Role of Hydraulic Fluid Pressure in Sheet Metal Forming

Dr.R.Uday Kumar
Associate Professor, Dept. Of Mechanical Engineering, Mahatma Gandhi Institute of Technology, Gandipet, Hyderabad – 500075, India.

Abstract – The stamping of parts from sheet metal is a straightforward operation in which the metal is shaped or cut through deformation by shearing, punching, drawing, stretching, bending, coining, etc. Production rates are high and secondary machining is generally not required to produce finished parts within tolerances. This versatile process lends itself to low costs, since complex parts can be made in a few operations at high production rates. Sheet metal has a high strength-to-weight factor, enabling production of parts that are lightweight and strong. Hydroforming process is divided into two main groups; sheet hydroforming and tube hydroforming. Tube HydroForming (THF) is a process of forming hollow parts with different cross sections by applying simultaneously an internal hydraulic pressure and axial compressive loads to force a tubular blank to conform to the shape of a given die. Geometry of die and workpiece, initial tube dimension, tube anisotropy, and internal pressure are of the important parameters in this process .With the advancements in computer control and high-pressure hydraulic systems, this process has become a viable method for mass production, especially with the use of internal pressure up to 6000 bars. Tube hydroforming offers several advantages as compared to conventional manufacturing processes. Double-blank sheet hydroforming can be used as an alternative to sheet hydroforming with a die, because in both methods the sheet metal is forced against the die by the liquid medium. However, in double-blank sheet hydro-forming, two parts can be produced in one production cycle, which increases productivity. This process potentially allows the forming of two different materials and/or two different sheet thicknesses in one production cycle. Double-blank sheet hydroforming is the potential to be practical for the production of relatively small batches of parts.

Index Terms – Hydroforming,Tube hydro forming, Double sheet hydro forming, Fluid pressure.

1. INTRODUCTION

In sheet metal hydroforming, controlled metal flow during the operation minimizes localized stress concentrations that may cause workpiece buckling or wrinkling. Sheet metal hydroforming is slower than traditional stamping, thus its use is limited to short runs of more highly specialized parts(1-2).Tubular hydro forming begins with the placement of either straight tubes, or more commonly preformed tubes, into the die. Sealing punches within the die close off the tube ends as fluid pressurization begins. The three surfaces of a tube that can act as sealing surfaces, include the outside diameter of the tube, the inside diameter of the tube and the end surface of the tube. During forming, a combination of increasing internal fluid pressure and a simultaneous axial pressing on the tube ends by the sealing punches cause the tubular material to flow into the contours of the die. Tubular hydro forming is generally divided into three operating techniques: Low-Pressure Hydro forming uses fluid pressures of 12,000 PSI/828 BAR or less. Cycle time is less than with other hydroforming methods, but components must be designed carefully to form properly using the lower fluid pressures (3-6).

High-Pressure hydroforming uses fluid pressures ranging from 20,000 to 100,000 PSI/1,379 to 6,895 BAR. The exact amount of pressure needed is dependent upon several factors such as material yield strength, tube wall thickness and the inside radius of the sharpest cross-sectional corner. When the tube is expanded by high pressure within the die cavity, material thickness may vary throughout the part. Additionally, larger presses are needed for high-pressure hydroforming and the higher operating pressures can result in longer cycle times.

Pressure sequence hydro forming utilizes the closing action of the hydraulic press to assist in the hydroforming of the blank(7-10). The blank is first placed in the die cavity and the die is partially closed, partly deforming the tube. Low-pressurized fluid is then pumped into the blank allowing it to resist compression. The die starts to close again with the desired low-pressure maintained while part cross section reduces. Once the die is fully closed, high pressure is applied to the fluid, forcing the blank material into the corner recesses of the die cavity with no wall thinning.

Maximum pressure for pressure sequence hydroforming is typically under 10,000 PSI/690 BAR. Tubular hydroforming cycles also include 'hydro-piercing' to create holes and slots in the part(11-16).The piercing tool is incorporated into the hydroforming die and activated during the forming cycle by hydraulic cylinders.The piercing action is usually inward against the pressurized fluid. Piercing can also be performed outwardly by retracting a plunger, or backup punch. The fluid pressure within the tube causes the surface material to fail, creating a hole in the unreinforced portion of the tube wall.

Hydroforming is a manufacturing process, where fluid pressure is applied to ductile metallic blanks to form desired component shapes. The blank are either sheet metal or tubular sections. If sheet metal blanks are used, the process is called sheet metal hydroforming, and if tubular section blanks are used, it is called tube hydroforming. The tubular geometries can be used for manifesting space frames, camshafts, I/P beams, and exhaust skims. A generic tube hydroforming setup comprises of the tube hydroformed, along with the hydroforming die halves and mechanisms for end sealing as well as for axial feed of the tube ends(17-20). Many tubular hydroformed components require the tube to be pre-bent to the general shape of the component so that it can be accommodated into the die cavity. Materials used in Hydroforming:Aluminum, Brass, Steel, Copper, Stainless Steel, Inconel and Exotic Materials (Waspalloy, Hastelloy, High Nickel Steels).

2. DOUBLE SHEET HYDROFORMING

The use of liquid-based forming processes represents an excellent way to manufacture complex sheet metal components with reproducible shapes and functions. However solutions for the production of complex hollow components in a single manufacturing step are offered only by the tubes hydroforming. Currently, new requirements, particularly in automotive industry, such as economical production of recessed products and the requirement for the improved material and component characteristics allow the assumption that, this process will be used to a significantly higher extent in the future.

The initial part is produced using two flat or pre-shaped sheet metal plates, arranged in parallel and in contact with one another with the same or different sheet metal thickness and of the same or different type of material with identical edge dimensions and welded to one another at the edge. The double plate produced in this manner is inserted into a tool consisting of upper and lower dies; after the tool is closed, the edge area of the plate including the weld is located between the sheet metal retaining surfaces of the upper and lower tool part with higher or lower width.

The component is shaped by a pressure medium between the plates (fig.1). Depending on the material used and the component geometry, the flange can be clamped stationary or the flange can be allowed to flow into the tool die. Moreover it is necessary to integrate a suitable docking system into the tool to allow the pressure medium to be fed in during the forming process. Various docking systems are suitable for injecting the pressure medium between the two plates depending on the material flow requirements and the most familiar are the sealing lance and the hemispherical sealing ram.

The sealing lance, is inserted at the unwelded point between the plates with the tool closed; the upper and the lower dies have a recess in this area, so that, the penetrating lance displaces the sheet metal material in the radial direction in the recess(2-3). This system is suitable for parts or part areas where a high material flow from the flange area into the actual tool die is required.

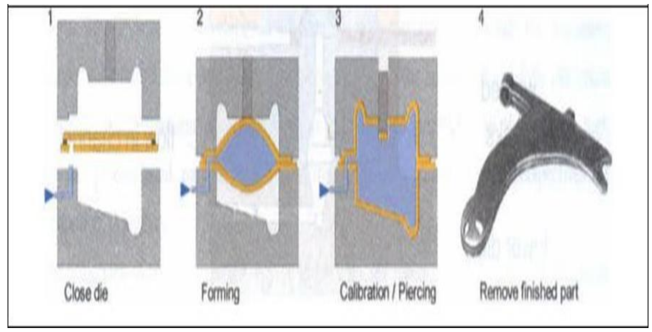

Fig.1 Process principle for parallel plate Hydroforming

As mentioned above, parallel plate hydroforming, in contrast to tubular hydroforming, offers the possibility of producing different sheet metal thicknesses and materials in one forming step without relevant additional costs. However, in varying the plate thicknesses, it is necessary to take into consideration the flow start and instability limit for the various plates, to obtain perfect forming results.

In spite of several advantages in comparison to deep drawing and to tubular hydroforming, it is necessary to consider the process limits, regarding particularly the components design. In fact, since the upper and lower plates are already welded to one another at the circumference at the beginning of the process, part flanges positioned on top of one another are pulled together into the die. At various drawing depths or extensions of the upper and lower component shells, the flange of the part with less depth therefore has a braking effect on the flange of the deeper part. On the other hand, the flange of the deeper part attempts to pull the flange of the less deep part into the die with itself. This can result in the deeper half shell tearing and/or formation of creases in the less deep half shell.

As a matter of principle, the same extended dimensions should be attempted for the upper and lower shell; deviations in the developed dimensions in the upper and lower shell in the magnitude between 5% and 10-15% are permissible, depending on the material. Moreover, in designing component corners, particular attention must be paid to the dimensioning of the corner radii: while convex component radii are completely formed when the ram enters the tool during deep drawing, formation of such radii during hydroforming is accomplished within the scope of calibration phase at the end of the forming process. This has permanent effects on the producibility particularly of small component corner radii with simultaneously deep part geometries. Due to the higher normal contact stresses and the resulting friction forces, the material flow from the areas of the parts adjacent to the corners into the corner area is impeded during hydroforming; therefore final forming of the corners is accomplished almost exclusively at the cost of the wall thickness in the corner area, particularly at the end of the calibration operation at extremely high internal pressures. This can lead to critical thinning followed by bursting particularly for small corner radii before the corner area is completely formed.

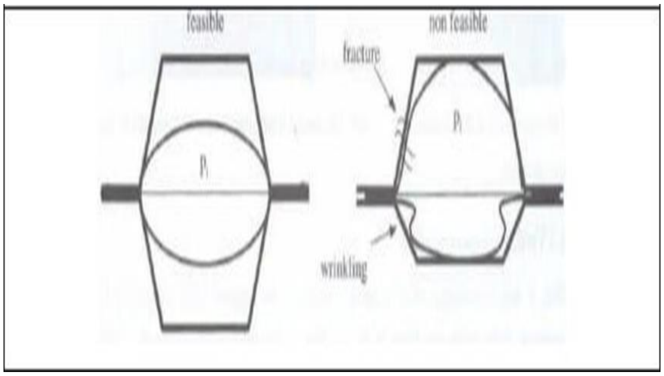

Fig.2 Example for producible and non-producible cross section geometries

The double blank is placed in the tool, which has both upper and lower dies with the shapes to be formed.The blank is held at the edges, and the pressurizing medium is introduced between the sheets. The sheets are formed by fluid pressure against the top and bottom dies to obtain the desired part shapes (fig.2).

3. TUBE HYDROFORMING (THF)

Tube Hydroforming (THF) has been called with many other names depending on the time and country it was used and investigated. The first industrial applications for this process, namely the production of T-shaped joints. The use of these processes increased rapidly in the automotive industry turned its attention to this process and, more importantly, to the possibilities for lightweight constructions.THF will be used to describe the metal forming process whereby tubes are formed into complex shapes with a die cavity using internal pressure, which is usually obtained by various means such as hydraulic, viscous medium, elastomers, polyurethane, etc., and axial compressive forces simultaneously.

Fig.3 shows the process principles for tube hydroforming (1-2). A tube is placed in the tool cavity, whereby the geometry of the die corresponds to the external geometry of the produced part. These tools, in most cases separated in longitudinal direction, are closed by the ram movement of a press, and the tube ends are loaded by two punches moving along the tube axis. Each of the loads applied to the tube ends for sealing the tube's interior must be at least equal to the force calculated from the product of the tube's internal area and the tube's internal pressure. However, the axial forces may be increased to a higher value if the forming job requires it. Then additional tube wall material is brought into the tool cavity. During the process the internal pressure is increased until the expanding tube wall comes into contact with the inner surface of the die cavity. This process principle may be used for hydroforming both straight and pre-bent tubes.

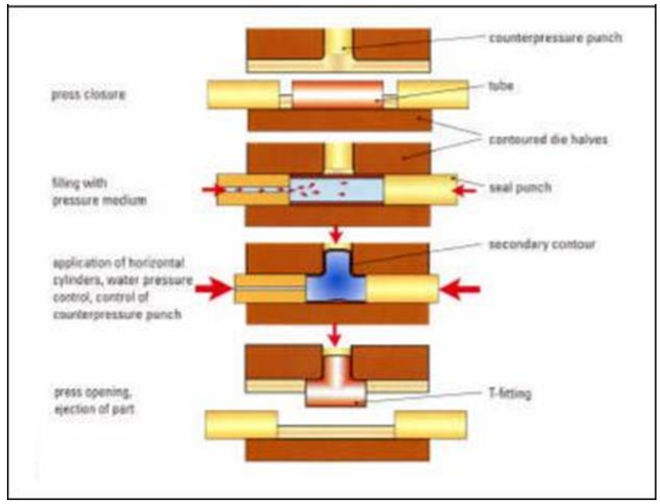

Fig.3 Process principle for tube hydroforming

As shown in fig.4, the applicability of the process implies that failures caused by plastic instabilities such as buckling, folding and bursting can be excluded. The risk of buckling is posed at the start of the process by too high axial loads on the initial tube, and it is also present for the entire starting phase. So that this risk of buckling can be avoided by compensation the unsupported tube length with increasing in the section modulus of the tube cross section through the simultaneous expansion of the tube wall.In the intake zone of the expansion shape, a formation of folds cannot be avoided; these folds, which are symmetrical to the longitudinal axis, can be reversed by an increase in internal pressure during the final phase of the expansion process. However further folds can occur at the centre of longer expansion forms as a result of too high axial forces, these can be avoided with a proper process controller. The risk of bursting is a result of too high internal pressure and is initiated by a local neck in the tube wall, whereby the onset of this local necking significantly depends on the initial tube wall thickness. To prevent this risk it must be ensured that the tube wall briefly comes into contact with the wall of the tool at the latest before the onset of necking.

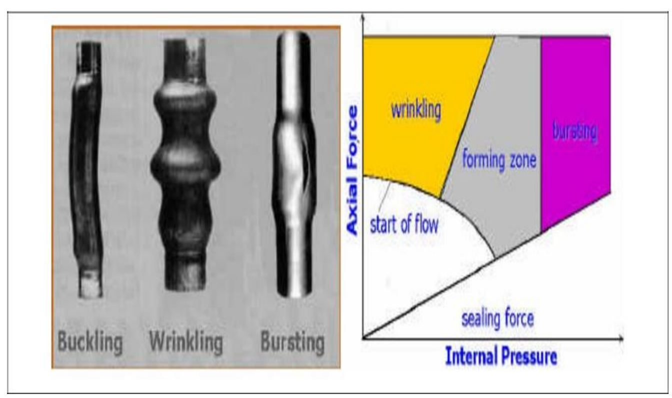

Fig.4 Most common failures and limits in tube hydroforming.

Work piece forming in the hydroforming process takes place through the internal pressure P_i inside the component and the axial load F_a exerted on its ends. With some processes, additional external loads are exerted, which cause stresses in the work piece wall. In the case of thin-walled components these stresses can be referred to as plain stress. It can be described by stress acting in circumferential direction and a transverse so called axial stress. Expansion of the work piece is ensured under the made assumptions when the comparison stress corresponds to the local yield stress of the work piece material and the exerted loads do not give rise to necking. The stress acting in circumferential direction is normally located in the area of tension and the stress acting along the length of the component can be located in the area of compression or tension. By considering these values the maximal pressure attainable in the forming tube can be calculated. The maximum values for P_i and consequently for F_a normally occur at the end of the forming process, when the work piece is calibrated through an increase in the internal pressure. Decisive for the necessary calibration pressure are the size of the component radii to be formed, the wall thickness in these areas and the yield stress.

4. DEEP DRAWING

With deep drawing processes by fluid can be formed parts with complex shapes. Some of advantages of deep drawing processes by fluid are: reduction of the number of operations, cheaper processes (fewer tools), simple die, forming complex shapes, reduction of friction during process, higher surface quality. Fig.5 shows example of sheet forming by deep drawing. With technology of deep drawing by fluid higher ratio of drawing are achieved, number of required operations and dies are reduced and manufacturing costs by part is reduced(12). Process is suitable for sheet metal forming and large dimension parts and complex geometrical shapes.

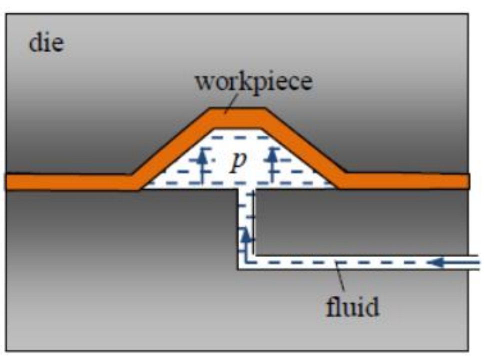

Fig.5 Sheet metal deep drawing by hydroforming

5. RESULTS AND DISCUSSION

In tube hydroforming there are two major practices high pressure and low pressure. With the high pressure process the tube is fully enclosed in a die prior to pressurization of the tube. In low pressure the tube is slightly pressurized to a fixed volume during the closing of the die. In tube hydroforming pressure is applied to the inside of a tube that is held by dies with the desired cross sections and forms. When the dies are closed on the tube the ends are sealed and the tube is filled with hydraulic fluid the internal pressure causes the tube to conform to the dies. In THF, compressive stresses occur in regions where the tube material is axially fed, and tensile stresses occur in expansion regions. The main failure modes are buckling, wrinkling (excessively high compressive stress) and bursting (excessively high tensile stress). It is clear that only an appropriate relationship between internal pressure curve versus time, and axial feed curve versus time, so called Loading Paths (LP), guarantees a successful THF process without any of the failures.

(a) (b) (c) (d)

Fig.6 Tube hydroformed parts: (a) cylindrical stepped tube (b) conical stepped tube (c) rectangular stepped tube (d) bellows

Hydro formed tubular parts vary over a wide range of shapes. This variety goes from a simple bulged tube to an engine cradle with multiple part features such as bends, protrusions, and complex cross sections. It is necessary to classify the THF parts into different categories with respect to common characteristics that they have in order to handle the design process more efficiently. Fig.6 shows some types of parts which are produced in this THF process.

App1ication of internal pressure and axial feeding allows the tubular blanks to makes the die. Tube material properties and formability will determine whether the final part can be formed under the existing process condition. Initial estimate of the process parameters (i.e. internal pressure, axial feeding and counter pressure) can be obtained through analytical calculations or computer simulation to reduce the development time. For reliable prediction of formability condition in tube hydroforming, accurate material data (flow stress, diameter and anisotropy) and process information (internal pressure, axial feeding, counter force and friction) need to be provided to the computer simulations.The input data should also include the strain history (Harding of the material during the bending and prediction) prediction of the thickness distribution in a structural component. Each step in the manufacturing process simulation starting from the bending operation and the strain history was carried over to the next step to improve the accuracy of prediction The reason for the computer modeling in the tube hydroforming process is mainly economical. Since the majority of the tube hydroforming process require high pressure it is not possible to do try-out using soft tooling to verify the process control parameter such as internal pressure and axial feed variation in time If major modifications are require on tooling after it is manufactured it will be very costly and time consuming. Therefore, computer simulations are used increasingly to verify and fine tune the initial design before the hard tooling is built.

This method has various names-pressure lubricating deep drawing, hydro mech, aqua draw and fluid former. It is generally known as hydraulic counter-pressure deep drawing. Looking at the forming process, it is the same as the normal deep drawing process, except for the fact that the die cavity is filled with liquid so that hydraulic pressure is applied during the forming process, but this makes a huge difference. In the normal deep drawing process, blank holding pressure is applied to control the blank but essentially no other force except to the punch and die is applied. Thus the mere application of hydraulic pressure from the bottom creates a huge impact on the forming process.

Fig.7 shows the details of the change in hydraulic counter-pressure during deep drawing. First when the punch moves and enters the die and forming starts, the hydraulic pressure increases rapidly. At the same time, the sheet metal is pressed firmly against the base of the punch by this hydraulic pressure. Hydraulic pressure reaches the relief valve p the liquid starts flowing out of the valve In addition by setting the valve pressure to strong level. The liquid will flow outside from the flange part via the die shoulder.

The conditions for flow out from the flange depend on the blank holding force mainly. In whichever case, the liquid flows out as the punch moves, so that the hydraulic pressure during maintained at a constant level. As forming reaches its final stages, the liquid flows out more easily from the flange and the hydraulic pressure drops. The punch force becomes great. Hydraulic pressure is added in addition to the normal deep drawing force. A larger blank holding force is also necessary for the hydraulic pressure imposed on the flange to prevent the flow of liquid from the range, or to attain a high hydraulic pressure at a low blank holding pressure.

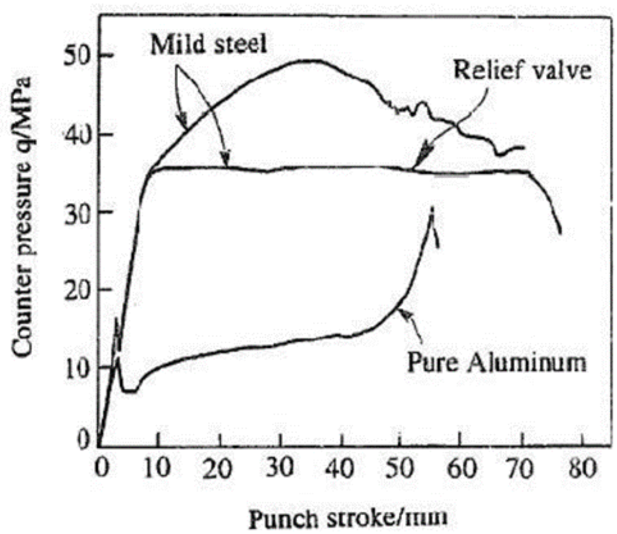

Fig.7 Variation of fluid pressure with punch stroke in hydro forming

6. CONCLUSIONS

Pressure required during hydroforming operations depends on material yield strength, Material wall thickness. It should be noted that as the material is pressurized and forms around the hydroform tool that material thining occurs as the materials yields and forms. Geometries that are typically Hydroformed: Automotive sheet metal, Complex shapes from cylinders, Pipe tees, Cycle handle bars, Bellow shapes. Hydroforming is capable of producing parts within tight tolerances including aircraft tolerances where a common tolerance for sheet metal parts is within 0.76 mm (1/30th of an inch). Then metal hydroforming also allows for a smoother finish as draw marks produced by the traditional method of pressing a male and female die together are eliminated. Tube hydroforming offers several advantages as compared to conventional manufacturing processes. These advantages include part consolidation, weight reduction through more efficient section design, improved structural strength and stiffness, lower tooling cost due to fewer parts, fewer secondary operations (no welding of sections required and holes may be pierced during hydroforming) and tight dimensional tolerances. Despite several benefits over stamping process, THF technology is still not fully implemented in the automotive industry due to its time-consuming part and process development. Advantages which are obtained by application of hydroformig processes of tubes are better mechanical and structural characteristic of parts, saving material and energy, possibility to form parts with complex geometry. As the female die is replaced by fluid pressure, only a punch is used and the drawing operations are reduced. Therefore, the process is cost effective and can be used in small batch production and even in sheet metal property tests. The process can be used for the manufacture of complex shaped workpieces and for the deep drawing of some materials that are not suitable for intermediate heat treatment. The process is flexible. When drawing automotive body panels higher deformation may easily be obtained to increase the stiffness of the product. However, the hydro forming process has required in a higher drawing force and a higher blank-holding force are needed compared with those of conventional forming technology.

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