CHAPTER 4

INVESTIGATION ON FORMABILITY OF THE MATERIAL BY WARM DEEP DRAWING

4.1 INTRODUCTION

The formability of a material is defined as the ability of the material to form the desired size and shape without any defects using optimum process parameters. Sometimes it is also termed as drawability when used in drawing operation. In general, forming occurs between the yield strength and the tensile strength of a material. If yield stress is not exceeded, forming does not occur, but exceeding the tensile strength results in material fracture. In higher strength materials, the window between the yield strength and the tensile strength is very small. It is almost impossible to achieve the desired formability and the required tensile strength in the same material without taking some additional steps (Ron Brucker 2001). Aluminium and Magnesium alloys are some of the low formability materials whereas Carbon steel, High strength low alloy steels are some of the high formability materials.

The limiting draw ratio (LDR) and the height of the deep drawn cup are some of the parameters used as an index of formability of a material. The LDR is defined as the ratio of the initial blank diameter to the inner diameter of the cup drawn from the blank or punch diameter which is shown by the equation (4.1) (George Dieter 1987). This represents the largest blank that can be drawn through a die without tearing.

$$\text{Limiting draw ratio (LDR)} = \beta_{actual} = \frac{\text{Blank diameter(D)}}{\text{Punch diameter}(d_p)} \approx e^{\eta} \qquad (4.1)$$

where, η is an efficiency term to account for frictional losses.

If $\eta = 1$,then LDR $\approx$ 2.7, while if $\eta = 0.7$, LDR $\approx$ 2. This agrees with the experience that even with the ductile materials, it is very difficult to draw a cup with height much greater than its diameter.

Some of the practical considerations which affect formability are:

Die radius – should be about 10 times the sheet thickness.

Punch radius	–	local thinning and tearing occurs when the radius is sharp.
Clearance between punch and die	–	should be 20 -40 % more than the sheet thickness.
Blank holder pressure	–	must be about 2 % of average of yield strength and tensile strength.
Material properties	–	low yield strength, high work hardening rate, normal anisotrophy value (R).
Lubrication of die	–	in order to reduce the friction in drawing operation (George Dieter 1987, Marciniak et al 2002).

In deep drawing, the draw ratio would set the limits for the allowable plastic deformation and this draw ratio is not only useful in predicting the drawability of the materials and also to determine the number of drawing operations that are necessary to produce a required drawn part

(Heinz Tschaetsch 2006)   Because of the complexity of sheet metal forming operations, simple mechanical property measurements made from the tension test are of limited value. Over the years, a number of testing methods have been developed, to evaluate the formability of the sheet material (George Dieter 1987). Formability tests can be divided into two types: intrinsic and simulative. The intrinsic tests measure the basic material properties under certain stress-strain states and simulative tests subject the material to deformation that closely resembles a particular press forming operation like Swift flat-bottom cup test, Olsen and Erichsen cupping test etc. A simulative test can provide limited and specific information that may be sensitive to factors other than the material properties, such as the thickness, surface condition, lubrication and geometry and type of tooling (Wagoner and chenot 2001).

A useful technique for controlling failure in sheet metal forming is the forming limit diagram (FLD). Another approach to predict sheet formability is the stretch-draw shape analysis. Useful formability charts have been developed for such processes as linear stretch forming, beading, spinning etc., which are the processes used in aerospace industries. The determination of the maximum strain for comparison with the FLD can be difficult if complex parts are dealt with, since the deformation cannot be calculated by analytical methods (Banabic et al 2000).

The objective of this investigation is to study the formability of AISI 304 austenitic stainless steel, which is indicated by the LDR and the height of the deep drawn cup. Also, to draw FLD at experimented temperatures to determine any region on the surface of the deep drawn cup is in the vicinity of fracture immediately or in future when in use.

4.2 EXPERIMENTAL PROCEDURE FOR THE INVESTIGATION ON FORMABILITY OF AISI 304 STAINLESS STEEL SHEET IN WARM DEEP DRAWING

4.2.1 Component Details

The components produced by warm deep drawing of AISI 304 austenitic stainless steel sheet at temperatures of 30°C (room temperature),100°C, 200°C and 300°C are used for the investigation on the formability of the material. The various dimensions of the components are shown in the Figure 4.1.

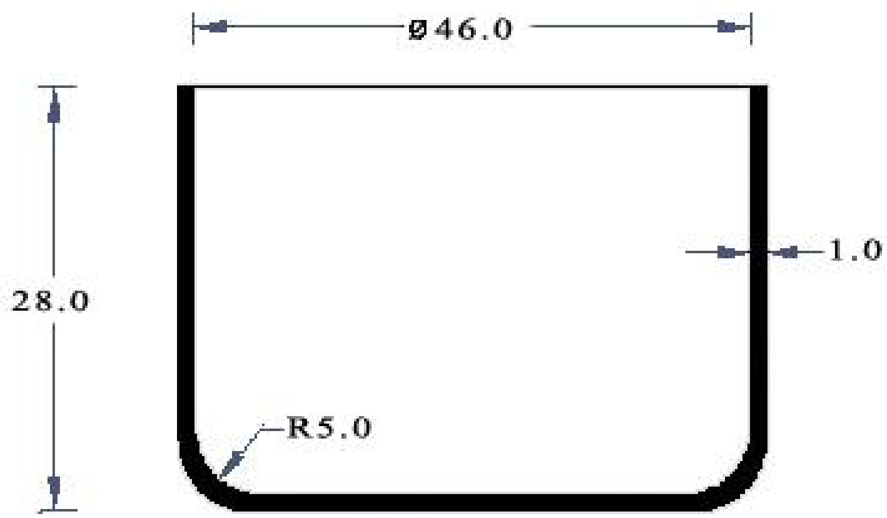

Figure 4.1 Component drawing

4.2.2 Experimental set-up

The inverted draw die set-up is used in this experimental approach, in which the die is clamped with the ram of the press and the punch and the blank holder are placed on the base of the press, to take advantage of gravity to eject the component from the die. The schematic diagram of the inverted die arrangement is shown in the Figure 4.2 and the close up view of the tooling set up is shown in the Figure 4.3.

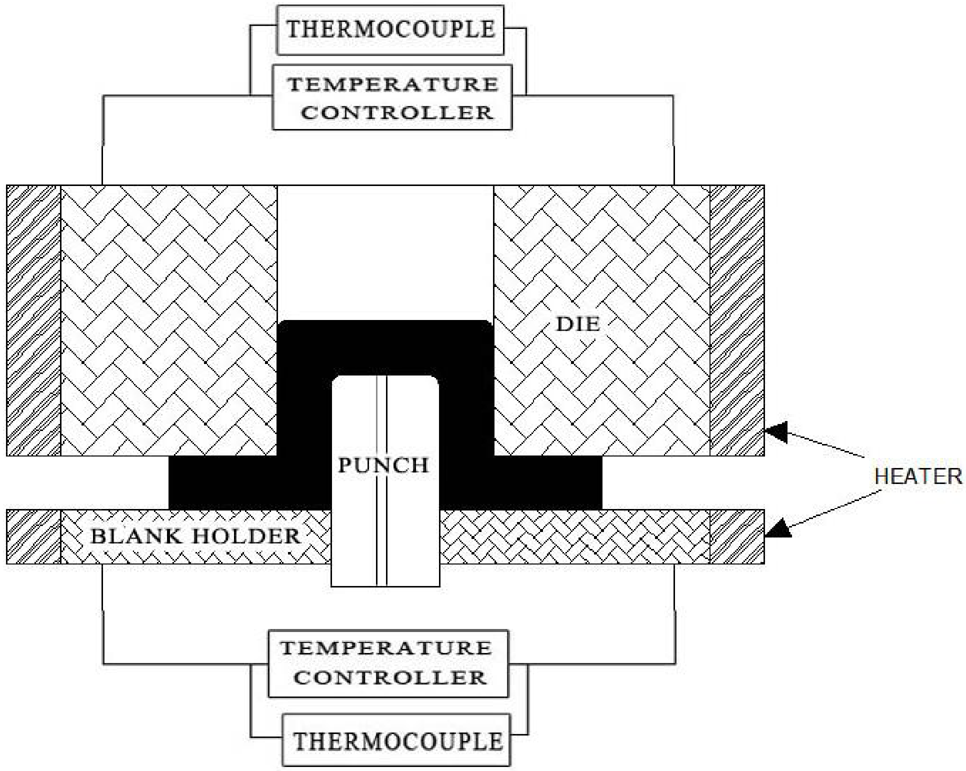

Figure 4.2 Schematic diagram of the die arrangement

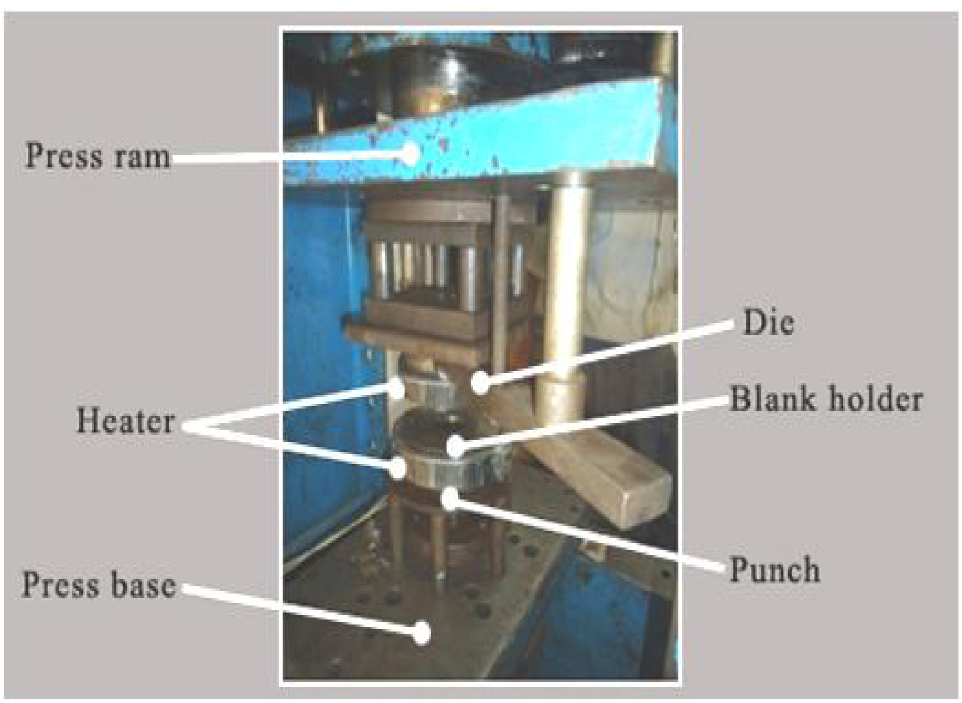

Figure 4.3 Close up view of the Tooling set-up

4.2.3 Experimental Procedure

The experimental procedure to determine the LDR of the deep drawn component material both in conventional forming and warm forming consists of the following steps:

(i) The theoretical blank diameter is determined using the equations (3.1) and (3.2) for the component shown in the Figure 4.1.

$$D = \sqrt{(d_o - 2r)^2 + 4d_o(h - r) + 2\pi r(d_o - 0.7r)}$$

$$= \sqrt{(48 - 10)^2 + 4 * 48(28 - 5) + 2 * \pi * 5(48 - 0.7 * 5)}$$

$$= 85.2 \text{ mm}$$

(or)

$$D=\sqrt{d_i^2 + 4d_ih}$$

$$= \sqrt{46^2 + 4 * 46 * 28} \quad = 85.3 \text{ mm}$$

From the above calculations, the initial blank diameter of AISI 304 stainless steel is chosen as 85.5 mm.

(ii) Blanks of AISI 304 stainless steel sheet material with diameters more than 85.5 mm with the steps of 1mm are also prepared. The Figure 4.4 shows the different blanks prepared for experimentation with or without the application of temperature.

Figure 4.4 Blanks with different diameters used in the experiment

(iii) First, the circular cups are drawn with the calculated initial blank diameter at room temperature.

(iv) If the component is successfully drawn, the next larger blank diameter is drawn. The process is continued until the fracture or defective component occurs. The last blank diameter which is drawn successfully is the LDR at that temperature.

(v) The experiment is repeated with the unsuccessful blank diameter from the previous experiment at a temperature of 100^{o}C and the above mentioned procedure is followed.

(vi) The same method is followed by drawing the unsuccessful blanks in the previous experiment at the temperatures of 200^{o}C and 300^{o}C.

The height of the successfully deep drawn cup at each temperature is measured. The LDR value and the height of the successfully deep drawn cups are compared to determine the improvement of formability of AISI 304 stainless steel material due to the application of temperature.

4.3 A STUDY ON FORMING LIMIT CRITERIA

Sheet metal formability tests are designed to measure the ductility of a material under conditions similar to those found in sheet metal forming and these tests may be used to assess the capacity of the sheet material to be formed into a useful part. The forming limit diagram (FLD) is defined in the axes of minor and major principle strains in the plane of the sheets. The curve obtained by plotting the limit strains observed for linear strain paths is the forming limit curve (FLC).

In order to draw the FLD, the surface of the sheet is marked with a grid of circles produced by electrochemical etching. When the sheet is deformed, the circles distort into ellipses and the major and minor axes of an ellipse represent the two principle strain directions in the forming operation. These strains are measured by the percentage change in the lengths of major and minor axes and are then compared with the standard forming limit diagram for that material. The strain states above the standard curve represent the failure and those below do not cause failure. If the points defined by the maximum strain are beyond the forming limit curve, some modifications have to be made of (i) the working conditions like blank holder force, lubrication etc, (ii) the design of the part itself like fillet radii, angles etc, and (iii) the material like thickness, quality etc. (Banabic et al 2000)

4.4 SUMMARY

The study and investigations on formability of AISI 304 stainless steel sheet in warm deep drawing are carried out by performing the deep drawing of different blank diameters at each temperature which is ranging from room temperature to 300^{o}C. The forming characteristics of the material are examined using LDR and the deep drawn cup height as an index. The formability limit diagrams are also drawn at different temperatures to identify any regions on the surface of the deformed cups which are in the vicinity of getting fractured.