REDUCING WRINKLING AND TEARING OF DEEP DRAW PART

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A report submitted in fulfilment of the requirements
for the award of the degree of
Bachelor of Manufacturing Engineering

Faculty of Manufacturing Engineering

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We certify that the project entitled "REDUCING WRINKLING AND TEARING OF DEEP DRAW PART" is written by Mohd Naeemil Mahmudi Bin Mahmud. We have examined the final copy of this project and in our opinion it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. We herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering.

Examiner Signature

SUPERVISOR'S DECLARATION

"I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Manufacturing Engineering."

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"I hereby declare that this final year project report, submitted to University Malaysia Pahang as a partial fulfilment of the requirements for the degree of Bachelor of Manufacturing Engineering is entirely my own research except as cited in the references and summaries. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree".

Signature : ....

Name : MOHD NAEEMIL MAHMUDI BIN MAHMUD

Date :

Dedicated to my parent,
Mahmud Bin Nihat
Zainon Binti Ahmad Kutty

And to my beloved wife,
Noraini Binti Tumiran

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In the Name of Allah, Most Gracious, Most Merciful

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ABSTRACT

Some of the most common outcomes in deep drawing process are tearing and wrinkling or the formation of uneven height at the top rim of a drawn part due to the material anisotropy. This project involves experimental and numerical studies of the die design to investigate the formability of sheet metal. The main objective of this project is to obtain the best deep drawing parameters in reducing wrinkle and tearing during a cylindrical cup deep draw process. The project begins with the die design using Computer Aided Design (CAD) software. The project is continued with modelling of finite element model (FEM) using simulation software. The variables for this project are **die clearance, die radius,** and **blank holding force**. The constant of this simulation are thickness of sheet metal and punch size to deform the material. All the data from finite element software showed the different value of displacement. From the data documentation, the discussion and result were concluded to determine the effect of different parameters on wrinkling and tearing phenomenon during sheet metal forming process.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS

A = area to be cut

L = length of material

T = Thickness of material

D = diameter of blank

W = width of rectangle

C = Clearance (per side)

Ø = Diameter

d = Depth of draw

LIST OF ABBREVIATIONS

JIS	Japaneese Industrial Standards
HB	Hardness Brinell
CAD	Computer aided design
mm	millimeters
CNC	Computer Numerical Control
rpm	Revolution per minute
2D	Two dimensional
3D	Three dimensional
FEA	Finite Element Analysis
FEM	Finite Element Model

CHAPTER 1

INTRODUCTION

1.1 PROJECT SYNOPSIS

In sheet metal forming, a blank sheet is subjected to plastic deformation using forming tools to achieve the designed shape. During this process, the blank sheet will develop defects if the process parameters are not selected properly. Failure of sheet metal parts during deep drawing processes usually takes place in the form of wrinkling or tearing. Therefore, it is important to optimize the process parameters to avoid defects in the parts and to minimize production cost. Many variables affect the failure, these includes material properties, the punch and die clearance, the punch and die radius, the blank holding force, the die cavity depth, and the cushion pressure. This experimental project is to overcome the wrinkling and tearing of the deep drawn parts. In this project, an 80 tonnage stamping machine and sheet metals of 1mm thickness are used to produce cylindrical cup shape product with 50mm diameter and 20mm length.

1.2 BACKGROUND OF STUDY

Deep draw stamping is a process that's been widely uses in the manufacturing field especially in the oil and gas industry, the automotive industry, and also used to produces a range of household items such as soup cans, battery casings, fire extinguishers, and even a kitchen sink. A part is called deep drawn if the depth of the part is at least half of its diameter. Otherwise, it is simply called general stamping. A deep drawn part may have one or more drawing operations depending on the complexity of the part. In a deep drawing process, a punch pushes a sheet metal blank into a die cavity, resulting the desired contoured part. Multi stage drawing process of a blank material experiences additional complex deformation in each stage compared to a conventional drawing process. The process generally involves additional bending, stretching, compression and shearing by different drawing ratios during the subsequent drawing stage. The deformation naturally proceeds with the irregular shapes of the cross section and conditions that cause failure such as tearing and wrinkling. Since the deformation mechanism is very complicated and the final mechanical properties are difficult to predict, the process design is not an easy task for the manufacture of a product of desired shape and material properties.

The success or failure of the forming process is influenced by many process parameters such as the drawing ratio in each stage, the difference of the drawing ratio within the cross-section, the shape of the die, the strain-hardening coefficient, material formability, the lubrication conditions and the degree of ironing. One of the key parameters affecting the forming process is the **blank holder force (BHF)**. The advantage of varying the blank holder force during the forming process is the two primary model of failure which are wrinkling and tearing (Fig. 1.1) are avoided. This gives rise to improved formability, higher accuracy and better part consistency.

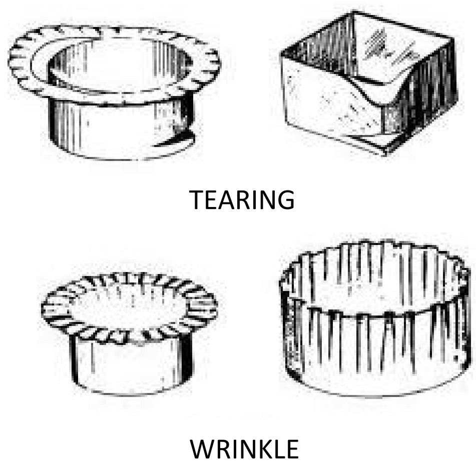

Figure 1.1: Wrinkling & tearing in deep drawing

Source: Huh H. and Kim S. 2001

1.3 PROBLEM STATEMENT

Wrinkling of sheet metal material in deep drawing operations generally occur in the wall or flange of the part. During the process, a blank between a die and a punch is held by means of a blank holding force (BHF). The flange of the blank undergoes radial drawing stress and tangential compressive stress during the stamping process that causes the sheet to buckle locally. The radial tensile stress is due to the blank being pulled into the female die, and the compressive stress, normal in the blank sheet is due to the blank holder force (BHF). The difference in the drawing ratio and the irregular contact condition between the blank and die which occur when using second and third method of redrawing, also induces non uniform metal flow which cause wrinkling, tearing, and severe extension of metal during the redrawing process. On the other hand, fracture or necking occurs in a drawn part which is under excessive tensile stresses. Wrinkling and tearing rupture thus define the deep drawing process limits (Pepelnjak and K. Kuzman, 2007).

Wrinkling and tearing are preventable if the deep drawing system and stamped part are designed properly in term of **die radius, die clearance** and **blank holding force (BHF).** It is important to adjust the blank holder force exerted on the edges of the blank so that it is not just sufficiently great to prevent wrinkle formation at the edges but at the same time not greater than what is necessary as this promotes tearing and furthermore leads to high frictional forces between the blank, the blank holder and the die itself. Such undesired forces cost unnecessarily much energy during deep drawing process which leads to wear and shorten the life of the punch and die.

1.4 OBJECTIVES

1. To design a deep drawing die for cylindrical cup drawing operation.
2. To investigate the effects of draw depth and blank holder force in deep drawing process.
3. To obtain the best deep drawing parameter in reducing wrinkle and tearing during deep draw process.

1.5 SCOPE OF STUDY

Cylindrical cups' drawing is responsible for the manufacture of billions of metal containers. Therefore, in this project a cylindrical cup shaped is studied in term of its **die radius, die clearance, and blank holding force**. A literature review about the process from any previous resource focuses on:

- The design of a cylindrical cup container using CAD software
- The fabrication process and the material used for fabrication
- The formability test using Hyperform software

1.6 PROJECT SPECIFICATION

Size of die	: 280mm x 280mm (L-R x F-B)
Die material	: Mild Steel with 320GPa Young Modulus of Elasticity
Sheet metal material	: Mild steel
Thickness of product	: 1mm
Diameter of cup	: 50mm (outer diameter)
Cup outer radius	: 5mm
Blank size	: Ø105mm
Part draw height	: 20mm
Machine tonnage	: 80 tonne

1.7 PROJECT FLOW CHART

Figure 1.2 shows the overall project flow chart.

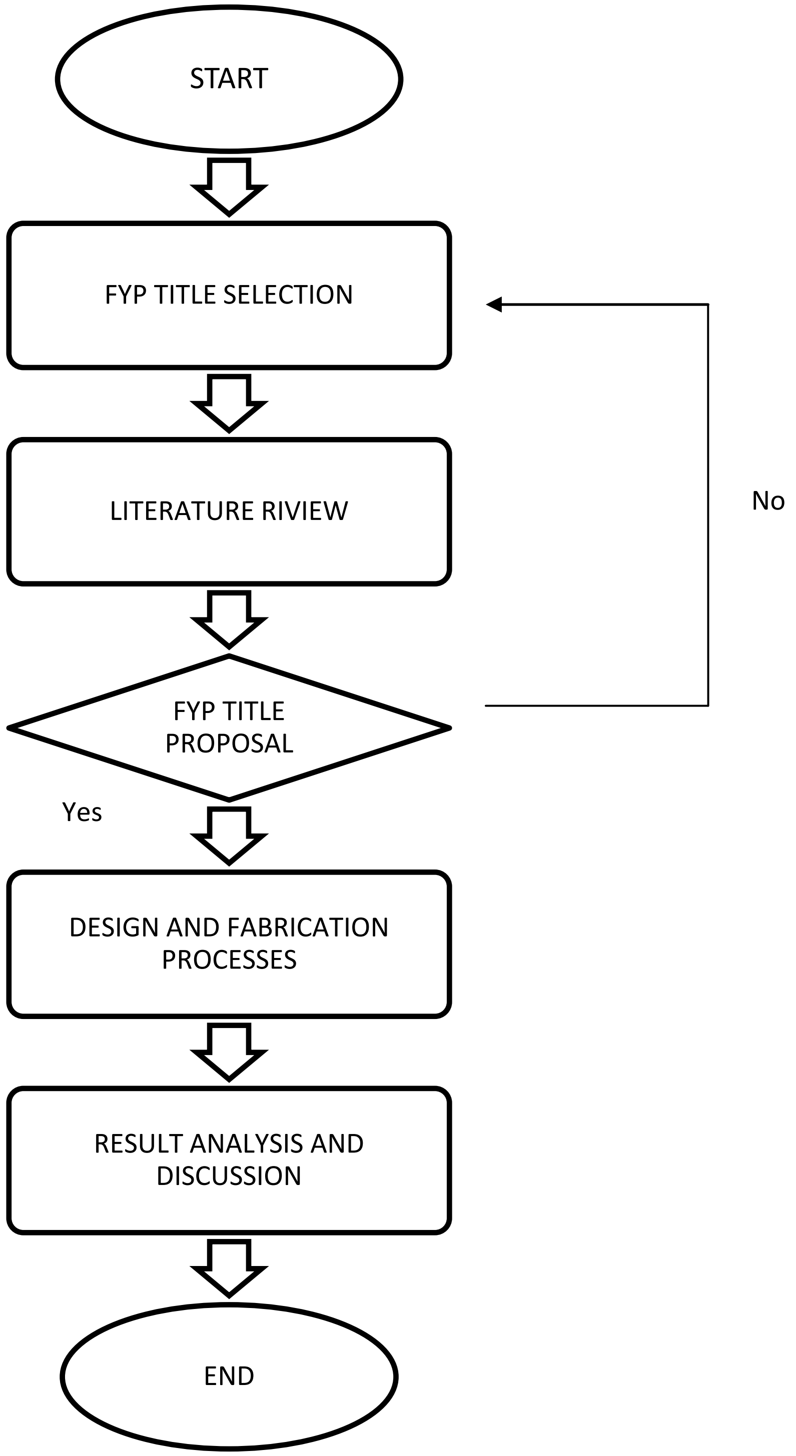

Figure 1.2: Project flow chart

CHAPTER 2

LITERATURE REVIEW

2.1 BASIC CHARACTERISTIC OF SHEET METAL FORMING PROCESS

Sheet metals forming refer to various processes used to convert sheet metal into different shapes for a large variety of finished parts such as aluminium cans and automobile body parts. Deep drawing process is one of the forming processes. The key to the formability of sheet metal is its ductility. Sheet metal parts are usually made in a cold condition but sheet metal parts also are formed in a hot condition as the material will have a lower resistance in hot condition. Blanks are very often used as the initial materials during sheet metal forming. The shape of a part generally corresponds to the shape of the tool (Vukota Boljanovic, 2004). Sheet metal forming process is used for both serial and mass production. Their characteristics are:

- High productivity
- Highly efficient use of material
- Easy servicing of machines
- The ability to employ worker with relatively less basic skills
- Advantageous economic aspects

2.2 MATERIAL SELECTION FOR DIE FABRICATION

Selection of materials for die components is an important activity during die design stage in stamping industries. The knowledge base on the system can be modified depending upon the availability of new materials and advancement in technology. A long life cycle time of all the die components is desired to reduce the maintenance or repairing cost.

2.2.1 Type of Tool Steel

The key components of a deep draw die are the ability of tool steel to withstand the high shock loading involved and to resist the abrasive forces involved. Tool steel refers to a variety of carbon and alloy steels that are particularly well suited to be made into tools. Their suitability comes from their distinctive hardness, resistance to abrasion, their ability to hold a cutting edge, and their resistance to deformation at elevated temperatures. Base from the advantages, tool steel is suitable to be uses in this project. Tool steels are made to a number of grades for different applications. Choice of grade depends on whether a keen cutting edge is necessary, as in stamping dies, or whether the tool has to withstand impact loading and service conditions encountered with such hand tools as axes, pickaxes, and quarrying implements. In general, the edge temperature under expected use is an important determinant of both composition and required heat treatment. The higher carbon grades are typically used for such applications as stamping dies or metal cutting tools (Vukota Boljanovic, 2004). In this project the JIS SKD11 tool steel is chosen as it is a high-carbon-chromium alloy tool steel which is soft annealed to about HB210. It has a good wear resistance and machinability after heat treatment and is suitable for making long life high precision cold work dies.

2.3 MECHANICS OF DEEP DRAWING

2.3.1 Die Concept

Deep drawing die is a metalworking tool that is designed and built to convert raw material into parts that conform to blueprint specifications. Before proceeding with the fabrication, the fundamental of deep drawing process must be known first. In deep drawing, dies are placed into a stamping press and when the stamping press moves up, the die opens. As the stamping press moves down, the die closes. The raw material or blank moves through the die while the die is open, being fed into the die in a precise amount with each stroke of the press. As the die closes, the die performs its work on the metal. The greater the die cavity depth, the more blank material has to be pulled down into the die cavity and the greater the risk of wrinkling in the walls and flange of the part. In stamping, most of the final part is formed by stretching over the punch although some material around the sides may have been drawn inwards from the flange. As there is a limit to the stretching that is possible before tearing, stamped parts are typically shallow. To form deeper parts, much more material must be drawn inwards to form it. One of the most common examples of deep drawing is the cup drawing operation. It is used to produce products such as cartridge bases, zinc dry cells, metal cans and steel pressure vessels (Hosford and Caddell, 2007). It is also used as a method for formability test of sheet metals such as the Swift cupping test (Theis, 1999). Forming a simple cylindrical cup is shown in Figure 2.1.

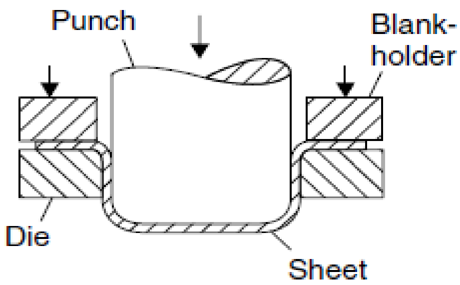

Figure 2.1: Cylindrical cup

2.3.2 Draw Stages

The number of successive draws required is a function of the ratio of the part height, h to the part diameter, d.

$$\frac{h}{d} = \frac{25mm}{50mm} = 0.5$$

Where :

N = number of draws

h = part height

d = part diameter

The value of N for the cylindrical cup draw is given according to table 2.1.

Table 2.1 Number of draws (n) for a cylindrical cup

h/d	<0.6	0.6 to 1.4	1.4 to 2.5	2.5 to 4.0	4.0 to 7.0	7.0 to 12
N	1	2	3	4	5	6

Source: Vukota Boljanovic (2004)

Therefore, in this project only one drawing operation is needed to produce the cup according to table 2.1 as the N value is 1.

2.3.3 Die Clearance and Radius

One of the factors that must be considered in determining a die dimensions is the amount of clearance (Fig. 2.2) between the punch and die members. A proper clearance of the die will give the desired force during the stamping process. The radius degree of the punch and die cavity edges control the flow of blank material into the die cavity. Wrinkling in the cup wall can occur if the radius of the punch and die cavity edges are too large. If the radius is too small, the blank is prone to tearing because of the high stresses. Proper clearance application also depends on the material degree of hardness and thickness. (Vukota Boljanovic, 2004).

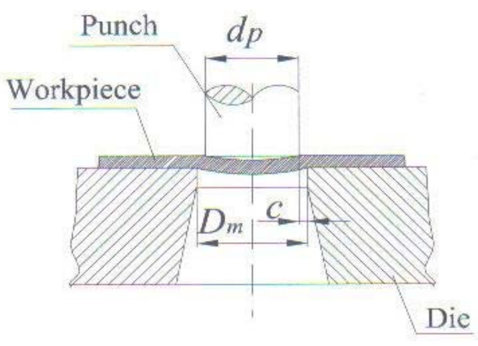

Figure 2.2: Punch & die clearance

Source : Vukota Boljanovic 2004

Table 2.2 illustrates the absolute value for clearance depending on the type and thickness of the material.

Table 2.2: Absolute value for clearance

Material thickness T (mm)	Material			
	Low Carbon Steel, copper and Brass	Medium steel 0.20 % to 0.25% Carbon	Hard steel 0.40% to 0.60% carbon	Aluminum
0.25	0.01	0.015	0.02	0.01
0.50	0.025	0.03	0.035	0.05
1.00	0.05	0.06	0.07	0.10
1.50	0.075	0.09	0.10	0.015
2.00	0.10	0.12	0.14	0.20
2.50	0.13	0.15	0.18	0.25
3.00	0.15	0.18	0.21	0.28
3.50	0.15	0.18	0.21	0.28
4.00	0.20	0.24	0.28	0.40
4.50	0.23	0.27	0.32	0.45
4.80	0.24	0.29	0.34	0.48
5.00	0.25	0.30	0.36	0.50

Source: Vukota Boljanovic (2004)

Punch diameter:

$$C = \frac{Dm - dp}{2}$$

Where:

C, Clearance per side = 1.1 (thickness 1mm)

Dm = diameter of die

dp = diameter of punch

$$1.1 = \frac{50mm - dp}{2}$$

dp = **47.80 mm**

Punch radius:

In this project, a punch with 5mm radius is desired as the final cylindrical cup radius.

2.3.4 Blank Size

The deep drawing process requires a blank. It's a part of metal stamping process (Vukota Boljanovic, 2004). The blank is a piece of sheet metal, typically a disc or rectangle, which is pre cut from the stock material and will be formed into the part (Wang Xi & Cao J, 2000). The volume of the developed blank before drawing should be the same as the volume of the cup after drawing. Provided that the thickness of the material remains unchanged, the area of the workpiece will not change. Thus, the blank diameter may be found from the area of blank before drawing. The cup in Figure 2.3 may be broken into matching components and Figure 2.4 illustrates the area of each component that need to be calculated.

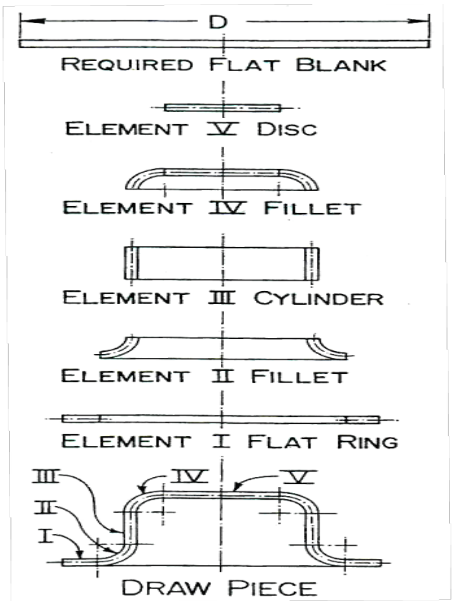

Figure 2.3: Draw element

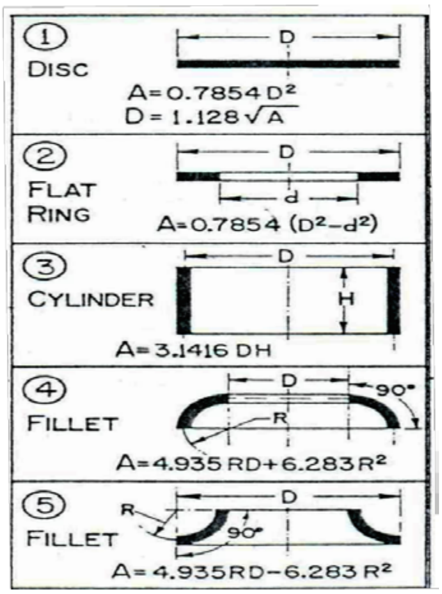

Figure 2.4: Draw area

Figure 2.5 shows the cup size to calculate total surface area.

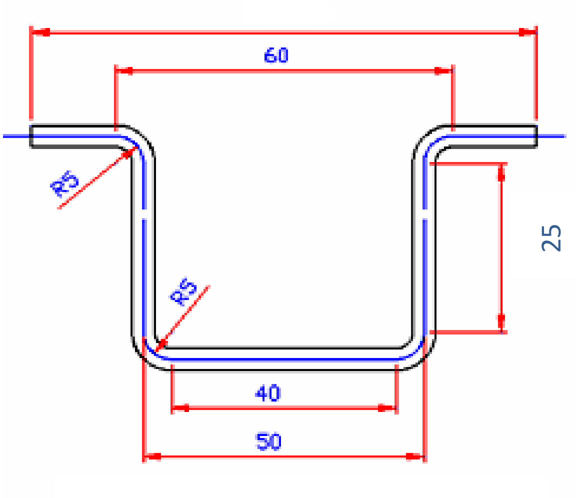

Figure 2.5: Cylindrical cup

Total Surface Area = Sum of Element I to V

Element I (Ring)

Area $= 0.7854 \times (D^2 - d^2)$
$= 0.7854 \times (70^2 - 60^2)$
$= 1021.02\ mm^2$

Element II (Inner Fillet)

Area $= (4.935 \times R \times D) - (6.283 \times R^2)$
$= (4.935 \times 5 \times 60) - (6.283 \times 5^2)$
$= 1323.4\ mm^2$

Element III (Cylinder)

Area $= 3.1416 \times D \times H$
$= 3.1416 \times 50 \times 25$
= 3927 mm2

Element IV (Outer Fillet)

Area $= (4.935 \times R \times D) + (6.283 \times R^2)$
$= (4.935 \times 5 \times 40) + (6.283 \times 5^2)$
$= 1144.1\ mm^2$

Element V (Disc)

Area $= 0.7854 \times D^2$
$= 0.7854 \times 40^2$
$= 1256.7\ mm^2$

Total surface area = Sum of Element I to V
$= 8672.22 mm^2$

Area of flat blank $= 0.7854 \times D^2$

Diameter of flat blank $= \sqrt{\text{Area} / 0.7854}$
$= \sqrt{8672.22 / 0.7854}$
= 105.08mm
= 105mm

2.3.5 Limit Draw Ratio

In deep drawing, the limits for the permissible deformation are set by the draw ratio. The draw ratio is used to:

i. Determine how many drawing operations are necessary to produce a drawn part;
ii. Judge the drawability of deep drawing steels;
iii. Determine the correction value $n = f$ (draw ratio) to calculate the drawing force.

The critical forming parameter for cylindrical cup drawing is the limit drawing ratio (LDR), which is the ratio of the maximum blank diameter to punch diameter that can be drawn in one draw operation.

$$\text{LDR} = \frac{\text{maximum blank diameter, D}}{\text{punch diameter, d}} = \frac{105}{47.8} = 2.2$$

Table 2.3: Mean values for $\beta_{permissable}$

Mean values for $\beta_{0\ perm}$, e.g. for WUSt 1403, USt 1303, Ms 63, Al 99.5

d/s	30	50	100	150	200	250	300	350	400	450	500	600
$\beta_{0\ perm}$	2.1	2.05	2.0	1.95	1.9	1.85	1.8	1.75	1.7	1.65	1.60	1.5

Source: Heinz Tschaetsch (2006)

Permissible draw ratio for the draw :

d/s = 47.8 / 1

where:

d = punch diameter

s = thickness of blank

From Table 2.3, the means value for β_{perm} is:

❖ $\beta_{perm} \approx 2.06$

As $\beta_{perm} < LDR$

$2.06 < 2.2$

The value for β_{perm} is lower than the limit draw ratio, therefore the part can be produced in a single operation.

2.3.6 Drawing Force

The drawing force is calculated using this formula :

$$\boxed{F_{dr} = C \cdot s \cdot R_m \cdot n = d \cdot \pi \cdot s \cdot R_m \cdot n}$$

F_Z	in N	drawing force
C	in mm	circumference of the drawing punch
d	in mm	punch diameter
s	in mm	sheet thickness
R_m	in N/mm^2	tensile strength
n		correction value

The correction value *n* (Table 2.4) takes into account the ratio of drawing tension to tensile strength. It depends mainly upon the actual draw ratio, which comes from the dimensions of the drawn part.

Table 2.4: Correction value, *n*

n	0.2	0.3	0.5	0.7	0.9	1.1	1.3
$\beta_{actual} = \frac{D}{d}$	1.1	1.2	1.4	1.6	1.8	2.0	2.2

Source: Heinz Tschaetsch (2006)

Diameter of punch, d= 47.8mm

Sheet thickness, t = 1mm

Ultimate Tensile Strength of sheet metal, UTS = 320Mpa (mild steel)

$\beta_{actual} = \frac{105}{47.8} = 2.196$, then drawing coefficient, n = 1.3

Fd (max) = 1.3 x 3.142 x 47.8mm x 1mm x 320MPa

= 62478.04 N

= 6.25 ton

2.3.7 Blank Holder Force

To prevent the flange from buckling, a blank holder is used and the clamping force is manipulated. Stretching over the punch is small and most of the deformation is in the flange, as this occurs under compressive stresses, large strains are possible and it is possible to draw a cup whose height is equal to or possibly a little larger than the cup diameter. The blank holder holds the edges of the sheet metal blank in place against the top of the die while the punch forces the sheet metal into the die cavity. The sheet metal deforms into the proper shape, instead of simply being pulled into the die cavity.

The blank holder however, does not hold the edges of the blank rigidly in place. If this were the case, tearing could occur in the cup wall. The blank holder allows the blank to slide somewhat by providing frictional force between the blank holder and the blank itself. Blank holder force can be applied hydraulically with pressure feedback, by using an air or nitrogen cushion, or a numerically controlled hydraulic cushion. Figure 2.6 shows the formula to calculate the blank holding force.

Blank holding force: $F_N = A_n . P_N$

where F_N = blank holding force (N)

A_n = blank holder area (mm^2)

$\frac{\pi}{4} (D^2_b - d^2_p)$ (mm^2)

P_N = Unit blank holding pressure (N/mm^2)

$[(\beta - 1)^2 + \frac{d_p}{200.t}] \frac{\sigma B}{400}$

Figure 2.6: Blank holder formula

Blank holder calculation:

$$F_N = \left[\frac{\pi}{4}\ (105^2 - 47.8^2)\right] \left[(2.196 - 1)^2 + \frac{47.8}{200}\right] \frac{320}{400}$$

$= (6.86x10^3)(1.43+0.239)(0.8)$

$= 9159.47$ N

$= 0.916$ ton

Spring calculation: $\frac{9156}{4}$ = 2289 N = 229kgf for each spring

2.4 FINITE ELEMENT METHOD

Finite element method (FEM) is originated from the solving complex elasticity and structural analysis problems. The finite element method is a numerical technique for finding approximate solutions of partial differential equation as well as of integral equation. The finite element method is one of a good technique for solving partial differential equations (PDE) over a complex domain. Finite element analysis allows detail visualization of where structures bend or twist. This software gives wide range of simulation for controlling the complexity of both modelling and analysis of a system. There are generally two types of analysis that are used in industry which are 2D modelling and 3D modelling. Within each of these modelling schemes, the programmer can insert numerous algorithms (functions) which may make the system behave linearly or non-linearly. Linear systems are far less complex and generally do not take into account plastic deformation. Non-linear systems do account for plastic deformation, and many also are capable of testing a material all the way to fracture.

The solution approach is based either on eliminating the differential equation completely (steady state problems), or rendering the PDE into an approximating system of ordinary differential equations, which are then numerically integrated using standard techniques such as Euler's method, Runge-Kutta, etc. There are many ways of doing FEM, this is because of the advantages and disadvantages. The FEM is a good choice for solving partial differential equations over complex domains like cars and oil pipelines, when the domain changes as during a solid state reaction with a moving boundary, when the desired precision varies over the entire domain, or when the solution lacks smoothness. For instance, in a frontal crash simulation it is possible to increase prediction accuracy in "important" areas like the front of the car and reduce it in its rear (thus reducing cost of the simulation). For sheet metal parts, the sheet metal can extract and mesh a mid-surface using 2D plate elements instead of 3D solid elements. These structures are represented much more efficiently using 2D elements without compromising accuracy, with minimal solution time and use of computer resources. We use sheet metal mid-surface for both static and modal analysis.

2.4.1 Advantage of Using Finite Element Method

The development in the finite element analysis is really an advantage in engineering especially, in designing and manufacturing products. This is because Finite Element Method (FEM) makes it easy to conduct test on products and materials virtually before even manufacturing the products. This allows the analysis can be done and the fault on the design or the material can be identified easily. FEM allows detailed visualization of where structures bend or twist, and indicates the distribution of stresses and displacements. FEM software provides a wide range of simulation options for controlling the complexity of both modelling and analysis of a system. Similarly, the desired level of accuracy required and associated computational time requirements can be managed simultaneously to address most engineering applications (Vukota Boljanovic, 2004).

FEM allows entire designs to be constructed, refined, and optimized before the design is manufactured. This powerful design tool has significantly improved both the standard of engineering designs and the methodology of the design process in many industrial applications. The introduction of FEM has substantially decreased the time to take products from concept to the production line. It is primarily through improved initial prototype designs using FEM that testing and development have been accelerated. In summary, benefits of FEM include increased accuracy, enhanced design and better insight into critical design parameters, virtual prototyping, fewer hardware prototypes, a faster and less expensive design cycle, increased productivity, and increased revenue.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter discussed the idea on how to implement this research. In this research a single stage deep drawing tooling was designed and constructed to carry out the experimental work required to produce a cylindrical cup of 50mm (outer diameter) formed from a circular flat blank of 105mm diameter. There are two categories in this methodology, first is the finite element analysis (FEA) using Altair Hyperform software, then continued with the fabrication of the deep draw die to validate the drawing parameters obtain from the simulations.

3.2 FLOW CHART

Process planning is important in this project in order to make sure this project completed on time. Process planning help to make sure all the tasks run systematically. Figure 3.1 shows an overview of overall steps during this research. Based on the literature review from the journals and books, the design factor, simulations and experimental work are developed.

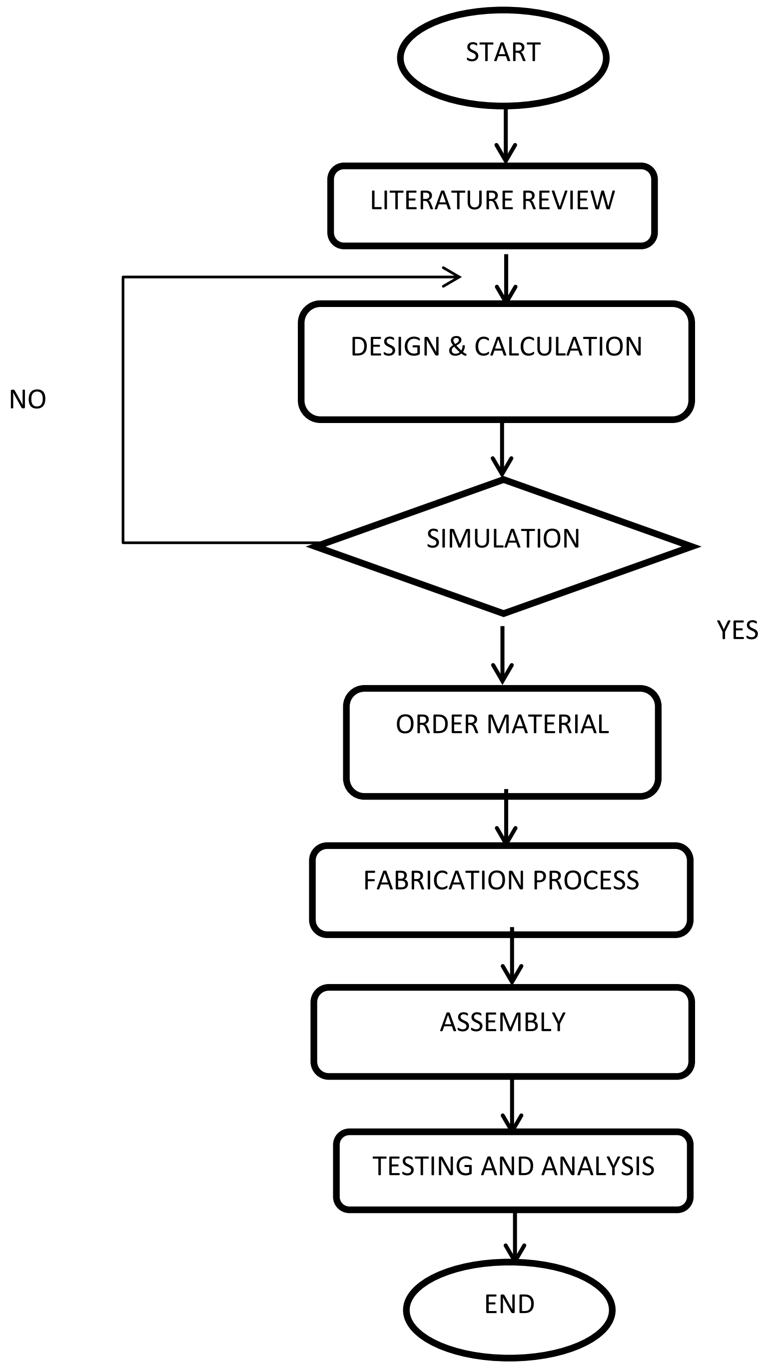

Figure 3.1: Process planning flow chart

3.3 DIE DESIGN

The die parts are design based on the literature review from previous chapter. Mild steel SKD 11 is used in fabricating the die because it has high strength to withstand stamping force during the drawing process. In this project, CAD software was used to design the die because it can simultaneously simulate the machining process and generate the numerical code needed by the CNC milling machine. Figure 3.2 shows the complete die design.

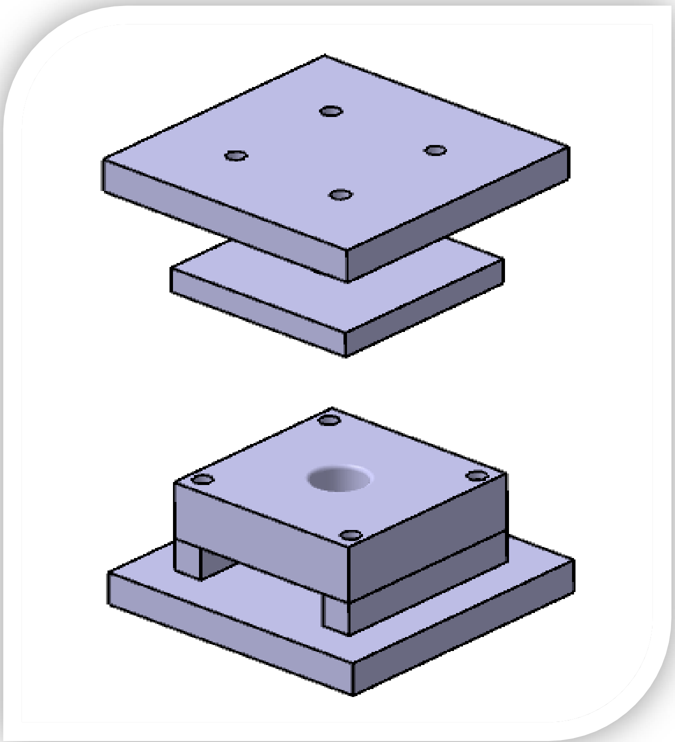

Figure 3.2: Die assembly

3.4 FINITE ELEMENT MODELLING

Figure 3.3 shows the general work flow diagram adapted to model and solves the cup drawing problem by FEA. The punch and die set assembly along with the specimen was modelled in CAD modelling software and exported as *.IGS in Hyperform software.

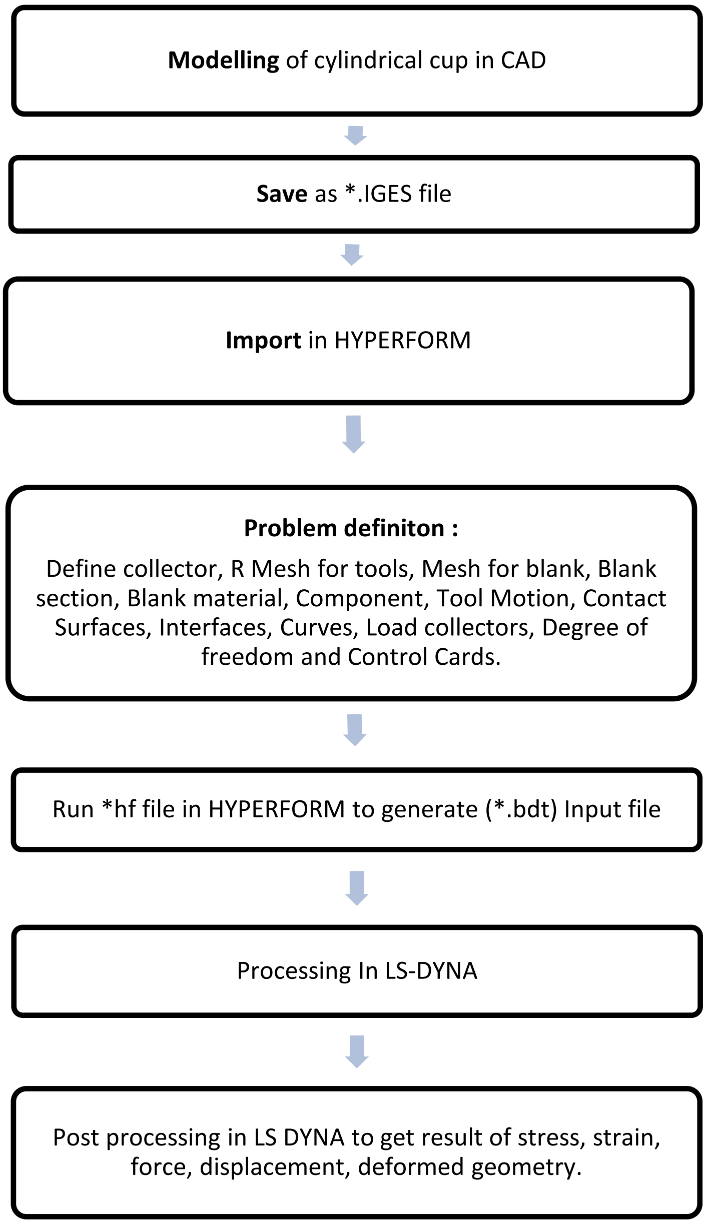

Figure 3.3: General work flow diagram

3.5 BILL OF MATERIAL

The materials required for the die fabrication process after the die is design listed in Table 3.1.

Table 3.1: Bill of material

Number	Capacity	Part Name	Dimension (L x W x T) mm	REMARK
1.	1	Upper die plate	280 x 280 x 40	
2.	1	Backup pressure plate	200 x 200 x 20	
3.	1	Punch (drawing)	D = 47.8 (actual size) Length = 125mm	
4.	1	Blank holder	200 x 200 x 30	
5.	1	Die block	200 x 200 x 70	
6.	1	Lower die plate	280 x 280 x 40	
7.	2	Die shoe / Spacer	200 x 30 x 40	
8.	4 x 2 set	Die spring	Load 1 = 229 kgf Load 2 = 260 kgf Max. Deflection= 25mm	Medium Heavy Duty (MHR 125150) P-M-E
11.	2	Guide post set	D=30mm L= 180mm	
12.	4	Dowel pin	EPJM p=6,h=10,t=6,l=100	To hold blank in place P-M-E
13.	4	M12 screw	L= 85mm L=55mm L=50mm	
12.	2	M8 screw	L= 60mm	
13.	25pcs	Sheet metal 1mm thickness	D = 135mm	- Mild steel with 320Mpa UTS -Copper
14.	4	Spring guide retainer		

3.6 FABRICATION PROCESS

In this stage several machining process involved in order to fabricate the die.

3.6.1 CNC Milling Machine

Computer Numerical Control (CNC) milling (Fig. 3.4) is used to machine all the plates needed to complete the die set such as blank holder plate, upper plate, backup plate and lower plate. CAD software is used to simulate the cutting process and to generate the G-code. The milling machine is used to do the pocketing process, drilling holes for the screws and boring process.

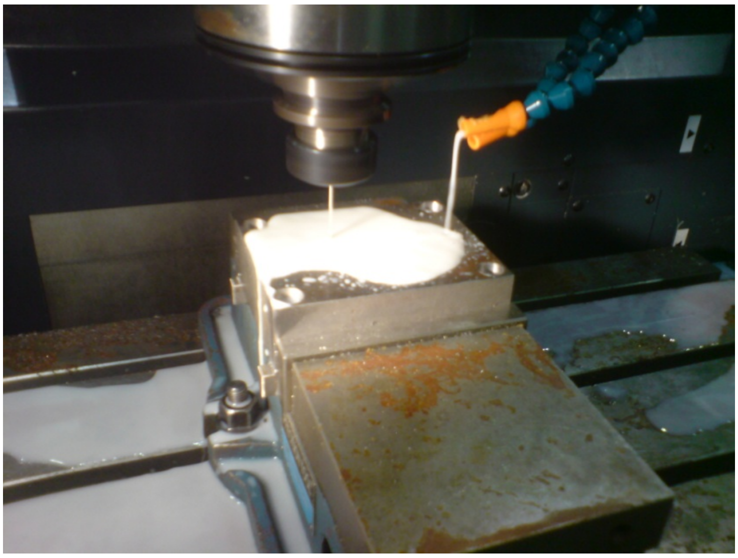

Figure 3.4: Milling process

3.6.2 CNC Lathe Machine

The lathe machine is used to produce the desired punch size and radius (Fig. 3.5). The workpiece is turned to get the specific diameter and mirror surface finish using appropriate spindle speed and federate. A mirror finish surface is important in deep drawing process to avoid high tension during forming process due to high friction force of rough surface. A numerical control program is used to get the 5mm corner radius at the bottom edge of the punch.

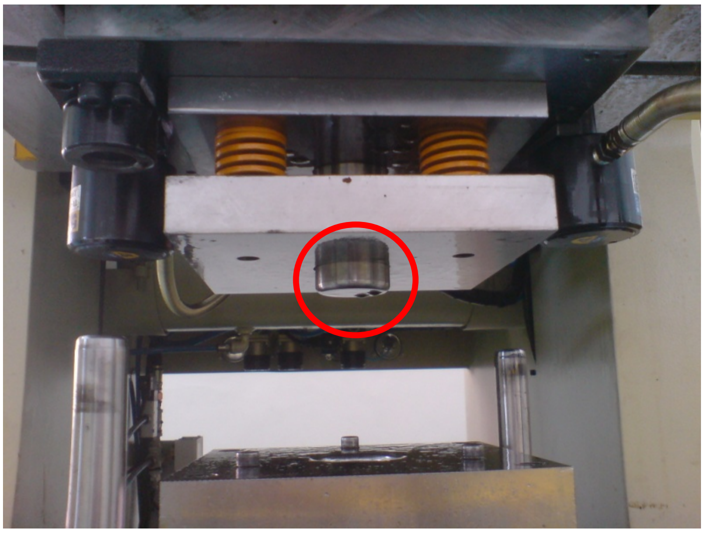

Figure 3.5: Punch with 5mm corner radius

3.7 DIE ASSEMBLY

When the die fabrication completed, parts are assembled. The machined parts and standard parts are being assembled (Fig. 3.7) together and matched to ensure that it can function correctly.

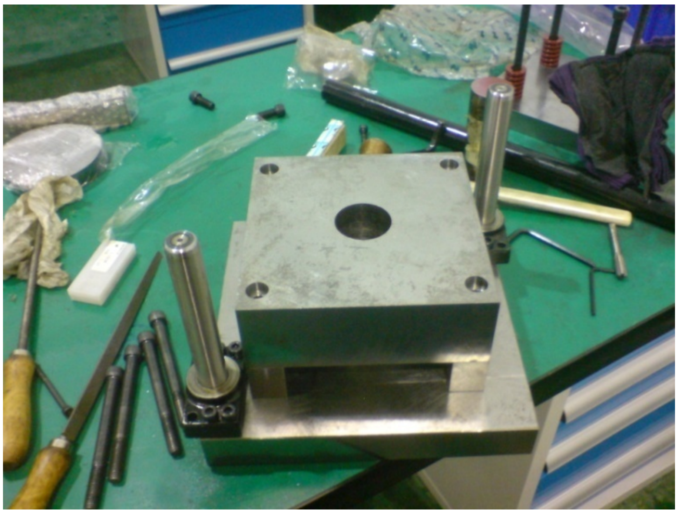

Figure 3.7: Assembly process

3.8 TESTING AND TROUBLESHOOT

The die was operated using an 80 tonnage stamping machine to get the data needed as shown in Figure 3.8.

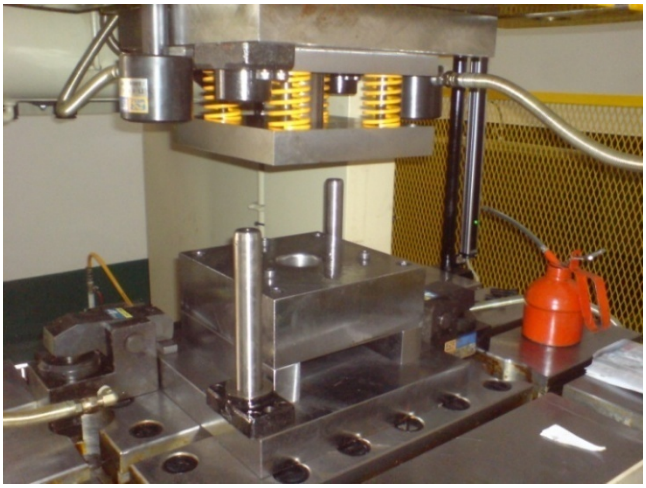

Figure 3.8: Stamping machine

In order to confirm the punch did not start entering the die block before being drawn, a paper is used to check the zero condition (Fig. 3.9). After that, the depth of the drawn cup which is 20mm was subtracted from the zero condition to get the die shut height (Fig. 3.10).

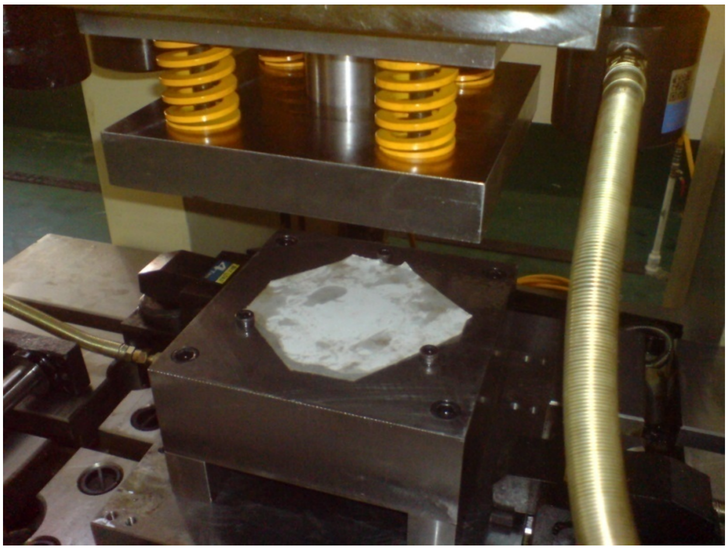

Figure 3.9: Pre stamping process

Figure 3.10: Die shut height

CHAPTER 4

RESULTS AND DISCUSSION

4.1 FINITE ELEMENT SIMULATION

4.1.1 Simulations for 20mm Cup Without Flange

In order to achieve the best die design, a few simulations has been done to obtain the best draw parameters before proceeding with the real production. The first simulation consists of three analysis using a cylindrical cup without flange. First, the blank for cylindrical cup is developed (Fig. 4.1). A red color shows the area where stress happen. A green color indicates the condition is in safety region while the blue color shows that stress does not occur at the area.

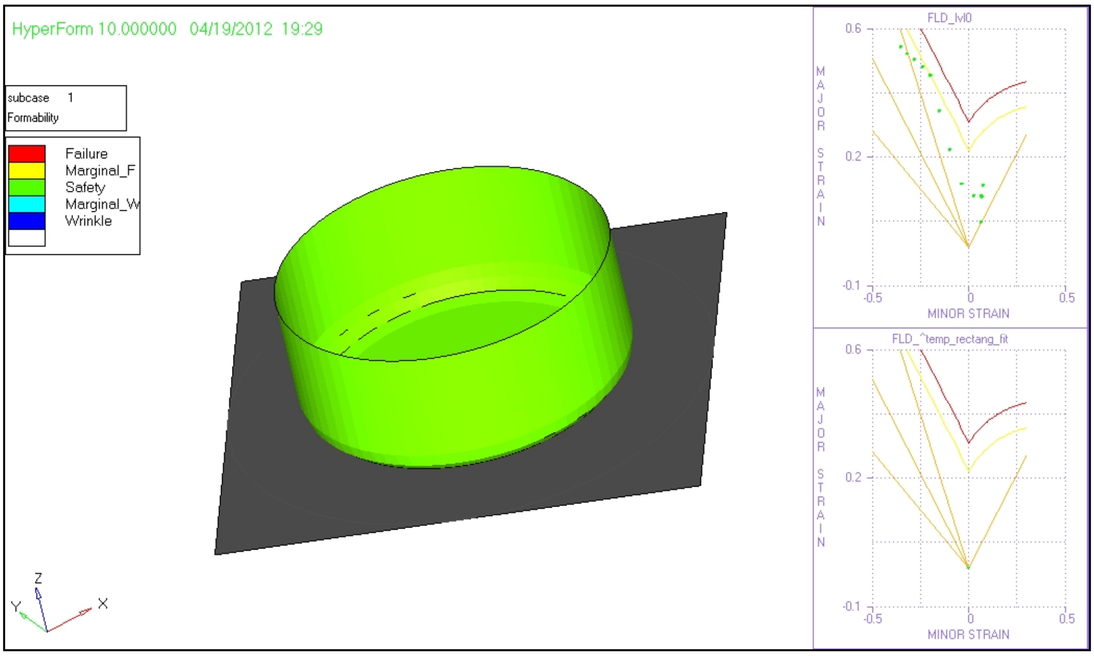

Figure 4.1: Blank development for cup without flange

The cup is then analysed for formability (Fig. 4.2) and lastly for thinning area (Fig.4.3) that may lead to tearing. During deep drawing process, metal flow law of drawn part can be known through the analysis of equivalent strain diagram. The value of major strain shows only 0.58megapascal. The formability is good as the result shown the area of thinning is at the safety region (green color) and there are no wrinkles.

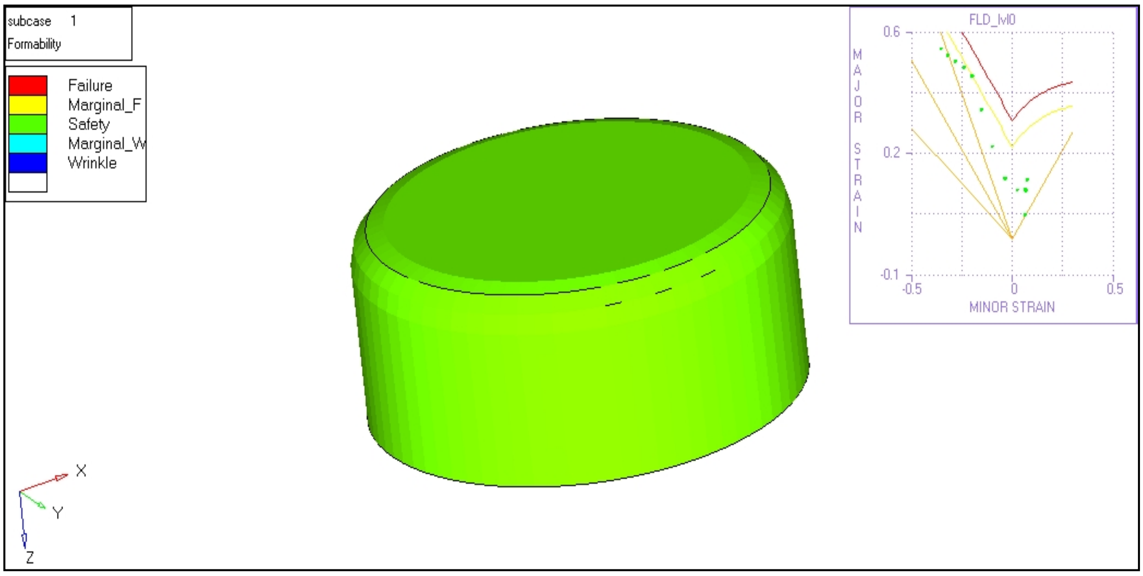

Figure 4.2: Formability result for cup without flange

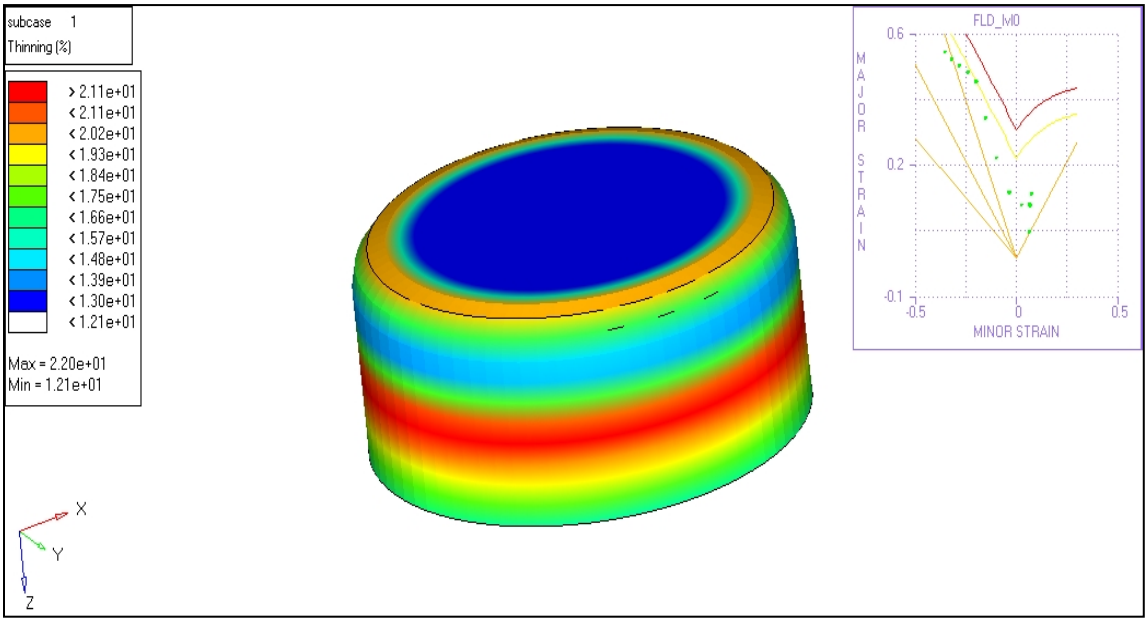

Figure 4.3: Thinning result for cup without flange

The thinning test for the 20mm cylindrical cup without flange shows high equivalent plastic strain occurs at wall region outside the die corner, because this area is the potential location for a crack. The thinning percentage is shown in the table of figure 4.3. The cup sidewall acts to transmit the punch to the areas bending, straightening, friction and compression. This results in a high state of tension at the side wall, maximum 21.1% thinning which equal to 0.211mm reduction of original thickness. Since the side wall is near the punch radius is stressed the highest, tears will often occurs at this region.

4.1.2 Simulations for 20mm Cup With Flange

The second simulation is done onto a cylindrical cup with 20mm height with flange. Three step of analysis has been done also which is blank development (Fig. 4.4), formality test (Fig. 4.5), and thinning test (Fig. 4.6). Several iterations are carried out till a satisfactory solution is reached. The size of blank suggested by the software is about 86mm which is smaller than the calculated value, 105mm.

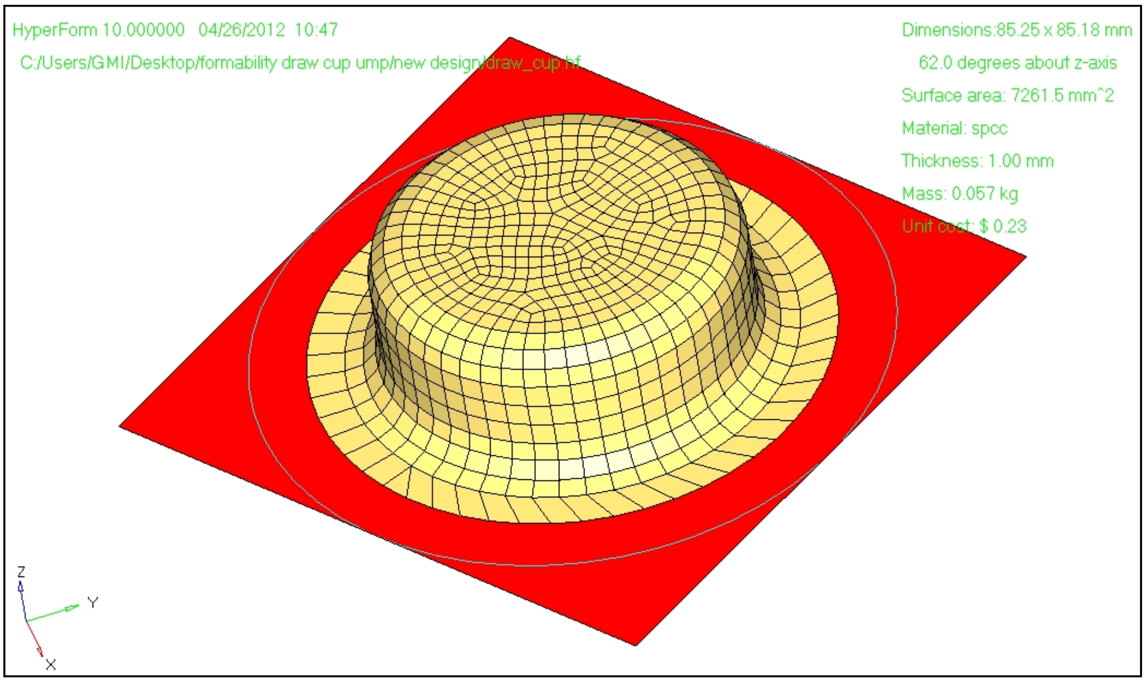

Figure 4.4: 20mm draw height blank development

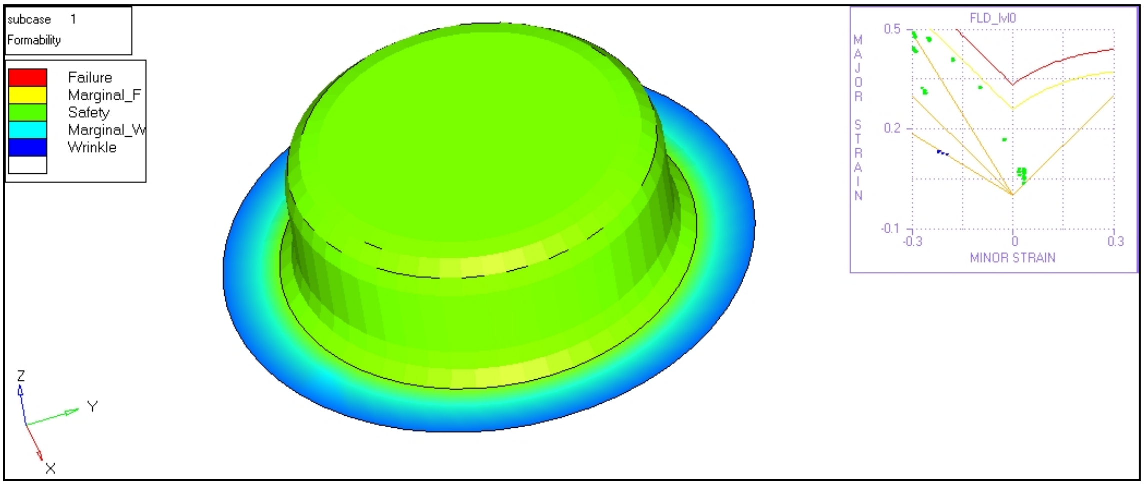

Figure 4.5: 20mm draw height formability result

During the formability test (Fig. 4.5), the cup is in the safety region (green colour) but the wall has a small area of marginal wrinkle (blue region). The value of major strains is 0.5megapascal which is still in the safety region.

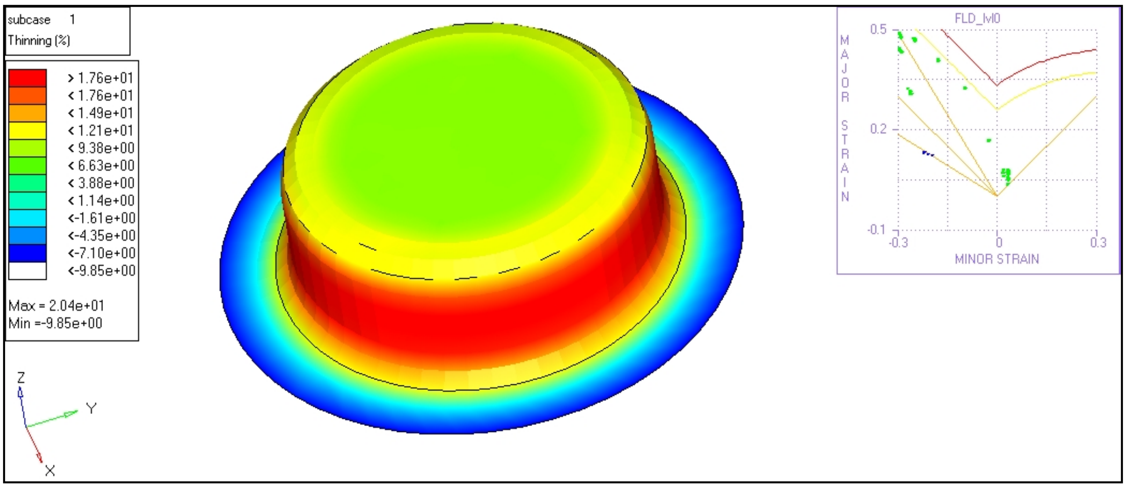

Figure 4.6: 20mm draw height thinning result

The thinning test for 20mm cup with flange shows that thinning occur at the side wall of the cup which is 17.6% thinning which equal to 0.176mm reduction from original thickness. There is a tendency of wrinkling at the flange (blue color) with the thinning percentage value of -9.85% which means 0.0985mm material thickness is gathered here to form the wrinkle.

4.1.3 Simulations for 25mm Cup With Flange

The last simulation is done onto a cylindrical cup with 25mm draw height.

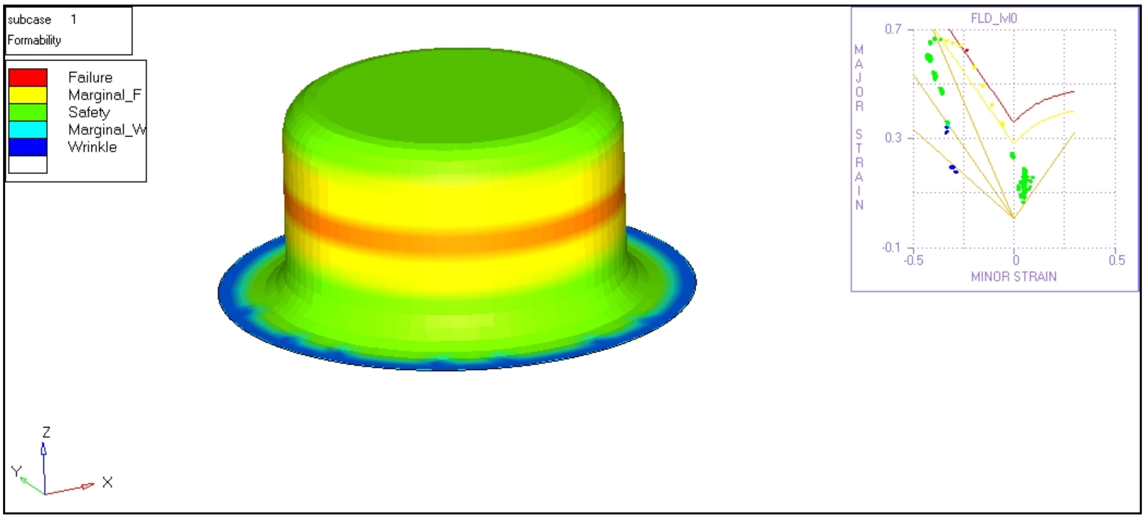

Figure 4.7: 25mm draw height formability result

The cup is not formable as it shows marginal failure at the centre of the wall (Fig. 4.7) and wrinkle at the top flange. The value of major strain is high which is 0.7 megapascal. This is due to compressive circumferential stress induced at the flange when the blank moves into the die during drawing process.

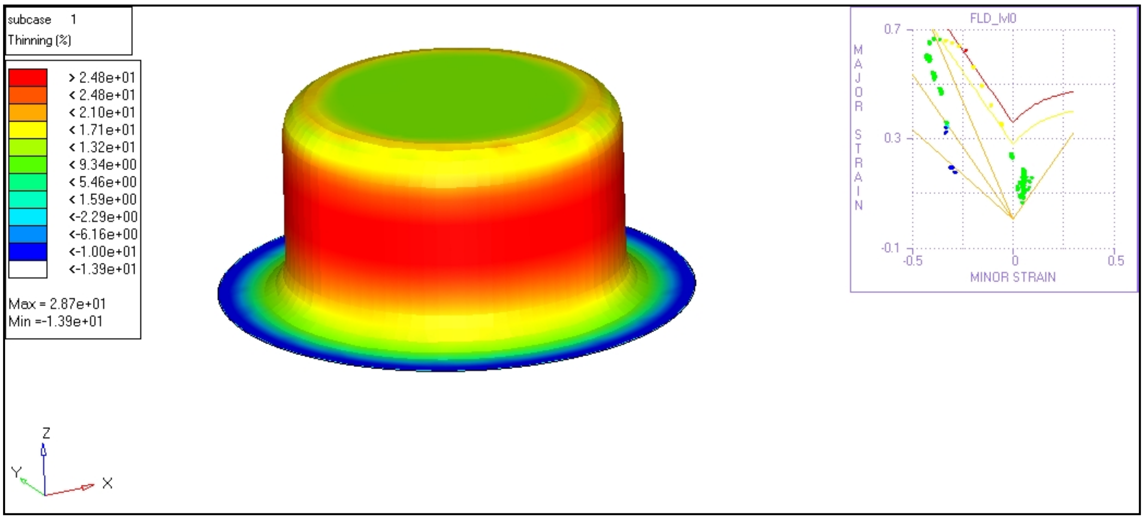

Figure 4.8: 25mm draw height thinning result

The thinning test shows a severe thinning at the wall of the cup (Fig. 4.8) with the thinning percentage of 24.8% which equal to 0.248mm reduction of thickness from the original thickness. This is due to radial tension at the side wall of the cup during the drawing process.

Therefore, a cylindrical cup with 20mm height is selected as the desired size for die design and fabrication. The blank holder force suggested by the simulation software for the drawing process is 1.2 tonne which is different from the value obtain by calculation, 0.9 tonne.

4.2 EXPERIMENTAL RESULT

The experiments are conducted using an 80 tonnage stamping machine to validate the result obtain from the FEA and calculations. The designed and fabricated die is used to test the blank. It is observed that the steel plate with 20mm draw height does not tearing but have the wrinkle defects when using the blank holder force calculated which is 0.9 tonne. This is due to the blank holder force exerted on the workpiece was not enough to hold the material during drawing process but if the blank holder force is too excessive, tearing will occur between the wall and the flange. The wrinkles value is 2.1mm.

Figure 4.9: 20mm draw height of steel plate

The test was repeated using a higher blank holder force which is 1.2 tonne, the value that was suggested by the simulation software. Using this value, the cup produced was free from wrinkle and tearing defect (Fig. 4.10).

Figure 4.10: 20mm draw height of steel plate with higher blank holder force

The parts produced are then being cut into pieces (Fig. 4.11) to measure their thinning and wrinkle value. Measurements are taken by using a micrometer (Fig. 4.12) and results are tabulated.

Figure 4.11: Parts cut into pieces

Figure 4.12: Micrometer

Table 4.1 shows the value of thinning between calculated BHF (0.9 tonne) and suggested BHF (1.2 tonne) from finite element analysis. It is observed that when using 0.9 tonne BHF, the value of thinning is 0.18mm while the value of thinning when using 1.2 tonne BHF is 0.24mm compared to FEA result which is 0.176mm only. The thinning value for 0.9 tonne is not available as only the 1.2 tonne BHF is being suggested by the software. Figure 4.13 and 4.14 shows the maximum thinning area where measurement is taken. The thinning area occurs at the region predicted by the simulation software.

TABLE 4.1 Maximum value of thinning for 20mm draw height

PARAMETER	**ANALYSED by FEA**	**ACTUAL**
0.9 tonne BHF	N/A	0.18mm reduction
1.2 tonne BHF	0.176mm reduction	0.24mm reduction

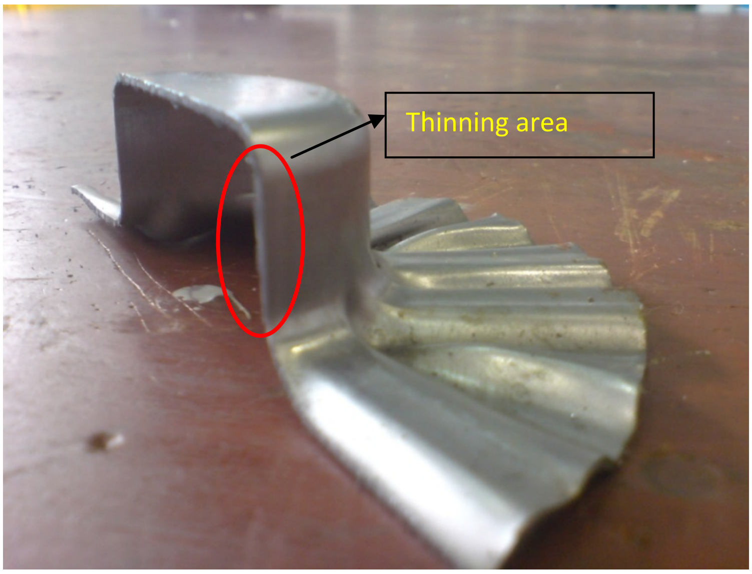

Figure 4.13: Maximum thinning area for 0.9 tonne BHF

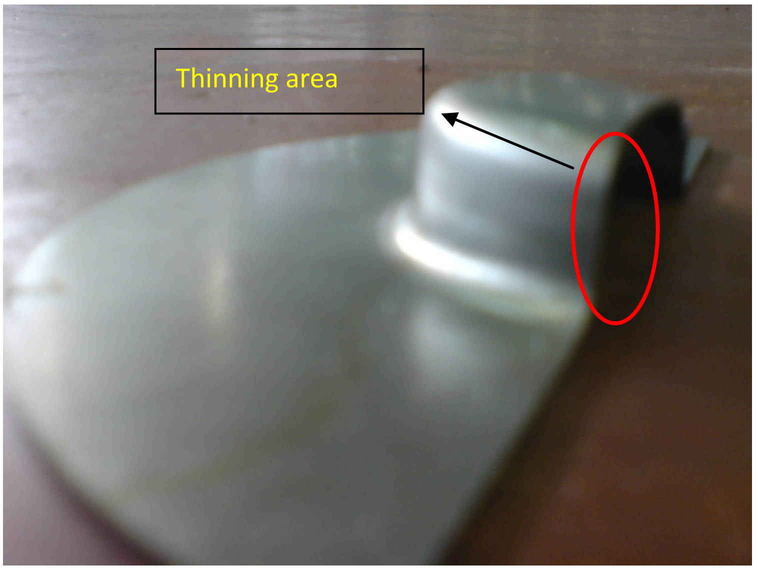

Figure 4.13: Maximum thinning area for 1.2 tonne BHF

Table 4.2 shows the value of wrinkle between calculated BHF (0.9 tonne) and suggested BHF (1.2 tonne) from finite element analysis. It is observed that when using 0.9 tonne BHF, the value of wrinkle is 2.1mm while winkle does not occur when using 1.2 tonne BHF compared to FEA result which is 0.0985mm. The wrinkle value for 0.9 tonne is not available as only the 1.2 tonne BHF is being suggested using the software. Figure 4.15 and 4.16 shows the maximum wrinkle area where measurement is taken. The wrinkle area occurs at the region predicted by the simulation software.

TABLE 4.2 Maximum value of wrinkle for 20mm draw height

PARAMETER	ANALYSED by FEA	ACTUAL
0.9 tonne BHF	N/A	2mm
1.2 tonne BHF	0.0985mm	0mm

Figure 4.15: Maximum wrinkling area for 0.9 tonne BHF

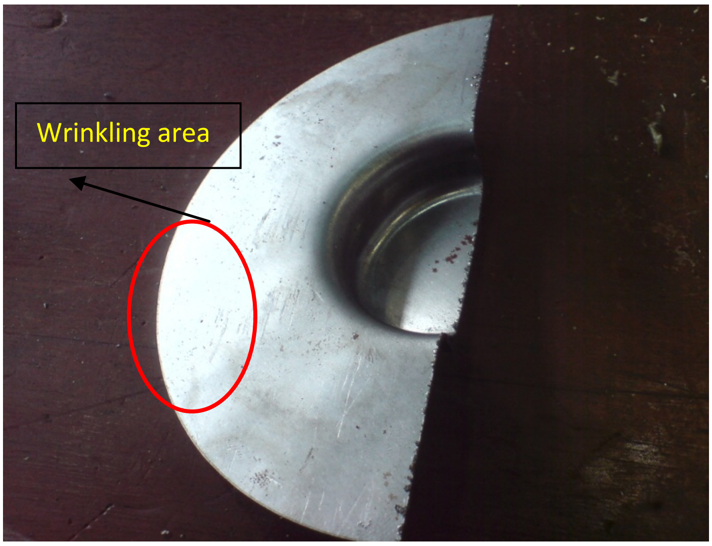

Figure 4.16: Maximum wrinkling area for 1.2 tonne BHF

4.3 CONCLUSION

Based on the analysis and results obtained, the best parameter to reduce wrinkle and tearing in this project is by using 5mm radius of punch, 20mm length of draw depth and 1.2 tonne blank holder force. A lower value of BHF will lead to wrinkle defect while a higher value of BHF will lead to tearing defect.

CHAPTER 5

5.1 CONCLUSION

In this project, deep drawing experiments conducted on an 80 tonne hydraulic press have been summarized and the analytical results using the finite element analysis have been compared with the measurements done during the experiments. The first objective of this research is achieved which is to design a die for cylindrical cup deep drawing. The second objective of this project which is to study the effect of draw depth and blank holder force in deep drawing process is also achieved through the simulations of finite element method using Altair Hyperform software. The FEA analysis shows a deeper draw depth will lead to higher possibility of tearing due to more material flow during the drawing process. The optimum value of blank holder force is crucial during deep draw process because a lower BHF will lead to wrinkle defect while a higher BHF will lead to tearing defect. The last objective is also successfully achieved as tearing and the wrinkle defect can be reduced by using a higher blank holder force. A higher blank holder force, 1.2 tonne as suggested by the FEA software was able to hold the cup flange during drawing process and the result shows no wrinkle detected.

5.2 RECOMMENDATION

For future experimental work on this project, in order to improve the study, the following recommendations are suggested:

(I) Use a variety of material or a higher malleability material such as SPCC for the blank.

(II) Use diamond paste to polish the die and punch to achieve mirror surface finish in order to reduce surface tension. A rough surface of the die and punch will lead to high friction during forming process.

(III) Other properties such as drawing speed, wear resistance, dimensional accuracy between product and die can be studied for further application in rapid manufacturing.

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APPENDIX A

Technical drawing for cylindrical cup