CHAPTER 1

Introduction and Literature Review

1.1 Introduction

Sheet-metal forming is one of the most important technology in modern industry allowing for production of light and high strength parts such as: aircraft structures, car bodies and other structural parts, utensils or household equipment. It allows for obtaining good quality products in a very short time which is very important because of the high competition in the manufacturing market [1]. Sheet metal forming operations can be classified into five major operations as shown in figure 1.1.

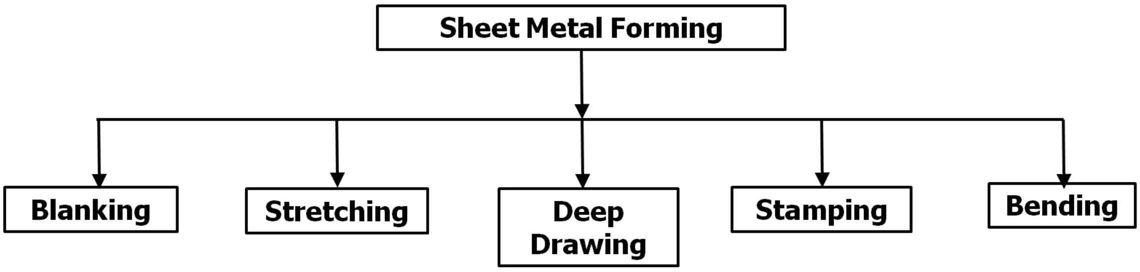


Figure 1.1: Classifications of Sheet Metal Forming operations

Among them Deep Drawing and Stamping are the widely used processes in aerospace and automobile industries. Application of high strength, low plasticity and difficult-to-form materials for complex-shaped parts makes the conventional deep drawing technology face new challenges. “Conventional forming” here means any sheet-metal forming process using rigid tools: die, blank-holder and punch. Very often manufacturing of structural parts is extremely difficult because conventional forming methods reach their limits [2]. In some applications radial drawing stresses and tangential compressive stresses pose a serious problem resulting in wrinkling, buckling, thinning and finally cracking. The presence of one or more of these imperfections can make the stamped part useless. To improve sheet formability hot

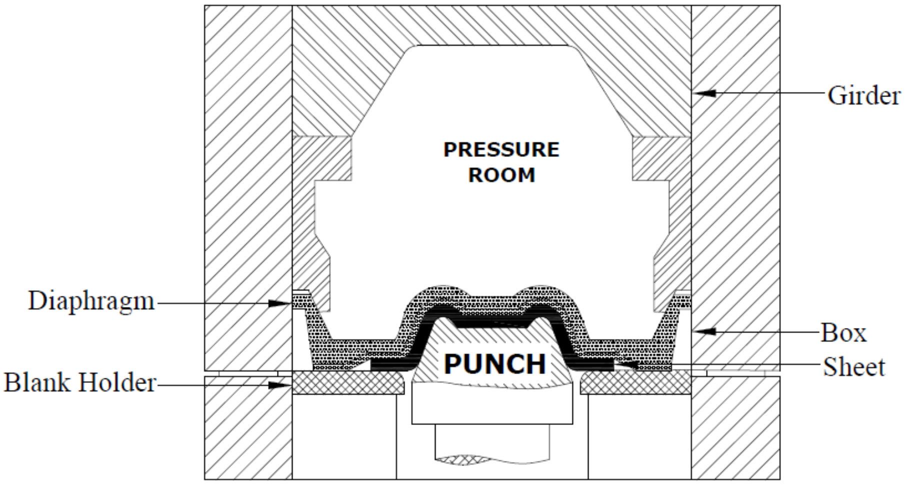


Figure 1.2: Rubber Based Sheet Hydroforming Set-up [6]

forming [3] or unconventional deep drawing techniques are used. Generally, impulse forming including e.g. electromagnetic or explosive forming [4], and flexible sheet forming technology, such as hydroforming [5] or forming technology using a flexible tool half etc. are used.

The present work is carried out to develop and evaluate unconventional sheet metal forming process which has potential to improve the formability. With this motivation, the research work has been carried out to develop and evaluate Rubber Based Sheet Hydroforming (RBSH) process for both shallow and deep drawing applications. The schematic diagram of rubber based sheet hydroforming process is shown in figure 1.2 [6] .

As shown in figure, this process includes flexible rubber diaphragm and hydraulic pressure instead of solid die. As both hydraulic pressure and rubber diaphragm creates hydrostatic compressive stress condition during forming which delays the necking of the sheet at the time of stretching on wall of the component, the deeper and complex features can be formed without cracking.

This process is basically the combination of three technologies

1. Deep drawing process

2. Hydroforming deep drawing process

3. Rubber pad forming process

1.1.1 Deep drawing process

Drawing refers to the family of operations where plastic flow occurs over a curved axis and the flat sheet is formed into a three-dimensional part with a depth more than several times the thickness of the metal. Drawing is typically used to form solid-bottom cylindrical or rectangular containers from sheet metal. When depth of the product is greater than its 0.5 times diameter, it is known "Deep drawing". When depth of the product is less than its 0.5 times diameter, it is known "shallow drawing". The drawing can be symmetric or non-symmetric as shown in figure 1.3.

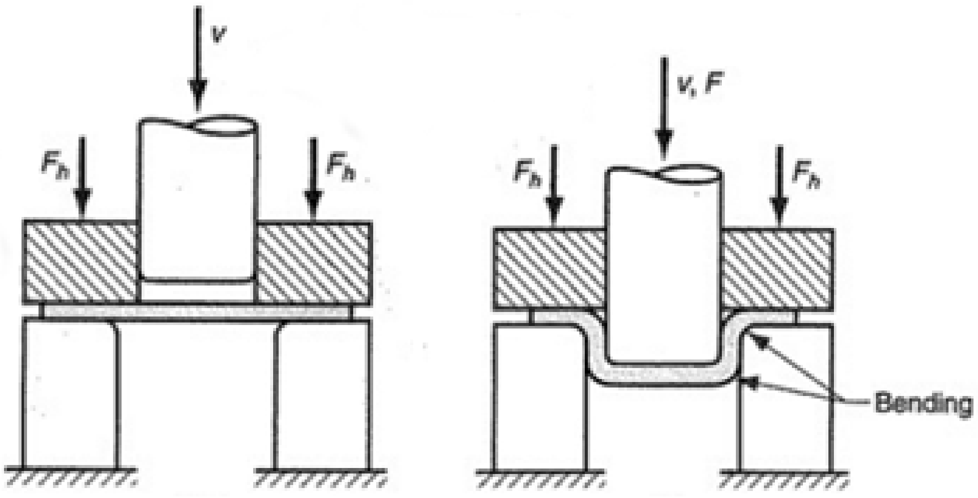
Symmetric Component **Non- Symmetric Component**

Figure 1.3: Symmetric and Non-symmetric drawn components

The stages of deep drawing process is shown in 1.4 [7]. The blank holder/pressure ring presses the upper surface of the blank preventing wrinkling of the metal as it is drawn radially over the upper surface of the die. Thinning results from this process, the worst being at the bottom radius as a result of drawing the full disc diameter inward under the pressure ring. The thinning is least at the top of the cup. For deep cup shapes, the deep drawing operation is split into a number of stages in order to get desired shape.

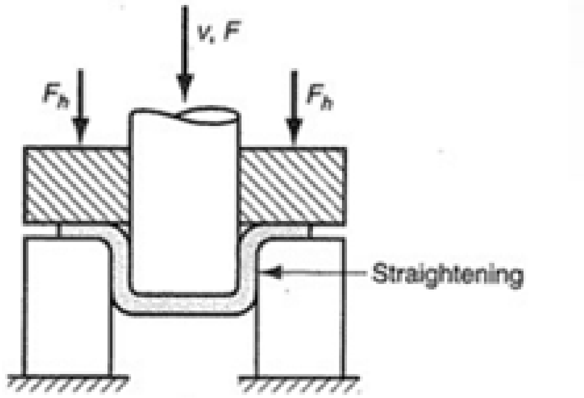
The main *advantages* of deep drawing processes are

1. Drawn metal parts are strong yet light
2. Particularly suited for cylindrical shapes in a single draw, such as aluminum cans

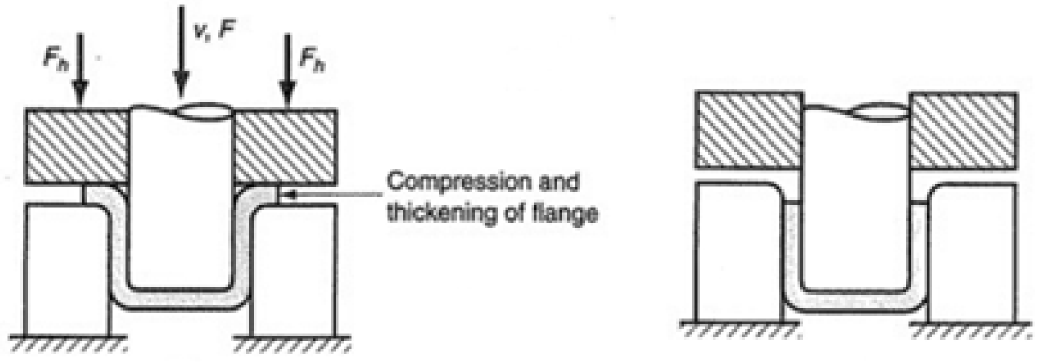


(a) punch makes contact with blank

(b) bending



(c) straightening (F$_h$ = Holding force, F = Punch force, ν = punch velocity)



(d) friction and compression

(e) final cup shape showing effects of thinning in the cup walls

Figure 1.4: Stages in deep drawing process [7]

3. Deep drawing is aesthetically pleasing - a seamless part is created from a single metal sheet
4. Highly accurate and detailed parts in a wide variety of shapes

Mechanics of deep drawing

For understanding the mechanics of deep drawing operation, the blank has been divided into three sections as shown in fig. 1.5 (i.e x, y, z) [8]. The material in section x will form the base of the cup which is in contact with the face of the punch. This material stretches and slides over the surface of the punch; however, minimal variation in thickness of this section is expected. Section y represents the cup bottom radius, which has undergone bending around the die radius first, then unbending and then bending around the punch radius in the opposite direction. Finally, the material in section z forms the sidewall of the cup and the flange. It has undergone bending around the die radius and then unbending as it is drawn to become the sidewall.

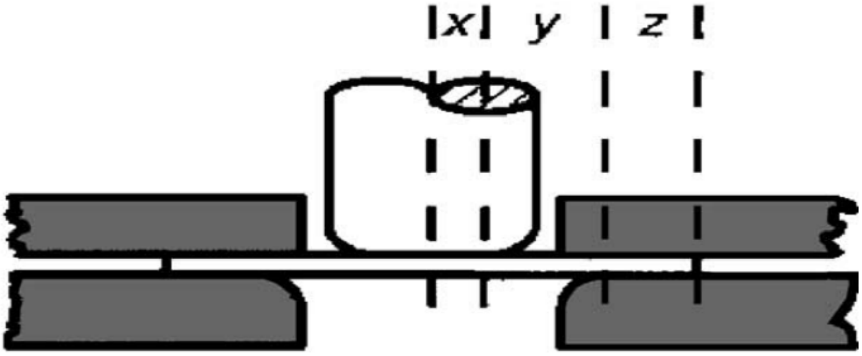


Figure 1.5: Three sections x, y, z[8]

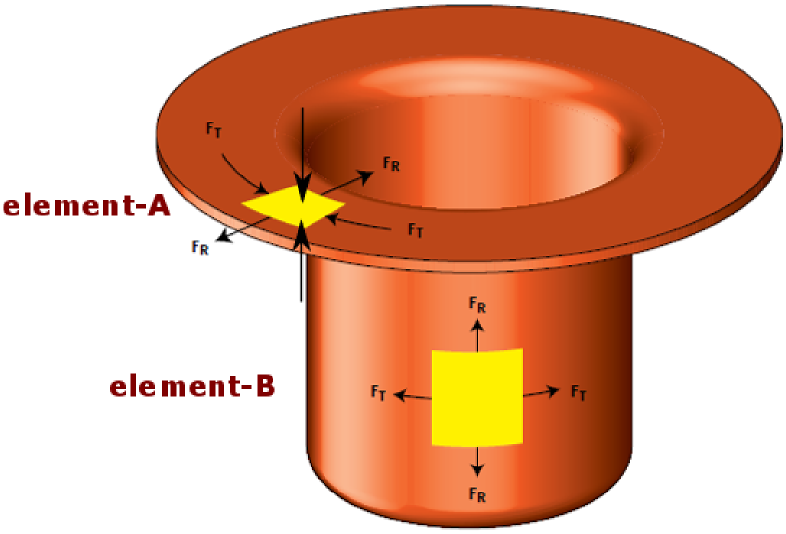


Figure 1.6: Workpiece stresses during deep drawing

During a deep drawing operation, the workpiece is subjected to the types of stress as shown in Fig. 1.6. There is a radial stress on *element A* due to the blank being pulled into the die cavity and there is also a compressive stress normal to the element which is due to the blank-holder pressure. The radial tensile stresses lead to compressive hoop stresses because of the reduction in the circumferential direction. The flange of the blank attempts to wrinkle because of this hoop stress; however, the blank-holder should prevent this from happening.

As seen in *element B* in Fig. 1.6 the wall of the cup is primarily experiencing a longitudinal tensile stress, as the punch transmits the drawing force through the walls of the cup and through the flange as it is drawn into the die cavity. There is also a tensile hoop stress caused by the cup being held tightly over the punch. The punch force is limited to the maximum tensile load that can be carried by the wall of the cup and this in turn limits the depth of flange that can be drawn.

Key Variables in Sheet Metal forming process

The following are the key variables in designing for any sheet metal forming process.

- Blank and punch diameter
- Punch and die radius
- Clearance
- Thickness of the blank
- Lubrication
- Hold-down pressure

Once a drawing process has been designed and the tooling manufactured, the primary variable for process adjustment is hold-down pressure or blank holder force. If the force is too low, wrinkling may occur at the start of the stroke. If it is too high, there is too much restrain, and the descending punch will tear the disk or some portion of the already-formed cup wall.

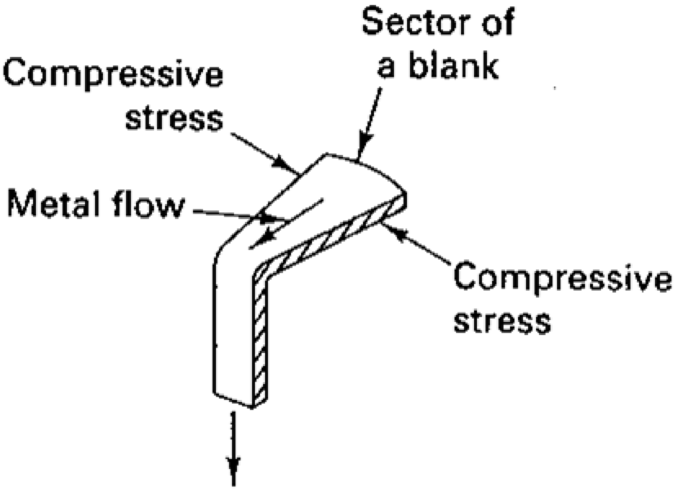


Figure 1.7: Flow of material during deep drawing [9]

The significance of blank holder pressure can be understood from figure 1.7 [9]. The flange zone experiences circumferential compressive stress, which results into thickening and wrinkling. In order to restrict the tendency of wrinkling, the blank holder force is adjusted in such a way that it control the material flow in circumferential direction. However, if blank holding force is more that optimum, the material flow towards wall direction gets restricted and results into tearing. The effect of blank holding force on wrinkles and tearing is shown in figure 1.8 [9]. Thus, they are considered as major defects in sheet metal forming. The other major defects are erring and scratching which are shown in figure 1.9 [7].

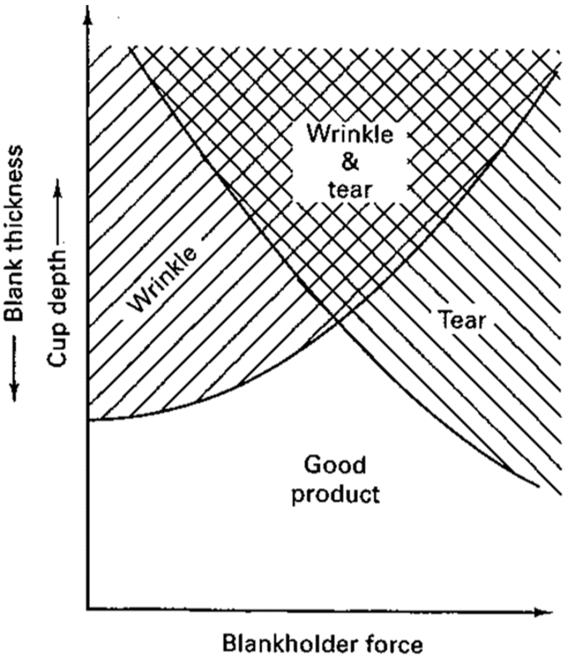


Figure 1.8: Effect of Blank Holding force on wrinkles and tearing [9]

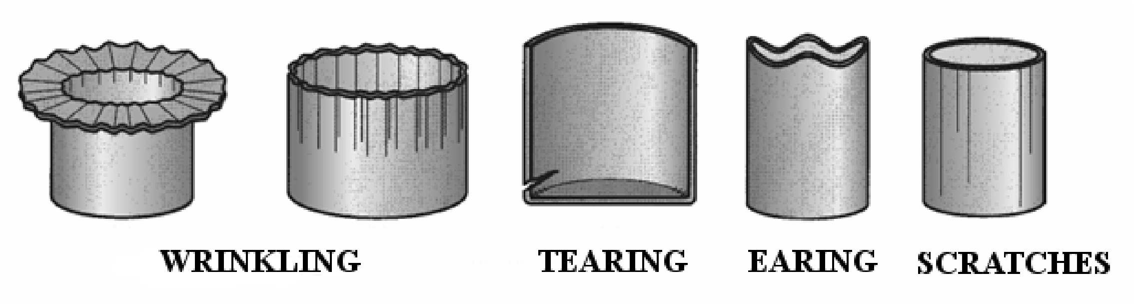


Figure 1.9: Common defects in deep drawn parts [7]

As cup depth increases or material is thin, there is an increased tendency for forming the defects. It is important to assess the limitation of the amount of drawing that can be accomplished.

Measures of Drawing

Drawing ratio (cylinder):

$$DR = \frac{D_b}{D_p} \tag{1.1}$$

Where D_b - blank diameter, D_p - punch diameter

The greater the drawing ratio, more severe is the drawing. An approximate upper limit on the drawing ratio is a value of 2.0. The actual limiting value for a given drawing depends on punch and die corner radii (D_p and D_d), friction conditions, depth of draw, and characteristics of the sheet metal (ductility, degree of directionality of strength in the metal). This drawing ratio can further be improved by employing hydraulic back pressure and rubber diaphragm.

1.1.2 Sheet anisotropy

Anisotropy is an important factor in sheet metal forming. Anisotropy is the directional variation of mechanical properties. In other words, the material will react differently to stress applied in one direction than it would to the same stress applied in a different direction. If a material is isotropic, then its properties are the same in any direction. Whereas, if properties of a material vary with different crystallographic orientations, the material is said to be anisotropic. Due to their crystallographic structure and the characteristics of the rolling process, sheet metals generally exhibit a significant anisotropy of mechanical properties.

The plastic properties of rolled sheets differ from the through thickness direction, normal anisotropy, and vary with orientation in the plane of the sheet, planar anisotropy. At a given angle, θ, to the rolling direction, the sheet anisotropy is defined by the plastic strain ration, r value, which is

$$r_\theta = \frac{\epsilon_w}{\epsilon_t} \tag{1.2}$$

where ϵ_w and ϵ_t are the width and thickness strains of a uniaxial tension specimen cut at an angle, θ, to the rolling direction, respectively. It should be noted that for thin sheets, it is difficult to measure the thickness strain. It is concluded from the constancy of volume that

$$r_\theta = \frac{-\epsilon_w}{\epsilon_1 + \epsilon_w} \tag{1.3}$$

Where $\epsilon_1 = \ln \frac{l}{l_o}$ and $\epsilon_w = ln \frac{w}{w_o}$. Thus,

$$r_\theta = \frac{ln[\frac{w}{w_o}]}{ln[\frac{w_o l_o}{wl}]} \tag{1.4}$$

However, for simulation of anisotropic sheets by using the finite element technique, it is necessary to introduce the yield stress ratios R value, as (Abaqus help manual)

$$R_{11} = \frac{\sigma_{11}}{\bar{\sigma}}, \qquad R_{22} = \frac{\sigma_{22}}{\bar{\sigma}}, \qquad R_{33} = \frac{\sigma_{33}}{\bar{\sigma}}, \qquad R_{12} = \frac{\sigma_{12}}{\bar{\sigma}}, \tag{1.5}$$

Where $\sigma_{11}, \sigma_{12}, \sigma_{22}$ and σ_{33} are the yield stresses of directions $0^o, 45^o, 90^o$ and thickness orientation, respectively, and $\sigma = \sigma_{11}$ is the yield stress at orientation 0^o. The plastic strain ratios can be converted by the following expressions:

$$R_{11} = 1 \tag{1.6}$$

$$R_{22} = \sqrt{\frac{r_{90}(r_0 + 1)}{r_0(r_{90} + 1)}} \tag{1.7}$$

$$R_{33} = \sqrt{\frac{r_{90}(r_0 + 1)}{(r_0 + r_{90})}} \tag{1.8}$$

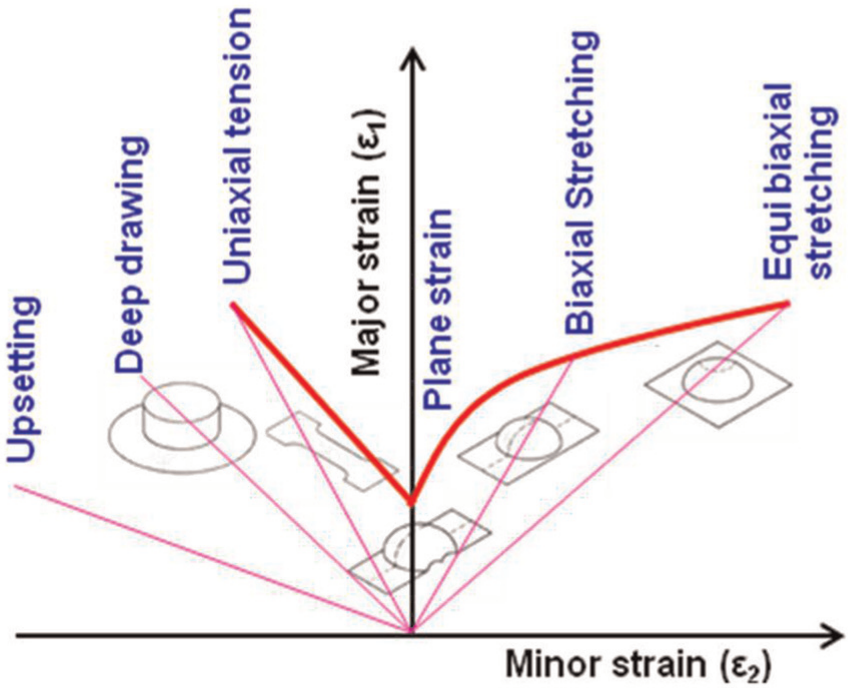


Figure 1.10: A schematic plot of forming limit diagram [11]

$$R_{12} = \sqrt{\frac{3r_{90}(r_0 + 1)}{2(r_{45} + 1)(r_0 + r_{90})}} \tag{1.9}$$

Many researchers [10] has done experiment on copper sheet and it has been found that the copper does not show any anisotropy. Hence, in the present study copper sheet has been assumed to be isotropic i.e Anisotropy coefficient ($r_0 = r_{45} = r_{90} = 1$).

1.1.3 Failure Criteria for Sheet Metal Hydro-forming

Every sheet metal can be deformed without defects only up to a certain limit, which is normally known as forming limit curve (FLC). FLC is generally governed by localized necking, which eventually leads to the ductile fracture. FLC can be represented as a curve of the major strain (ϵ_1) at the onset of localized necking for all values of the minor strain (ϵ_2), and the resulting full graph is named as forming limit diagram (FLD). A schematic of FLD is illustrated in Figure 1.10 [11]. The FLC can be split into two branches: "left branch" and "right branch". Keeler and Backhofen [12] have first introduced the "right branch" of FLC, which is valid for positive major and minor strains. Goodwin [13] has completed the FLC by introducing the "left branch" of FLC, which is applicable for positive major and negative minor strains.

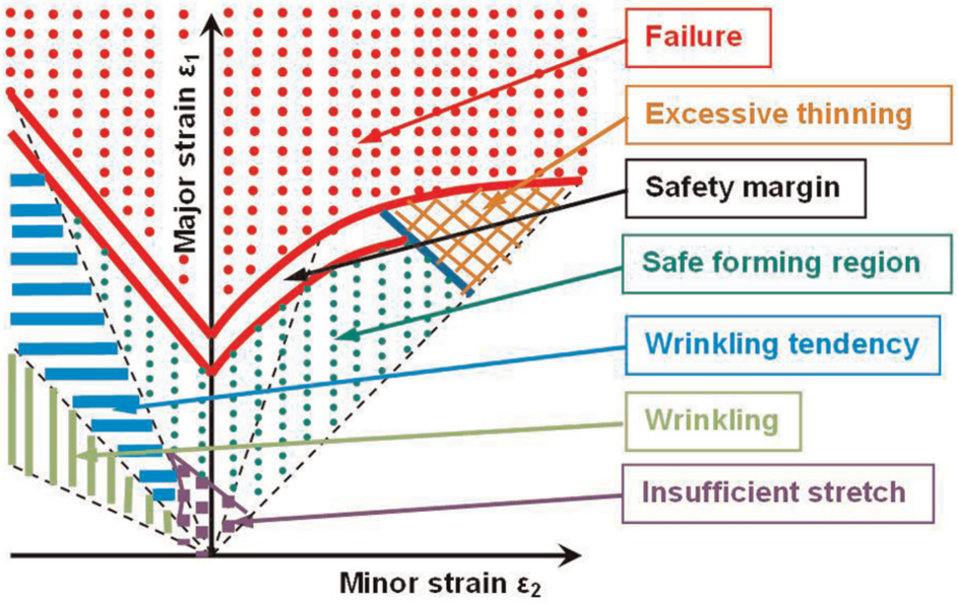


Figure 1.11: Forming limit diagram showing different failure zones [11]

FLC is solely applicable for proportional strain path. Therefore, to construct FLC, different ratios of major and minor strains are chosen in proportional strain paths. The "left side" represents strain paths with strain ratios ($\alpha = \frac{\epsilon_2}{\epsilon_1}$) that vary from uniaxial tension ($\alpha = -0.5$) to plane strain ($\alpha = 0$). On the "right branch", the strain ratios differ from plane strain to full biaxial ($\alpha = 1$) stretching. Usually, FLD is determined by using one of the following two types of test method [14]:

(a) Marciniak et al. in-plane test , where a sheet metal sample is strained by a flat-bottomed cylindrical punch and it creates a friction less in-plane deformation of the sheet, and

(b) Nakazima et al. out-of-plane test (dome), which uses a hemispherical punch.

In order to avoid any type of failure, the strain levels in the deep drawing parts should be below the FLC everywhere. The deep drawn parts can fail in excessive thinning (necking), wrinkling etc. The type of failure depends on the strain levels. The different zones of FLD constructed from FLC, is shown in figure 1.11 and figure 1.12 [11].

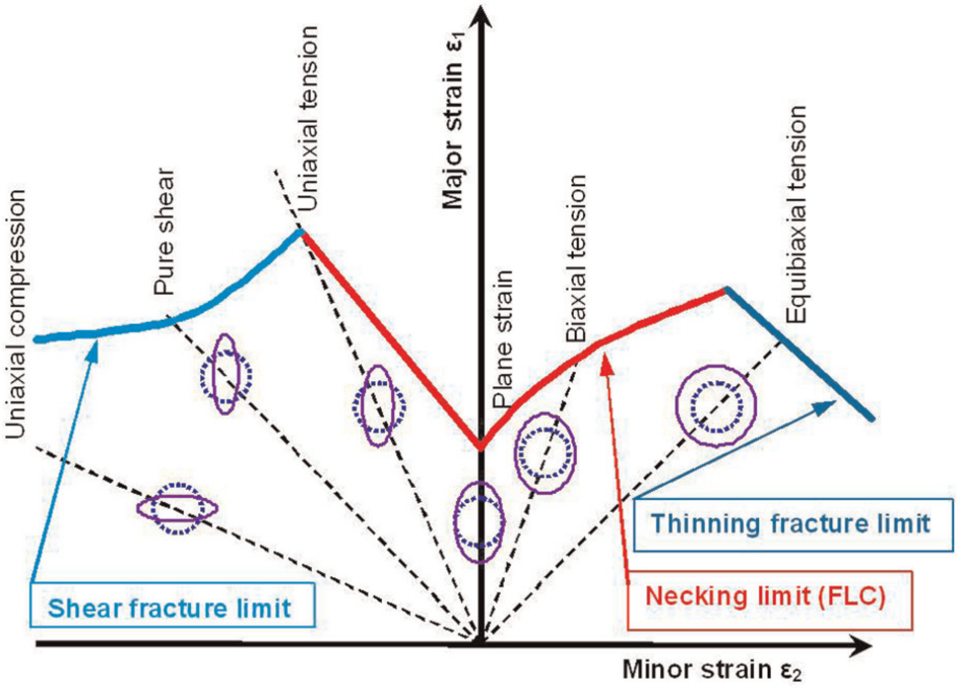


Figure 1.12: Forming limit diagram and other failure limits [11]

1.1.4 Hydro-forming deep drawing process

Hydroforming has become very popular forming process today to meet the challenges of these industries. Tube hydroforming (THF) and sheet hydroforming (SHF) are relatively complex manufacturing process. The (SHF, THF) process is better than the conventional manufacturing via stamping and welding such as: (i) Part consolidation resulting in weight reduction of the component (ii) weight reduction through more efficient section design and tailoring of the wall thickness (iii) reduced tooling cost (iv) improved structural strength and stiffness (v) less number of secondary operations (vi) reduced dimensional variation (vii) significant reduction in spring back effects and (viii) reduced scrap rate. The analysis and performance of the process depends on many factors such as part geometry, design, work material, process parameters and the boundary conditions of forming.

The principle of sheet hydroforming is illustrated in figure 1.13 [15], wherein blank holder is provided with a seal (figure 1.13(a)). A container maintains the pressure medium, usually water-oil emulsion (figure 1.13(b)). A hydraulic servo valve controls the counter pressure during the process (figure 1.13(c)). After the blank is placed on the die, the blank holder presses the sheet and the punch forms the sheet against the medium (figure 1.13(d)), creating a pressure that is controlled throughout the punch stroke. Forces in SHF should be equivalent and blank holding force should be equal to a function of summation of forming load and PG (counter pressure/ backward pressure/ gage pressure).

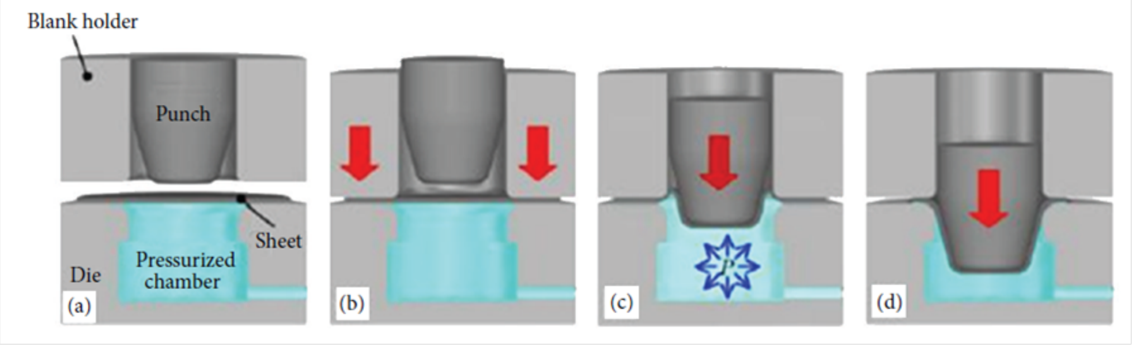


Figure 1.13: Sheet hydroforming: (a) blank setting (b) blank holding; (c) drawing and (d) finishing [15]

In another version of Hydro mechanical deep drawing, punch pushes sheet/blank

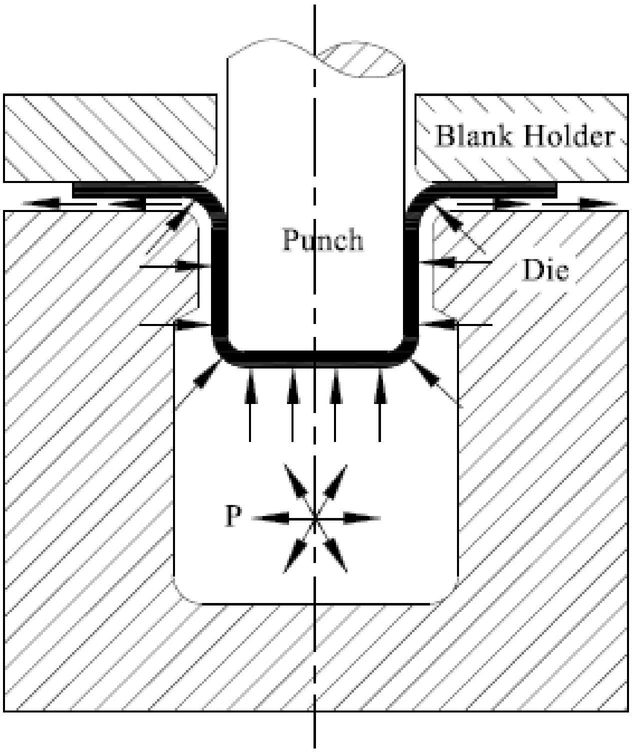


Figure 1.14: Hydro mechanical deep drawing [15]

to the die profile and backward pressure pushes back sheet to the periphery of the punch. Therefore sheet is formed between two pressures as shown in figure 1.14 [15].

In another category of SHF, a membrane diaphragm seats between fluid and sheet. Fluid pressure is transferred to sheet through rubber diaphragm as shown in figure 1.15 [15].

1.2 Rubber Based Sheet Forming Process (RBSF)

Rubber based forming process is a versatile metal fabrication process used in commercial aerospace, automotive and defence applications. It is well suited for prototyping and production of small quantities of sheet metal parts. Rubber based forming employs a rubber pad contained in the rigid chamber or flexible diaphragm as one tool half, requiring only one solid half to form a part to final shape [16]. The solid tool half is similar to the punch as in conventional process. The rubber exerts nearly equal pressure on all workpiece surfaces due to its incompressibility

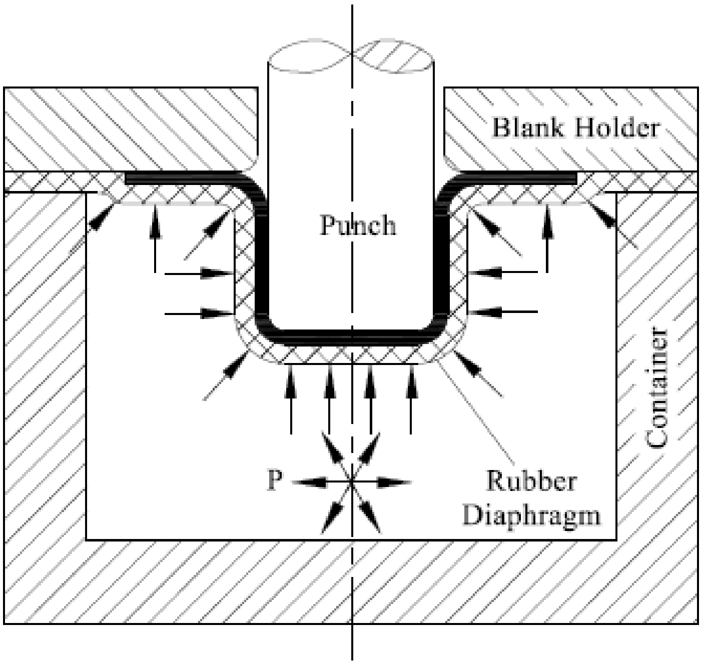


Figure 1.15: Hydroforming using a membrane diaphragm [15]

[17]. As the punch advances, the rubber acts somewhat like a hydraulic fluid in exerting nearly equal pressure on all workpiece surfaces as it is pressed around the form block or punch. The multi-directional nature of the force from rubber pad produces variable radius during forming and thus enhances uniform elongation of the workpiece.

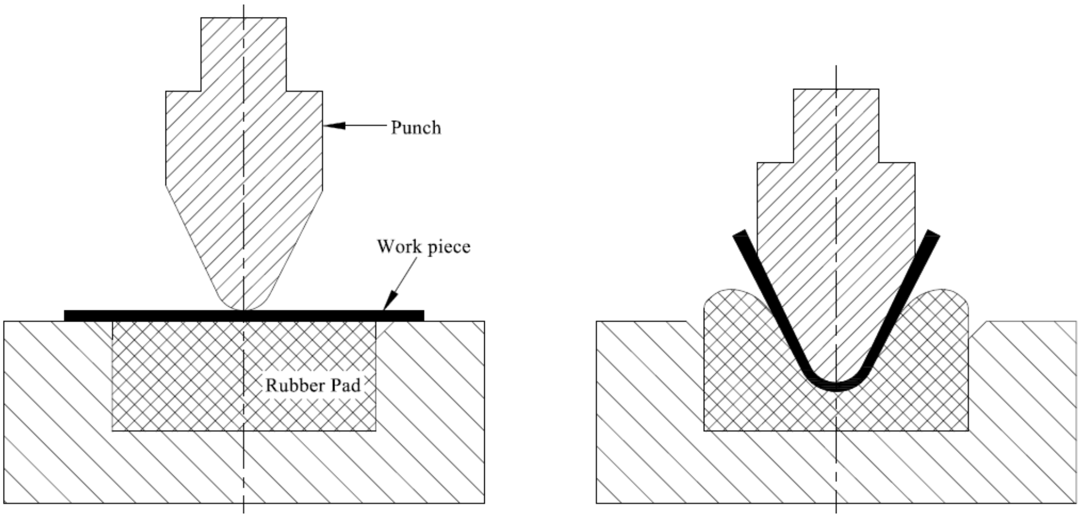


Figure 1.16: Schematic Representation of Rubber Based Sheet Forming [7]

The process exploits the benefits of flexible rubber punch and produces the complex shaped sheet metal components with minimal spring back and profile deviation.

Parts with excellent surface finish can be formed with no tool marks and severe variations in the metal thickness, as occurs in conventional forming processes, is reduced considerably. The schematic representation of Rubber Based Sheet Forming process is shown in figure 1.16.

The Rubber Based Sheet forming processes are broadly classified into four categories:

1.2.1 Guerin process

The Guerin process [6] is oldest and simplest rubber pad forming process. Aluminum alloys, Austenitic Stainless Steels and titanium alloys can be shallow drawn using this process. The schematic diagram of Guerin process is shown in figure 1.17. As the ram descends, the rubber presses the blank around the form block, thus forming the workpiece. The rubber-pad retainer fits closely around the platen, forming an enclosure that traps the rubber as pressure is applied. The pressure produced in the Guerin process is ordinarily between 6.9 and 48 MPa.

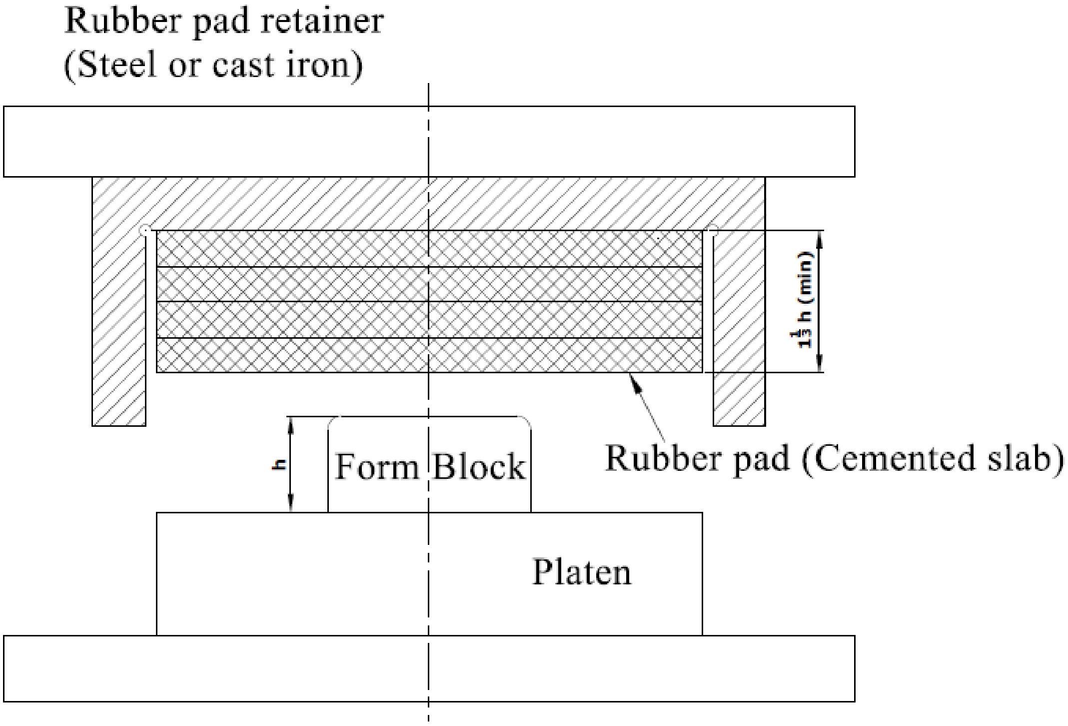


Figure 1.17: Set up for rubber forming by Guerin Process [6]

1.2.2 Marform Process

In Marform process [18], deep-recessed parts with either vertical or sloped walls can be formed [19]. The set up details are shown in figure 1.18 [18]. Compared with Guerin process, tooling includes a steel blankholder supported by a hydraulic actuator equipped with a valve controlling pressure

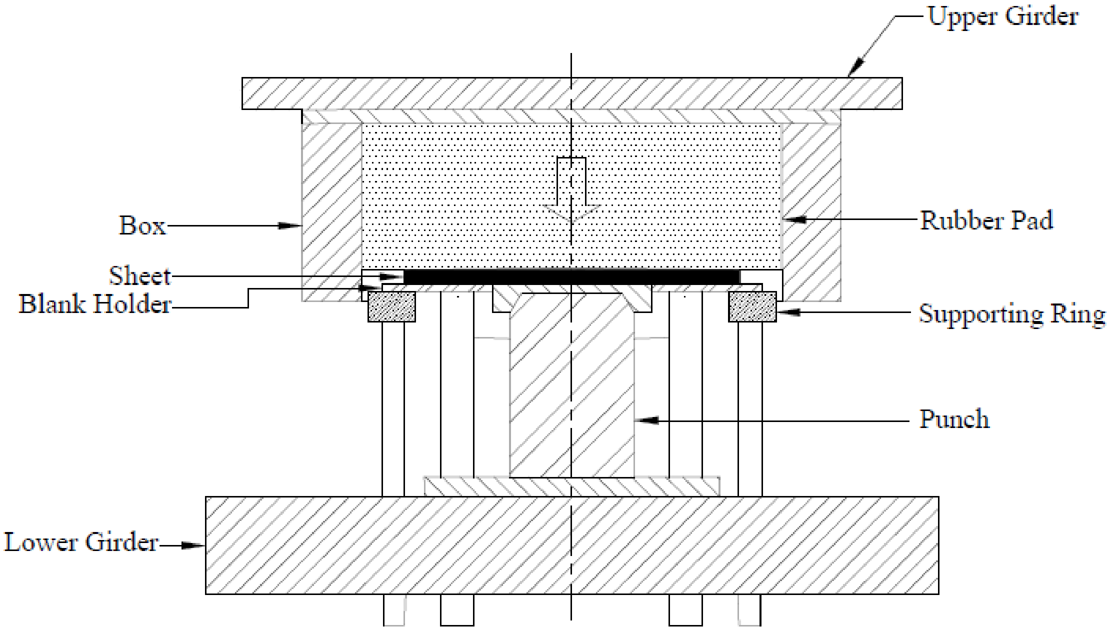


Figure 1.18: Marform Process [18]

1.2.3 Verson Hydroform Process

In this process, hydraulic pressure under control would act on rubber membrane covering the blank. Verson Hydroform process is different than other processes in the sense that it contains the die cavity which is partially filled with hydraulic fluid. The forming pressure is balanced by fluid pressure. Figure 1.19 shows the schematic details of this process [6]. More severe draws can be made by this method than in conventional draw dies because the oil pressure against the diaphragm causes the metal to be held tightly against the sides as well as against the top of the punch.

1.2.4 Maslennikov's process

In 1957, Masennikov introduced a punch less drawing technique using annular technique. Maslennikov's process is a deep drawing technique that uses annular

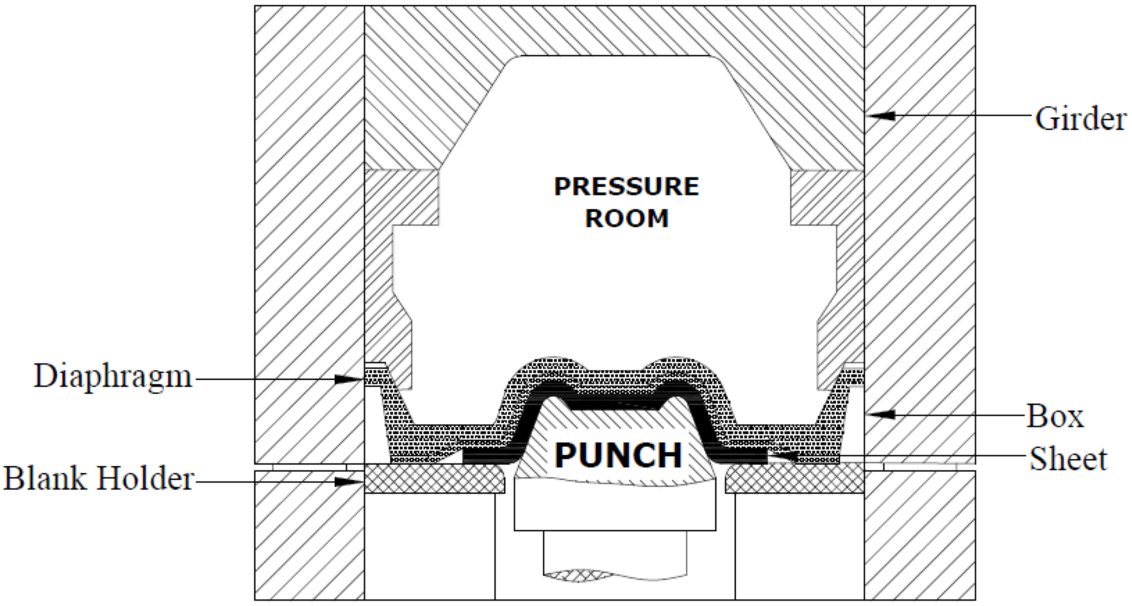


Figure 1.19: Verson-Hydroform process [6]

rubber pad to draw very deep cups. As can be seen in the figure 1.20, the punch squeezes the rubber ring and makes it deform radially inward. It develops a radial frictional force between the rubber ring and the blank and causes the blank to draw inside the die cavity [20].

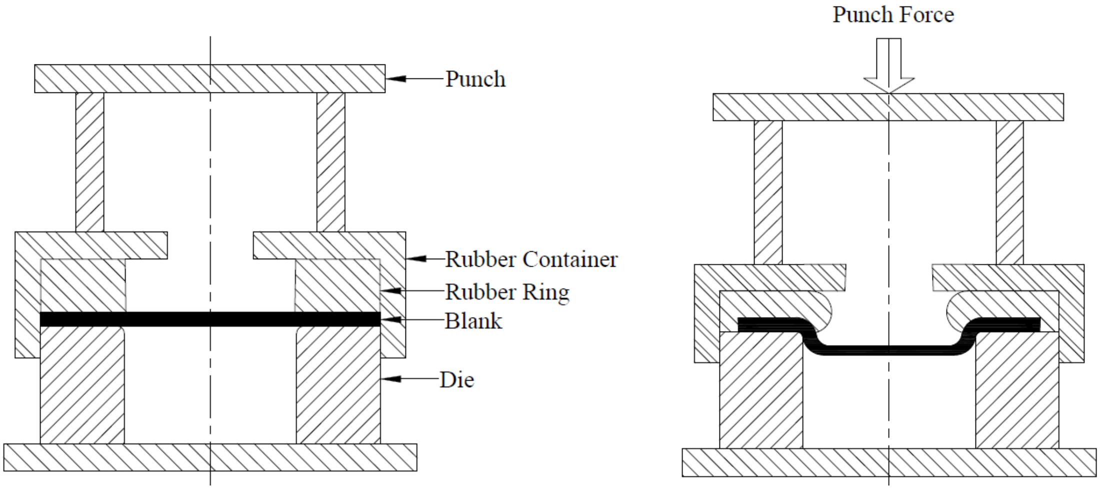


Figure 1.20: Maslennikov's process [19]

1.3 Advantages and Disadvantages of RBSF Processes

The advantages and disadvantages of Rubber Based Sheet Forming Processes are as follows:

1.3.1 Advantages

- Since, it requires a single punch, and a rubber pad replaces many dies of different shapes.
- The punch, more conveniently loaded, can be realized with cheaper materials.
- The bending radii change progressively during forming process. Material thinning is reduced.
- The same tool set-up can be used to stamp different materials and different thicknesses.
- Due to low hardness of the rubber pad, the sheet metal does not suffer from wear when compared to deep drawing.
- The small plastic zone and incremental nature of the process contributes to increased formability, making it easier to deform low formability sheet.

1.3.2 Disadvantages

- Since the amount of pressure exerted by rubber is limited by the strength of rubber itself, forming of sheet metal parts with small forming radius may not be possible and the wear of the rubber is an issue in larger quantity manufacturing.
- This process is suitable for prototype development or for low-volume production.
- The other disadvantages are lower forming pressure and consequently large amount of wrinkles and low production rate.

1.4 Literature Review

The origin of Rubber Pad forming can be traced back to 19th century when Adolph Delkescamp in 1872 employed rubber pad for cutting and shearing of thin sheet. In 1912, Leonard Beauroth used a rubber bulging technique to form metal barrels. However, it was three patents of Henry Guerin in 1938, 1939 and 1940 that led to wide introduction of rubber forming techniques [19]. Later on Guerin process was modified and improved to develop Marform deep drawing process. Hybrid processes such as Verson-Wheeler, Verson Hydroform and SAAB Rubber Diaphragm techniques were developed to exploit the benefits of pressurized fluid and hyper-elastic nature of rubber diaphragm.

Most of the research work is limited to the Guerin process, its numerical simulation, friction coefficient studies and computer aided modeling probably because of its simplicity and greater utility. Thiruvarudchelvan S., [21, 22] in his review paper stated that rubber use as flexible tool started at the beginning of the 20th century in bulging processes but only in the sixties with the introduction of the polyurethanes such elastic means began to be largely used due to their much higher hardness and resistance to wear and to chemical attacks by lubricants. After polyurethanes became available combined elastic and solid die forming developed fast and was the subject of research in many countries. Process investigated using this technique included; blanking, bending, extrusion, deep drawing and tube forming [23]. Al-Qureshi developed a theoretical analysis for predicting the total ram movement for a piercing operation using rubber pad and found a remarkably good agreement between theory and experiment [24]. The significance of polyurethane as flexible tool has been reiterated by many academic researchers. N.Alberti , A. Forcellesez, L. Fratini and F. Gabrielliz (1998) have described Urethane as a polymer which shows non linear elastic stress-strain behavior [25]. Such elastomers are often referred to as rubber-like materials even though no natural rubber exists showing a pure elastic behavior. Moreover, it should be noticed that the elastomers show an initially random orientation of the long-chain molecules and as a consequence the materials can be assumed isotropic; as the deformation increases the molecules orient themselves following the stretching direction: nevertheless the elastomers can be considered fully isotropic all along the deformation path. The poly- urethane rubber is a hyperelastic material, and generally it is assumed as nearly incompressible during deformation [26]. Xiao Wang [27] proposed that rubber is similar to the liquid which has good flow property. If compressed in one direction, it will expand in the other direction, and delivering pressure. Geiger and Sprenger (1998) has conducted a study on the characterization of polyurethane pads and experimental bending using elastomer pads [28].

1.4.1 Numerical Simulation

Numerical simulation has been a useful tool for engineering design and analysis. It is the process of solving physical problems by appropriate simplification of reality. Finite Element Analysis is the most established numerical simulation technique to solve a physical problem in virtual environment. Problems can be solved even there is no prototype or product is available, which means the problems can be solved in the Conceptual Phase from CAD model itself. It helps in improving productivity and faster realisation of new product. A typical flow chart of FEA is presented in figure 1.21 [29]. It begins with defining problem and building up of simplified simulation model. The model is then meshed and boundary conditions are applied. Subsequently, the FEA model is solved and obtained results are interpreted. If results meet the requirements, then design is freezed otherwise simulation model is modified till results satisfy the design requirements.

Several numerical investigations using Finite Element Method and corresponding experimental investigations have been carried out in last 3 decades. Sala [18] proposed a numerical and experimental approach to optimize aluminium alloys rubber forming. Guerin rubber-forming process was used to fabricate an aluminium alloy fuselage frame belonging to AerMacchi MB-339 trainer aircraft. David and Emil [30] presented an experimental study of the rubber forming process in order to produce sheet metal components. The capability of the process and optimization of process parameters to ensure defect-free products by using a 100 T double-acting hydraulic press was investigated. Husnu and Akdemir [31] studied the significant parameters associated with FFP (flexible forming process) by numerical simulation with a commercially available finite element package. It was concluded that finite element method is very much effective in process design. Sala G [18] also optimized the process with numerical simulation and experiments. Lei Chen (2014) studied straight flanging and springback of aluminum materials in rubber forming process [32]. In another study, Kwon et.al. [33] have investigated the flexible bending of a structural aluminium frame using rubber. From the experimentally bent profiles, a parametric study for process design was performed. Yamashita et al [34] carried out numerical simulation of a cup drawing process using dynamic explicit finite element code DYNA3D and studied the effect of the forming parameters, such as dimension and hardness of the rubber ring, frictional coefficient of the interface between the sheet and the rubber ring and mechanical properties of the sheet, on the sheet deformation is investigated and concluded that the numerical simulation may be helpful in determining the forming conditions for the sheet metal drawing by Maslennikov's technique

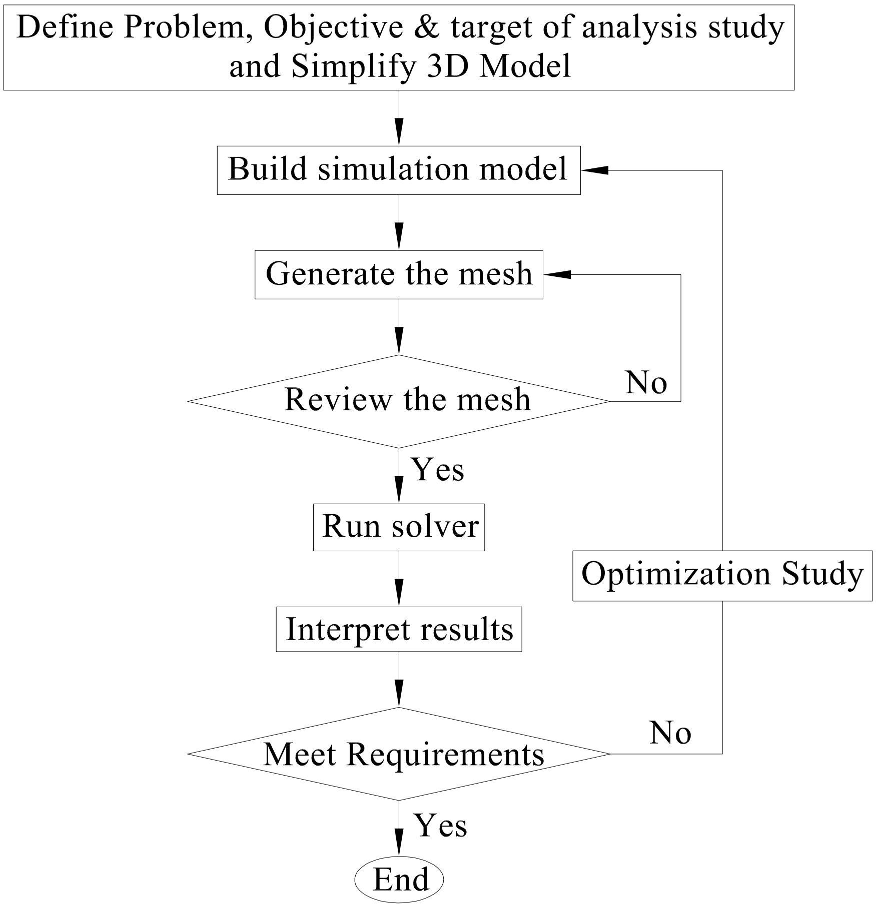


Figure 1.21: Flow chart for Finite Element Analysis

1.4.2 Effect of Process Parameter

Literature survey indicates that friction has remained one of the important process parameters to be studied during numerical simulation. PENG Lin-fa (2009) highlighted the influence of friction on material formability and product quality. In similar study Maziar [35] and Dirikolu [31] concluded that the friction condition cannot change the forming limit strain of the sheet metal but can change the distribution of stress and strain, which can affect the defects in the metal forming. PENG et al (2009) carried out finite element simulation using the Coulomb friction model and Maziar et al (2009) presented the theoretical friction model to investigate the effects of various friction coefficients on the blank thinning and stress distribution in the rubber forming. Dirikolu and Akdemir (2004) investigated the parameters associated with rubber pad forming such as the rubber hardness, blank material type, contact friction and so on, through simulation by using the commercial software ANSYS. The use of different types of lubricants at the blank and its interfaces was also analyzed. Wax (Vestoplast 703) was found to be the best lubricant for the process. Maziar Ramezani (2009) made an exhaustive study in friction models and proposed to use static friction and kinetic friction models instead of coulomb's friction model.

1.4.3 Recent Developments

In recent years, Rubber pad forming has been used to form micro and meso features. Peng Lin-fa [36] established a finite element analysis (FEA) model to study sheet forming process using soft punch at micro/meso scale. The forming parameters (material grain size, friction and hardness of soft punch) related with the forming process are detailed investigated. It is found that sheet metal with small grain size is prone to obtain high formability. Lager friction coefficient between the sheet and the rigid die may make the sheet thinning quickly that decreases the formability, while the friction between the sheet metal and the soft punch does not play an important role. The hardness of soft punch is not a decisive parameter to the final quality of the workpiece. Chul Kyu Jin (2014) used rubber forming method is used to fabricate titanium bipolar plates for proton exchange membrane fuel cells. The size of the channel is 0.8 mm (width) x 0.4mm (depth) and rib width of 1.4 mm [37]. On similar line, Yanxiong Liu (2009) numerically investigated, using ABAQUS, the rubber forming process to fabricate metallic bipolar plate for proton exchange membrane fuel cells [38].

1.4.4 Design and Development of Rubber based forming setup

Literature review indicates that lab scale rubber pad forming set up have been developed to study the effect of various parameters. David J. Browne and Emil Battikha (1995) designed a rubber pad forming setup for Marform process using 100Ton capacity press which is integrated with load cell and data acquisition system [30]. It enabled the researchers to analyse load/displacement. The curve was plotted between Punch load (Y axis) and ram travel (X axis). It was concluded that clamping force has reduced the wrinkling and buckling in the formed component. It was also shown that high press speeds leads to incomplete formation of parts. However marform process is suitable for forming of thin aluminium sheets and shallow forming applications.

N.Alberti' . Forcellesez, L. Fratini' and F. Gabrielliz (1998) carried out rubber pad forming experiment using urethane pad of 82 A shore hardness [26]. The components were formed using rigid punch having the profile of the desired shape , while urethane pad replaced the rigid die. It was shown that only using a urethane male pad and a female rigid tool is possible to produce a sound component.

G Sala (2000) designed and developed a set up to simulate the Guerin process. The Guerin rubber-forming process of an aluminium alloy fuselage frame belonging to AerMacchi MB-339 trainer aircraft was optimised through this approach. It is shown how the preliminary tuning of parameters such as stamping velocity, component geometry, sheet metal heat treatment, elastomeric rubber pad constitutive law and thickness allow us to minimise defects, increase component quality and reduce set-up times, complying at the same time to the demanding aeronautical requirements.

The experiment set up of using soft punch for micro forming application has been developed by Linfa Peng , Peng Hu, Xinmin Lai , Deqing Mei and Jun Ni [36]. In this set up soft and flexible rubber has been used as punch to form the micro channels. Thus here again Guerin process has been simulated using the lab scale set up. The forming parameters (material grain size, friction and hardness of soft punch) related with the forming process are detailedly investigated. It is found that sheet metal with small grain size is prone to obtain high formability.

Lei Chen, Huiqin Chen , Weigang Guo, Guojin Chen and Qiaoyi Wang (2013) carried out flanging experiments to analyse and study spring back using Quintus Fluid Cell Press at the maximum available pressure of 140 MPa [27]. The springback was analyzed by straight flanging in rubber forming process with different die radii and blank thicknesses. Springback decreased with the increase of the blank thicknesses, whilst increase with the increase of the die radii. In rubber forming die design, the die radius is the most important factor to be considered. The springback can be eliminated with $r/t < 2$. The increase of pressure and time in rubber forming has little effect on the springback.

Q. Zhang, Z.R. Wang, T.A. Dean [39] developed a set up to analyse the mechanics of multi point sandwich forming. In this set up, top die is made up of urethane rubber while bottom die consists of multi point pins. Gurein process using experimental set up is again investigated by Yanxiong Liu, Lin Hua,, Jian Lan, Xi Wei [40] for manufacturing of metallic bipolar plates containing micro flow channels. Yong-na SUN, Min WAN, Xiang-dong WU [41] investigated the wrinkling in rubber bad forming of Ti-15-3 alloy using Guerin set up.

Hence, it is clearly evident that most of researchers developed Guerin set up to investigate and analyse the rubber pad forming processes. David J. Browne and Emil Battikha (1995) made an effort to develop full-fledged setup consisting of load cell and data acquisition system. However, no arrangement was made for hydraulic back pressure. Lei Chen, Huiqin Chen , Weigang Guo, Guojin Chen and Qiaoyi Wang (2013) used Quintus Fluid Cell Press to study spring back but set up was not developed at lab scale.

In view of above, the attempt has been in made present work to design and develop lab scale rubber based sheet hydroforming set up to study, investigate and analyse the various forming process parameters.

1.5 Objectives of the Present Research

Based on previous literature, the following gaps in the research of Rubber based sheet hydroforming process have been observed

1. The Rubber forming set up was only developed for basic rubber pad forming processes especially Gurein process.
2. Literature on RBSH set up to monitor forces and hydraulic back pressure simultaneously has not been found.
3. FEA is carried out for primitive shapes such as 'U'-channels and axisymmetric shapes.
4. Poly-urethane is the most common rubber pad used in experiments. Other varieties of rubber such as natural and silicon rubber have not been experimented.
5. Comparative study of effect of different rubbers on formability has been not studied till date.

Hence, the objectives of the present research may be divided into two phases

1. Design and Development of Rubber Based Sheet Hydroforming Machine Setup:
    - To develop double acting Press containing 2 hydraulic packs and load cell to control and monitor Punch Load, Blank Holding force and Hydraulic Pressure.
    - To design and develop appropriate tooling for the process.
    - To select the appropriate rubber material for successful forming of various shapes for different materials and alloys.
    - To Design a system to attach Rubber Diaphragm with the tooling set up.

2. Simulation and Experimental Investigations :
    - To develop a CAD Model of Rubber Based Sheet Metal forming set up.
    - To carry out the simulation of the CAD Model into some simulation software like ABAQUS, Hyperform etc.
    - Modeling with rubber of different hardness.
    - To investigate the effect of various process parameters like blank holder force, strain rate, rubber hardness, fluid pressure, rate of forming etc.
    - To carry out the forming and metallurgical studies of strain distribution, grain size and flow and study of accuracy of geometrical profile including optimization of the process.

1.6 Organization of Thesis

The thesis work has been presented in six chapters explaining the complete methodology of the thesis work. The organization of chapters in the thesis is given as below:

An introduction and Literature survey of deep drawing, rubber pad forming and sheet hydro-forming is discussed in chapter 1. The detailed account of basic concepts of sheet metal forming, deep drawing, forming issues and need aspect of present research are presented in this chapter.

Chapter 2 discusses the material characterisation part of RBSH process. The forming properties of metals and rubbers has been described which are useful in carrying out FEA simulation and understanding the suitability of material for forming into complex shapes.

The product design aspect of RBSH set up is discussed in chapter 3. This chapter presents the detailed account of design, fabrication of RBSH set up components and online monitoring of forces and hydraulic back pressure. The obtained results are explained for each experiment.

Chapter 4 mainly deals with comparative study of conventional and Rubber based forming processes. The comparative study of shallow forming of SS 304 cup, deep drawing of copper cone and hemispherical cup are discussed in detail. The comparative micro-structure analysis and stress analysis are also included. This chapter also includes formability study using Grid analysis and measurement of developed major and minor strains.

The FEA study of various experiments carried out in chapter 4 is discussed in chapter 5. The comparative analyses of Von mises stress, plastic strain and thickness variation in the component are discussed extensively. Also, FEA model for non-symmetric shape is also included in this chapter.

In chapter 6, conclusion and scope for future research are explained and discussed.