PREDICTION OF WRINKLING USING FINITE ELEMENT SIMULATION

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ABSTRACT

Deep drawing is a process for shaping flat sheets into cup-shaped articles without fracture or excessive localized thinning. The design and control of a deep drawing process depends not only on the work piece material, but also on the condition at the tool work piece interface, the mechanics of plastic deformation and the equipment used. This final project is about prediction of wrinkling in deep drawing part. The prediction methods can be broadly divided into two categories which is by experimental and simulation. The project deals with the Finite Element Analysis (FEA) and one step simulation of cup 50 mm using Altair Hyperform. In this project, the effect of some variables like blank holder force, blank thickness and drawn depth are investigate on flange wrinkling. Based on the result, the first analysis shows that wrinkle will occurred when the blank holder force is low. By increasing the blank holder force, the wrinkle is reducing. Second analysis shows that more thicker part will decreased tearing ratio due to the strength and stiffness of material. The last analysis give a result on effect of blank holder force and drawn depth on flange wrinkling where as if the depth increased, the percentage of wrinkling also increased. FEA software can be effectively used not only to predict the extent of damage, but damage control measures can also be simulated to suggest appropriate action to be taken at forming stages.

ABSTRAK

Penarikan yang mendalam adalah satu proses untuk membentuk kepingan rata ke dalam artikel-artikel yang berbentuk cawan tanpa patah atau berlebihan setempat menipis. Reka bentuk dan kawalan proses penarikan yang mendalam bukan hanya bergantung kepada bahan bahan kerja, tetapi juga kepada keadaan di bahan kerja, mekanik ubah bentuk plastik dan peralatan yang digunakan. Projek akhir semester ini adalah mengenai peratusan ramalan kedutan di bahagian lukisan yang mendalam. Kaedah ramalan boleh dibahagikan secara umumnya kepada dua kategori iaitu dengan eksperimen dan simulasi. Projek ini memerlukan Analisis Unsur Terhingga (FEA) dan simulasi cawan 50 mm menggunakan Altair Hyperform. Dalam projek ini, kesan beberapa pembolehubah seperti kuasa pemegang kosong, ketebalan kosong dan mendalam disediakan adalah menyiasat kedutan bebibir. Berdasarkan keputusan dari analisis pertama, peratusan kedutan di bahagian lukisan mendalam akan berlaku apabila kuasa pemegang kosong di kuarangkan. Apabila kuasa pemegang kosong di tingkatkan, peratusan kedutan menjadi semakin kurang. Analisis kedua menunjukkan semakin tebal bahan kerja, semakin sukar bahan kerja itu untuk merekah. Analisis terakhir menunjukkan apabila kedalaman bahan kerja bertambah, peratusan kedutan juga bertambah.

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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 OVERVIEW

Sheet metal forming process is widely used in manufacturing engineering especially in an automotive industries such as making fuel tank. During the process, the sheet metal blank is subjected to plastic deformation using forming tools to shape the design. Usually in deep drawing process the depth of the part must be more than half its diameter. In deep drawing process, the blank is placed over the die and is pressed into the die cavity using a punch. A blank-holder is apply pressure to the outer section of the blank, called the flange, during the forming process. The ratio of the original blank diameter to the diameter of the shaped part is called the draw ratio. Failure in operations may result in wrinkling of the formed part. This project is to study the prediction of wrinkling in sheet metal parts. In order to predict the wrinkling, some of the variables parameters need to considered and analyze by HYPERFORM software (simulation software). Variables thickness of blank, blank holder force and depth of cup are considered in this analysis to predict the flange wrinkling.

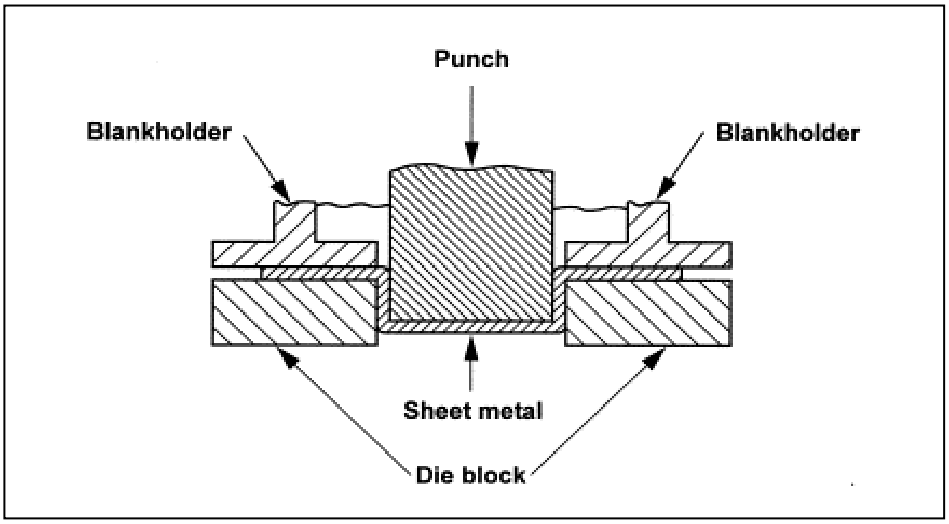


Figure 1.1 : Schematic of deep drawing operation

Source : Vukota Buljanovic, 2004

1.2 PROJECT BACKGROUND

Wrinkling is one of the most failure in forming process especially in deep drawing process. Wrinkling occurs when compressive stress in the circumferential direction reaches a critical point of instability. Severe wrinkles may damage or even destroy dies. Therefore, the prediction and prevention of wrinkling are extremely important in sheet metal forming and thus it can reduce scrap parts and minimize production cost. By measured the circumferential deflection profile at various radii from the center of the part, wrinkling failure can be detected. Wrinkling height and the number of wrinkles per profile are two parameters determining the severity of the wrinkling. Higher wrinkling heights and more wrinkles per profile indicate a more sever wrinkling condition in the formed part.

By considered the variables of parameters in deep drawing operation may result in a good formed parts. The parameters influenced in deep drawing operation are thickness of blank, blank holder force, material property, punch and die radii, surface condition and lubrication, and process factors. There are two type of wrinkling which is wall wrinkling and flange wrinkling. The flange of the blank undergoes radial drawing stress and tangential compressive stress during the stamping process, which sometimes results in wrinkles. Wrinkling is preventable if the deep drawing system and stamped part are designed properly. Figure 1.2 shows a different between flange and wall wrinkling.

Wall wrinkling **Flange wrinkling**

Figure 1.2 : Schematic of wall and flange wrinkling

Source : Vukota Buljanovic, 2004

1.3 PROBLEM STATEMENT

The appearance of dimensional deviations of shape and position of the defects in the sheet metal that have been subjected to a deep drawing especially in wrinkling failure and it represents a critical problem for the specific industry, especially for the mass production, like the machine manufacturing industry. The aim of this project is to predict the wrinkling by considered the principal aspects that effect of various factors like blank holder force, punch radius, die edge radius, and coefficient of friction on the wrinkling of cylindrical parts in deep drawing process. The initiation and growth of wrinkles are influenced by many factors such as stress ratios, the mechanical properties of the sheet material, the geometry of the work piece, and contact condition. It is difficult to analyze wrinkling initiation and growth while considering all the factors because the effects of the factors are very complex and studies of wrinkling behavior may show a wide scattering of data even for small deviations in factors. In this present project, the optimum parameters of wrinkling in the cylindrical cup deep drawing is investigated in detail by using finite element software.

1.4 OBJECTIVE

The objectives of this project is to predict wrinkling in cylindrical cup by do a simulation one step analysis on that part. Then finite element analysis is study to get the optimum parameters for a cylindrical cup. In this project, the thickness of blanks, blank holder force and height of cup are variables in order to study the effect of this parameters on flange wrinkle.

1.5 PROJECT SCOPE

The scope of this project is to study wrinkling failure in deep drawing parts. The parameters influenced to wrinkling are identified. Then simulate the drawing part and finite element is analyze towards the part. The variables thickness of blank which is 1, 2 mm are used to get the optimization of parameters. The blank holder force are calculated and height of cup are 10 and 20 mm.

1.6 PROJECT FLOW CHART

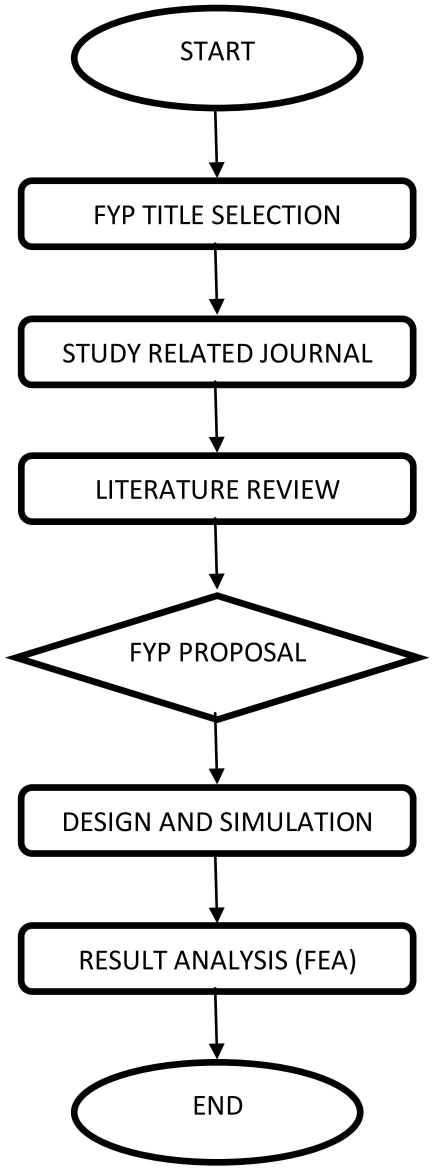


Figure 1.3 : Project Flow Chart

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter are presents about the current searching that related to the title. Firstly, theory of deep drawing will be discussed. Secondly, the parameters and possible failure in deep drawing are discussed such as fracture and wrinkling. Then, the wrinkling failure will be described consists of theory, and prevention method. At the last chapter, Finite Element Analysis will be discussed.

2.2 DEFINITION OF DEEP DRAWING PROCESS

Mostly, an automobile components are made by deep drawing process such as tank and lamp cup. Deep drawing is one of the sheet metal forming process which is to fabricate a hollow parts. In a deep drawing process, a sheet metal blank is insert and clamped between die and a blank holder. Then, a punch with a specific force is pushes a sheet metal blank into a die cavity and resulting the contoured part [9].

In order to have a success deep drawing part, the influenced parameters need to be considered such as material characteristics, friction, condition of punch and die, clearance of deformation, punch force, blank holder force and others [7]. By neglecting this parameters, wrinkling may occurs in the formed part. Wrinkling is the major failure in deep drawing part and it occurs in the wall or flange of the part. By using simulation, the optimum values of parameters can determined. It also can identify the problems areas and solution in the part, reduce tryout and manufacturing cost. Sandeep Patil and Tated, 2011 have using Altair HyperForm software to predict the various of parameters on formability of a trapezoidal cup [13].

2.3 TYPE OF FAILURE IN DEEP DRAWING PROCESS.

Failure is one of the most important aspects of material behavior, because it is directly influences the selection of a material for a particular application, the methods of manufacturing, and the service life of the component. In deep drawing process, there are some failures such as wear, fracture, and wrinkling.

2.3.1 Wear

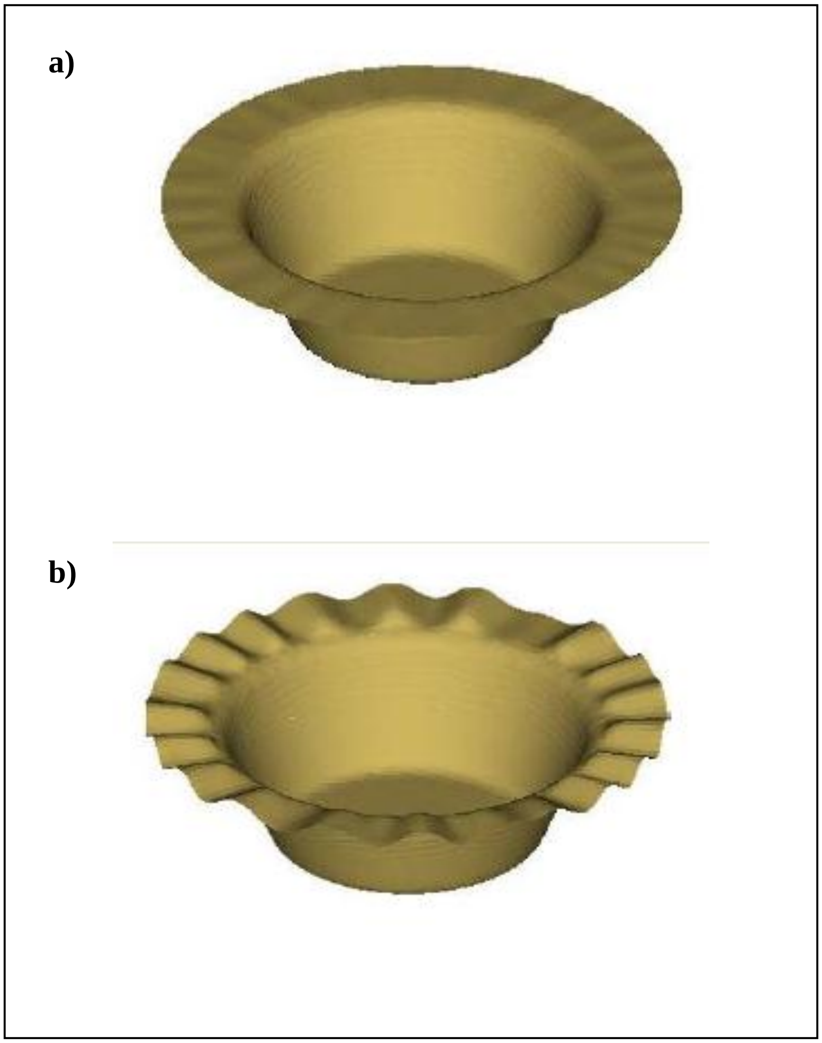
There are two types wear in deep drawing which is adhesive and abrasive wear. During sliding of the sheet metal on die, the two materials may cold weld at the top of the surface. Adhesive wear takes place when further relative movement between work piece and tools induces breakage of the cold welds inside the tool material rather than the interface.

2.3.2 Fracture

Fracture is one of the common defects during deep drawing. There is limited by fracture, so that the quantitative determination of a fracture criterion such as limit stress (or load) and limit strain is the basis for determining the limit drawing ratio to draw up a process plan and for controlling the forming operation to prevent or delay failures by fracture.

2.3.3 Wrinkling

Wrinkling is known as a failure phenomenon in forming sheet metal parts (Fig 2.1). It damage to the wall or flange area and the functioning. Thus is affect to the manufacturing cost because mostly the wrinkling part become a scrap and cannot be reprocessed [11].



a) Marginal Wrinkle (b) Wrinkle

Figure 2.1 : Wrinkling area

2.4 CLASSIFICATION OF PARAMETERS AFFECTING WRINKLING.

2.4.1 Blank holder force

The blank holder is a tool that 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 [8]. It also used for preventing the edge of a sheet metal part from wrinkling. A high blank holder force can leads to fracture at the cup wall while low blank holder force leads to wrinkling in the flange of the cup [9]. So, it is important to meet the optimum blank holder force in order to prevent wrinkling. The blank holder force can be calculated by a formula (2.1) :

$$\boxed{\textit{Blank holding force:} \qquad F_N = A_n . P_N}$$

where F_N = blank holding force (N)

A_n = blank holder area (mm^2)

$$= \frac{\pi}{4}(D^2_b - d^2_p)\ (mm^2) \qquad \text{(2.1)}$$

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

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

2.4.2 Draw bead

Draw beads are placed to the die (small protrusions on the die surface) in order to control the flow of the material during the forming operations. The material fills the groove, this results in a change in the strain distribution in the flange region. Thinning of the blank is achieved and compressive stresses are decreased so wrinkling is avoided.

2.4.3 Drawing Force

The drawing force formula (2.2) :

$$\boxed{F_{dr} = C \cdot s \cdot R_m \cdot n = d \cdot \pi \cdot s \cdot R_m \cdot n} \quad (2.2)$$

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

2.4.4 Die edge radius and clearance.

The value of clearance between punch and die must be considered in order to meet a success deep drawing part. During the forming process, the clearance between punch and die will give a desired force to the sheet metal blank. The other parameters that need to be considered is punch and die radius. The large radius can cause wrinkling to the part while the smallest radius can cause fracture or breaking the part due to the high stresses [1].

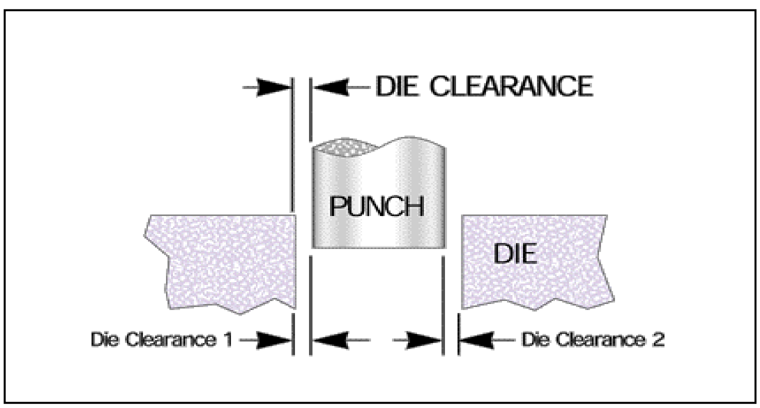


Figure 2.2 : Punch and Die clearance

Table 2.1 illustrates the absolute value for clearance depending on the type and thickness of the material.

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

Table 2.1 : Value for clearance on type and thickness material

Source : Vukota Buljanovic, 2004

2.4.5 Die Cavity

The design of the punch and die cavity can be optimized to reduce the probability of wrinkling. Choosing a flange radius that is just large enough to prevent cracking can minimize the potential for wrinkles. Additionally, considering minimizing the part complexity and any asymmetry can also help. Incorporating a multi-step drawing process offers a variety of advantages in preventing wrinkling in deep-drawn parts. Designing the blank geometry to minimize excess material can reduce the potential for wrinkling. The sheet metal blank has an inherent grain structure, so the stresses can vary depending on the design of the die and the orientation of the grain. Adjusting the grain in an asymmetrical design to minimize the compound of grain stresses and the general stresses of the deep draw process is something to take into consideration.

.2.4.6 Limit Draw Ratio

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. The limit draw ratio is used to determine how many drawing operations are necessary to produce a drawn part, the correction value *n* = *f* (draw ratio) to calculate the drawing force (2.3).

$$\boxed{\text{LDR} = \frac{\text{Maximum Blank Diameter, D}}{\text{Punch Diameter, d}}} \quad (2.3)$$

2.4.7 Blank thickness and shape

Blank thickness is important to give a clearance between punch radius and die radius. Without an optimum clearance, ironing will occur. Ironning can be defined as thinning of the blank at the die cavity. So, clearance should be %25 larger than the initial blank thickness in order to prevent the wrinkling. The limiting drawing ratio decreased as sheet thickness decreased while blank holder force increased as the sheet thickness decreased. It is seen that BHF is strongly influenced by sheet thickness. [13]

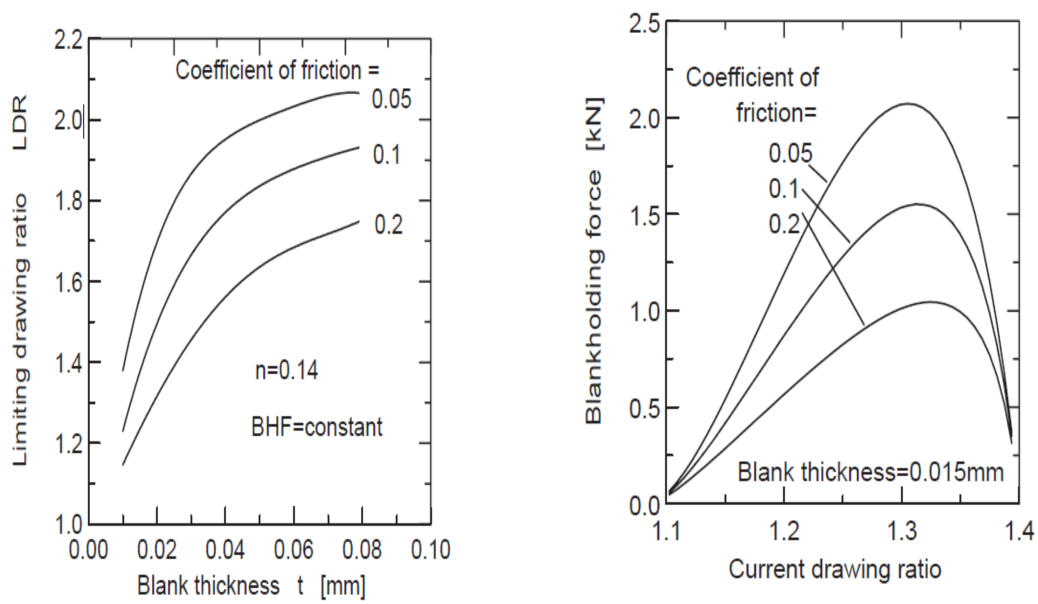


Figure 2.3 : Diagram sheet thickness on the limit drawing ratio and blankholder force

2.4.8 Friction Coefficient

Surface conditions of each component can be tailored to improve overall performance. Lubricants reduce the friction between the blank and the punch and die cavity and can be liquid (wet) or films (dry). Generally, they are applied to the blank before drawing. While lubricants can facilitate the metal flow into the die cavity, consider increasing the blank holding force to account for the reduced friction.

2.4.9 Summary of wrinkling parameters

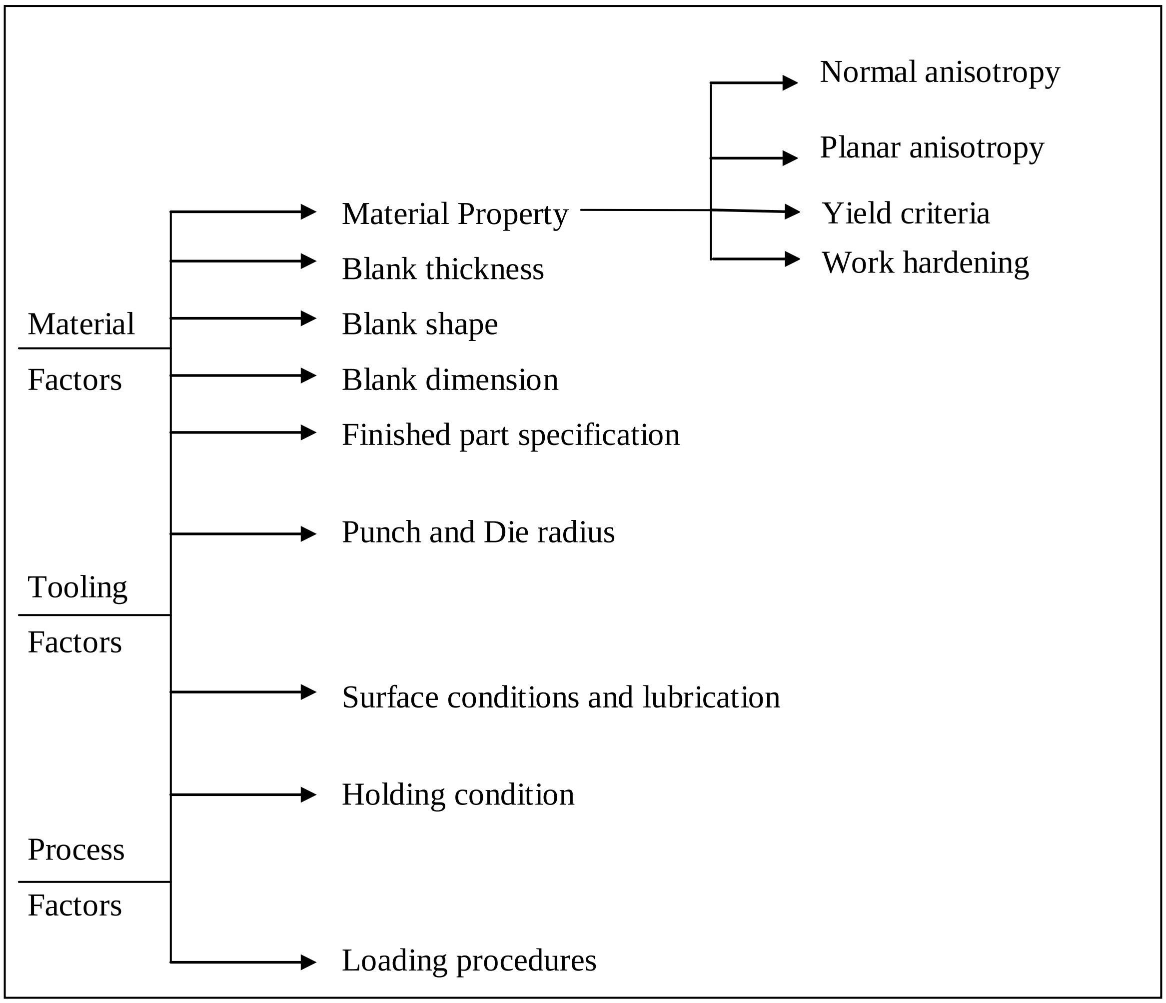


Figure 2.4 : Summary of wrinkling parameters

2.5 THEORY OF WRINKLING

Wrinkling is often observed in sheet metal part. Wrinkling also one of the common failure in deep drawing parts because of the trend toward thinner, and high strength sheet metal. It occurs in areas which are not in contact with tool. It can lead to expensive redesign and remanufacture of tooling, lost press and operator time, and scrapped parts. It is important to predict wrinkling in Finite Element Analysis by simulate the sheet metal parts especially for cylindrical cup. However, prediction of the specific conditions that will result in wrinkling is a difficult task. There have been a large number of theoretical, experimental and numerical investigations of wrinkling in single step drawing of relatively thin sheet. [2]

2.5.1 Previous study

Xi Wang and Jian Cao [5] have analyze wrinkling by applied on bending of thin walled product edges. They concluded that wrinkling reduces when the length of bent edge is increased, and that thickness has no influence onto number of wrinkles, but increased thickness leads to increase in critical length of bend edge.

Janardhan Reddy, Dr.G.C.M. Reddy [1] also study the same title which is the effect of tooling parameters on wrinkling failure. The different between the previous study are the experimental. The previous study are using finite element method to solve wrinkling. The brothers are use 112.4mm diameter and 42.5mm height of cup, 5mm blank thickness, 9.0 ton of drawing force. The Blank Holder plate is supported by 8 cushion pins which are transfer the load from the die cushion to the Blank Holder supporting plate. The BHF was measured by providing load cells at sides of the cylindrical Blank Holder. As a result, the wrinkle height increases along with the deep drawing depth.

P.V.R. Ravindra Reddy and P. Radhakrishna Prasad [8] have investigated the effect of tooling parameters like punch and die profile on wrinkling using a finite element solver LSDYNA3D. In their analysis, they have constant the blank holder force. The study show that the minimum blank holding forces thus find out is the wrinkling limit**.** R. Venkat Reddy, Dr T.A. The figure shows that wrinkling limit almost remains constant with the variation of die corner radius. But the fracture limit decreases with the increase of die corner radius it may be due to the increase of the punch force on the side wall.

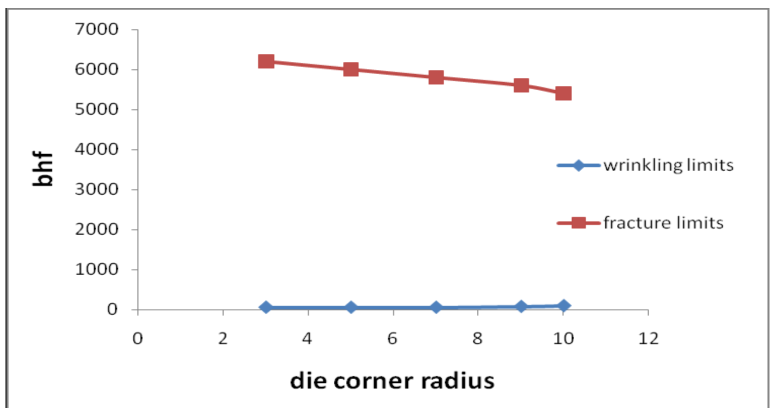


Figure 2.5 : Variation of Wrinkling and fracture limits with die corner radius

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The wrinkling behavior of blanks during deep drawing was studied by Jamal Hematian [2]. In his study, finite element method was used to simulate the forming operation. The study shows that initial imperfections in material and tooling, play a key role in the initiation of wrinkling in finite element modeling of a deep drawing process. More specifically, it was shown that tooling imperfections are a critical factor while material imperfections have little impact on the formation and growth of wrinkles.

A.Mosallam [10] presents a finite element-based assessment of the performance of some non-conventional blank holding techniques. This includes friction actuated, pulsating, and pliable blank-holding techniques. A 3-D explicit-finite element analysis is used to investigate the influence of various blank-holder force (BHF) schemes on sheet metal formability limits especially wrinkling and tearing rupture. The study finds that the comparison with fixed blank holder force (BHF) scheme revealed that slight improvements in the formability are observed for the three BHF schemes under consideration.

Y. Marumo, H. Saiki, L. Ruan [13] study the influence of sheet thickness on blank holding force and limiting drawing ratio. The study shows that variation in the blank holding force required for the elimination of wrinkling and the limiting drawing ratio with sheet thickness. The blank holding force required for the elimination of wrinkling increased rapidly as the sheet thickness decreased. When the sheet thickness was very thin, the blank holding force was strongly influenced by the coefficient of friction. The limiting drawing ratio decreased as sheet thickness decreased and it decreased rapidly below 0.04 mm thickness. When the sheet thickness was very thin, the limiting drawing ratio was strongly influenced by the coefficient of friction.

Kopanathi Gowtham and all [12] study simulation of the effect of die radius on deep drawing process using Deform3D software. This study is about to determine the factors influencing a drawing process and analyzing the process by varying the die radius and keeping the friction, punch radius and blank thickness as constant. Aluminium alloy 6061 is used for deep drawing with initial diameter as 56mm. The different analytical, numerical and experimental methods are developed in order to analyze the best combination of them. For a given constant friction, the load required increases with increase in die radii.

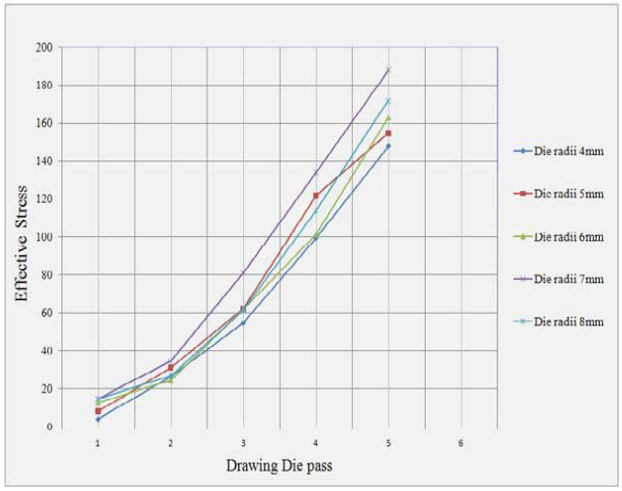


Figure 2.6 : Effective strain after each die pass for different Die radius

2.6 FINITE ELEMENT ANALYSIS (FEA)

Finite element analysis can be known as a finite element method and is the basis of a multibillion dollar per year industries. FEA is one of the numerical solutions and important in introductory treatments of Mechanics of Materials. It is used in a new product design, and existing product refinement to analyze for specific result. In case of structural failure like a wrinkling, FEA may be used to help determine the design modifications to meet the new condition and optimize the parameters. There are generally two types of analysis that are used in industry: 2-D modeling, and 3-D modeling. While 2-D modeling conserves simplicity and allows the analysis to be run on a relatively normal computer, it tends to yield less accurate results. 3-D modeling, however, produces more accurate results while sacrificing the ability to run on all but the fastest computers effectively. Within each of these modeling schemes, the programmer can insert numerous algorithms 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. FEA uses a complex system of points called nodes which make a grid called a mesh. This mesh is programmed to contain the material and structural properties which define how the structure will react to certain loading conditions. Nodes are assigned at a certain density throughout the material depending on the anticipated stress levels of a particular area. FEA is used to optimize mass, volume, temperature, strain energy, stress strain, force, velocity and others. In this project FEA is study in terms of displacement.

2.7 FORMING LIMIT DIAGRAM (FLD).

2.7.1 Concept of Forming Limit Diagram

The concept of forming limit diagram (FLD) was introduced by Keeler and Goodwin [15] which represents the first safety criterion for deep drawing operation. Marciniak [9] have proposed a mathematical model for the theoretical determination of FLD that supposes an infinite sheet metal to contain a region local imperfection where heterogeneous plastic flow develops and localizes [9]. From FLD, the forming limit of sheet metal can be predicted by measured the reading of minor strain and major strain from the experiment and converted the data into FLD.

The FLD, which is consequently been widely referenced in the sheet metal forming industry is now a standard characteristic in the optimization of sheet metal forming processes. In FLD, the higher level of FLD can obtain, the more good of material that was used [11].

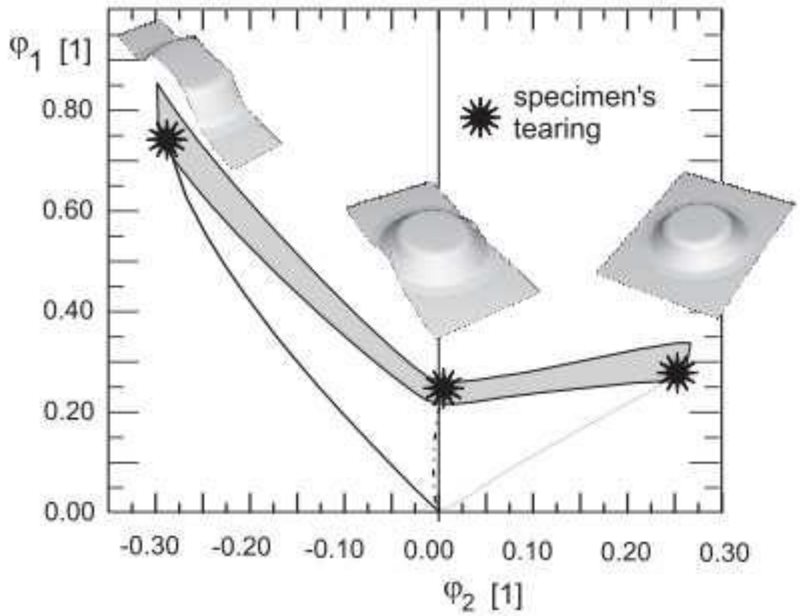


Figure 2.7 : Example of FLD in sheet metal forming

Source : Pepelnjak and Kuzman, 2007

The FLD can be predicted by running the experiment on various types of sheet metal, the sheet metal thickness and with different value of BHF. Narayanasamy [12] has done the test with variable blank thickness with IF steels as a material while Assempour and all [7] has done the experiment with variable size of diameter with ST12 low carbon steel as a material.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In order to achieve the aim and objectives of this project, there are several method uses. The sequence of the methods has been planned as shown in figure 3.1. The method consists of design cylindrical cup and several calculation, define mechanical properties, simulation process, comparison with experimental result. The finite element simulation is performed in HYPERFORM software. Analysis of deep drawing process is based on variables thickness and height of product in order to meet the optimization of blank holder force.

3.2 FLOW PROCESS

Process planning is important in order to make sure this project is completed on time. It also to ensure that all the tasks will run systematically. Based on the literature review from the journals and book, the simulation of cylindrical cup are developed.

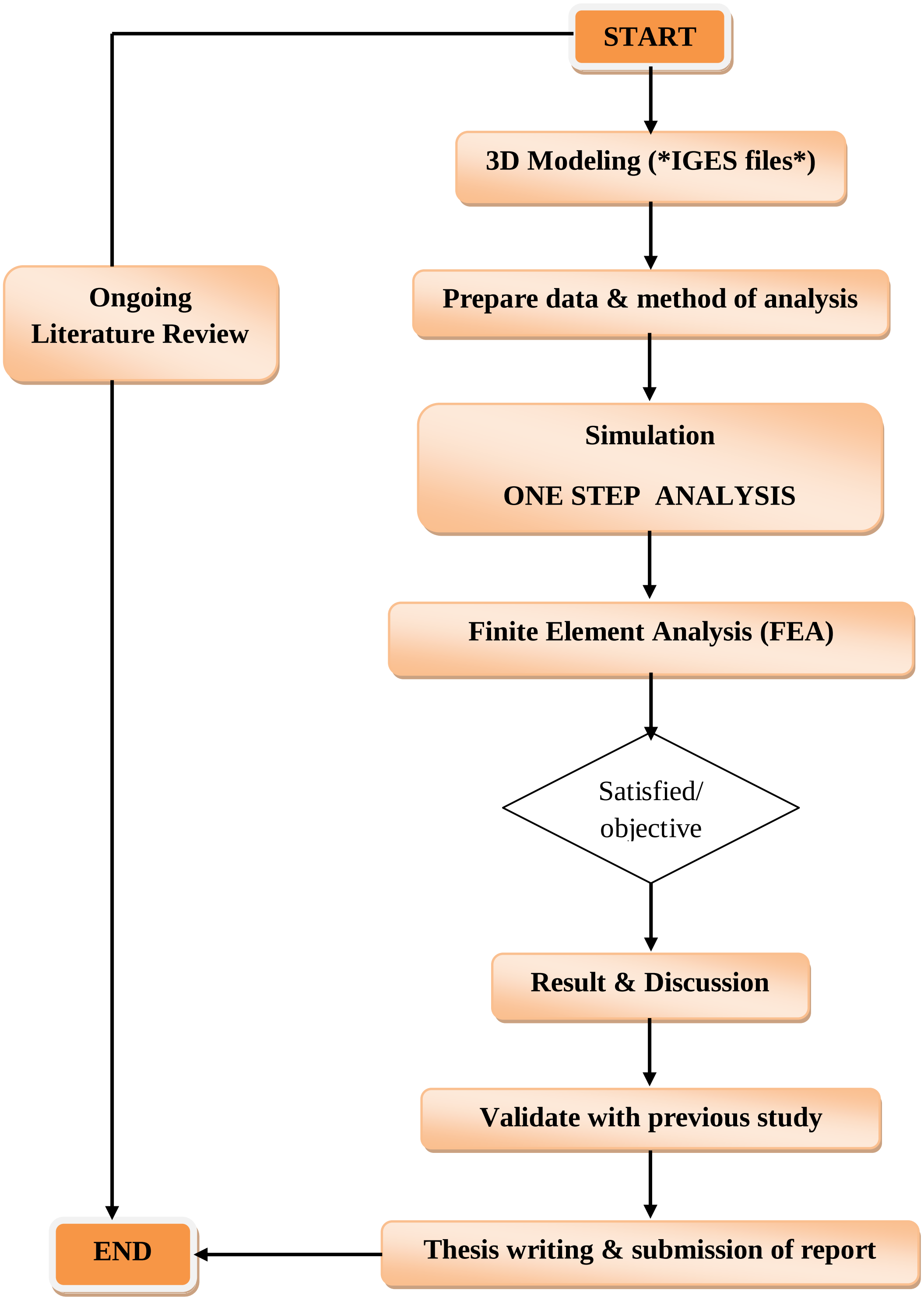


Figure 3.1 : Process planning flow chart

3.3 PARAMETER SELECTION

The formability of blank sheet during deep drawing operation depends on the process parameters such as blank holder force, punch force and blank thickness. Hence, using proper process parameters are essential to predict the wrinkling. Figure 3.1 shows the parameters selection with the value. The value have calculated using formula in literature review.

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

Table 3.1 : Value of parameters

PARAMETERS	VALUE	
Blank Thickness	1 mm	2 mm
Blank Holder Force	0.916 ton	1.018 ton

3.3.1 Table of Experiment (DOE)

Design of Experiments (DOE) is the design of any information-gathering exercises where variation is present, whether under the full control of the experimenter or not. In this project, simulation process need to follow table of experiment in order to achieve the result. Table 3.2 shows the parameters that need to defined.

Table 3.2 : Design of Experimental (DOE)

Thickness, mm	Height of Cup, mm	Blankholder Force, ton	Press tonnage, ton	FEA result
1	10	0.916		
2				
1	20			
2				
1	10	1.018		
2				
1	20			
2				

3.4 PART DESIGN

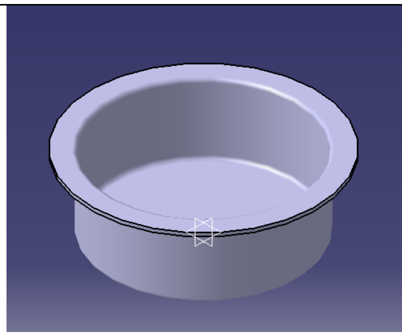
Part Design	**Dimension**
	• Inner diameter : 50mm • Outer radius : 5mm • Thickness : 1mm • Height : 20mm

Figure 3.2 : Cup drawing with thickness 1 mm

The concept of design is cylindrical cup. The parts are design with same dimension but different thickness 1 mm, 2 mm and depth drawn 10 mm and 20 mm. All the design have been design using a CATIA software as in figure 3.1. Since the mild steel is one of the softer material and easy to formed, it is used as a blank sheet in this project.

3.5 BOUNDARY CONDITION

Material	: Mild Steel
Young Modulus, E	: 320GPa
Poisson ratio	: 0.303
Tensile stength	: 350MPa
Strain hardening, nu	: 0.21
Hardening coefficient	: 530
Yield strength	: 248
Friction	: 0.125
E0	: 0.07

In order to predict wrinkle problems, it is very important to understand how boundary condition act on flange wrinkles while simulation. Computer simulation makes it possible to investigate the effect of one property change. Influences of each parameters upon displacement were evaluated under the same boundary condition.

3.6 FINITE ELEMENT ANALYSIS (F.E.A)

The finite element method is practical application often known as finite element analysis (FEA). The finite element analysis (FEA) is a numerical technique for finding approximate solutions of partial differential equations (PDE) as well as of integral equations. The solution approach is based either on eliminating the differential equation completely (steady state problem), 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.

In solving partial differential equations, the primary challenge is to create an equation that approximates the equation to be studied, but is numerically stable, meaning that errors in the input data and intermediate calculations do not accumulate and cause the resulting output to be meaningless. There are many ways of doing this, all with advantages and disadvantages. The Finite Element Method is a good choice for solving partial differential equations over complicated 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). Another example would be the simulation of the weather pattern on Earth, where it is more important to have accurate predictions over land than over the wide open sea.

3.7 TYPE OF ANALYSIS

In this project, one step analysis is used to simulate and do Finite Element Analysis (FEA). The part will designed in CATIA with dimension cup 50 mm and 10, 20 mm height. Then the designed will save in IGES files, proceed with import into HYPERMESH and do simulation. The figure below show one step analysis is more styling of the part and product itself.

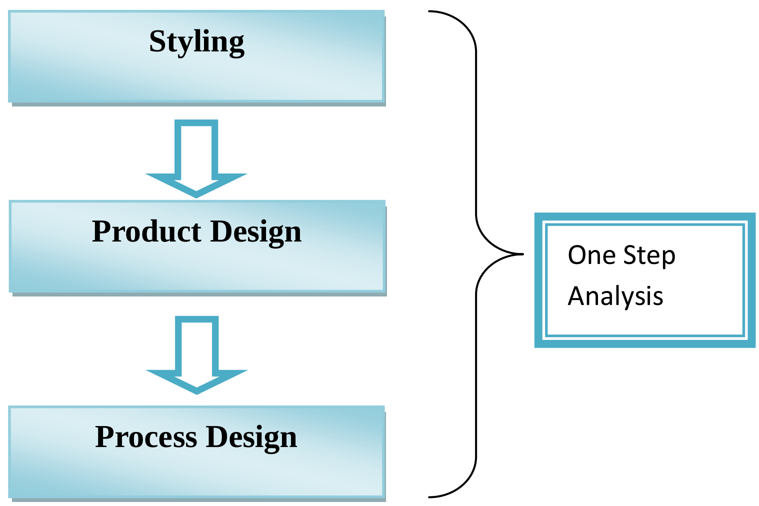


Figure 3.3 : General analysis flow chart

3.7.1 One – Step Simulation

Following are some of the steps in the one steps simulations:

a) Import the CAD model of the final component (IGES files).
b) Fill holes if they are to be created after the forming.
c) Generate a shell mesh of the component
d) Orient the part so the draw direction is along the z axis.
e) Check for undercuts and tip the component if needed
f) Specify the material properties.
g) Specify the thickness of the component
h) Save the files
i) Run the analysis
j) Inspect the result – Thinning, formability and press tonnage
   (Thinning percentage is best viewer as a contour, while formability is best viewed as the FLD)

3.8 ALTAIR HYPERFORM SOFTWARE

Altair Hyperform is one of the finite element simulation software. Hyperform is suitable for this project because it is accurate blank-shape prediction and intuitive nesting interface, and it also the fastest inverse solver for quick one-step analysis. Finite element analysis can be known as a finite element method and is the basis of a multibillion dollar per year industries. FEA is one of the numerical solutions and important in introductory treatments of Mechanics of Materials. It is used in a new product design, and existing product refinement to analyze for specific result. In case of structural failure like a wrinkling, FEA may be used to help determine the design modifications to meet the new condition and optimize the parameters. There are generally two types of analysis that are used in industry: 2-D modeling, and 3-D modeling. While 2-D modeling conserves simplicity and allows the analysis to be run on a relatively normal computer, it tends to yield less accurate results. 3-D modeling, however, produces more accurate results while sacrificing the ability to run on all but the fastest computers effectively. Within each of these modeling schemes, the programmer can insert numerous algorithms which may make the system behave linearly or non-linearly.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter focuses on the result and the discussion that made from the one step simulation and wrinkling analysis. Thus, an understanding on how to interpret the result is important in order to avoid wrong assumption of the output results. Following are some type of the output that the result will generated.

4.1.1 Forming Limit Diagram

Forming Limit Diagram (FLD) is based on a material Forming Limit Curve (FLC) where the major and minor strain output results of a forming simulation.

Table 4.1 : Colour scheme indication on FLD

Colour	***Indication***
Red	Failure (Points above the FLC)
Yellow	Marginal (Points between the FLC and safety curve)
Green	Safe (Points between ±45 degree line and safety curve)
Blue	Compression (Points to the left of -45 degree line)
Light Blue	Loose metal (Points within a radius of 2% major or minor strain)

The FLC identifies the edge of the cliff (Figure 4.1). The FLC defines the major-minor strain combinations at the onset of a local or thickness neck in stamping. Figure 4.1 shows the major strain is the largest positive strain and is computed from the long axis of the ellipse. The minor strain is perpendicular to the major strain and can be positive, zero, or negative. A standard curve exists for low carbon steel (mild steel). The height of the curve is set by FLC_o, which is a function of the sheet thickness and the work hardening exponent (n value) for the steel sheet being formed.

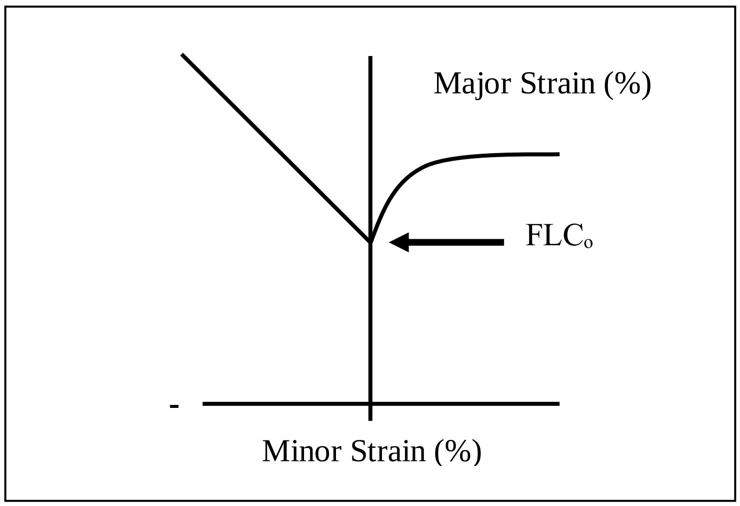


Figure 4.1 : Typical FLC with height specified by FLC_o

One definition of a marginal safety zone is a band below the FLC with a bandwidth of ten strain percent (Figure 4.2). The forming severity or safety margin for any point located on the stamping is the difference between allowable deformation (FLC) and the actual deformation (FLC_o).

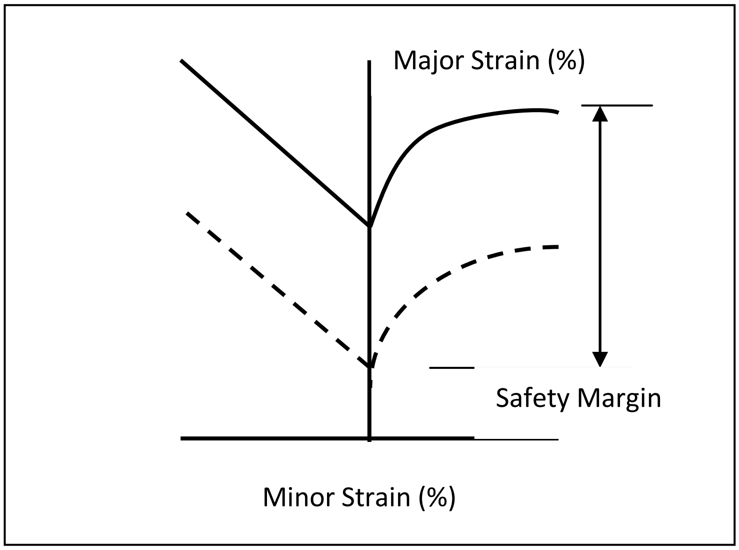


Figure 4.2 : A safe zone of 10 strain percent is created below the FLC

If the actual strain state is above the FLC (Figure 4.3 – point A), the die has negative safety margin and is represent as a 'red zone' die. Point B is a marginal which is within safety margin between 0 and 10 strain percent and is represents as a 'yellow zone' die. The goal is to achieve a safety margin greater than 10 strain percent (point C) for all locations, which is defined as a "green zone" die.

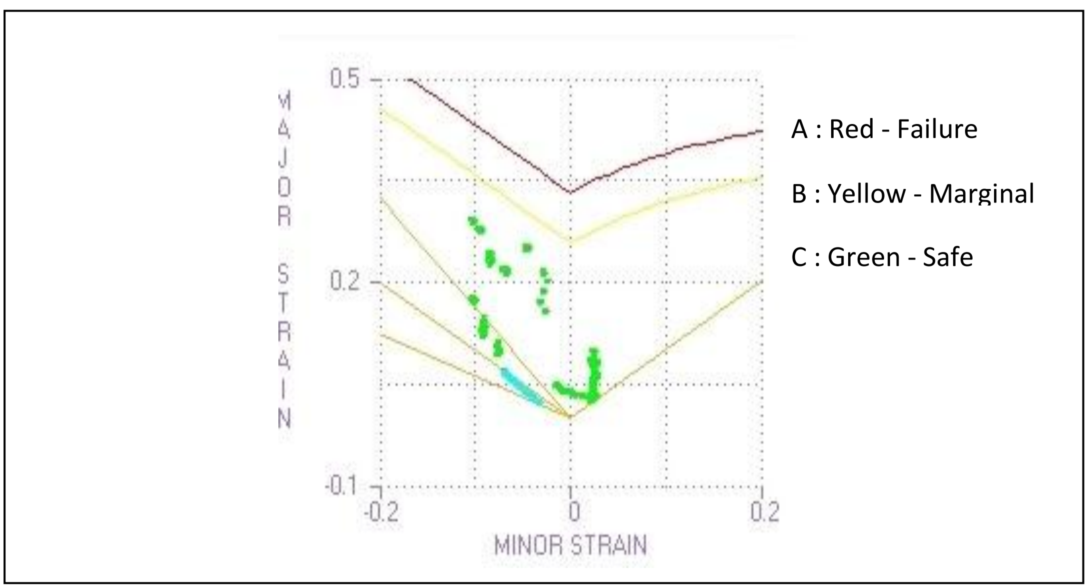


Figure 4.3 : Schematic showing the three zones for the FLC

4.2 FINITE ELEMENT SIMULATION FOR 1 mm.

4.2.1 Simulation for bhf 0.916 ton, 10mm height.

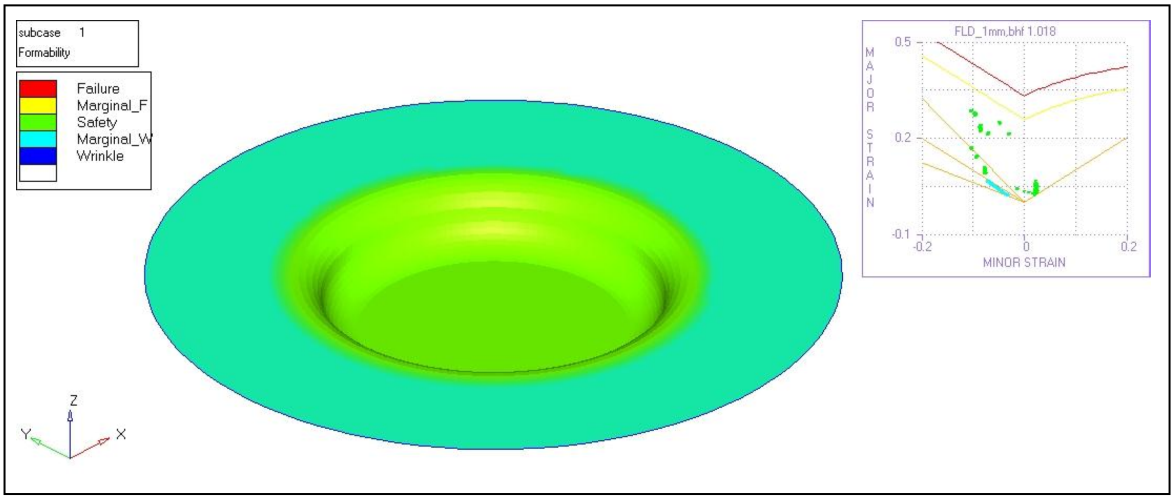


Figure 4.4 : Formability result for bhf 0.916 ton, 1mm thickness, 10mm height.

During deep drawing process, metal flow of drawn part can be known trough the analysis of equivalent strain diagram. The value of major strain is 0.34 megapascal. According to the blank holder force calculation, 0.916 ton is not suitable value for thickness 1 mm and height 10 mm cup. The result shows that formability of part is good in the inside area while the flange area is marginal wrinkle. The thinning value is between 13.1% to 17.4% which is safety and no tearing.

4.2.2 Simulation for bhf 1.018 ton, 10 mm height.

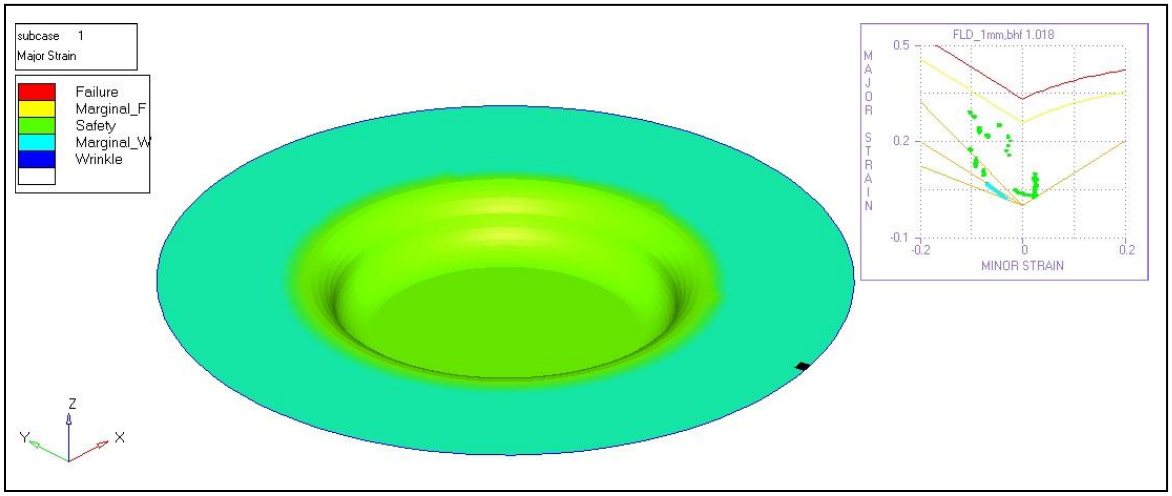


Figure 4.5 : Formability result for bhf 1.018 ton, thickness 1 mm, 10 mm height.

The blankholder force value is 1.018 ton which is used for thickness cup 2mm. The bhf were used in order to see the difference result between low and high bhf. During the formability, the cup is in the safe region (green colour) while the flange area is in marginal wrinkle (light green). The value of major strain is 0.48 megapascal. This results shows that maximum 17.5% thinning which equal to 1.75 mm reduction of original thickness, there are not tearing on this part.

4.2.3 Simulation for bhf 0.916 ton, 20 mm height.

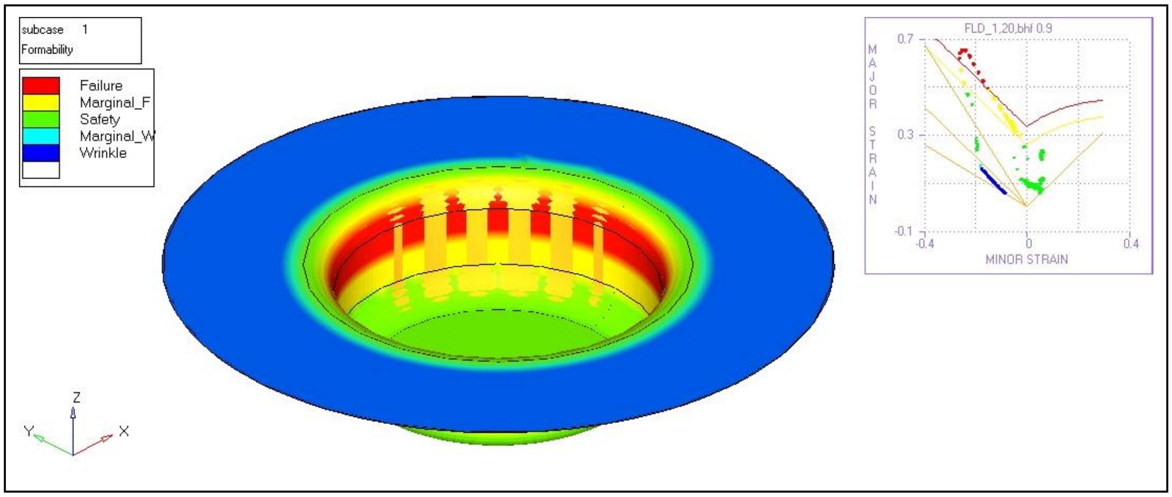


Figure 4.6 : Formability result for bhf 0.916 ton, thickness 1 mm, 20 mm height.

Figure 4.6 shown that the wrinkle phenomenon was occur on the flange area. The side of wall cup was marginal tearing and some of that was tearing. The maximum major strain value is 0.7 megapascal. The minimum minor strain value is 0.4 mega pascal. The maximum thinning ratio is 31.8 % and the minimum thinning ratio is – 37.3 %. The formable of this part is failure.

4.2.4 Simulation for bhf 1.018 ton, 20 mm height.

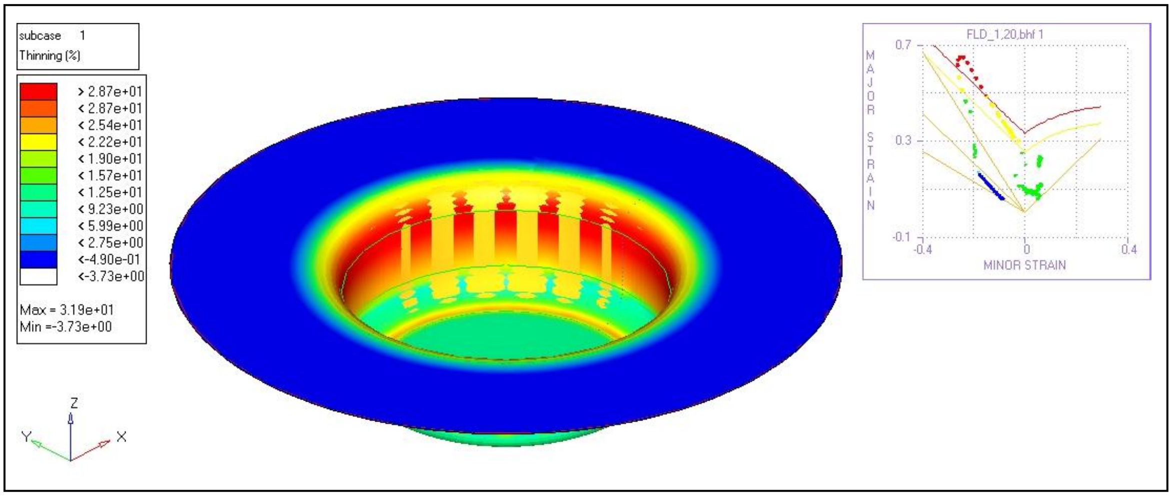


Figure 4.7 : Thinning result for bhf 0.916 ton, thickness 1 mm, 20 mm height.

Figure 4.7 shown that wrinkle occurred on the top flange area while the corner area was marginal wrinkle. The maximum major strain value is 0.7 mega pascal. The thinning occur at the side wall of the cup which is 28.7 % thinning which equal to 2.87 mm reduction from original thickness. There is a tendency of wrinkling at the flange (blue color) with the thinning percentage value of -3.73 % which means 0.0373 mm material thickness is gathered here to form the wrinkle.

4.3 FINITE ELEMENT SIMULATION FOR 2 mm.

4.3.1 Simulation for bhf 0.916 ton, 10 mm height.

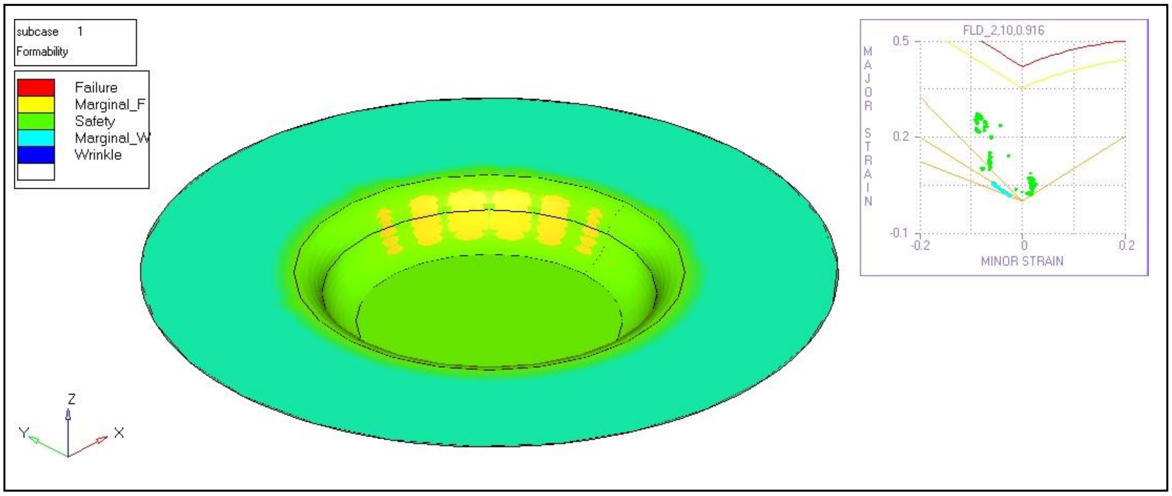


Figure 4.8 : Formability result for for bhf 0.916 ton, thickness 2 mm, 10 mm height

The cup is in the safe region (green colour) while the flange area is in marginal wrinkle (light green). The value of major strain is 0.5 megapascal. This results shows that maximum thinning value is 16.5 % which equal to 1.65 mm reduction of original thickness. The minimum thinning value is – 9.97 % which means 0.0997 mm reduction thickness. This part are not tearing.

4.3.2 Simulation for bhf 1.018 ton, 10 mm height.

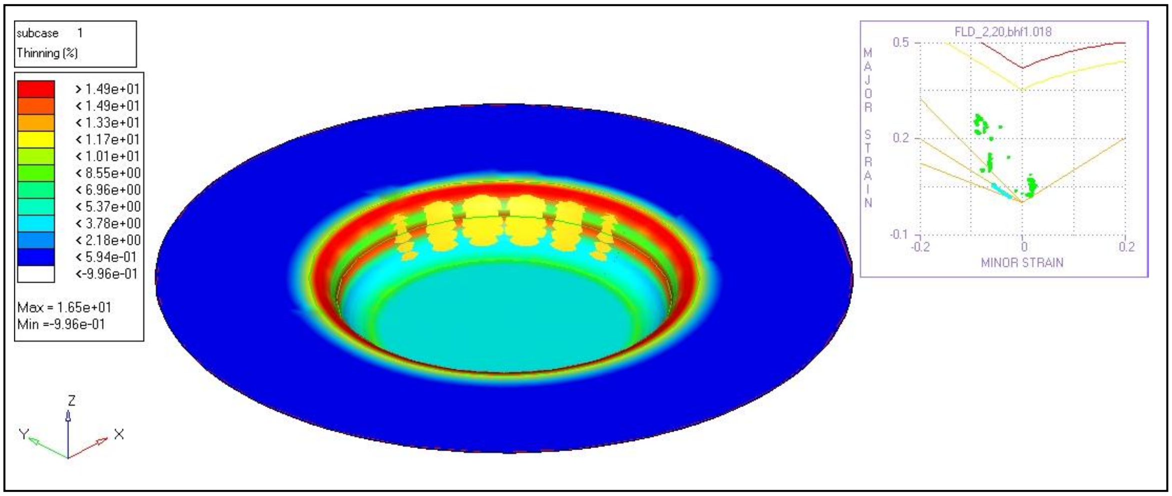


Figure 4.9 : Thinning result for bhf 1.018 ton, thickness 2 mm, 10 mm height.

The thinning test shows high equivalent plastic strain occurs at wall region outside the die corner, because this area is the potential location for a crack. This results in a high state of tension at the side wall, maximum 14.9 % thinning which equal to 0.0149 mm reduction of original thickness. Since the side wall is near the punch radius is stressed the highest, tears will often occurs at this region. The formability of this cup is marginal wrinkle while the side wall is marginal failure.

4.3.3 Simulation for bhf 0.916 ton, 20 mm height.

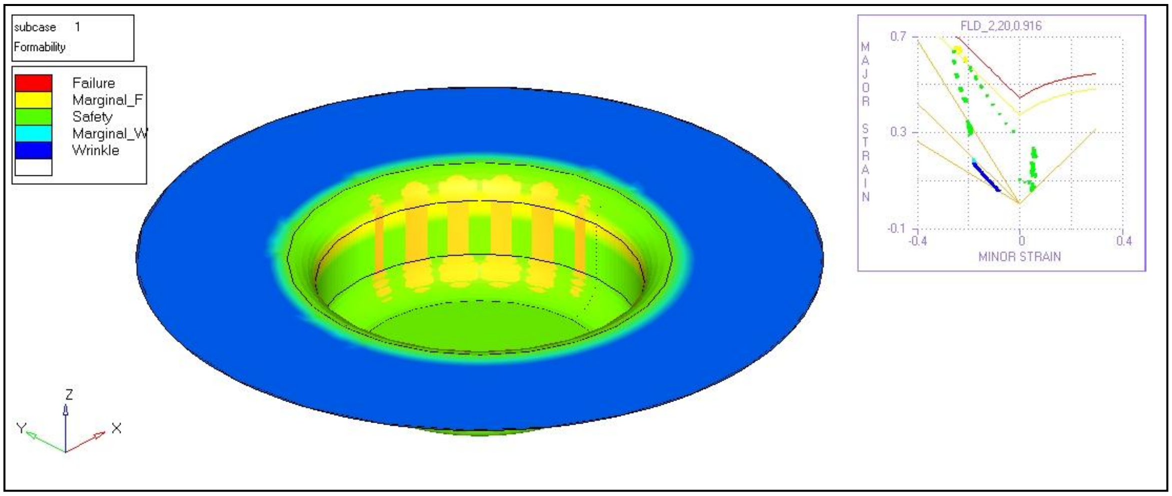


Figure 5.0 : Formability result for bhf 0.916 ton, thickness 2 mm, 20 mm height.

The result shown that marginal wrinkle occur on the flange area. The major strain value is 0.7 mega pascal. The maximum thinning value is 31.4 % which equal to 3.14 mm reduction of original thickness. The minimum thinning value is – 3.48 % which means 0.0348 mm reduction thickness. The side wall was marginal failure which is near to tearing.

4.3.4 Simulation for bhf 1.018 ton, 20 mm height.

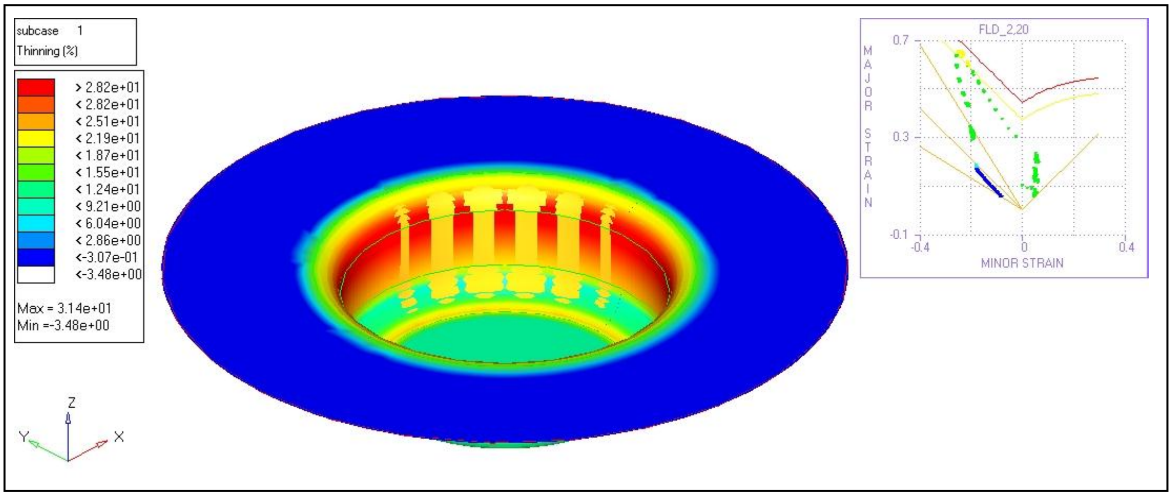


Figure 5.1 : Thinning result for bhf 1.018 ton, thickness 2 mm, 20 mm height.

The figure 5.1 shown that wrinkle occurred on the flange area. The maximum thinning value is 31.4 % which equal to 3.14 mm reduction of original thickness. The minimum thinning value is – 3.48 % which means 0.0348 mm reduction thickness.

4.3.5 Summary Simulation

Table 4.2 : Status of simulation result

Thickness, mm	Height of Cup, mm	Blankholder Force, ton	Press tonnage, ton	FEA result
1	**10**	**0.916**	0.650E + 01	Margin wrinkle
2			0.132E + 02	Margin wrinkle
1	**20**		0.145E + 02	Wrinkle, Tearing
2			0.277E + 02	Wrinkle
1	**10**	**1.018**	0.650E + 01	Margin Wrinkle
2			0.130E + 02	Wrinkle, Tearing
1	**20**		0.159E + 02	Wrinkle, Tearing
2			0.275E + 02	Wrinkle, Tearing

4.4 EFFECT BLANKHOLDER FORCE ON FLANGE WRINKLING.

Table 4.3 : Effect of variables Blankholder force

No.	Blankholder force, Fp	Thick thinning ratio (%)	Pressure MPa	Status
1	0.2	21.3	0.430	Wrinkle
2	0.916	16.5	0.650	Marginal wrinkle
3	1.018	14.9	0.664	Marginal wrinkle
4	5	8.2	0.758	Safety

If low blank holder force there is wrinkle usually in the flange of the drawn part. When increasing the blank holder force, wrinkle is reducing. However, the large value of the blank holder force will cause fracture.

4.4.1 Blankholder force VS Thinning ratio

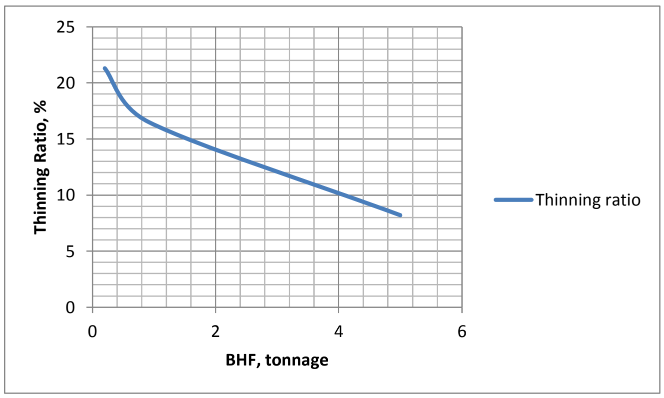


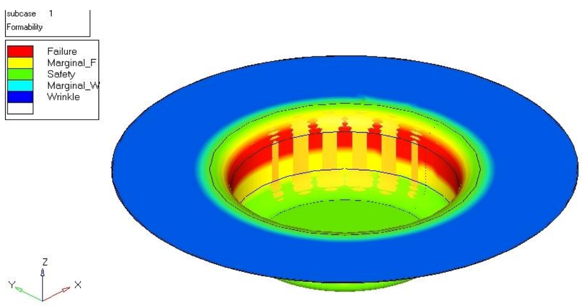
Figure 5.2 : Graph thinning ratio vs blank holder

The graph shown that if blankholder force increased, the thinning ratio decreased. It means that the wrinkling also increased towards the thinning ratio.

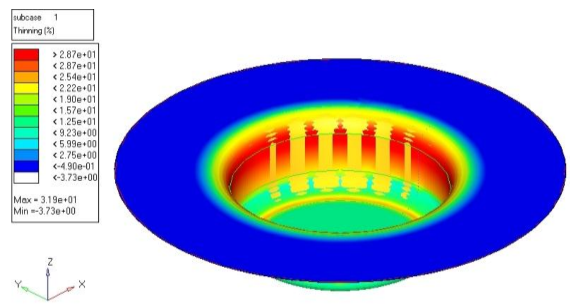
4.5 EFFECT OF SHEET THICKNESS ON FLANGE WRINKLING.

Sheet metal thickness is an essential parameter. As previous studies, with a thickness ratio of 5 % or under even a blankholder may not stop wrinkling. The figures below shows the simulation result of different sheet thickness but with same blankholder force (1.018 ton) and height of cup (20 mm).

i. <u>Thickness 1 mm</u>

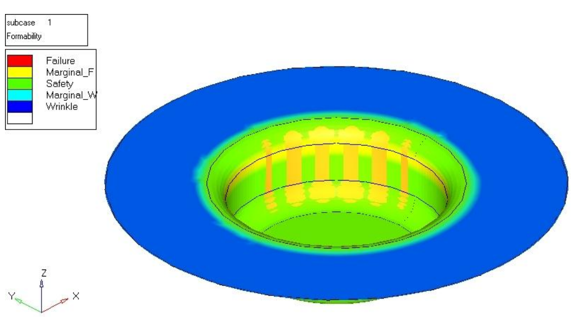


Formability result

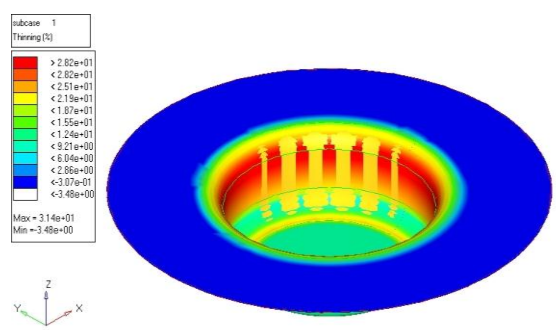


Thinning result

ii. <u>Thickness 2 mm</u>



Formability result



Thinning result

Figure 5.3 : Difference thickness result

4.5.1 Figure (a)

The figure (a) shows that the cup is designed with 20 mm height but using the same blankholder force and blank thickness. The cup is not formable as it shows the wrinkle on the top flange while the wall side of cup is failure (tearing). The value of major strain is high which is 0.7 megapascal. The thinning result shows that maximum 31.8% thinning which equal to 3.18 mm reduction of original thickness, there are high tearing on this part.

4.5.2 Figure (b)

The figure (b) shows that the cup is not formable as it shows that wrinkle occurred on the top flange but there are marginal failure at the wall side of cup. When the thickness is increase, the strength and stiffness of the material become increase. So it is hard for the material to tearing. The FLD shows that value of major strain is 0.7 megapascal and thinning ratio is 31.4 %. The part is almost become failure due to the high thinning ratio.

4.5.3 Sheet thickness VS Thinning ratio

The thinnest part thickness determines the maximum stress that can be transferred to the deformation zone. Thinning ratio increased, it shows that fracture limit also increased towards the thickness part.

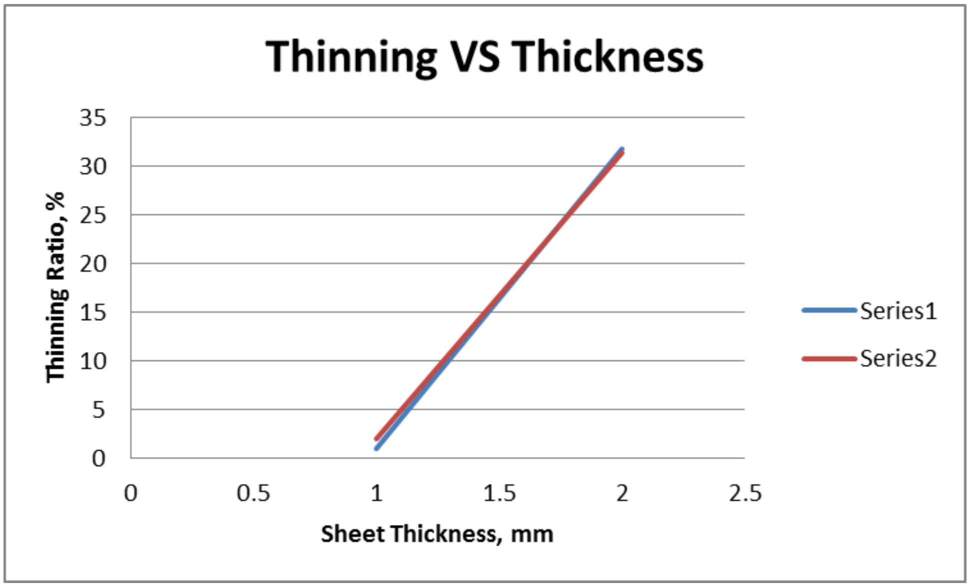


Figure 5.4 : Graph sheet thickness with thinning ratio

4.6 EFFECT OF BLANKHOLDER FORCE AND DRAWN DEPTH ON FLANGE WRINKLING.

From the previous study if the depth increased, the percentage of wrinkling also increased. Figures below shows the simulation result of variables blank holder force and drawn depth.

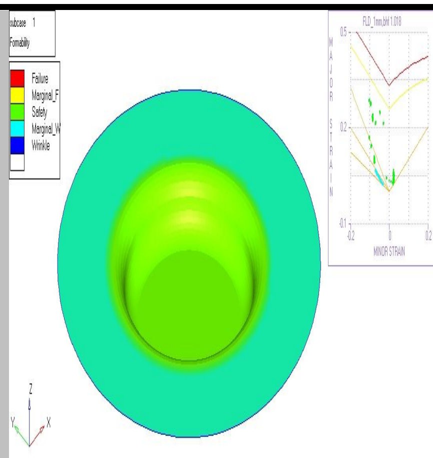
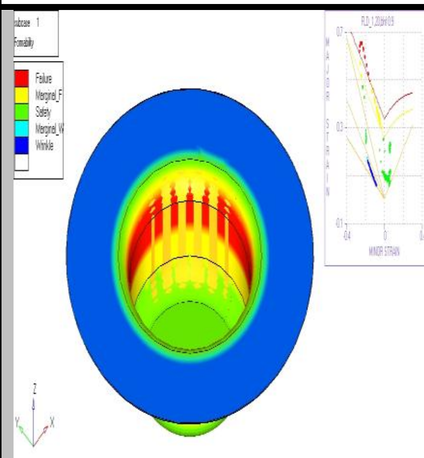
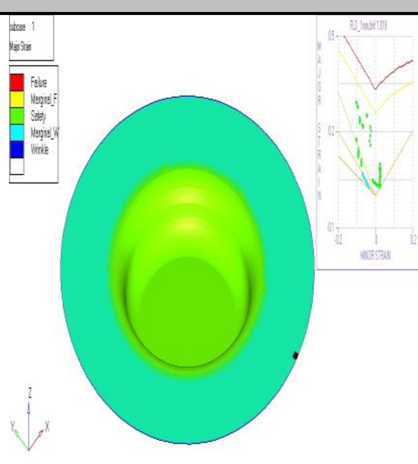
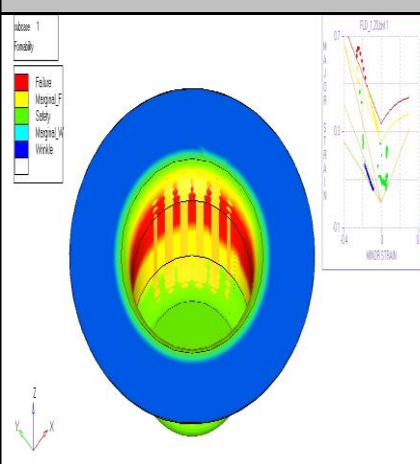
Depth drawing	**10 mm**	**20 mm**
Bhf = 0.918 ton		
Bhf = 1.018 ton		

Figure 5.5 : Difference depth result between 10 mm and 20 mm

As it can be seen in figure 5.4, in 0.918 ton blank holder case, the blank starts wrinkling in 10 mm punch depth and the wrinkling grows bigger as the punch progress to 20 mm depth. Figure for 20 mm depth also shows that tearing occur at the wall side cup and the formability of cup is failure. It means that depth 20 mm are not suitable for diameter 50 mm.

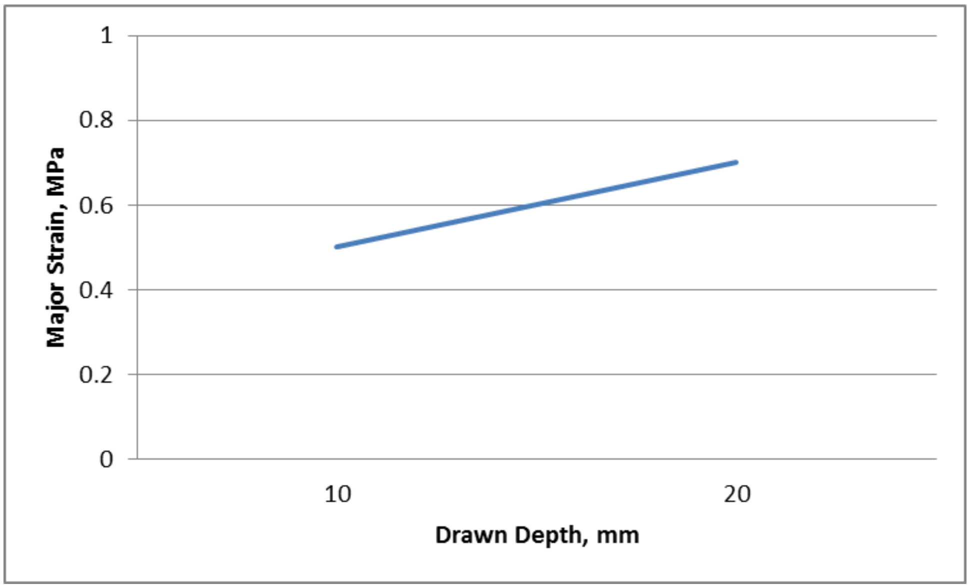


Figure 5.6 : Graph Drawn depth with Major strain

4.7 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

This project studies about what are the effect of blankholder force, thickness and drawn depth on the flange wrinkling using Finite Element Analysis. The use of FE analysis software tools has magnanimously enhanced ease in research work by saving on the time as well as expensive and extensive time consuming experimental tests. Once the analytical results compared to the preliminary experimental results conform, then sound basis is established for computer simulations and implementation in the final design of products without going into repeated experimentation. The results of current analysis will provide a basis for the simulation and analysis of wrinkle formation in different sheet metals under varying load applications. Based on analysis, all factors that were selected by using Finite Element Analysis (FEA) are related causes the flange wrinkling phenomenon and the most sensitive factor is blankholder force. In this study one step simulation is used for predicting wrinkling in deep drawing part. With this FEA, engineers, part and die designers are able to focus on the most sensitive factor to predict the wrinkling phenomenon, thus minimizing the time spent in trial and errors.

5.2 RECOMMENDATION

Following are the recommendation for future research :

a) Used a variety of material or a higher malleability material such as SPCC for the blank.
b) Used an incremental analysis which is very accurate and can solve other parameters.
c) Study on other parameters such as drawing force, friction, die clearance, and etc.

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APPENDIX A

GANTT CHART SEMESTER 7

UMP		Gantt chart for the final year project (Semester 7)													
Item	**Status**	**W1**	**W2**	**W3**	**W4**	**W5**	**W6**	**W7**	**W8**	**W9**	**W10**	**W11**	**W12**	**W13**	**W14**
FYP title	Plan														
Meeting with supervisor, Dr Noraini Razali	Actual														
Briefing about project scope and proposal															
Search and study related journal of the project	Plan														
Searching in ezproxy website	Actual														
Study Deep Drawing	Plan														
List out all parameters that influenced of wrinkling.	Actual														
Drafting	Plan														
Select the product and draft by Catia	Actual														
Writing Proposal	Plan														
Writing on chapter 1 : Introduction, chapter 2: literature review,	Actual														
and chapter 3: methodology															
Send proposal to the supervisor	Plan														
Complete the proposal	Actual														
Prepare slide presentation															
Do a Simulation	Plan														
Meet someone to study on how to do a simulation	Actual														
by some software.															
Finite Element Analysis	Plan														
Study on how to do a Finite Element Analysis from	Actual														
the simulation															

APPENDIX B

GANTT CHART SEMESTER 8

UMP	Gantt chart for the final year project (Semester 8)																
Item	**Status**	**W1**	**W2**	**W3**	**W4**	**W5**	**W6**	**W7**	**W8**	**W9**	**W10**	**W11**	**W12**	**W13**	**W14**	**W15**	**W16**
CATIA Drawing Draw a cylindrical cup and complete die with specification using CATIA	Plan Actual																
Parameters Calculation Calculate Blankholder force, punch force for simulation	Plan Actual																
Simulation Do simulation on the product using Altair Hyperwork	Plan Actual																
Finite Element Analysis Result Analyse FEA from Simulation result	Plan Actual																
Writing Final Report Writing on chapter 4 : Result, chapter 5: Conclusion and Recommendation	Plan Actual																
Validate with previous study Validate simualtion result with prevoius study	Plan Actual																
Send Final Report to Supervisor Completed Final Report and send to Supervisor	Plan Actual																
Final presentation for FYP Present all final work that have already done. Get ready for booth presentation.	Plan Actual																

Plan

Actual