CHAPTER 1

Introduction

1.1 SHEET METAL FORMING PROCESSES

Metal forming is one of the most important steps in manufacturing of a large variety of products. It involves obtaining desired shape and size by subjecting the material to large plastic deformation. Equally important is the control of mechanical properties and product quality [1]. Metal forming or metal working processes are divided into two categories i.e. bulk forming and sheet metal forming. Bulk forming refers to processes like forging, rolling, extrusion etc. where there is a controlled plastic flow of material into useful shapes.

Sheet metal forming (also called press working) involves conversion of flat thin sheet metal blanks into parts of desired shape. Sheet metal forming processes like deep drawing, stretching, bending etc. are widely used to produce a large number of simple to complex components in automotive and aircraft industries, household appliances etc. Some of these components are shown in Fig. 1.1. Most of these parts are manufactured using one or more of the sheet metal forming processes [2,3]. These processes are also called sheet metal stamping operations.

In deep drawing, which is also called cup drawing or radial drawing, flat thin sheets (blanks) are formed into cup shaped components by pressing the central portion of the sheet into die opening using a punch to draw the metal into the desired shape. The principle of deep drawing is schematically represented in Fig. 1.2 [1].

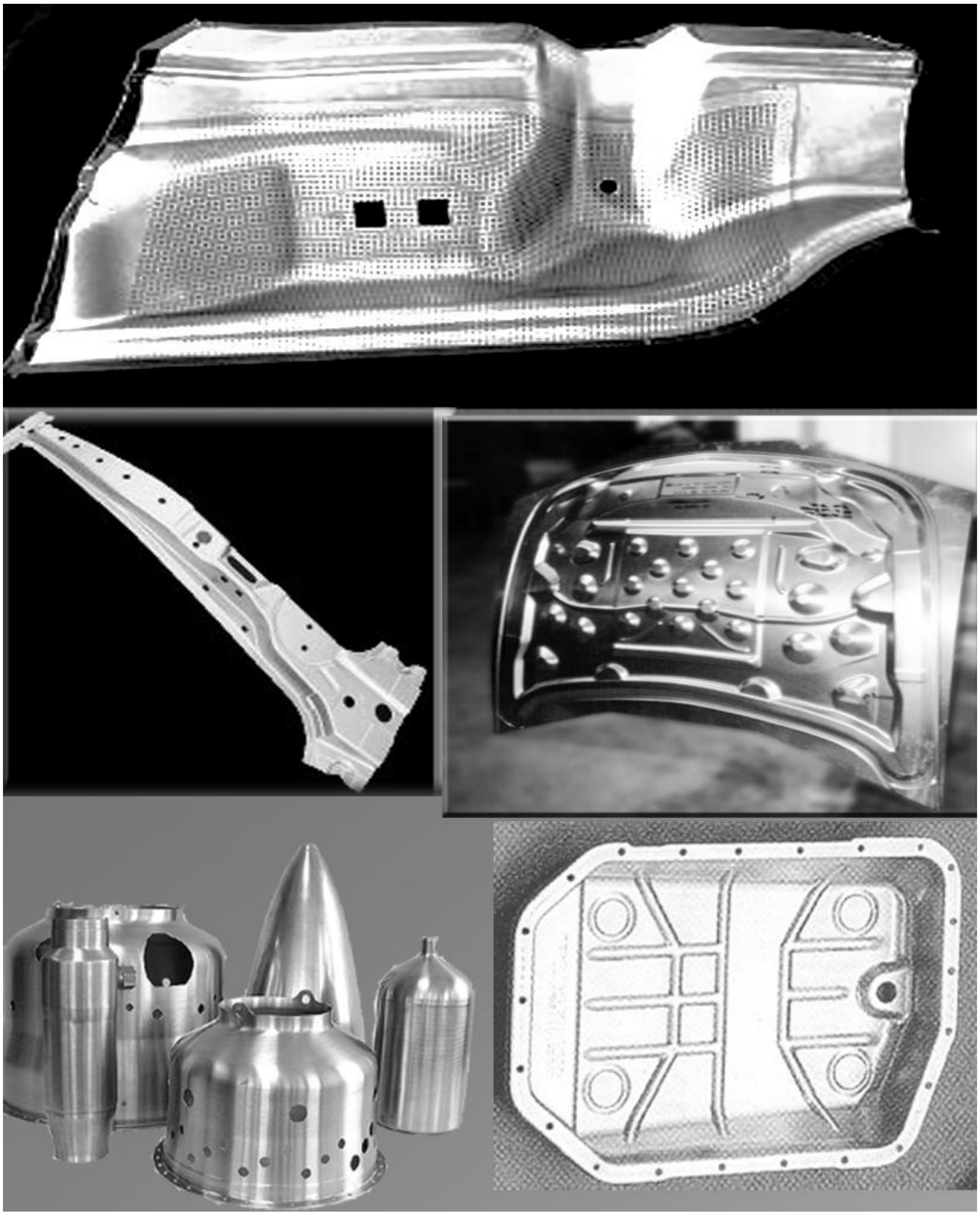

Fig. 1.1 Some parts manufactured by sheet metal forming operation [4]

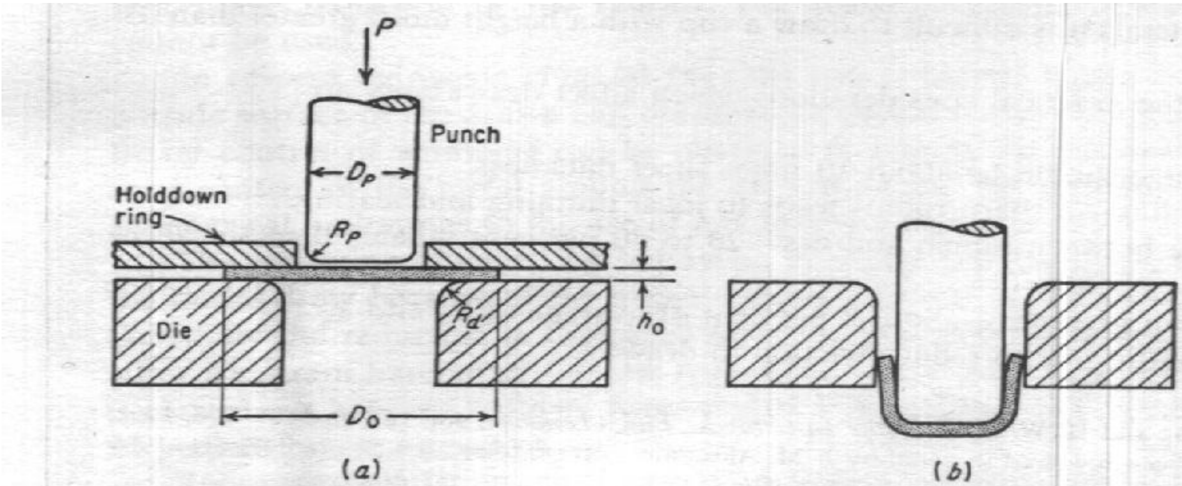

Fig. 1.2 Deep drawing of a cylindrical cup (a) before drawing and (b) after drawing [1]

The blank may be circular or rectangular, or of a more complex outline. Blank holder is loaded by a blank holder force, which is necessary to prevent wrinkling and to control the material flow into the die cavity. The punch is pushed into the die cavity, simultaneously transferring the specific shape of the punch and the die to the blank. The material is drawn out of the blank holder-die region during the forming stage and the material is subjected to compressive and tensile stresses in this portion. When a very high blank holder force is applied, the deep drawing process becomes a stretching process.

In stretch forming or stretching, shown in Fig. 1.3 [5], the flange of the flat blank is securely clamped. In some cases, the material is fixed under the blank holder and the remaining part of the blank is formed over a tool. Normally a rigid punch is used to form the part [6].

Stretching is characterized by bi-axial tensile stresses leading to significant thickness reduction in the deformed portion.

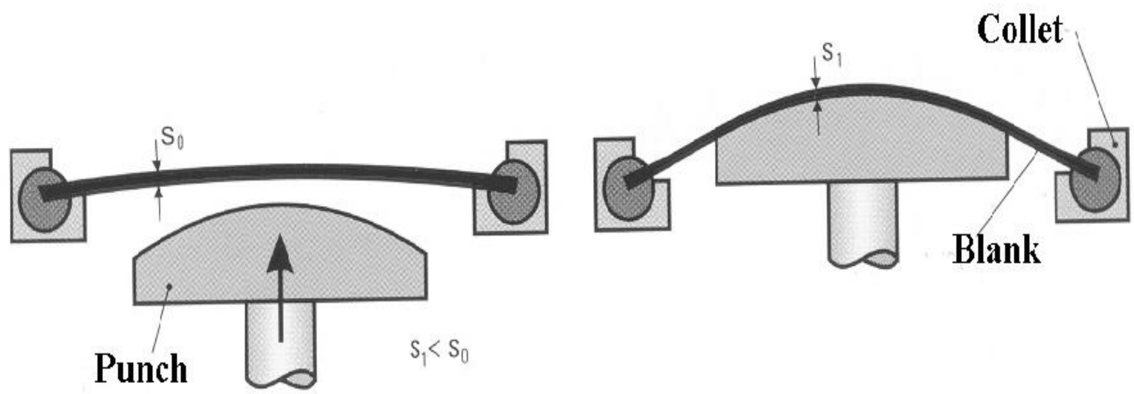

Fig. 1.3 Stretch forming of a sheet .[5]

Bending is the plastic deformation of metals about a linear axis (called the bending axis) with little or no change in the surface area (Fig. 1.4).

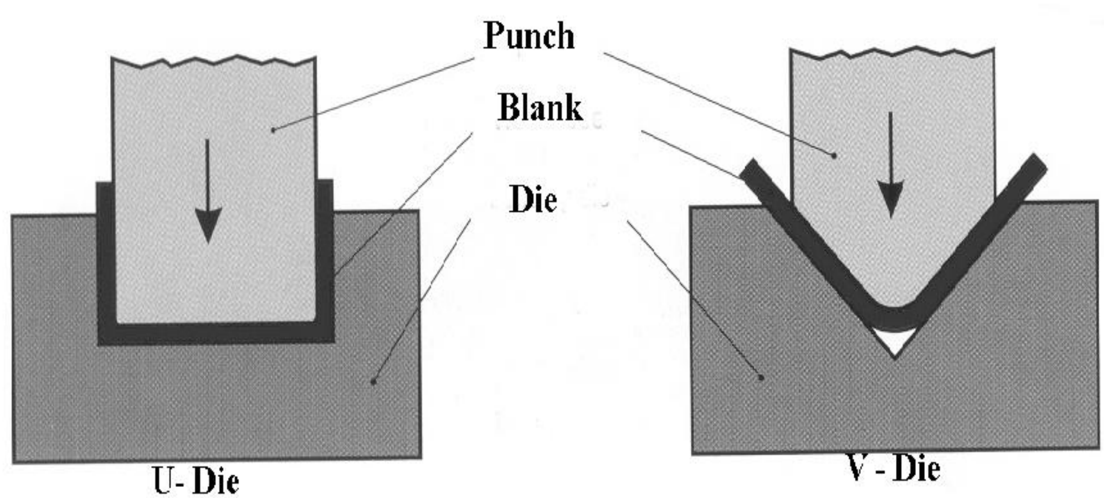

Fig. 1.4 Sheet bending using U-die and V-die [5]

By bending process stiffnesss of the part can be increased by increasing its moment of inertia. It is the most common type of deformation that occurs in almost all sheet forming operations. In deep drawing operation, bending of sheet takes place over the die curvature. The bend zone experiences localized strains which are tensile on the outside of the neutral axis and compressive on the inside.

Sheet metal forming processes are basically tensile in nature and are limit the onset of instability and necking.

1.2 CONVENTIONAL FLOW FORMING

Flow forming is an advanced form of metal spinning. Metal spinning utilizes a relatively thinner piece of starting material than flow forming, and produces the shape of the finished part from a larger diameter starting blank than the largest diameter of the finished part very similar to deep drawing. No reduction of the wall thickness is contemplated, but is often experienced and is very difficult to control. Flow forming, on the other hand, is based upon a predetermined reduction of the thickness of the starting blank or preforms, a reduction, which is very accurately controlled.

In last two decades or so, flow forming has been gradually matured as a metal forming process for the production of engineering components in small to medium batch quantities. Due to its inherent advantages such as flexibility, simple tooling and low forming loads, flow forming has enabled customers to optimize designs and reduce weight and cost, all of which are vital, especially in the automotive industries. The flow forming process, including shear forming, which grew out of spinning, is a process whereby the workpiece is rotated while the tool, which rotates about its own axis, may move axially or radially to the axis of rotation of workpiece, manipulating it to the final desired shape. It is most widely used to produce thin walled, high precision tubular products where the tubular workpiece is held onto the mandrel, the material being displaced axially by one or more rollers moving axially along a mandrel, as shown in Fig. 1.5

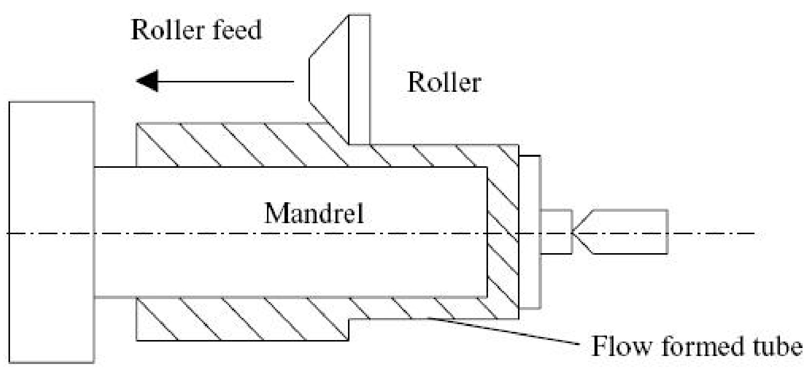

Fig. 1.5 Conventional Flow forming principle[7]

1.3 CONVENTIONAL DEEP DRAWING

In conventional deep drawing (CDD) process, the sheet metal is formed into a cup shaped component (as mentioned before). In this process, a flat circular sheet of metal called blank is placed over the opening in the die and then pushed through and deformed by a moving punch. As the punch moves downward, the outer annulus of the blank (flange) moves radially inward. The tendency of the flange to fold upward (wrinkling) is restricted by the blank holder force.

In CDD, the majority of the deformation occurs in the flange of the cup. The metal is subjected to three different types of stress systems (as shown in Fig. 1.6).

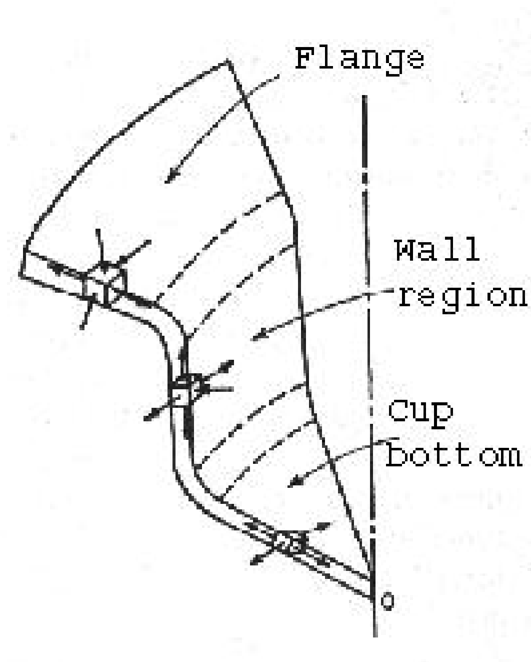

Fig. 1.6 Stresses and deformation in a section of a cup during deep drawing [1]

These stresses have influence over thickness variation in drawn cup. The primary deformation occurs in the flange of the deforming cup which undergoes radial tension and circumferential compression. Because of this, thickness increases in the flange portion. The second deformation zone is the bending around the die radius while the third deformation zone is the uni-axial stretching (plane strain) in the cup wall, which causes thinning of the metal. In the cup bottom, which is subjected to biaxial tension, the thickness is more or less equal to the initial sheet thickness [1].

The draw ratio (DR) of a deep drawing process is calculated as the ratio of blank diameter to the cup diameter. For achieving very high draw ratio, redrawing and ironing or annealing between draws is performed. The maximum draw ratio that can be obtained under perfect deep drawing conditions is called limiting draw ratio (LDR). The LDR is considered a good measure of drawability of a material.

The total force required to draw a cup is sum of frictional force, drawing force and ironing force. If this force exceeds the limit then failure occurs, generally at punch radius region.

Fig. 1.7 shows the variation of force with respect to the punch displacement. The force needed to cause deformation is applied through a punch at the central portion of the blank. This force is transmitted through the cup wall to the flange. As the blank size increases, there is an increase in the total force and if the total force exceeds beyond a certain value, fracture occurs in the cup wall. This puts a limit on the blank size that can be successfully drawn into a cup without failure.

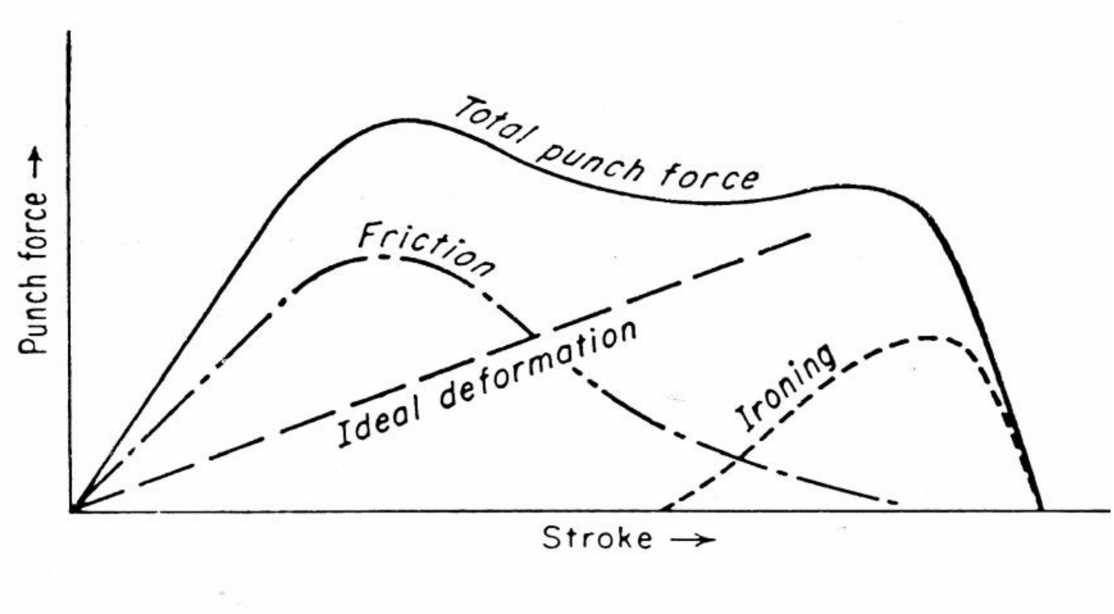

Fig. 1.7 Punch force vs punch stroke diagram for deep drawing process [1]

1.4 COMMON DEFECTS IN DEEP DRAWING

The three major common defects which occur during deep drawing are fracture, wrinkling and earing. Fracture occurs when the sheet metal is subjected to strains exceeding the safe strain limits of the material. For ductile sheets this fracture usually occurs near the punch corner. It is because maximum forming load appears in the material in this region and also stress concentration lines are converging in this section. Once this necking exceeds beyond a certain value, fracture appears in the drawn cup. A formed cup with a fracture at the cup bottom is shown in Fig. 1.8.

Fig. 1.8 Fracture in deep drawing [8]

Wrinkling occurs in the flange when compressive stresses in the circumferential direction reaches a critical point of instability. It can occur in regions where the work piece is unsupported or when the blank holding force is insufficient. Wrinkling defect is shown in Fig. 1.9. The wrinkling can be prevented by increasing blank holder force and by using a draw bead [9]. The draw bead bends and unbends the work piece material as it passes through the blank holder. This bending over the bead increases the radial tensile stresses and thus reduces the possibility of wrinkling.

Fig. 1.9 Wrinkling in deep drawing[8]

Deep drawing of anisotropic sheets results in a drawn cup with uneven top edge i.e. some kind of ears are formed at the top as shown in Fig. 1.10. This defect is called earing and it is because of planar anisotropy of the blank material.

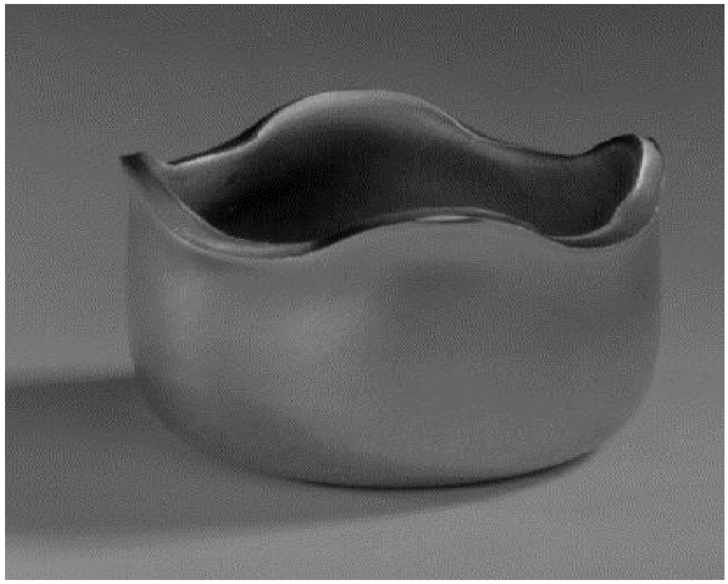

Fig. 1.10 Earing in deep drawing[5].

1.5 FORMABILITY IN DEEP DRAWING

Formability is defined as the ability of a sheet material to be formed into a specific shape without crack/fracture or excessive thinning [6]. Formability of sheet metal plays an important role in the success of the sheet stamping operations. Formability can be more specifically discussed in terms of drawability and stretchability as deep drawing and stretching are the most common modes of deformation in stamping operations. Several formability tests have been developed [10,11 and 12] that simulate drawing and/or stretching conditions that exist in press forming operations. Some of these predictive tests are Erichsen test, Olsen test and Fukui cup test [13]. For more complete information on formability, Forming Limit Diagrams (FLDs) are widely used. The diagrams indicate the combination of maximum principal surface strains that the sheet can withstand without failure or excessive thinning (which causes necking) under all possible conditions of deformation [14]. Equally important in the assessment of formability is the strain distribution during deformation. Materials which have the ability to distribute strains more uniformly are expected to have higher formability [15].

Enhancement of formability leads to higher maximum possible deformation that can be given in a single step and hence parts of larger depth or parts of complex geometry can be formed. It reduces the number of production steps and increases productivity. Therefore, there have been many attempts to improve formability and product quality in general, by improvement in the properties of sheet metal or by optimization of tool design and process parameters [16, 17 and 18].

1.6 LIMITATIONS OF CONVENTIONAL DEEP DRAWING

The main limitations of conventional deep drawing are:

1. Very high limiting draw ratio can not be obtained due to excessive thinning and fracture in the cup wall, associated with large draw ratios. For most of the common sheet materials, an LDR of more than 2.2-2.3 is extremely difficult to achieve in conventional deep drawing [1].

2. Very sharp corners of the punch and the die lead to fracture.
3. High friction between the die and the sheet puts a limit on the LDR and increases the punch force required for drawing.
4. The surface finish of the component obtained usually is of low quality due to the friction between the sheet and the punch and between the die and the sheet.

Beyond a certain extent enhancement in formability is not possible because of inherent limitations of conventional sheet forming processes. But it was shown [19] that higher forming limits than in conventional forming processes would be possible with the modification of the process itself.

1.7 COMMON DEFECTS IN CONVENTIONAL FLOW FORMING

Following major limitations in conventional flow forming

1. Thickness reduction per pass is low in conventional flow forming, particularly in cold conditions.
2. Close control of the tool is required for even thickness distribution over the cup wall.
3. Presently, flow forming is done commercially in cold conditions which is limited only to soft materials like Al –Mg alloys

4. Robust machine tools with higher power requirements to rotate the mandrel and complicated fixturing restricts the use of flow forming process

This has led to investigate the flow forming of cylindrical jobs in deep drawing setup under warm conditions. This process may reduce forming loads, and thus reduces the robustness of the machine tool, and also high strength alloys may be formed in minimum number of steps.

1.8 FLOW FORMING IN WARM CONDITION UNDER DEEP DRAWING SET UP

In conventional flow forming process mandrel rotates and a roller deforms the material over the surface and a cylindrical part is produced . The most common application of this process is in making missile cases. With extended literature survey, it is revealed that until now investigations are not done to form cup shaped products by flow forming process under deep drawing process. Some excessive plastic deformation over the wall is achieved in the present investigation by subjecting the material to excessive ironing in deep drawing setup. To give larger deformation, the temperature of the material is increased. Hence an attempt has been made to form defect free cups at different temperatures in deep drawing setup.

1.9 ADVANTAGES OF FLOW FORMING IN WARM CONDITIONS IN DEEP DRAWING SETUP

Following are the major advantages of warm flow forming in deep drawing setup

1. Number of passes in the redrawing can be reduced to the given thickness reduction.
2. Simple press tool is sufficient to form the product.
3. Minor fixturing is sufficient for the process.
4. Surface defects are less.
5. Uniform wall thickness can be easily maintained.
6. Ironing will be done simultaneously along with wall reduction, and it will increase surface quality.

1.10 APPLICATIONS

1 To form high strength alloys with uniform thickness axisymmetric components in aerospace industry

2 To form alloy wheels in automobiles

3 To form different shapes in ship building