International Journal of Advance Engineering and Research Development (IJAERD)
Volume 1,Issue 6,June 2014, e-ISSN: 2348 - 4470 , print-ISSN:2348-6406

Experimental and Simulation study of Deep drawing process-A review

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Abstract: Deep drawing is part of forming process in which sheet metal drawn into die cavity by action of a punch. So, due to action of punch desired shape can be achieved. For reduce various defects in deep drawing process it is essential to control or vary physical and geometric parameters of deep drawing process. Sheet-metal drawing is a more complex operation than cutting or bending, and more things can go wrong. A number of defects can occur in a drawn product. It is essential to reduce otherwise production cost is simultaneously increased. A blank holding force, punch force, material property of sheet metal, thickness of sheet, velocity of punch, these are all affecting parameters in deep drawing process to regulate wrinkling effect, tearing effect and fracture defect. Nowadays composite material is extensively used in manufacturing industries due to its better strength. Therefore with the help of experimental and simulation tools investigation of stress and strain distributions in the deep drawn cup were also done and the Finite element results can predict the same place of tearing and wrinkling error for bimetal cup as occurred in experimental tests.

Key Words: Deep drawing, Experimental work, Simulation process

1. INTRODUCTION

Metal working process has been divided into following given categories such as forming, cutting, and joining. They above mention process can be used for different purposes depending on the requirement. Before carrying out operations, the work to be done on the metal should be marked out and/or measured depending on required product to be achieved. Marking is process of converting design or pattern to a work piece and it is primary step in metal working. It is done in industries as they need to mark out every piece. In metal treading marking out is transferring engineers' plant to work piece for preparation of next step which may be machining or manufacturing. Thus metal working is basically process of marking, planning and manufacturing by using various manufacturing process [1].

Manufacturing process is basically classified in to six main categories which are mention. Primary shaping is process of creating of initial shape from molten, gaseous or formless solid state, Material forming, Dividing is process of separation of local material, Joining is process of assembling individual work piece so that sub-assemblies are created. Filling and saturation of pours work piece takes place in joining process, Modify material property is process of altering material characteristics of work piece for achieving certain useful properties such as heat treatment process which includes hardening or recrystallization annealing, Coating is process of applying thin layer on components.

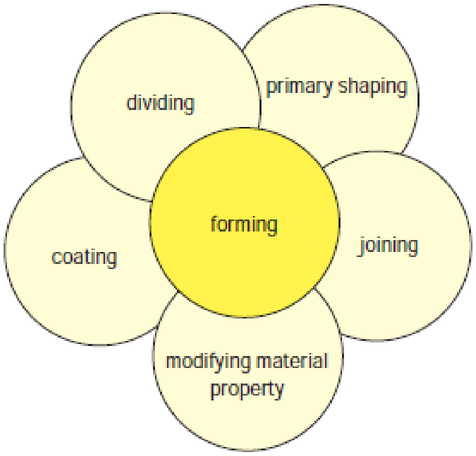

Figure 1: Manufacturing system [1].

Nowadays continuous rolling mills are producing bulk quantity of thin sheet metal at low price. Huge amount of all metals are produced as hot rolled striped or cold rolled sheet. Secondary process is done in automobiles, domestic application, building products, aircraft, drink cans. Sheet metals posses' advantage for the material having high elastic modules and yield strength. So, that the parts obtain can have good stiffness and excellent strength to weight ratio. In sheet metal working process the cross section of work piece does not change but material is only subjected to change in shape the ratio of cross section area to volume is more [2].

1.1 Important process parameters of metal forming process

Metal forming process must be done economically so, that the cost is reduced. The important parameters for metal forming process which influence the result of production process is to get the optimum result. The work piece plays an important role which provides sufficient formability which allows required amount of plastic deformation which is without cracks or defects. The main things measured in work piece are stress, strain, flow stress and temperature that material will be given. The local parameters between the work piece and die are temperature (T), contact pressure (p), shear stress (τ) which occurs mainly due to friction forces transferred from work piece to die. The other important parameter which plays important in metal forming process is the type of lubrication used [3].

2. DEEP DRAWING PROCESS

In 2001, few research were done on deep drawing, this process has been studied intensively by several experiment and investigations. To overcome difficulties of deep drawing process very thin metal foils were used as new concept. Required shape and dimensional accuracy where achieved by using auxiliary metal punch together with polyurethane ring. Another approach use of hot isostatic pressing to form micro channels from ultra thin foils. Mechanical micro deep drawing process is compared with new laser deep drawing process through which shock waves are produced. Lubrication is most important as the sheet slide between die and blank holder. Deep drawing has been carried out with the help of die, blank holder, punch and sheet metal which is show in below [2].

2.1 Geometric parameters of deep drawing process

Drawing is sheet metal forming operation used to make cup shaped, box shaped, and complex curved and concave cup. The common parts made by deep drawing process are beverage cans, ammunition shells, sinks, coking ports and automobile body parts. The sheet of metal is formed into 3-D product by deep drawing process. The main tools used in deep drawing process are blank, punch, die and blank holder. The geometry parameters used in deep drawing process are [4] Punch Radius (R_p), Punch Edge Radius (r_p), Blank Thickness (t), Blank Radius (R_b), Die Radius (R_d) , Die Edge Radius (r_d).

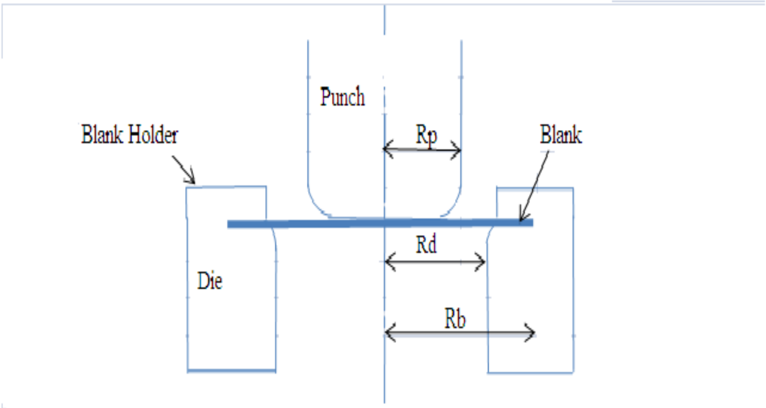

Figure 2: Tool geometry parameter of deep drawing process [4].

The geometry parameters must be selected carefully because the final product depends highly on above mention geometries. Clearance is the important parameters which is obtain by the difference between die radius and punch radius ($c= R_d-R_p$). Clearance must be 25% larger than initial blank thickness. The above mention physical and geometrical parameters are explained in brief below [4].

2.2 Physical parameters of deep drawing process

Physical properties of deep drawing process plays vital role in achieving high accuracy for the final product. Deep drawing process depends on type of blank material, blank holder force, punch speed, die edge radius (r_d), lubrication and drawn depth. Blank holder force mainly produces effect on failure on sheet metal. [4] By reducing BHF wrinkling effect comes as failure and increasing BHF results in splitting and fracture. Die edge radius produces stress concentration which results in tearing effect on the edges of vertical wall of cup [5]. Proper lubrication results in reducing stress, wrinkling and hence results in reducing error in deep drawing process.

2.3 Defects in deep drawing process

Deep drawing process is more complicated than cutting or bending because many things can go wrong in deep drawing process which may results in some defects which are mentioned below with neat sketches [6].

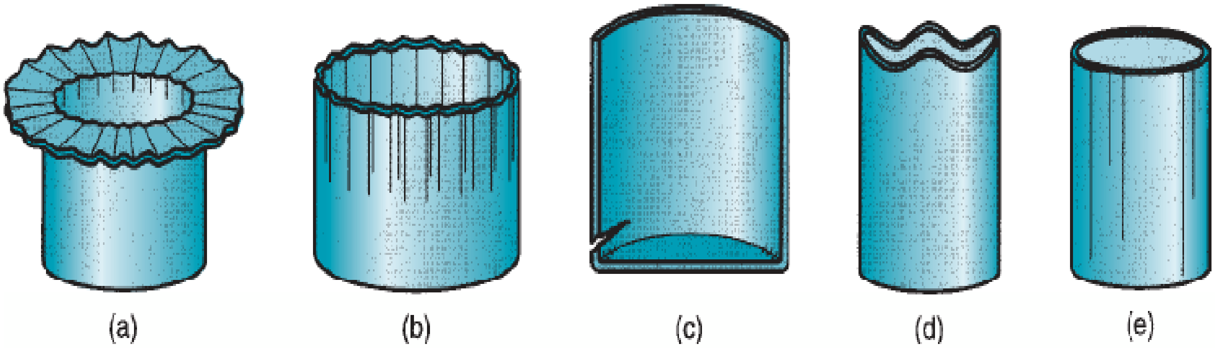

Figure 3: Defects in deep drawing process [6].

Figure (a) represents wrinkling in the flange. Wrinkling is mainly cause on flange due to compressive buckling on the undrawn flange. Figure (b) represents wrinkling on the wall. Wrinkling of wall generally take place in the cup shaped flange. Figure (c) represents tearing and open crack produced in vertical wall which usually take place near the base of drawn cup thus results in high tensile stress which may lead to thinning and failure of metal at the location shown in the figure (c). Tearing may also occur in metal due to pulling over a sharp die corner.

Figure (d) represents earing. Earing is mainly cause due to forming of irregularities which are called ears and generally occurs on the upper edge of finished part. Earing is also caused by anisotopric in sheet metal. Material must be made up of perfectly isotropic which results in removing of earing. Figure (e) represents surface scratches. Surface scratches mainly occur on the drawn part if the punch and die are not smooth or if the is not done properly.

3. EFFECTS OF PARAMETERS ON THINNING OF SHEET METAL IN DEEP DRAWING PROCESS

3.1 Description

Sheet metal forming is process by which automobile industries produce most of the body parts in this process thin blank sheet are subjected to plastic deformation using forming tools to obtain designed shape. Defects are produce in blank sheet in the parameters are not selected properly. Optimization is required to avoid defects in part and minimize production cost. Optimization of parameters such as die radius, blank holder force, friction co-efficient can be achieved based on the degree of importance in sheet metal forming [5].

The deep drawing process is very important in the industries which use cold pressure. Sheet metal deformation processes, deep drawing are very complex operation in which the process parameters plays huge role. The processes are punch, die shape, blank shape, blank holder force which acts contact between element and material properties. Prediction of material can be done by decreasing wall thickness of the container and the retaining of container can be done by providing strength for allowing container to serve its purpose without the fear of failure. The designer must meet the expectation and also determine the material requirements and properties suitable for the food or drink to be packed. This process as well as metal forming techniques experimental tested by using trial and error method or empirical method for dies, blank holders and punches which are manufactured are expensive and time consuming process. The objective of the work is to simulate the deep drawing process and the results obtain are validated by making a comparison with literature published previously. The literature contains both experimental and numerical results which are used as benchmark for comparing purpose. The purpose for doing research is that deep drawing process makes manufacturing process efficient by reducing the cost. The success of deep drawing process in simulation depends on successful modeling which helps in numerical analysis to achieve higher accuracy. The use of finite element analysis and statistical method helps in prediction of punch force, blank holder force and the lubrication requirements can be determine through the thickness of metal. This can gradually reduce the production cost, reduce time for production and provide engineers ability to respond to the market changes [5].

3.2 Tool geometry parameter

1. Die shoulder radius

In deep drawing process the geometry of die influence the thickness distribution and thinning of sheet metal. Die shoulder radius plays important role in sheet metal thickness distribution [7].

2. Punch nose radius

The geometry of punch plays important role in the thickness distribution and thinning of sheet metal in deep drawing process. Punch nose radius plays important role in metal thickness distribution. When punch nose radius is less than three times thickness of blank the cup fails and when punch nose radius is greater than three time thickness of blank, thinning is stable.

3. Blank thickness

The original blank thickness plays vital role in thickness distribution and thinning of sheet metal deep drawing process. The average distribution of blank thickness improves with increase in blank thickness. Also the percentage of thinning increases with increase of blank thickness. The blank thickness and punch diameter affect the limiting drawing ratio and limiting drawing ration decrease as the relative punch diameter increases. Thicker material can be gripped properly as diameter increases. Thicker sheets have more volume so it can be stretched greater extend with increasing.

4. Radial clearance

Radial clearance is difference between die radius and punch radius. Sheet metal thickness increase when radial clearance decreases. When radial clearance is less than blank thickness the cup fails due to increase in thinning. When the radial clearance is greater than blank thickness thinning is stable.

3.3 Physical parameter

1. Blank holder force

Blank holder force is required to hold a blank which is one third of drawing pressure. Higher the blank holder force greater will be the strain over the punch face. The process is limited by strain produce in the side wall. When tension reaches maximum value the side wall will fail by splitting. Cup collapse due to thinning with increase in blank holder force over 0.5 ton [7].

2. Cracking Load

The largest allowable drawing load is limited by the load that can be transmitted by the sheet in the region of the punch radius or at the transition form cup wall to bottom radius, which is known as cracking load. It must always be larger than the maximum drawing load [8].

3. Friction parameter

Friction is one of the important parameter in deep drawing process. Friction determines the punch force and blank holder force in case of deformation of sheet. Friction use energy which is needed to deform a sheet material. Friction plays vital role to determine stress and strain in the work piece. It is important to control friction between tool and work piece. In deep drawing process hollow bodies from metal blanks using punch, die and blank holder. In deep drawing process lubrication and friction is complex as compare to other process. In one operation low friction is required in one area and high friction is required in other area [9].

4. EXPERIMENTAL WORKS

4.1 Preliminary Test:

Brass is wide decorative applications and its thermal and electrical conductivities are much better and its specific heat is considerably less higher, compared with those of the stainless steel. However, tarnish resistibility, strength/density ratio and surface quality of the stainless steel are higher than brass. Therefore, by making a parts made of brass and stainless steel, one can take different advantages of these metals at the identical time [10].

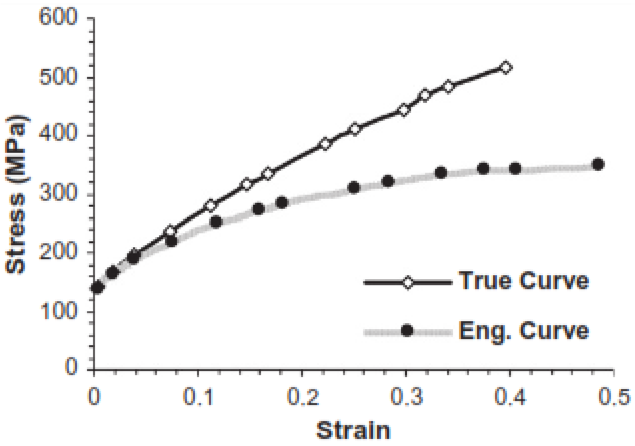

Figure 4: Engineering Stress vs. Strain Diagram [10]

In the practical experiments, it is firstly necessary to find the mechanical properties of the selected materials as well as the Coulomb friction co-efficient between the sheet and the dies. These data are also required for performing the FE simulations of the process. For this case, the tensile tests, based on ASTM (E8M-98) standard, were used to specify the stress–strain curves of the brass and stainless steel under consideration. This type of test is usually adopted for sheet metal forming processes, because of the stress state involved. For more precise evaluation of strain, all the tensile tests were conducted using an extensometer. The thicknesses of the steel and brass sheets were 0.39 and 0.62 mm, respectively to meet enough clearance between the punch and die. [11]. Figs. 4 and 5 depict the true and engineering stress–strain curves of these alloys. To determine Coulomb friction coefficients under various conditions, the friction tests were employed. Fig. 6 represents schematically the fixture used for evaluation of the friction coefficients. For each frictional condition, a normal force (N) was applied to the sheet by the press and, then, the horizontal force (F) needed for initiation of motion of the sheet between the die faces was measured. Afterwards, using the Coulomb friction formula, the friction coefficient was calculated. Three different frictional conditions were tried for both the steel and brass sheets.

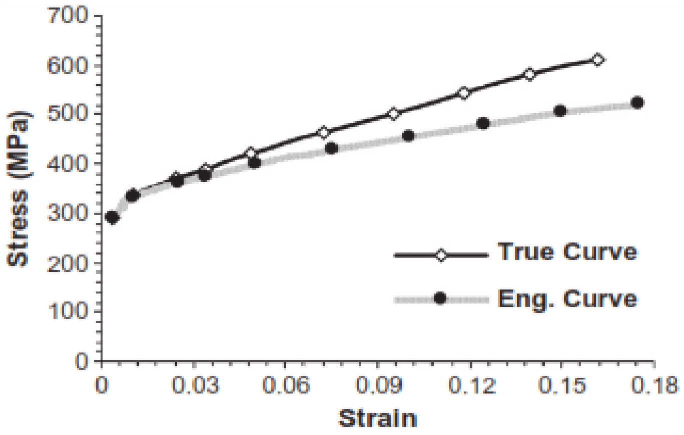

Figure 5: Engineering Stainless steel Diagram [10].

4.2 Deep drawing Test

The process variables selected for investigation were the layer stacking sequence, blank diameter, blank-holder force and lubrication. Therefore, blanks with three diameters 7.5, 8.5 and 10 cm from stainless steel and brass sheets were punched to make composite sheets. Lubrication with nylon film and dry condition were also two different contact conditions maintained between laminated sheet and punch, die and blank-holder. The blank holder force was adopted with three levels, namely 0.71, 2.14 and 3.56 KN. These values were selected considering the guidelines suggested by Johnson and Mellor [10]. The blank holder force was exerted by means of eight B-16/76 standard springs. This force was kept constant during each drawing experiment. It is helpful to note that recommended blank-holder force to have defect-less products must obey Equations.

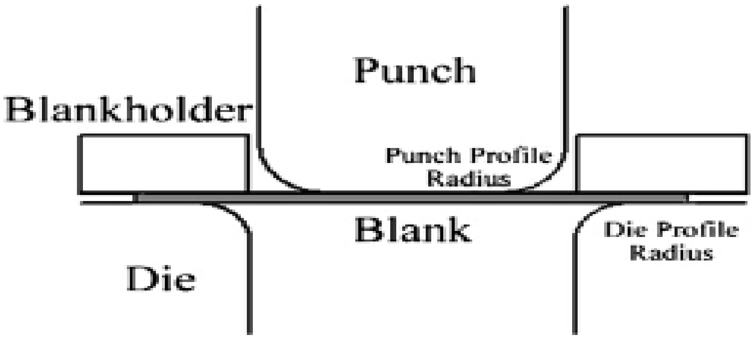

Figure 6: Engineering Stainless steel Diagram [10].

Dry condition and nylon sheet as a lubricant were considered for tool workpiece interface. The stacking sequence involved two cases, namely BS and SB. In BS case, the stainless steel layer was in contact with the punch and the brass sheet was positioned underneath. In SB state, there was a reverse situation, i.e. the brass material layer in case of the composite blank contact with the help of punch.

Additionally, Fig. 6, schematically, shows these parts of the die set. After adjusting all the process conditions, the main tests were conducted at the room temperature by means of a 600 kN Instron testing machine with 0.5 mm/s displacement rate.

5. SIMULATION TECHNIQUES

The first sandwich material to be use in industry was in 1994, wooden sandwich material consists of plywood and balsa which was used in air craft there was rapid development in aircraft industry whose demand was light, stiff, and strong material which led to wide spread development of different sandwich material. In 1987 and advance sandwich material to known as GLARE (Glass laminate aluminum reinforce epoxy). This sandwich material offers better damage tolerance, excellent corrosion and fire resistance with reduction of weight [12].

Earlier research work on the optimization in deep drawing used simple rule-of-thumb optimization techniques that play on less rigorous mathematical and analytical tools. The reason for that is due to the convolutedness of the mathematical models that describe the deep drawing process.

The work of Conry et al (1980) is a good example for that. They work out a nonlinear mathematical programming model to determine the unsurpassed die profile. This model turned to be very stubborn and complex to be solved mathematically. They evolved an iterative optimization approach combining regression curve fitting and the techniques for constrained optimization. Nevertheless, since there is no experimental or simulation verification of this study, there is no pledge for its realistic pertinence [13].

So, the Finite element (FE) simulation and analysis gives a fertile environment for improvement and optimization in deep drawing. To overcome the unconvinced in the mathematical models of the deep drawing process, some researchers worked on developing empirical formulas that are based on the FE simulation results. Such empirical formulas are simple to deal with using a suitable optimization algorithm.

The inverse approach is developed for sheet metal forming processes and it is a simplified efficient finite element method. It is based on the idea of estimating the large plastic strains in thin metallic plates. It is mainly express the knowledge of the 3D shape of the final work piece, and used to find the original position of each material point in the flat blank after that it is possible to estimate the strains and stresses in the final work piece.

5.1 Simulation Procedure for deep drawing process [14].

First of all 2D model is created and give the material properties which selected for testing than load will applied as per experimental test and then check the results.

This simulation work follows following steps

Preprocessing: defining the problem;

- Define key points/lines/areas/volumes (Solid Modeling)
- Define element type and material/geometric properties
- Mesh lines/areas/volumes as required

Solution: assigning loads, constraints and solving;

- Apply the loads (point or pressure),
- Specify constraints (translational and rotational)

Post processing: further processing and viewing of the results;

- Lists of nodal displacements and show the deformation
- Element forces and moments
- Stress/strain contour diagrams

1. Solid Modeling

The process of creating solid model in CAD system. A solid model is defined by volumes, areas, lines, and key points. By using various geometrical data of presented setup a solid modeling of the same is created in ANSYS. Solid modeling of the experimental set up is done by using various dimension of the geometry [15].

2. Elements

The type of element to be used in the analysis influences the exactness and accuracy of the results to a great extent. Literature review and examination of peer researchers' works show that PLANE42, 2-D elements with axis symmetric behavior have been conveniently used in the numerical analysis of axis symmetric forming process [15].

3. Material Properties

The material of back plates is mild steel IS 2062 grade. It was selected as a structural, non-linear, isotropic hardening material model in the presented ANSYS simulation. Various material properties like yield stress, Modulus of elasticity, Poisson's ratio etc, which are required for fem simulation are obtained from various authentic literature. Tools are assumed as rigid, so there is no need to define material, however the material of punch and die is tool steel [15].

4. ANSYS meshing

A quad mapped mesh was generated on all areas apart from the punch/die which is taken as rigid. This was done to achieve a higher number of elements along this line so a solution using contact conditions could be found easier [15].

5. Loading and boundary condition

As part of FE analysis, applying loads and constraints i.e. boundary conditions consists of defining which parts from geometrical model moves i.e. defining degree of freedom. Contact surfaces used in the presented work are top blank - bottom punch, bottom blank - top die. In current study movement of blank part is restricted in x- direction. Displacement load of the part of the blank which initially not in contact with die is given in y-direction. Movement of horizontal part of the blank which is on the die is restricted in x- direction as well as in y-direction both. The tools i.e. punch, die and blank holder, in finite element simulation are considered rigid because they are extreme stiff compared to the sheet. For this reason the tool can be presented as a surface only [15].

6. Finite Element simulation model

Author Amir Atrian has presented result of simulation by finite element method and it is show in Figure-7 In which they have for each frictional condition, the average value of the friction coefficients obtained for brass and steel were used as the friction coefficient between the steel and brass layers. All parts of the die set were modeled rigid to reduce calculation time. Figure- 8 illustrates the deformed finite element model in ANSYS.

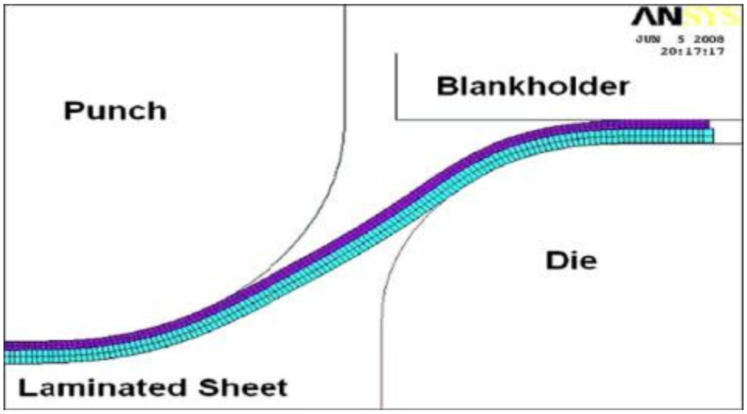

Figure 7: 2D Finite-element modeling of the deep drawing of composite sheets.

7. Results of FEM [10].

The effects of all the variables on the load–displacement curve are presented and discussed in this section. Fig. 8 typically compares the load–displacement curves obtained from two different solutions.

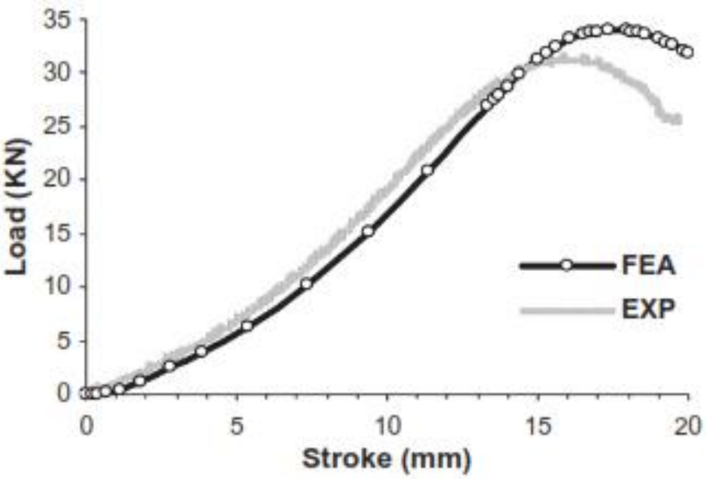

Figure: 8 A typical comparison of experimental and finite element load–displacement curves.

This figure illustrates that FE results usually predict a greater forming load for doing the operation. This overestimation of the FE solution is about 10% and more or less is observed in other comparisons between the experimental and finite element results. Therefore, selection of the forming machine capacity based on the FE results includes a safety factor for having a successful operation.

In the composite sheet behavior in a forming process differs from single-layer sheets and depends on the layer sequence and thicknesses. Despite the effect of friction, the early part of the curve is also changed, as can be observed in Fig. 8. It was also observed that the friction condition can change the influence of the stacking sequence.

As an example, for dry condition, when the steel layer was in contact with the punch (BS), the maximum load was about 7% greater than the similar situation with SB case. But when nylon sheet was employed as lubricant, the SB condition needed nearly 14% greater force, compared with the BS case under similar conditions. These observations are almost confirmed by the FE finding. Under the dry condition, when the steel layer was in contact with the punch (BS), FE results showed that a greater force, about 1.5%, was needed compared with the other arrangements. However, with nylon lubricant, 8.5% greater force was required for the SB stacking sequence.

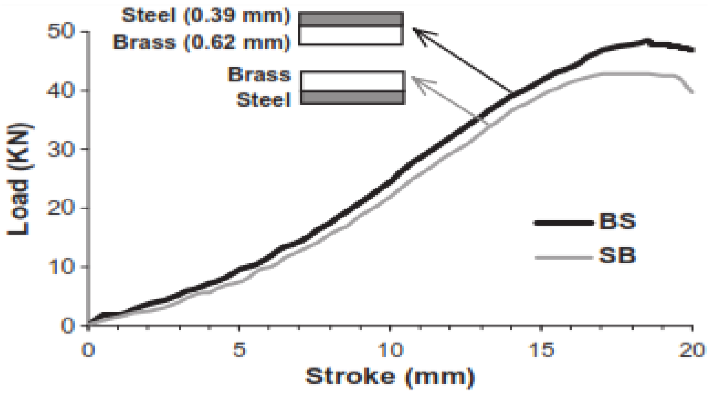

Figure 9: Effect of layer stacking sequence on the load–displacement curve for dry condition

For deep drawing of composite blanks, the selection of appropriate blank holder force is also critical. It is evident from Fig. 9

Figure 10: The effect of decreasing the blank holder force (from left to right) on occurrence of wrinkling at the edges of composite blanks.

Its good combination between experimental and finite element result which is show that Finite element method can be used in various industrial process. Sequence of layer is also important on the behavior of finished part. By changing the order of layer various defects can be observed in the deep drawing process of bi-metallic strip. Circumferential stress and thickness strain produced in drawn cup in the region of punch radius area which is most critical area for the drawn cup. From that point it is more chance to fracture and splitting.

6. CONCLUSION

It has reviewed that in manufacturing world forming process is most concerning process. Forming is process through which desired shape can be achieved without metal removing. In forming process a deep drawing process has been covered. So, this paper deals with the various parameters of deep drawing process which plays major role to obtain the finish part as well as optimization technique to improve the productivity and quality of product. Lubrication is also plays effective role in fine deep drawing process. By using lubrication in deep process wrinkling effect is firmly reduced. In recent years composite material is widely used in aerospace, automotive and utensil industries which are stated in paper.

ACKNOWLEDGMENT

The authors wish to thank the department of Mechanical Engineering at R.K. University, Rajkot for their support in the research work. The author would like to thank Mr. Kartik D. Kothari (Head of Department) for his support in the writing of this paper.

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