Tool Design of Cylindrical Cup For Multi-Stage Drawing Process

Pradeep M Patil
Department of Mechanical Engineering
S.S.G.B.COE & T, Bhusawal, Maharashtra, India

Prof. Prashant S Bajaj
Department of Mechanical Engineering
S.S.G.B.COE & T, Bhusawal, Maharashtra, India

Abstract- This paper reports on the initial stages of a combined experimental and finite element analysis (FEA) of a deep drawing process. A deep drawing rig was designed and built for this purpose. Punches and dies of various geometries were manufactured. It has also been observed from the work to date that the speed of drawing plays an interesting role, in so far as, the higher is the speed the further is the draw, which is not entirely as expected. The cause of this will be further investigated. If the blank-holder force is not kept within the upper and lower limit of reasonable range it does have a significant effect on depth of draw, with the punch tearing through the bottom of the cup if the force is too high and if too low wrinkling of the flange area occurs.

Keywords – deep drawing, productivity, sheet metal forming, tool profile.

I. INTRODUCTION

The use of brass for cartridge cases has a long history and is particularly embedded into the culture of ammunition for small arms. For more than 100 years, brass has served adequately and admirably as a material for cartridge cases. Its relatively high strength and ductility provide it with the twofold ability to withstand large rupture pressures while undergoing deformations that provide the means to seal combustion gases in the chamber. These properties have made brass the intuitively obvious material of choice for cartridge applications.

However, more recently, interest in ammunition weight reduction has increased and therefore, investigations into materials other than the high-density brass have arisen. In order to adequately assess alternate lightweight materials for cartridges, it is first necessary to understand the performance of brass in this role. It was with this thought that an effort was undertaken to employ modern finite element techniques to represent the behavior of brass cartridges. Interestingly enough, despite the long history of brass usage, little information was found in the literature that reported about the mechanical properties of “cartridge brass,” a copper alloy composed of 70% copper and 30% zinc. This report details the literature findings and specifies those extrapolations that were required to provide a complete characterization of the material over the full range of strains encountered.

Deep drawing is a sheet metal forming process in which a sheet metal blank is radially drawn into a forming die by the mechanical action of a punch. It is thus a shape transformation process with material retention. The process is considered "deep" drawing when the depth of the drawn part exceeds its diameter. This is achieved by redrawing the part through a series of dies. The flange region (sheet metal in the die shoulder area) experiences a radial drawing stress and a tangential compressive stress due to the material retention property. These compressive stresses (hoop stresses) result in flange wrinkles (wrinkles of the first order). Wrinkles can be prevented by using a blank holder, the function of which is to facilitate controlled material flow into the die radius.

Deep drawing is a popular selection due to its rapid press cycle times. The drawing process can produce complicated axis-symmetric geometries and several non-axis-symmetric geometries in few operations with low technical labors requirement is also an advantage in manufacturing applications. Examples of deep drawing applications include containers of all shapes, sinks, beverage cans, automotive body and structural parts and aircraft panels. In mass production the deep drawing process is advantageous than any other manufacturing process.

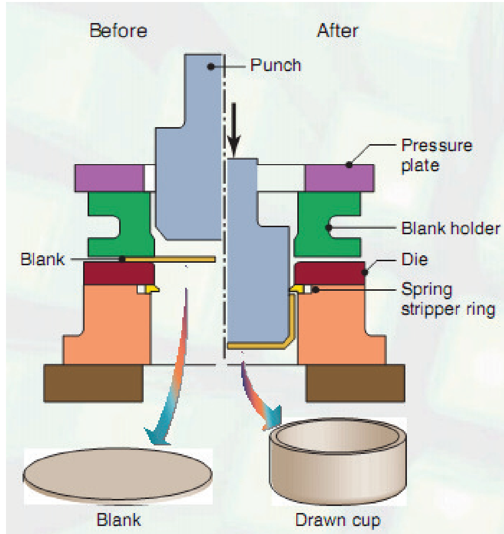


Fig 1 Schematic illustration of deep drawing process

II. INFLUENCE OF PROCESS PARAMETERS

A) The most important criteria in selecting a material are related to the function of the part qualities such as strength, density, stiffness and corrosion resistance. For sheet material, the ability to be shaped in a given process, often called its formability, should also be considered. To assess formability, we must be able to describe the behavior of the sheet in a precise way and express properties in a mathematical form; we also need to know how properties can be derived from mechanical tests. As far as possible, each property should be expressed in a fundamental form that is independent of the test used to measure it. The information can then be used in a more general way in the models of various metal forming processes. In sheet metal forming, there are two regimes of interest – elastic and plastic deformation. Forming a sheet to some shape obviously involves permanent plastic flow and the strains in the sheet could be quite large. Whenever there is a stress on a sheet element, there will also be some elastic strain. This will be small, typically less than one part in one thousand. It is often neglected, but it can have an important effect, for example when a panel is removed from a die and the forming forces are unloaded giving rise to elastic shape changes, or springback. The material properties can be found by performing tensile test and the load extension diagram.

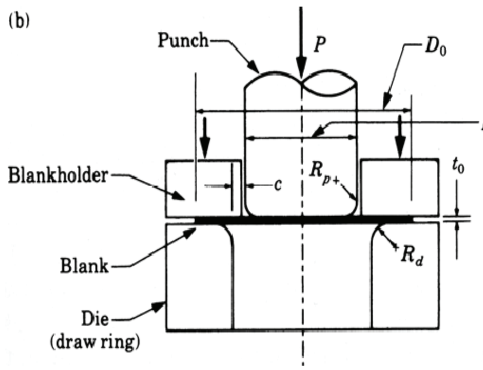
The influence of each one of these parameters in the cylindrical cup deep drawing process is nowadays well known. However, it is important to note that they are all connected and sometimes the variation of one implies changing the others. All these parameters play an important role in the sheet metal forming, which will be briefly described in the following subsections. However, in this study only the tools geometry and the lubrication conditions will be analyzed.

a) Tools geometry : The tools geometry is an important and difficult problem in sheet metal forming. The limit drawing ratio and the residual stress are greatly linked with the tools geometry, particularly the shoulder radius. Their surface condition is also essential to reduce the friction and give a good appearance to the final part. The tools should not mark, damage or weaken the final part.

b) Blank-holder forces: The main goal of using a blank-holder is to control the blank sheet flow and avoid wrinkling. A too high value for the blank-holder force leads to materials rupture, but a too low blank-holder force allows the sheet wrinkling. Therefore, it is of paramount importance to find the appropriate value for the blank-holder force. Higher values of blank-holder force also contribute for a higher punch force and reduce the thickness on the cups wall.

c) Temperature: Traditionally the deep drawing process takes place at room temperature. However, some researchers have focused their attention in exploring the influence of temperature in the mechanical properties of metallic sheets.

d) Deep drawing speed : Deep drawing speed has a greater influence in the deformation process. The use of a high drawing speed can lead to rupture, but a slow speed is also not possible in industrial processes, because in industry time is money. This parameter is directly linked to the materials mechanical behavior and, consequently, to the deep drawing forces. The strain rate sensitivity indicates if a material is sensitive to the strain rate or not.



D_o : Diameter of a circular sheet blank.
to : Thickness of the circular sheet blank.
Rd : Corner radius of the die opening.
Dp : Punch diameter.
Rp : Corner Radius of the punch.
Wp : Plastic Work required for deep drawing
Vo : Initial volume of blank to be drawn
Vc : Volume of drawn cup.
R : Drawing Ratio Do/Dp.
ē : The effective strain.
ó : Effective stress.

Fig 2 Variables in deep draw of a cylindrical cup.

e) Friction : Friction is primarily connected with the contacting pair of materials and the lubricant conditions. Basically, higher punch force values are linked with higher global friction coefficient values. In fact, high friction coefficient values are dangerous to the drawing process, but the friction can be easily reduced through the use of a lubricant. Unfortunately, this parameter cannot be experimentally measured with the desired accuracy, because it changes with many conditions including the contact pressure and sliding distance.

f) Lubricant conditions evolution : The lubricant conditions play a key role in minimizing the tools wear and in reducing the friction. Proper lubricant conditions reduce the formation of scratches on the sheet and also reduce the friction coefficient. However, the lubricant conditions depend from parameters like temperature, sliding velocity and pressure. These parameters have a greater influence in the fluids viscosity and, consequently, in its elasto-hydrodynamic deformation.

B) Methodology :- The main aim of this study is to investigate the deep drawing process systematically. Deep drawing is one of the most important sheet metal forming process. The process includes many aspects that affect the final product. In order to understand Deep Drawing one must investigate all these variables and their effect on the process. Without extensive knowledge of all these variables, achieving a defect free deep drawn product is hardly possible. There are some possible failures likely occur during the process, like wrinkling, necking, scratching and surface defects. While developing the method of deep drawing all the above failures to be considered at the time of designing of die and punch. The study also aims to investigate the defects and its prevention. For this purpose the commercial finite element analysis code will be used. Deep drawing module uses a dynamic-explicit approach in analysis. The elasto-plastic material model is utilized in the program in order to achieve accurate deformation behavior of the material.

In order to satisfy the demand by the industry, sheet metal forming processes must be investigated very carefully. To reduce the cycle time of the process the operations of the two machines are combined in such a way that one of the draw operations is eliminated. After feeding the raw material i.e. cup to the machine, the cup undergoes for 1st modified draw operation, then to final modified draw operation. After this the component is sent for trimming operation. In these processes the tools are modified such that the final product is as per requirement and defect free. In order to understand the drawing process various phenomenon has been studied like earing, wrinkling, and fracture of cups. These defects increases the production cost and reduces the efficiency of the plant.

Fig 3 Deep Drawn Parts

Design Calculations :- On based of the various formulae, discussed in the previous chapter, the design calculations have to be carried out. It requires some basic data of the material and tool geometry. The design calculations are based on the approximation of the data, which can be concluded only after the comparing with the FEM results.

Let, K - Modulus of elasticity (110 GPa)
n - Strain Hardening Coefficient (0.49)
α - Force angle (90^0)

a. $\text{Strain } (\varepsilon) = \frac{1}{2} \ln\left(\frac{D}{d_1}\right)$

b. $\text{Flow Stress}(\sigma_f) = k.\varepsilon^n$

c. $\text{Estimated Applied Force}, F_{applied} = \pi.d_1.t.\sigma_f.\ln\left(\frac{D}{d_1}\right)\sin\alpha$

d. $\text{Estimated Work (W)} = \text{Force x Stroke}$

CALCULATIONS FOR OLD METHOD

a) I^{st} Draw old method :-
D = 14.40mm, d_1=13.16mm, t=1mm, h=22mm(Effective Stroke)
  a. Strain (ε) = 0.0450
  b. Flow Stress σ_f = 24.069 Mpa
  c. Estimated Applied Force ,$F_{applied}$ = 89.600 kN
  d. Estimated Work,W = 1.970 kJ

b) Design Calculations for the II^{nd} Draw old method :-
D = 13.16mm, d_1=12.06mm, t=0.717mm, h=36mm(Effective Stroke)
  a. Strain (ε) = 0.0436
  b. Flow Stress σ_f = 23.711 Mpa
  c. Estimated Applied Force ,$F_{applied}$ = 56.233 kN
  d. Estimated Work,W = 2.024 kJ

c) Design Calculations for the III^{rd} or Final Draw old method :-
D = 12.06mm, d_1=11.24mm, t=0.35mm, h=50mm(Effective Stroke)
  a. Strain (ε) = 0.0352
  b. Flow Stress σ_f = 21.342 Mpa
  c. Estimated Applied Force ,$F_{applied}$ = 18.573 kN
  d. Estimated Work,W = 0.928 kJ

CALCULATIONS FOR NEW METHOD

a) Design Calculations for the I^{st} Draw :-
D = 14.40mm, d_1=12.40mm, t=0.967mm, h=27mm(Effective Stroke)
  a. Strain (ε) = 0.0747

b. Flow Stress σ_f = 30.866 Mpa
c. Estimated Applied Force ,$F_{applied}$ = 155.444 kN
d. Estimated Work,W = 4.197 kJ

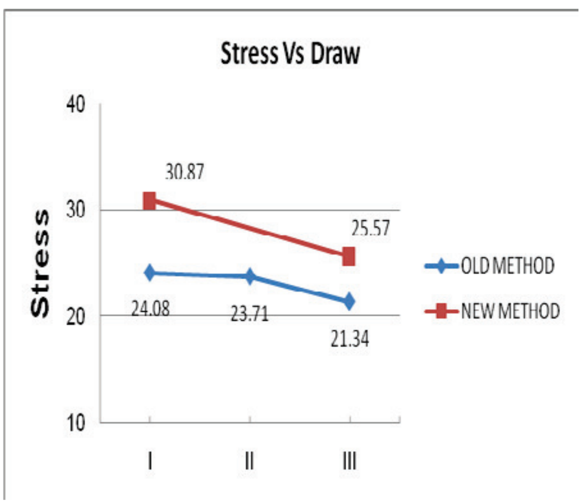
b) Design Calculations for the II[nd] or Final Draw :-
D = 12.40mm, d_1=11.20mm, t=0.34mm, h=50mm(Effective Stroke)

a. Strain (ε) = 0.0508
b. Flow Stress σ_f = 25.565 Mpa
c. Estimated Applied Force ,$F_{applied}$ = 27.829 kN
d. Estimated Work,W = 1.3915 kJ

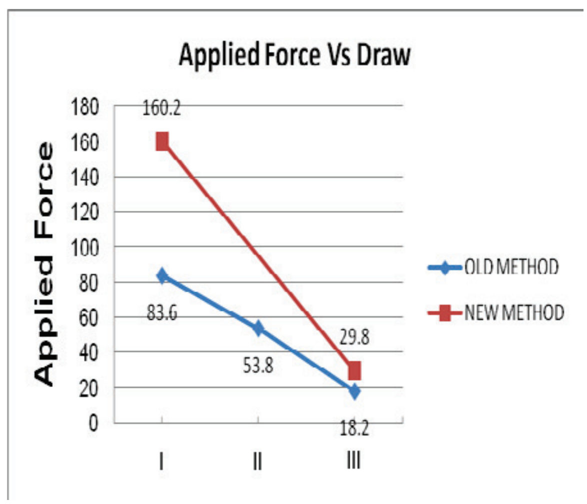
The drawing process can produce complicated axis-symmetric geometries and several non-axis-symmetric geometries in few operations with low technical labors requirement is also an advantage in manufacturing applications. Examples of deep drawing applications include containers of all shapes, sinks, beverage cans, automotive body and structural parts and aircraft panels. In mass production the deep drawing process is advantageous than any other manufacturing process.

III. Experiment and Result

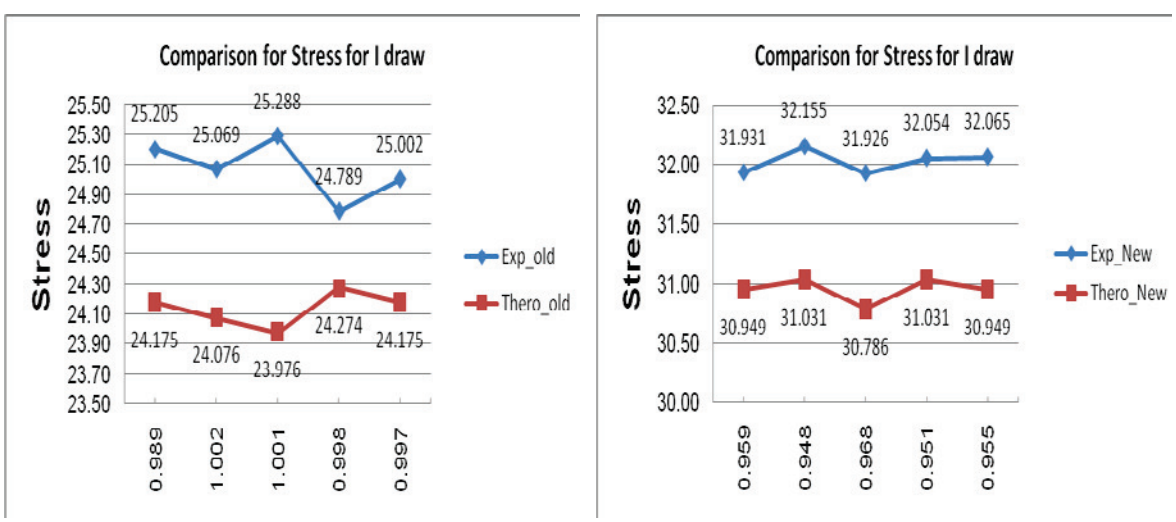
Graph 1 Stress Comparison



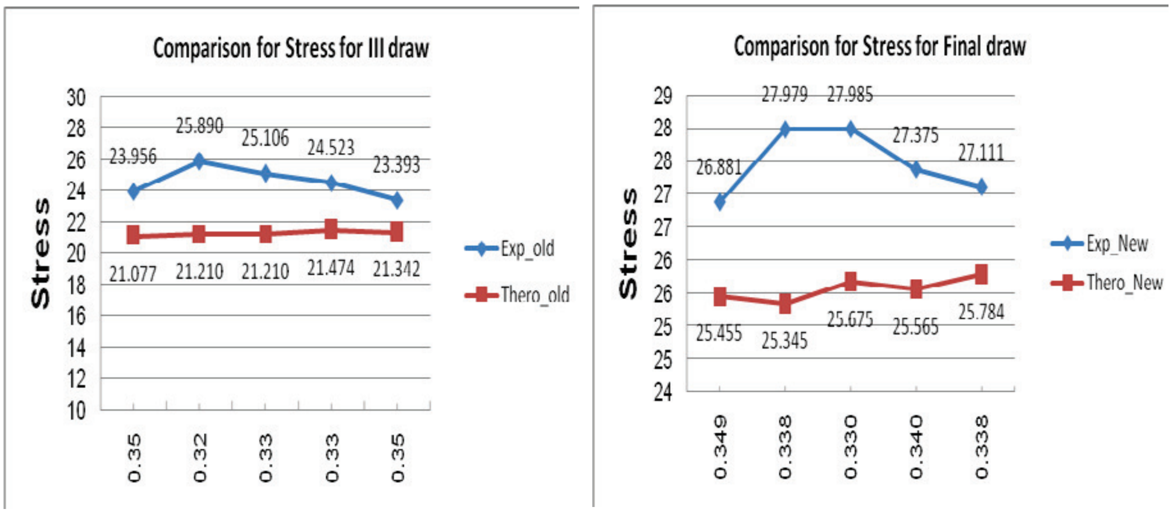
Graph 2 Estimated Forces



Graph 3 Ist Draw Method



Graph 4 III Draw Method



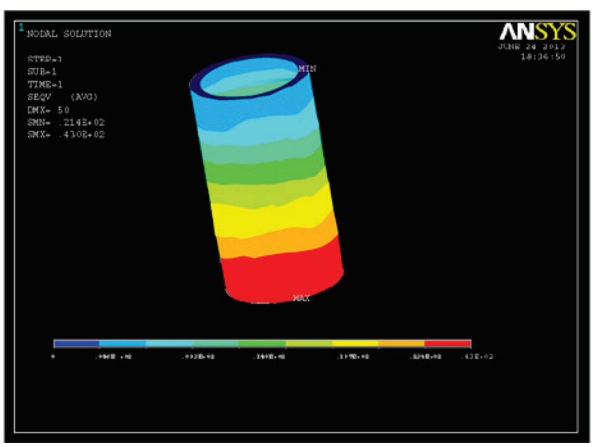


Fig 4 Final draw of old method Constraint Surface

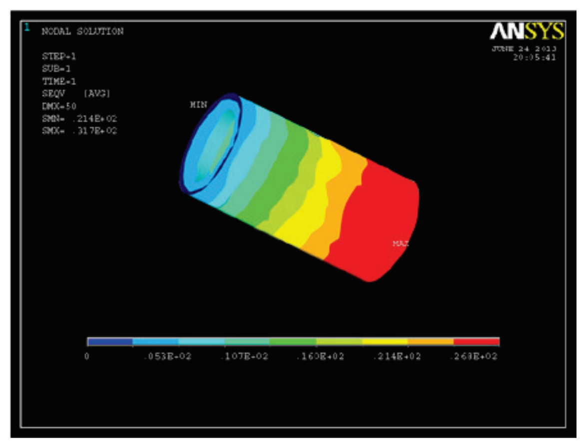


Fig 5 Final draw of new method Constraint Surface

IV.CONCLUSION

As deep drawing materials are easily shapeable, their strengths are lower compared to other materials. However, multi-stage shaped soft materials that will be ultimately used as a pressure cup require a higher strength requirement. With this purpose, although it is a negative outcome that as the drawing stage increases, the ductility of material reduces; increasing of the hardening is a profit in terms of cup yield. In above, though the force and stress is seems to be increased, the major outcome is increase in productivity. The material is stressed more below its allowable stress. The present model can be useful in conducting parametric studies on the different parameters affecting the process including die design, process and material parameters. This is beneficial in the mass production industry where time, machine and manpower is important.

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