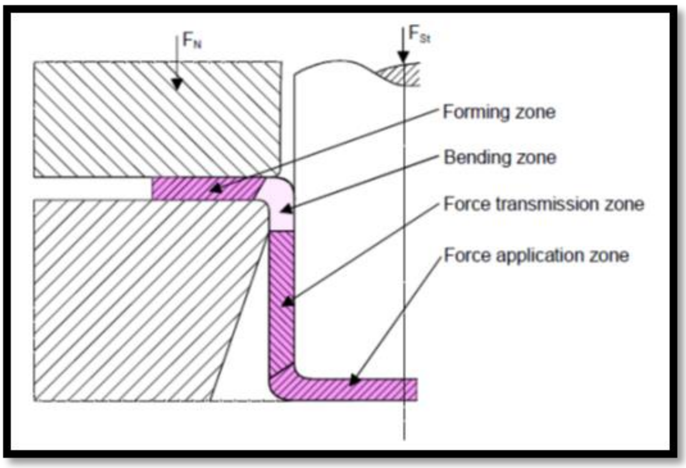

Fig.2 Stress Zones During Deep Drawing

There are four zones formed during the drawing process of the cylindrical cup as shown in Fig.2**,** with different state of stress and deformation. The forming zone is the sheet material between the flange outer edge and the outlet of the material to be formed from the drawing ring radius. The surface area of the drawn part is about the same as that of the starting blank. Consequently, the sheet thickness remains almost constant. The base of the drawn part is formed on the same principles that apply to mechanical Drawing.

Application of Deep drawing process is for Closed Cylindrical shapes as Cans, pots and pans, Rectangular container of all shapes and sizes Shells, Cartridge cases, Automobile panel, Cylindrical parts, End automotive exhaust application, LPG bottles and Household goods.

Principle of Deep Drawing process

A flat blank is formed into a cup by forcing a punch against the center portion of a blank that rests on the die. A Sequence of deep drawing is shown in fig. 4

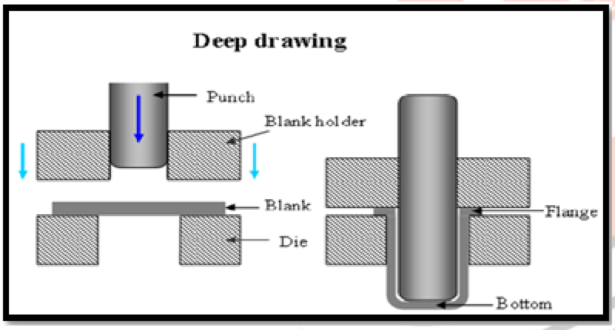

Fig. 3 Principle of Deep Drawing

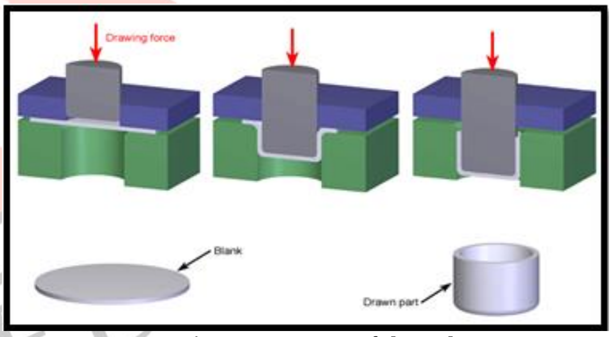

Fig. 4 Sequence of deep drawing

Classification of deep drawing

Based on the type of force application, the deep drawing processes can be divided into two methods:

1. Deep drawing with tools
2. Deep drawing with an active medium

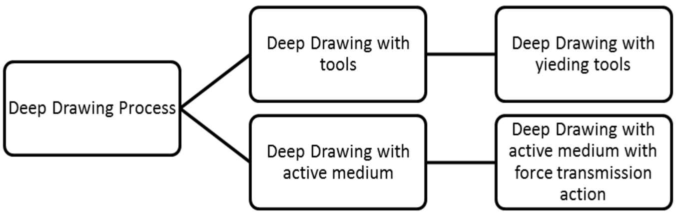

Fig. 5 Classification of deep drawing

II. LITERATURE REVIEW

J.P. Fan et al considered parameters like Coulomb friction and Blank holding force for 3D finite element simulation of steel of deep drawing and using ABAQUS software for simulation. The result came as determination the position of crack initiation on sheet blank [6].

R. Padmanabhan et al considered Blank holder force, Friction co-efficient and Die radius parameters for deep drawing of stainless steel sheet blank in experimentation and optimization with taguchi method. The result came as Die radius more influence than blank holder force parameter at particular friction coefficient [13].

Hong Seok Kim, MuammerKoc and Jun Ni considered parameters like Temperature, Forming rate, Blank holder pressure, for warm deep drawing of aluminum alloys. Development of analytical model relationships between limiting drawing ratio (LDR) and process parameters had been carried out [9].

Johannes Winklhofer et al considered parameters like Drawing depth, Drawing ratio, Punch velocity, Blank holder pressure for Deep Drawing at Elevated Temperatures of Aluminium Sheet Metal. Results relieved that Tool velocity has more influence on formability. Optimization on process strategy formability, time and cost has also been developed [17].

F. Ayari and E. Bayraktar considered square cup geometric and material parameters and coefficient of frictions for square cup deep drawing process of steel and using Abaqus/Explicit standard software for Parametric Finite Element Analysis. The result came as effect of the geometric parameter like punch fillet radius and die section radius their interaction on drawability of DDP are analyzed [5].

Mihael Volk et al considered Punch velocity, Drawing radii and Punch stroke parameters for deep drawing process and the Holding System with Segments Inserts and using explicit dynamic in Pam-Stamp software package for simulation. Result came as Because of a relatively small area where guiding blank holder force is in contact the blank had a big influence but value of the force did not and Optimize geometry and the structure of the blank holder [16].

Gyadari Ramesh and Dr.G.Chandra Mohan Reddy considered blank holding force, Die radius, and Co-efficient of friction parameters for Analysis of Optimization of Blank Holding Force in Deep Drawing and using LS Dyna Software for simulation. The result came as Blank holding force decreases with increase of coefficient of friction for a small range of coefficient of friction and a linear relation exists and finding vonmises stress [15].

R. Venkat Reddy et al considered BHF, punch radius, die edge radius and Coefficient of friction parameters for Deep Drawing Cylindrical Cups in experimentation. And result came as The height of the wrinkles is reduced by increasing the blank holding force, decreasing friction, increasing the tools edge radius and reducing deep drawing depth all together in one operation [18].

LaxmiputraM Nimbalkar and Sunil Mangshetty considered Blank holding force and Die radius parameters for Analyzing the Effect of Blank Holder Shape in Deep Drawing Process and using ansys software for simulation. The result came as Contact pressure development at both blank holder and die surfaces showing distribution of punch loads. And find critical stresses of radial, hoop and vonmises stresses [12].

Amir Atrian and Faramarz Fereshteh-Saniee considered blank holding force, Stroke length and punch force for Deep drawing process of steel/brass laminated sheets and using ansys software for simulation. The result came as Drawing force is overestimated about 10% by the FE simulations and also similar to single layer deep drawing [2].

Y. Morishitaa et al considered Punch pressure and Dome height for Role of counterpunch for square-cup drawing of tailored blank composed of thick/thin sheets in experimentation. The result came as the limiting cup height increases markedly with increasing counterpunch pressure. Counterpunch method is also effective for deep drawing of a nonsymmetrical TB and measure strain thickness distribution [11].

M.A. Hassan et al considered drawing pressure, distance from center of blank parameters for Friction aided deep drawing of sheet metals using polyurethane ring and auxiliary metal punch and using slab method analysis. The result came as Control each process parameter in friction aided deep drawing of sheet metal and determine radial and compressive stress [7].

Abdullah A. Dhaiban et al considered Punch force, Punch displacement, and Blank thickness for Finite element modeling and experimental results of brass elliptic cups using a new deep drawing process through conical die and using ansys software for simulation. The result came as Effects of blank thickness and clearance ratio on the LDR and punch load. Present technique appears to be convenient for deep drawing of brass sheets of thicknesses between 1.9 and 3 mm and measure thickness distribution of blank [3].

Najmeddin Arab considered Distance from bottom of cup and thickness of wall for experimental and simulation analysis of deep cylindrical cup process for steel and using ABAQUES Software. The result came as thickness distribution is obtained for entire cup along with flange by simulation and experimentation [10].

R. Padmanabhan et al considered Blank holder force, Punch and Die radii, Die-punch clearance for Numerical simulation and analysis on the deep drawing of LPG bottles and using DD3IMP(contraction of Deep Drawing 3d implicit code). The result came as the proposed variable blank holder force scheme and friction condition resulted in an increased minimum thickness in the deep drawn part, expending relatively less energy in restraining the Flange through the blank holder [14].

Kareem NajmHussien considered Punch stroke and Blank diameter for Finite element analysis of deep drawing and using ansys software for simulation. The result came as prediction the failure shape of the process according to the thinning of the thickness of the formed cup. By spring back approach a parametric design could be done and an optimized selection of parameters could be achieved [8].

H. Zein et al considered Die shoulder radius, Punch nose radius, Sheet metal thickness, Radial clearance for Effect of Die Design Parameters on Thinning of Sheet Metal in the Deep Drawing Process and using ABAQUS/EXPLICIT FEA software for simulation. The result came as optimize all parameters and find its values developed for successful deep drawing process [4].

Pop Alin et al considered Punch radius, Die radius and Blank holder force for Parameters influence on Wrinkling in Deep drawing cylindrical cups and using ABAQUS 3D software for simulation. The result came as with 0.01 friction coefficient, the blank holder force to have less in influence than Die radius in deep drawing process [1].

H. Tukada et al considered parameters like drawing radius and temperature for warm deep drawing of aluminium alloy sheet (A5182-O) and numerically analyses with FEM for simulation. The result came as high drawability attained by in warm forming only in case where the sheet is partially cooled [22].

S.H. Zhang considered chamber pressure and blank thickness parameters for analysis of hydro mechanical deep drawing of mild steel and aluminium and used explicit finite element method is used for numerical analysis. The result came as limiting drawing ratio reached 2.5 for the aluminum workpiece and 2.6 for the steel workpiece and local thinning is predicted to take place on the punch profile when the chamber pressure is lower, and to take place on the die profile when the chamber pressure is very high [23].

S.H. Zhang et al considered chamber pressure blank holding force parameters for analysis of hydro mechanical deep drawing of mild steel and aluminium in parabolic shaped and used explicit finite element method is used for numerical analysis. The result came as defects of wrinkling and ruptures have been predicted for some forming conditions, the thickness distribution results are in good agreement with the experimental results [24].

Lihui Lang et al considered pressure in die cavity, drawing force and punch stroke in hydrodynamic deep drawing for aluminiun alloy Al6016-T4. The result came as maximum drawing ratio can reach 2.46 for feasible process and the optimal gap between the blank holder and the die is about from 0.98 to 1.035 times the blank original thickness. The optimal pre-bulging pressure is about 200 bar and the optimal pre-bulging height is around 0.0 mm, and the forming zones do not change significantly with the increase of the drawing ratio [21].

Mark Colgan and John Monaghan considered parameters like the punch and die radii, the punch velocity, clamping force, and friction and draw depth in deep drawing for steel. For optimization, ANOVA method is used. The result came as the smaller is the die radius, the greater is the drawing force induced and the greater is the overall thinning of the cup sidewall. Wrinkling of the cup as it approaches 20 mm is a problem that is not actually encountered in the experimental work [20].

Wenfeng Zhang and Rajiv Shivpuri considered parameters blank dimensions, blank holder forces (BHFs), press strokes in aluminum sheet drawing. The result came as to optimize all parameters for designed Probabilistic design of aluminum sheet drawing for reduced risk of wrinkling and fracture [25].

III. FINDINGS OF LITERATURE SURVEY

Importance of control of Parameters

There are more material sheets and energy loss in traditional method. For improvement in process performance, parameters play important role in deep drawing process. There are two types of parameters (1) Geometric parameters and, (2) Physical or Process parameters. Geometric parameters including die shoulder radius, punch nose radius, sheet metal thickness and, radial clearance.

Physical or process parameters including punch force, blank holding force, punch velocity and, co-efficient of friction. But geometry parameters are not controlling properly. So we can control only physical or process parameters. If we controlling process parameters properly, then we can solve damage problem of sheet metal and winkling, tearing, cracking in deep drawing process.

Effect of Process Parameters

There are various process parameters used in deep drawing process like punch force, blank holding force, blank thickness, punch velocity, punch stroke, and co-efficient of friction, which are controllable. Effect of these parameters on blank is described in Table 1.

Table 1 Effect of parameters on blank

Sr. no.	Parameters	Effect of parameter on blank
1	Punch force	The cup height increases with an increase in punch force. So does the damage in lower edge corner, where stress concentration is observed.
2	Blank holding force	**a.** Increasing blank holding force by using a blank holder of an appropriate size will ensure a reduction in wrinkling height. **b.** A feedback based variable blank cushion ensures a uniform flow of metal. **c.** Too rigid holding with a greater friction factor will induce tears in the cup region.
3	Blank thickness	**a.** The average distribution of the blank thinning is increasing with increasing of the blank thickness. **b.** The maximum percentage thinning however do not bear any independent relation to blank thickness.
4	Punch velocity	**a.** Higher the values of punch velocity, greater are the chances of tear in the cup region. **b.** Low to medium velocities result in a controlled metal flow rate and thus a uniform product.
5	Punch stroke	**a.** Stroke length is controlled by the depth to be achieved. **b.** A punch stroke should be minimized as longer strokes will result in a greater pull and greater probability of tear. **c.** Blank thickness required increases with an increase in a punch stroke.
6	Co-efficient of friction	**a.** Throughout the system, the coefficient of friction between blank and punch as well as blank and die along with blank and blank holder is required to be minimum to ensure the maximum metal flow. **b.** Friction factor can also be used as a controlling factor to control the flow of metal from flange to cup region, wrinkling effect and percentage thinning.

IV. CONCLUSION

Deep drawing process is used for years and many numerical and experimental attempts are made to understand the behavior of the process and its process variables. A typical decision making process for deep drawing involves choosing an appropriate blank size from required die & punch sizes, setting up an appropriate punch stroke and punch velocity and holding the blank with an appropriate blank holding force to allow just the right amount of metal flow. The findings as described in Table-1 indicate that

1. Tear in cup region is the most common unfavorable outcome if punch parameters (force, stroke and velocity) are not maintained.
2. A Wrinkling in the flange region can occur if improper blank holding force is applied or improper coefficient of friction is available in the region.
3. Blank thickness and percentage thinning are also dependent on the type of material used, type of plasticity nature it presents (bilinear or multi-linear) and surface finishing of the blank.

Thus, a complex interdependency of various deep drawing process parameters limits universal use of any mathematical model and experimental analysis is preferred to numerical analysis of the deep drawing process.

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