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MECHANICS OF HYDROFORMING OF SHEETS AND TUBULAR COMPONENTS

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ABSTRACT

Automobile has become one of the largest consumer products, which is influencing the human social lives. Low cost, high quality and High productivity are the common targets in all manufacturing industries in a customer based market structure. Automobile and other industries dealing with sheet metal products seek for economical production methods to reduce the manufacturing cost with increased quality. Moreover sheet metal parts are preferred in many situations for their high strengths to weight ratio and easier production methods with few operations combined together in one operation.This paper deals with one of the most important sheet metal forming and Tubular component manufacturing methods, which is being widely accepted nowadays by many automobile and sheet metal forming industries. This process employs a pressurized cavity and a shaped punch to form the components. The mechanics involved in the forming of components using such type of arrangement is explained in detail. The advantages and applications of the process are also highlighted.

Keywords: Hydroforming, Cavity Pressure, Punch displacement, Tubular Hydroforming, Aqua deep drawing.

1. INTRODUCTION

Sheet metal components and Tubular components are formed to the required shape-using flexible forming media, for so many decades. The following figure (1) gives the classification of the processes using different media types (1). The various processes using liquid are dealt in detail by author 1and 3 in one of their papers (5).

Out of these processes, the processes that use liquid media (i.e. Internal high pressure of fluid) are the focus of study in this paper. Many research works are being carried out in this Hydroforming process. Researches have studied the different aspects of the Hydroforming and Tubular Hydroforming processes

The results of these studies are used by the automobile industries.(8) (6) (3) (2). Various factors and parameters related to Hydroforming such as

1.Supression of Plastic buckling (12)
2.Permissible fluid pressure path (10)
3. Rupture Instability (9)
4. Maximum Drawing ratio (11) was studied.

This paper is an attempt to explain the mechanics of the Hydroforming and Tubular Hydroforming process taking in to consideration the review of the associated factors related to the process.

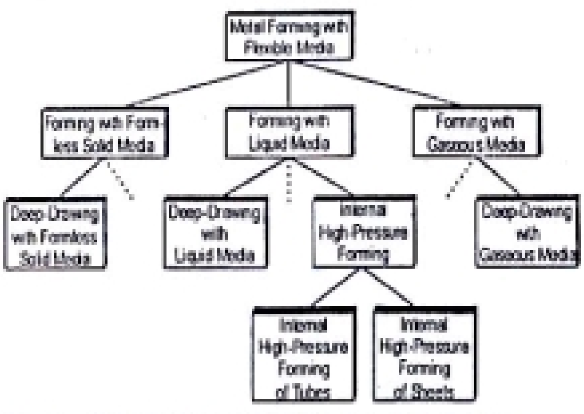


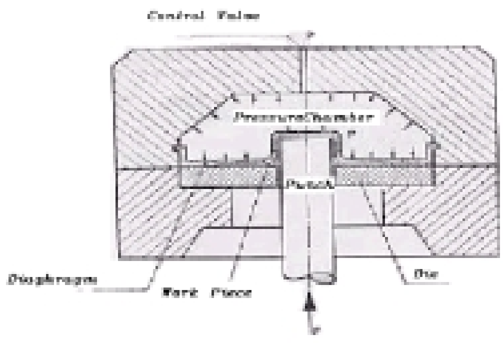
Fig. 1: Cassification of processes by media types

2. HYDROFORMING OF SHEETS

This process uses hydrostatic pressure to form a sheet rather than the mechanical forming with a punch against a die. Here the punch forms the sheet against a hydraulic fluid chamber. The penetration of the punch into the chamber causes a counter pressure. It leads to a significantly more uniform strain distribution over the part and thus increases the component life with greater draw depths. The sheets forms freely or against a flexible (membrane) Punch.

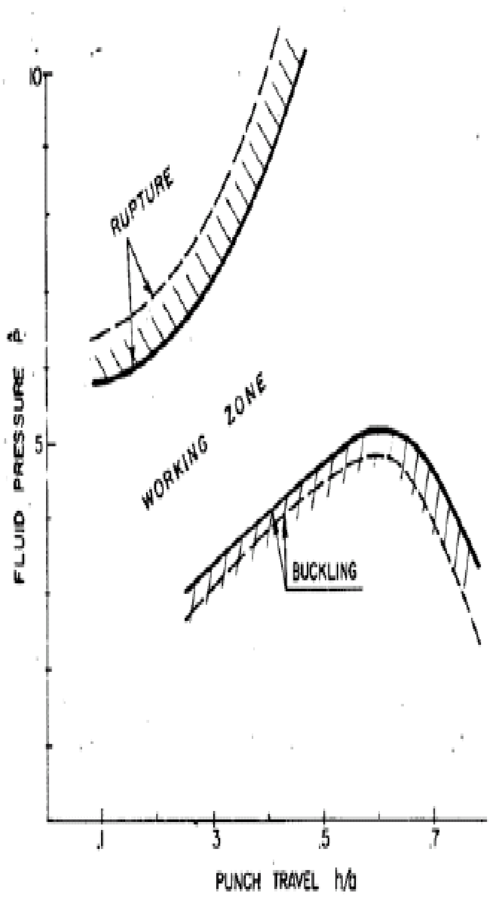
The Hydroforming process is conceptually different from the conventional deep drawing process. In Hydroforming there is rigid die to support the blank, instead there is a pressure-controlled fluid, which reacts via a thin rubber membrane against the moving punch. As a result of the controllable back pressure a desired pressure path with respect to the punch travel can be sought to meet the technical requirement. The component formed has more uniform wall thickness with increased limit drawing ratio (LDR). The cavity pressure plays a major role in forming the part / component without defect. Excessive cavity fluid pressure results in failure by rupture and insufficient pressure results in failure by wrinkling. By controlling the pressure path the above said failures can be eliminated. The normalized fluid pressure is given by the equation.

$$P_{cr} = \left[\left(\frac{1+R}{\sqrt{1+2R}} \right)^{n+1} n^n \_ (R)^{n/2} \int_a^{a+\rho} 1/r \left(\ln \frac{F(r,\rho,h)}{r} \right)^n .dr + \int_{a+\rho}^{b} 1/r \left(\ln \frac{G(r,\rho,h)}{r} \right)^n .dr \right] \Big/ \left(2\,\mu\,(b/a - \rho/a - 1) - t/a \right)$$



Schematic Diagram of Hydroforming Process

The graph below shows the regions prone to Buckling and rupture for a specified fluid pressure to the punch travel. It is safe to do the forming in the working zone.



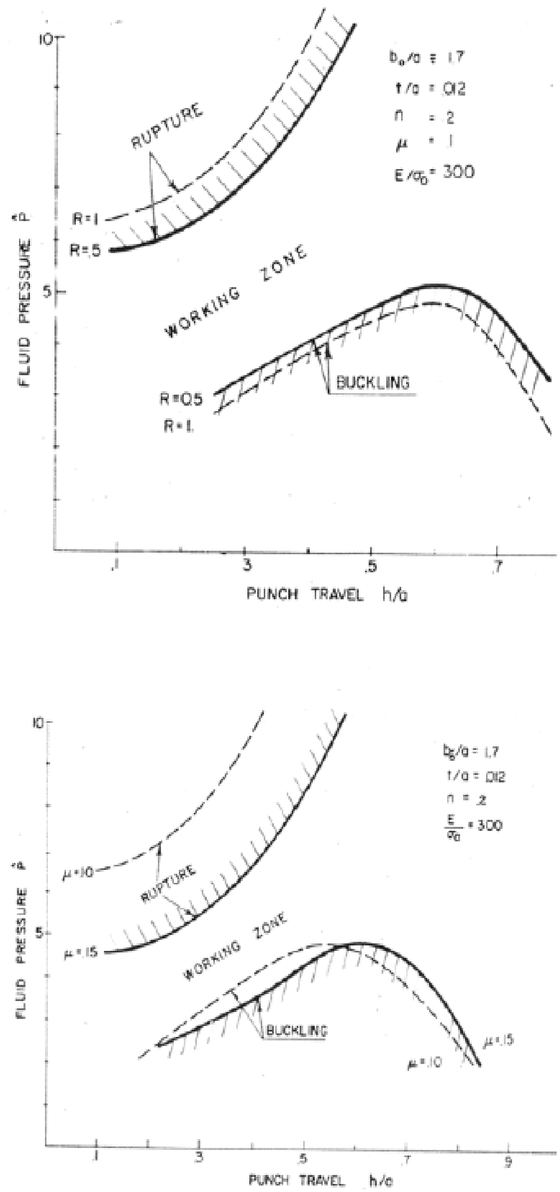
Graph showing Rupture Buckling and working zones

The drawing ratio at which the curves are about to touch each other but still allowing the loading path to travel through the narrow passage between the curves defines the Maximum Drawing Ratio (MDR).

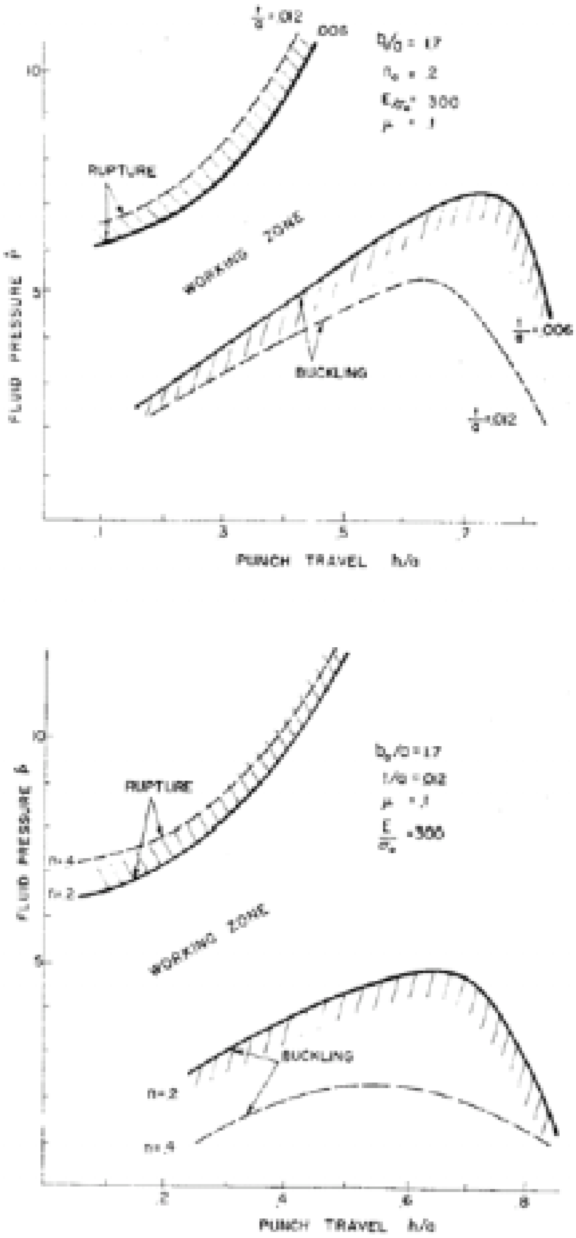
Compared to the classical deep drawing processes where rupture occurs at the bottom of the cup, in fluid assisted processes the rupture takes place at the upper part of the cup just at the end of the lip as a result of the partial relaxation of the load exerted by the ram on the flat bottom of the cup.

For maximizing the LDR the fluid pressure should be kept at the minimum possible level. However this minimum pressure is subjected to a limit under which failure by wrinkling at the rim may occur. The different parameters that influences the working zone in a fluid pressure vs. punch travel graph are strain hardening exponent (n), average friction co – efficient (μ) ,normal anisotropy (R) and the thickness (t).

The effect of the above said parameters in the Hydroforming of the sheets can be best understood by the graph shown below.



Effect of the normal anisotropy parameter (R) and average friction co - efficient (μ) on the working zone



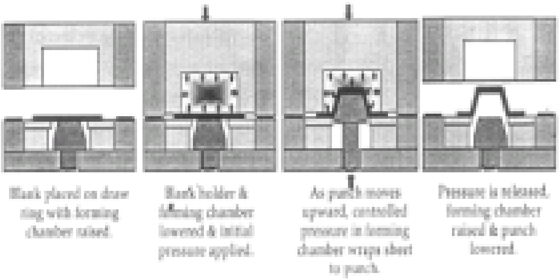
Effect of the Thickness (t) and Strain Hardening Exponent (n) on the working zone

3.HYDRO MECHANICAL FORMING OR AQUA DEEP DRAWING PROCESS

The previous topic deals with Hydroforming of sheets where the pressure cavity and the sheet were separated by a rubber diaphragm. When the punch advances the rubber diaphragm wraps the punch along with the sheet. But in the case of Hydro mechanical forming or Aqua deep drawing process there is an absence of the rubber diaphragm. The punch shapes the sheet against the direct fluid pressure in the cavity The result of this is friction between the sheet metal and the die decreases which turn increases the drawing ratio (4). The thickness strain variation in the flange in Aqua Deep Drawing is considerably diminished comparatively to the classical deep drawing process for the same drawing ratio. The punch load also increased due to the die cavity pressure but a continuous flow can reduce the pressure in the die chamber. The penetration of the punch into the chamber causes counter – pressure which presses the sheet the against the punch. All the methods, which influence metal flow in deep drawing like, draw beads, blank shape, lock beads and optimization of the blank holder pressure can be used for this process. Greater draw depths can be obtained. Parts with tapered ,shaped walls can be drawn in one operation unlike conventional multistage deep drawing followed by mechanical stretch forming. The elimination of female die makes the die set less expensive. The blank holder should be able to withstand the internal pressure or else the part will form wrinkles. The internal pressure and the punch stroke should be shallow till the blank covers the punch.

Other advantages of this process are increased dimensional accuracy, better surface quality and

reduction of tool costs, best suited for small quality production (1).
The Figure Below Shows the working principle of the Aqua deep draw process.



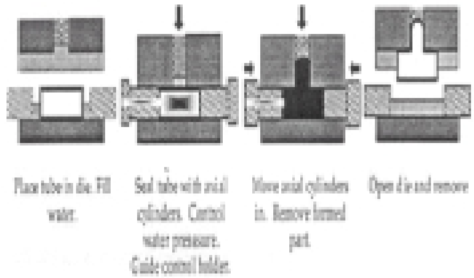
Schematic Diagram showing the working principle of Aqua Deep Draw Process

4. TUBE HYDROFORMING

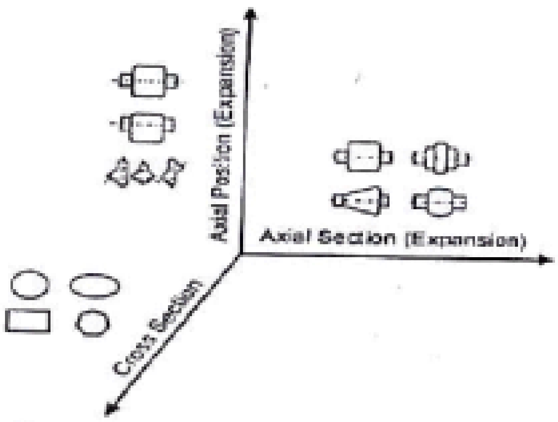
This is a method, which is employed to form Tubular components of different shapes. The process sequence is described below.

- Tube sections or preforms cut to the appropriate length are placed in the die.
- The tube is then sealed at the ends by hydraulic pistons and filled with a hydraulic fluid. The pistons apply an axial compressive load on the tube.
- The fluid is then pressurized so that the material expands circumferentially to take the internal shape of the die. Here the thinning of the tube wall from the hydraulic fluid expansion compensates for the thickening of the tube wall from the axial compression.

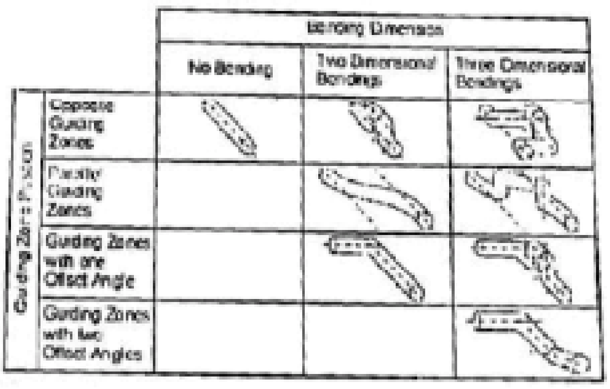
The quality of the tubular blank material is critical for successful tube Hydroforming. Single wall tubes, double wall tubes extruded profiles, laminar blanks (welded / not welded) conically roll formed can be used. A major aspect in choosing the diameter of the tubular blanks is that the smallest component diameter should largely match the tube diameter of the blank. If the diameter of the tubular blank greatly exceeds the smallest component diameter the cross section will collapse, and the die closes or the blank will be squeezed in to the parting line of the die halves. The generalized rule for optimum tube diameter to Wall thickness ratio is D/d should be between 20 and 45 and the unsupported bucking length should be less than twice the blank diameter. Less axial compression results in wall thinning and lead to breakage. Greater axial compression will make the tube buckle or wrinkle.



Schematic Diagram Showing the working principle of Tube Hydroforming



Geometry and Position of the expanding zones of a tubular internal high-pressure formed component

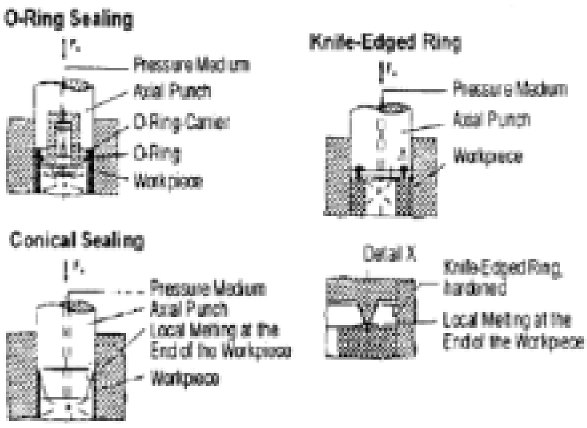


Course of the longitudinal axis of an internal high-pressure formed component

5. SEALING PRINCIPLES

A basic criterion for reliable forming by liquid media depends on sealing of the tube ends. Three frequently used methods are 1. Using ‘O’ ring 2. Using a Knife edged ring 3. Using a Conical sealing.

‘O’ Ring seal provides reliable sealing effect in a simple way. However due to the high wear of such rings the use is limited for industrial applications. Knife edged ring seal can be used on thick walled tubes. The knife-edges penetrate into the front end of the tubes making a perfect seal incase of force transmission between the axial plungers and tube ends. Conical seals provide reliable sealing in the case of force transmission between the plunger and tube ends.



Sealing Principles used for Hydroforming Process

6.ADVANTAGE OF INTERNAL HIGH PRESSURE FORMING

- Complex Geometries can be easily formed with less number of operations.
- Low Component weight can be achieved.
- High and homogeneous component strength.
- High rigidity and good crash behavior due to load optimized component geometries.
- High accuracy of shape and dimensions due to very small resilience.
- Good corrosion behavior due to reduction of number of constituent parts assembled.
- Integration of additional manufacturing operations in the forming tool such as punching or joining is possible.
- Section modulus can be increased at local areas where high stiffness is required.
- Minimum and controllable wall thinning.
- Close tolerances and surface finish.
- Wide range of materials like Mild Steel, Aluminium, Stainless Steel, Copper, Brass and their alloys can be processed by Hydroforming.

7. APPLICATIONS

- Automotive components such as pillars, wind shield header, body panel, exhaust manifold, chassis cross members etc can be Hydro formed.
- Sanitary fittings such as Tee, Y-shape can be formed.
- Ball seat for hydraulic valves can be formed.
- Catalytic converter housing, shock absorber housing, muffler housing are some of the parts that are formed using tube hydro forming.

8. NOMENCLATURE:

$\bar{p}$ - Normalized fluid pressure ($pa/\sigma_o t$)(bar)
R - Ratio of natural strain to natural thickness strain in uniaxial tension

$\bar{R}$ - Function of R=2(1+R)/(1+2R)
n - Strain hardening exponent
a - Punch radius (mm)
ρ - Curvature radius of the flange/cup transition (mm)
r -Instantaneous radius
h - curve-traveling distance of the punch (mm)

$\bar{\mu}$ -average Coulomb friction ($=\mu_1+\mu_2/2$)

μ_1 - Coulomb friction coefficient between the work piece and blank holder
μ_2 - Coulomb friction coefficient between the work piece and diaphragm
b - instantaneous outer radius of the flange(mm)
t - blank thickness (mm)

$$F(r,\rho,h) = a\left[1+2h/a-2\rho/a+2\rho/a\left((1+\rho/a)\cos^{-1}\left(\frac{1+\rho/a-r/a}{\rho/a}\right)-\rho/a\left(1-1\frac{+\rho/a-r/a}{\rho/a}\right)^{1/2}\right)\right]^{1/2}$$

$$G(r,\rho,h) = (r/a)^2+\left(2h/a-0.86(\rho/a)+0.14(\rho/a)^2\right)^{1/2}$$

9.CONCLUSION

The Hydroforming of sheets and tubes is a potential process, which has so many applications in real life situations. Employing this process can benefit industries related to sheet metal. As mentioned in the applications several industries find it as a useful and economical process for mass production. The buckling phenomenon in Hydroforming process takes place at the die curvature zone unlike buckling in regular deep drawing without blank holder where buckling occurs at the flat flange. Buckling is practically suppressed by imposing a lateral fluid pressure path. The rupture occurs at the area between the lip and the cup wall. It can be prevented or delayed by applying a lateral fluid pressure not exceeding the critical rupture pressure line. Higher the friction co – efficient narrow the working zone with a slight shifting of the buckling lines. The higher the drawing ratio and with thin sheet the narrower the working zone. A higher normal anisotropy parameter and strain hardening exponent widens the working zone which can be understood from the graphs presented in topic

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