EXPERIMENTAL STUDY OF FORMABILITY OF SHEET METAL IN DEEP DRAWING PROCESS

MUHAMMAD SAFWAN BIN ISMAIL

BACHELOR OF ENGINEERING

UNIVERSITI MALAYSIA PAHANG

2010

UNIVERSITI MALAYSIA PAHANG

BORANG PENGESAHAN STATUS TESIS♦

JUDUL: **EXPERIMENTAL STUDY OF FORMABILITY OF SHEET METAL IN DEEP DRAWING PROCESS**

SESI PENGAJIAN: **2010/2011**

Saya **MUHAMMAD SAFWAN BIN ISMAIL (881206-02-5223)**
(HURUF BESAR)

mengaku membenarkan tesis (Sarjana Muda/~~Sarjana /Doktor Falsafah~~)* ini disimpan di Perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Tesis adalah hakmilik Universiti Malaysia Pahang (UMP).
2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. **Sila tandakan (√)

[ ]	**SULIT**	(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)
[ ]	**TERHAD**	(Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)
[√]	**TIDAK TERHAD**	

Disahkan oleh:

____________________________	____________________________
(TANDATANGAN PENULIS)	(TANDATANGAN PENYELIA)
Alamat Tetap:	
NO. 55 LORONG 1, TAMAN PERUDA	**DAYANGKU NOORFAZIDAH BTE**
08000 SUNGAI PETANI	**AWANG SHRI**
KEDAH DARUL AMAN	(Nama Penyelia)
Tarikh: **30 MEI 2011**	Tarikh: **30 MEI 2011**

CATATAN:
* Potong yang tidak berkenaan.
** Jika tesis ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali tempoh tesis ini perlu dikelaskan sebagai atau TERHAD.
♦ Tesis dimaksudkan sebagai tesis bagi Ijazah doktor Falsafah dan Sarjana secara Penyelidikan, atau disertasi bagi pengajian secara kerja kursus dan penyelidikan, atau Laporan Projek Sarjana Muda (PSM).

UNIVERSITI MALAYSIA PAHANG

FACULTY OF MECHANICAL ENGINEERING

We certify that the project entitled "Experimental Study of Formability of Sheet Metal in Deep Drawing Process" is written by Muhammad Safwan bin Ismail. 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 Mechanical Engineering. We herewith recommend that if it be accepted in partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering.

(CHE KU EDDY NIZWAN BIN CHE KU HUSIN)

Examiner Signature

EXPERIMENTAL STUDY OF FORMABILITY OF SHEET METAL IN DEEP DRAWING PROCESS

MUHAMMAD SAFWAN BIN ISMAIL

Report submitted in partial fulfilment of the requirements
for the award of degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

MAY 2011

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature
Name of Supervisor: DAYANGKU NOORFAZIDAH BINTI AWANG SHRI
Position: LECTURER
Date: 30 MAY 2011

STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledge. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature
Name: MUHAMMAD SAFWAN BIN ISMAIL
ID Number: MA07047
Date: 30 MAY 2011

TABLE OF CONTENTS

Dedicated to my beloved parents

ACKNOWLEDGEMENTS

In the name of Allah, the most beneficence and the most merciful. Alhamdulillah, all praise to Allah for his blessing and love for me to complete the project by the given duration.

I would like to express my sincere gratitude to both of my supervisor, Mdm. Dayangku Noorfazidah binti Awang Sh’ri and Mr. Asnul Hadi bin Ahmad for their invaluable guidance, ideas, constant encouragement and continuous support in making this project possible. I am grateful for their consistent support throughout the project with their patience and knowledge whilst allowing me the room to work in my own. I would like to thank both of them for the time spent on proofreading and correcting the mistakes in the report.

Also, I acknowledge my sincere indebtedness to my parents Mr. Ismail bin Shaidan and Mdm. Siti Mariyam binti Shafie for their prayers, love, sacrifice and faith on me for throughout all of my life and also my siblings for their willingness to help in this project.

My sincere thanks also go to the technical staffs of UMP Faculty of Mechanical Engineering, who helped me in many ways especially in the operation of machines and equipments. I would also like to express my special thanks to Dr. Ahmad Syahrizan bin Sulaiman for his letting me used of his deep drawing die machine in metal forming laboratory and also Mr. Jasri bin Mohamad for his advises and ideas in my project. Not to be forgotten also Mr. Asmizam bin Mokhtar for his assistance in guiding me to cut the materials all the way throughout the project.

Last but not least, I would like to thank to my presentation’s panel members for their comment and suggestion on my project which was crucial for the successful completion of this study.

ABSTRACT

One of the most common outcomes in deep drawing process is a cup fractures that occur at the bottom of the cup shell. This cup fracture is cause by many parameters like blank holder force (BHF), blank diameter, friction between punch and blank, normal anisotropy of material, blank thickness and many more. The main objectives of the present study is to find the value of limiting drawing ratio (LDR) in LDR test and to predict the forming limit behaviour of sheet metal in deep drawing by construct a forming limit diagram (FLD) in FLD test for both aluminium AA1100 and copper. To determine the drawability of aluminium AA1100 and copper, LDR test with variable of blank diameters (80mm, 85mm, 90mm, 95mm and 100mm) and two set of BHF (with spring constant is 16.3 N/mm and 10 N/mm) was utilized. On the other hand, the parameters that have used in FLD test is variable of blank thickness (1mm and 0.6mm) and surface condition of a blank using aluminium AA1100 as a constant material. In surface condition of a blank, a lubricant have been added to investigate the effect of friction between blank and punch in deep drawing process. It is observed that higher blank diameter and BHF raises the value of LDR and thus increases the drawability of aluminium AA1100 sheet and copper sheet. For FLD test, the level of FLD is increasing with increasing of blank thickness of aluminium AA1100. Besides that, the present of lubricant also raised the level of FLD and thus lessen the tendency of aluminium AA1100 sheet to rupture. From both of the experiment, it can be concluded that the formability of sheet metal is increasing due to increasing of blank diameter, blank thickness, BHF and present of lubricant. Besides that, the formability of aluminium AA1100 sheet is better compare to copper sheet.

ABSTRAK

Salah satu hasil yang paling umum berlaku dalam penarikan dalam adalah keretakan cawan yang berlaku di bahagian bawah kulit cawan. Keretakan yang berlaku pada cawan ini disebabkan oleh pelbagai parameter seperti daya penahan bahan (BHF), diameter bahan, geseran antara penumbuk dengan bahan, anisotropi bahan, ketebalan bahan dan sebagainya. Objektif utama penyelidikan ini dijalankan adalah untuk mencari nilai nisbah penarikan terhad (LDR) di dalam ujian nisbah penarikan terhad dan juga untuk meramalkan perilaku had pembentukan lembaran logam dalam proses penarikan dalam dengan membina gambarajah had pembentukan lembaran logam (FLD) di dalam ujian FLD untuk kedua-dua bahan yang digunakan iaitu aluminium AA1100 dan juga kuprum. Untuk mengkaji keboleh tarikan lembaran logam aluminium AA1100 dan juga kuprum, ujian LDR telah dijalankan dengan menggunakan pemboleh ubah diameter bahan (80mm, 85mm, 90mm, 95mm dan 100mm) dan juga dua set BHF (dengan kemalaran spring 16.3 N/mm dan juga 10 N/mm). Di sudut yang lain pula, parameter yang telah digunakan di dalam ujian FLD adalah ketebalan lembaran logam (1mm dan 0.6mm) dan juga keadaan permukaan bahan dengan menggunakan bahan yang sama iaitu aluminium AA1100. Untuk keadaan permukaan bahan, satu pelincir telah digunakan bagi menyiasat kesan geseran antara lembaran logam dan juga penumbuk dalam proses peanarikan dalam. Daripada ujian LDR yang telah dijalankan, ianya dapat diperhatikan yang pengunaan diameter bahan yang besar dan juga BHF yang tinggi dapat meninggikan lagi keboleh tarikan lembaran logam aluminium AA1100 dan juga kuprum. Untuk ujian FLD, tahap sesebuah FLD akan meningkat sekiranya ketebalan lembaran logam aluminium AA1100 yang digunakan juga meningkat. Selain daripada itu, kehadiran pelincir juga akan meningkatkan lagi tahap FLD lembaran logam aluminium AA1100 seterusnya menunjukkan kecenderungan lembaran logam aluminium AA1100 untuk retak juga akan berkurang. Daripada pemerhatian kedua-dua eksperimen yang telah dijalankan ini, ianya dapat disimpulkan bahawa keboleh bentukkan lembaran logam sesebuah logam akan meningkat sekiranya diameter yang besar, ketebalan yang tinggi, BHF yang tinggi dan juga kehadiran pelincir digunakan. Selain daripada itu juga, keboleh bentukkan lembaran logam aluminium AA1100 juga adalah lebih tinggi berbanding lembaran logam kuprum.

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

D_1	Initial blank diameter before drawing process
$D_{0,cg(major)}$	Diameter of circle grid after deformation on major axis
$D_{0,cg(minor)}$	Diameter of circle grid before deformation on minor axis
D_0	Maximum diameter of successful formation of cup
$D_{1,cg(minor)}$	Diameter of circle grid after deformation on minor axis
$D_{1.cg(major)}$	Diameter of circle grid before deformation on major axis
F_i	Punch forces for subsequent drawing
F_p	Punch forces for first drawing
P_d	Blank holder pressure
$\bar{R}$	Normal anisotropy
R_d	Die corner radius
R_i	Punch corner radius
Y_0	Yield strength
d_1	Inside diameter of cup after the first drawing
d_i	Punch diameter
d_{s1}	Mean diameter of cup after the first drawing
ε_1	Minor strain
ε_2	Major strain
µ	Coefficient of friction
a	Radius of punch
b	Radius of specimens
c	Clearance
F	Maximum drawing force

K	Limiting drawing ratio
k	Spring constant
n	Strain hardening exponent
v	Speed of punch
t	Material thickness

LIST OF ABBREVIATIONS

AA1100	Aluminium alloy grade 1100
Ag	Silver
Al	Aluminium
As	Arsenic
Be	Beryllium
BHF	Blank holder force
BHP	Blank holder pressure
Cd	Cadmium
CNC	Computer numerical control
Co	Cobalt
Cr	Chromium
Cu	Copper
EDM	Electric discharge machine
FCC	Face-centred cubic
Fe	Iron
FLD	Forming limit diagram
Ga	Gallium
LDR	Limiting drawing ratio
Mg	Magnesium
M-K	Marciniak and Kuczynski
Mn	Manganese
Ni	Nickel
Pb	Lead

Sb	Antimony
Si	Silicon
Sn	Tin
Ti	Titanium
UTS	Ultimate tensile strength
V	Vanadium
Zn	Zinc

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION TO DEEP DRAWING PROCESS

Deep drawing process is a sheet metal forming process where a punch is utilized to force a flat sheet metal to flow into the gap between the punch and die surfaces. As a result, the sheet metal or blank will deformed into desired shape like cylindrical, conic, or boxed-shaped part and also complex parts which normally require redrawing processes by using progressive dies. Deep drawing is a popular selection due to its rapid press cycle times. Its capability of producing complicated shaped and geometries with low labours requirement is also an advantage in manufacturing industries (Boljanovic, 2004). A few examples of deep drawing applications that is widely use nowadays include beverage cans, automotive bodies, aircraft panels and sinks.

The important variables which affect the formability of sheet metal in deep drawing process can be divided into two categories: Material and friction factors; and tooling and equipment factors. With the right and proper selection of these variables, the formability of the material can be process at its optimum result and reducing the defects in deep drawing process like fracture, wrinkling and earing (Tzou et al., 2007).

Sheet metal forming process is used for both serial and mass production. Their characteristics are high productivity, highly efficient use for material, easy servicing machines, the ability to employ workers with relatively less basic skills and other advantageous economic aspects. Part that made from sheet metal has many attractive qualities: Good accuracy of dimension, adequate strength, light weight and a broad range of possible dimensions (Boljanovic, 2008).

1.2 PROBLEM STATEMENT

In many cases after the sheet metal was successful draw in deep drawing process, the fracture at the shell of the specimens always occurred and thus cause the defects on the product. It is one of the most common undesired outcomes in deep drawing because if this happen, the product is in defects condition and the deep drawing process must be redone again using another specimen. This fracture is caused by excessive punch force, excessive blank holder force, excessive friction between blank and tooling, insufficient clearance between punch and die and insufficient punch or die corner radius. Hence, many experimental work that have been done lately to prevent or reduce this fracture when running a deep drawing process. The common method that have been use to investigate the formability of sheet metal in deep drawing process is by calculate the limiting drawing ratio (LDR) of sheet metal to investigate their drawability and the other method is by construct the forming limit diagram (FLD) of sheet metal to predict their formability behaviour during deep drawing operations.

1.3 PROJECT OBJECTIVES

1) To investigate the effect of variable blank diameter and blank holder force on LDR for aluminium AA1100 and copper.
2) To predict the forming limit of aluminium AA1100 with variable of blank thickness and effect of lubricant by construct the FLD diagram.

1.4 SCOPES OF THE PROJECT

1) To conduct an experimental study of deep drawing process by using a deep drawing machine with supported of hydraulic press machine.
2) The punch diameter that was used is 50 mm with punch and die corner radii of 6.36 mm.
3) Blank material that was used is aluminium AA1100 and copper that is widely uses nowadays in deep drawing process.
4) Blank diameters that was used is 80 mm, 85 mm, 90 mm, 95 mm and 100 mm in LDR study.

5) Blank diameter was cut using electric discharge machine (EDM) wirecut because of its cutting precise.
6) The blank holder force that was used in present study is 16.3 N/mm and 10 N/mm.
7) Blank thickness is 1 mm and 0.6 mm with the diameter of 95 mm for Aluminium AA1100 in FLD study.
8) The diameter of circle grid that was used in FLD test is 2 mm according from previous studies.
9) Lubricant that was used in LDR and FLD test is Lithium grease.

CHAPTER 2

LITERATURE REVIEW

2.1 SHEET METAL

Sheet metal is one of the most important semi finished products used in the steel industry, and sheet metal forming technology is therefore an important engineering discipline within the area of mechanical engineering. Sheet metal is characterized by high ratio of surface to thickness. Sheet metal forming is basically conversion of flat sheet metal into a product of desired shape without defect like fracture or excessive localised thinning (Gardeen and Daudi, 1983).

The products made by sheet metal forming processes include a large variety of shapes and sizes, ranging from simple bends to double curvatures with shallow or deep recesses. Typical examples are metal desks, appliance bodies, aircraft panels, beverage cans, auto bodies, and kitchen utensils. In many cases while deforming the sheet metal, the component fractures at certain point. The causes of failure are parameters related to forming process. The sheet metal is available as flat pieces. The sheet metals are formed by running continuous sheet of metal through a roll slitter. The sheet metal thickness is called gauge and the gauge of sheet metal ranges from 30 gauges to 8 gauges. The thinner the metal is, the higher of gauge.

There are many application that using sheet metal like car bodies, airplane wings, roofs, lab table and many more. In automobiles the sheet metal is deformed into the desired and brought into the required form to get car part body pressings like bonnet, bumpers, doors, etc. In aircraft’s sheet metal is used for making the entire fuselage wings and body. In domestic applications sheet metal is used for making many parts like washing machine body and covers, iron tops, timepiece cases, fan blades, cooking utensils and etc.

2.2 DEEP DRAWING PROCESS

Deep drawing is a manufacturing process of forming sheet metal stock, called blanks, into geometrical or irregular shapes that are more than half their diameters in depth. Deep drawing involves stretching the metal blank around a plug and then moving it into a moulding cutter called a die. Common shapes of deep drawn products including cylinders for Aluminium cans and cups for baking pans. Irregular items, such as enclosure covers for truck oil filters and fire extinguishers, are also commonly manufactured by the deep drawing method.

The drawing of sheet metal or commonly known as deep drawing is a process which a punch is used to force a sheet metal to flow between the surfaces of a punch a die. As a result, a cylindrical, conical or box-shaped part is formed in the die with minimal material scrap (Boljanovic, 2004). In this process, a flat sheet metal was kept under a blank holder force (BHF). The blank holder should allow the material to slide into the die surface but at the same time, that force must be a great enough to prevent wrinkling of the sheet as it drawn as shown in Figure 2.1. The punch transferred the force through the punch and thus the punch transmits the force through the walls of the cup as it drawn into the die cavity (Singh, 2008).

In deep drawing process, it can be divided into two types that is pure bending and ironing. Pure bending is type of deep drawing without a reduction in the thickness of the workpiece material while in ironing, it a deep drawing with a reduction in the thickness of the workpiece material (Boljanovic, 2004). A schematic illustration of these two types of deep drawing is shown in Figure 2.2. From the Figure 2.1, it is clear that the basic tools for deep drawing are the punch, the drawing die ring, and the blank holder. However, some products cannot be drawn in a single draw and requires secondary drawing that is redrawing process. As a result, the design of the die will be more complicated as a progressive die is normally required to allow multiple drawing operations under one production line.

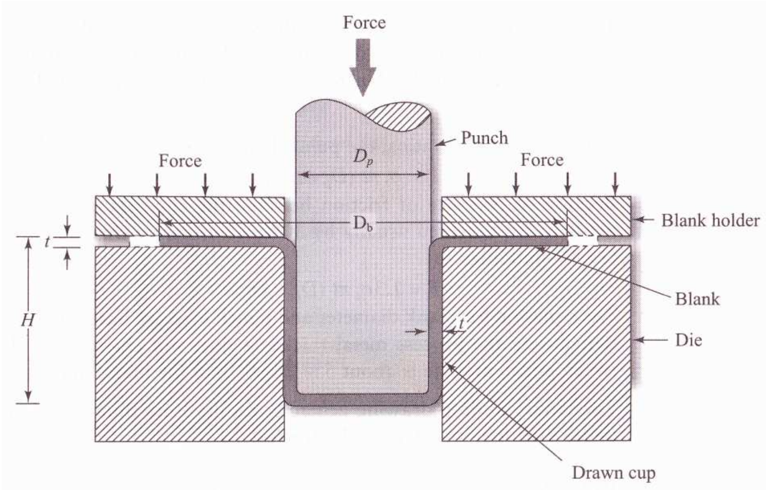


Figure 2.1: A deep drawing operation

Source: Singh, 2008

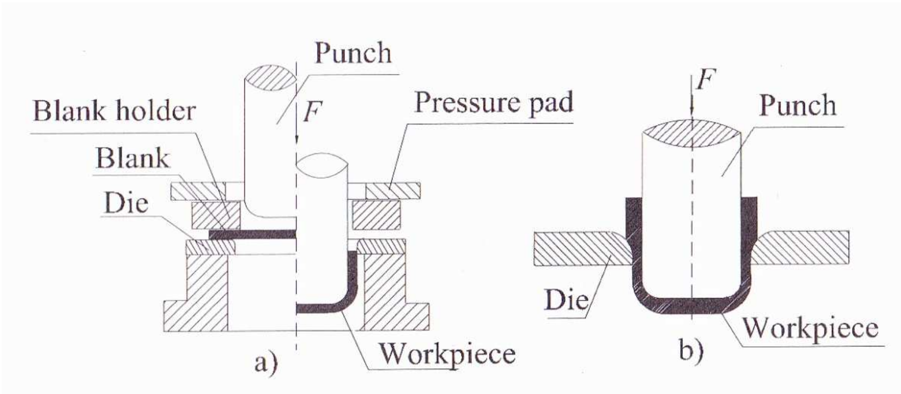


Figure 2.2: Schematic illustration of deep drawing process: (a) Pure Bending; (b) Ironing

Source: Boljanovic, 2004

A percentage reduction of 48% is considered excellent on the first draw. Succeeding draws are smaller. There should be no appreciable change in the thickness of the material between the blank and the finished part.

Results of deep drawing are mostly empirical in nature and research has been done only limited almost exclusively to the drawing of cylindrical cup. For other shapes theoretical analysis is too much complicated and has no practical significance (Singh, 2008).

In deep drawing process, there are several factors that can be affected the process which are categorized into two groups: Material and friction factors, and tool and equipment factors. Thus it is important before running the deep drawing process, these factors was considered well to prevent an undesirable result like earing, fracturing, and wrinkling.

In Figure 2.3, it shows clearly these two factors (material and friction, tool and equipment) that need to consider in deep drawing process. Recently more studies have been develop by refer to these factors in order make an improvement while running deep drawing process.

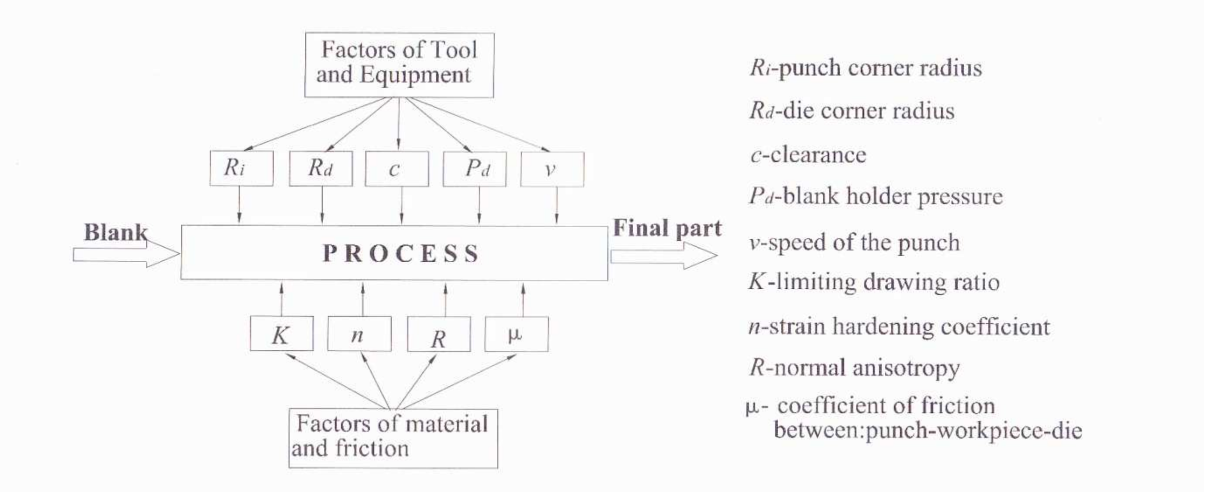


Figure 2.3: Significant variables in deep drawing

Source: Boljanovic, 2004

2.3 FORMABILITY TEST

Sheet metal formability is undergoing a transition from art to science. Formability within each forming mode can be related to specific metal formability parameters. The successful sheet metal forming process which is can be converts initially from flat to desired shape. There are many major failures that always happened such as splitting, wrinkling or shape distortion. The formability test is use to access of sheet to be deformed into useful part (Wick et al., 1998).

The testing can be divided into two types: Intrinsic and simulative. The intrinsic tests measure the basic material properties under certain stress strain states, for example the uniaxial tensile test and the plane strain tensile test. Traditional evaluation of formability is based on both intrinsic tests and simulative tests. The intrinsic tests measure the basic characteristic properties of materials that can be related to their formability. These tests provide comprehensive information that is insensitive to the thickness and surface condition of the material. Examples of intrinsic tests are Hydraulic Bulge test, Marciniak In-Plane Sheet torsion test, and Miyauchi shear test. The simulative test can provide limited specific information that may be sensitive to factors other than material properties like the thickness, surface condition, surface lubrication and etc. Subject the material to deformation that closely resembles the deformation that occurs in a particular forming operation. Examples of these tests include Ericksen, Olsen, Fukui and Swift Cup Tests (Wagoner and Chenot, 2001).

2.4 SHEET METAL FORMING IN SWIFT CUP TEST

The Swift Cup test is usually considered to provide a measure of the drawability of sheet metal. A schematic representation in Swift Cup test is shown in Figure 2.4. A disc-shaped sheet specimen of metal is placed between the blank holder and the die and then it is drawn into a cup by a cylindrical punch. A cup with a cylindrical shape will be form after that. Various shapes were proposed by Swift for the bottom of the punch, but in the present study only flat-ended punches will be consider (Budiansky and Wang, 1966).

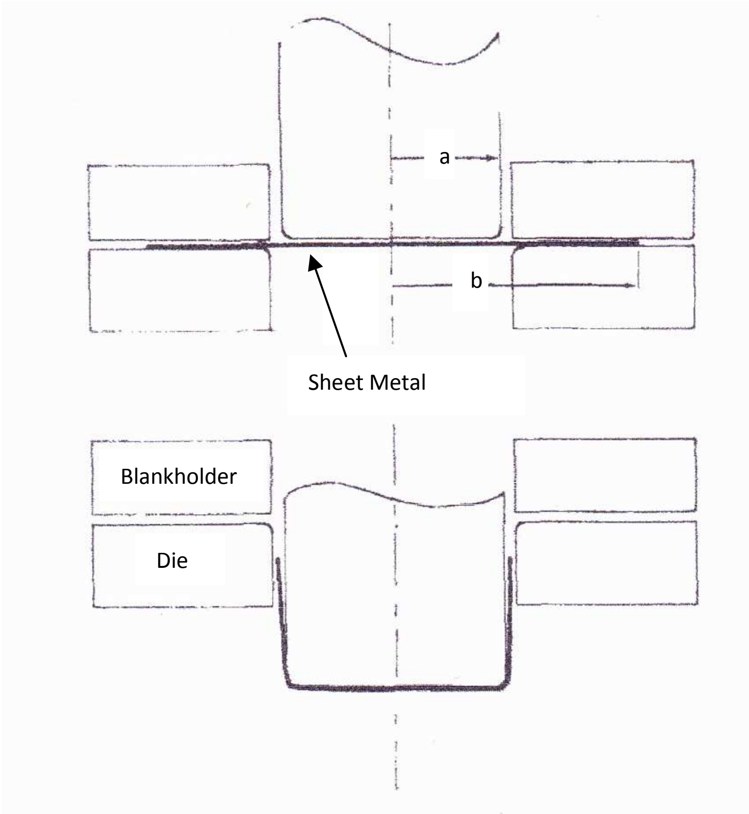


Figure 2.4: Schematic representation of Swift cup test

Source: Budiansky and Wang, 1966

Let the radius of the punch and the radius of the specimen be *a* and *b* respectively. Then the ratio between these two radius that also known as drawing ratio, can be write as *b*/*a*. One of the principal objectives of the Swift Cup test is to determine the limiting drawing ration, LDR which is defined as the largest drawing ratio from which a cup can be drawn without fracture. The better drawing materials are recognized as those having the higher LDR's.

The result in Swift Cup test is correlates well with the performance of sheet metal in deep drawing components. It can be tested with a variable size of sheet metal blank by increasing the diameter. The maximum blank size that can be drawn without fracture occurring over the punch nose can be uses to calculate the LDR's. Because the condition of the edge of each blank can have an important effect on the test result, the blank edges usually turned in a lathe to ensure strain-free, hurt-free edges (Khoruddin, 2009).

2.5 LIMITING DRAWING RATIO

The limiting drawing ratio (LDR), is commonly used to provide a measure of the drawability of sheet metal. The correlation of the LDR of a sheet metal with its material properties and process parameters has been activated by industrial necessity for improving drawability (Leu, 1999).

LDR is a ratio between the maximum blank diameter that can be drawn successfully to the cup diameter, is often taken measure as measure of drawability (Verma and Chandra, 2006). The drawability of sheet metal or LDR can be determined from different diameters of blanks with constant thickness. The LDR can be expressed as shown in Equation 2.1.

$$LDR = {}^{D_1}/_{D_o} \tag{2.1}$$

Where,

$D_0 =$ Maximum diameter of successful formation of cup

$D_1 =$ Initial blank diamater berfore drawing process

The blank diameter or sheet metal diameter is one of the most important parameter that have to consider in determine the LDR. Theoretically, the bigger the blank diameter it is, the higher value of LDR (Verma and Chandra, 2006). It means the blank with high value of LDR is a good material to consider in deep drawing process.

Many researchers have studied the effect of normal anisotropy, $\bar{R}$, and strain hardening exponent, *n*, on the limiting drawing ratio using either the experimental studies or the numerical models. The anisotropy is important in symmetrical draws was first shown by Whiteley (1960) and that research that has been done by Whiteley was used widely nowadays. Whiteley state that the LDR depends on $\bar{R}$. The higher $\bar{R}$, the better is the LDR. It was also concluded that LDR does not depend in any significant manner on the strain hardening exponent. Similar conclusions were also reached by several experimental investigations (Verma and Chandra, 2006).

Table 2.1: LDR values from previous studies

Material	**LDR (calculated)**	**LDR (experimental)**
Steel CA-DDQ	2.3025	2.1805
Steel BA-DDQ	2.2135	2.1805
Steel BA-CQ2	2.2575	2.1758
Mild Steels	2.4246	2.2486

Adapted from: Leu (1999)

Nevertheless, sheet metal with higher average strain value such as alpha-titanium are generally more desirable in deep drawing due to its higher formability. However, in actual applications, the price of the material needs to be considered to keep production cost realistic. In addition, the planar anisotropy also needs to be considered as it would affect the formation of ears.

Most of the deep-drawn products today are usually made of steel and aluminium alloys as they have higher formability and lower price compared to the other metals such as copper and tin. The high strength stiffness to weight ratio, good formability and good corrosion resistance of aluminium alloys make it an ideal candidate to replace heavier materials such as steel in fulfilling the weight reduction demand in automotive industry (Miller et al., 2000)

2.6 FORMING LIMIT DIAGRAM

2.6.1 Concept of Forming Limit Diagram

The concept of forming limit diagram (FLD) was introduced by Keeler (1965) and Goodwin (1968) which represents the first safety criterion for deep drawing operation. Marciniak and Kuczynski (M-K) 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 (Slota and Spisak, 2005). 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 (Elangovan and Narayanan, 2010).

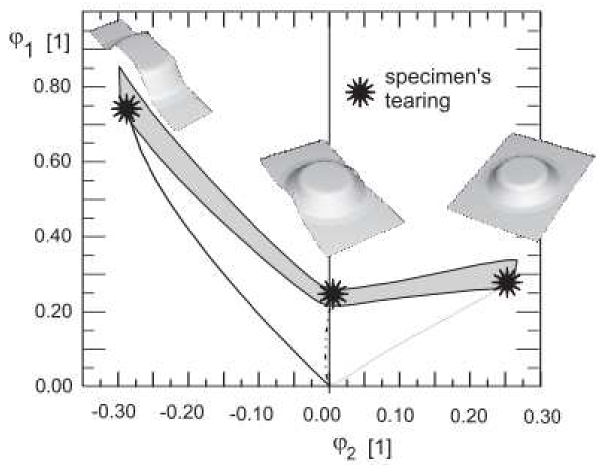


Figure 2.5: Example of FLD in sheet metal forming

Source: Pepelnjak and Kuzman, 2007

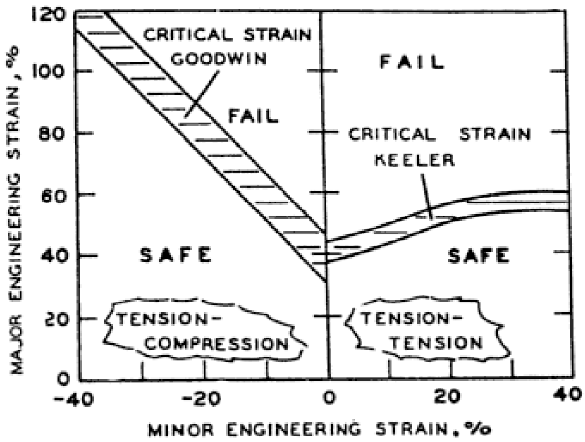


Figure 2.6: Forming limit diagram defined by Keeler and Goodwin.

Source: Banabic et al., 2000

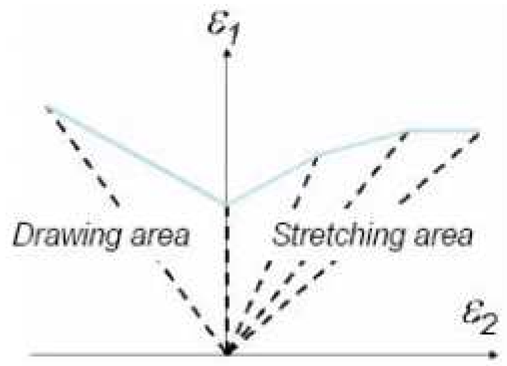


Figure 2.7: Forming limit diagram principle

Source: Chinouilh et al., 2008

The first pioneer works of the experimental determination of FLD by Keeler and Goodwin were followed by numerous research activities ranging from improved methods for experimental determination of FLD to analytical concepts allowing the calculation of FLD up to numerical approaches which are based on the simulations of various testing methods in digital environment (Pepelnjak and Kuzman, 2007).

Among several developed experimental tests, there are two experiments which have shown exceptional suitability for the evaluation of the entire range of FLD combined with simple tooling and experimental procedure that is Nakazima and Marciniak test. Marciniak (1973) has proposed a method for determination of the FLD with a flat punch (Banabic et al., 2000). The test tool consists of the drawing die, the blank holder and the punch. The punch has an even and partially sunk forehead. Various strain conditions are achieved by different widths of the analysed specimens which enable the determination of the entire range of FLD with one tool geometry only. During the testing procedure the even punch forehead causes the plane strain conditions in the analysed specimen area (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 and Narayanan (2007) has done the test with variable blank thickness with IF steels as a material while Assempour et al. (2008) has done the experiment with variable size of diameter with ST12 low carbon steel as a material.

Table 2.2: Parameter that have been used in FLD experiment from previous studies

Material	Blank Diameter (mm)	Blank Thickness (mm)
IF Steels [1]	80	0.6, 0.9, 1.2, 1.6
Low Carbon Steels ST12 [2]	80, 90, 100	2.5

Adapted From: [1]Narayanasamy and Narayanan, 2007; [2]Assempour et al., 2008

2.5.2 Calculation for Forming Limit Diagram

The circle grid is the first methods that have been done by Keeler (1964) and Goodwin (1968) to evaluate the FLD. The circle grid will show the deformation of sheet metal after through the deep drawing process. The difference between diameter length of the circle before and after deformation can be recorded to evaluate the FLD. The major strain, ε_1 and minor strain, ε_2 of the blank can be calculated by using the formula as shown in Equation 2.2 and 2.3.

$$Major\ Strain, \varepsilon_1 = \frac{D_{1.cg(major)} - D_{0,cg(major)}}{D_{0,cg(major)}} \tag{2.2}$$

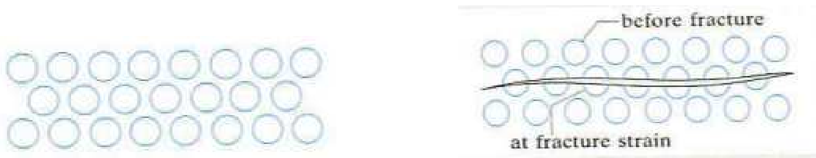
$$Minor\ Strain, \varepsilon_2 = \frac{D_{1,cg(minor)} - D_{0,cg(minor)}}{D_{0,cg(minor)}} \tag{2.3}$$

Where,

$D_0 =$ Diameter of circle grid before deformation (mm)

$D_1 =$ Diameter of circle grid after deformation (mm)

Before running the deep drawing process, the sheet metal or blank was marked with a close packed array of circles grid. This circle grid was important at the place where the deformation of sheet metal will deform because it can see clearly at that circle the deformation of the circle. Common length of circle grid that have been used in FLD test is ranging from 2mm to 8mm.



(a) (b)

Figure 2.8: Example of circle grid in FLD: (a) Before deformation; (b) After deformation

Source: Udomphol, 2007

Figure 2.8 show that a rupture of material after undergoes a deep drawing process. The rupture of the specimens occur because of the elongation of the material may pass the limit of its plasticity limit (Craig, 2000). The circles nearest to the fracture line gives the strain ratio at the critical point (Schey, 2000).

When the die is punch the blank into desired shape, the deformation of the circle grid will resulting the stretching the circles into ellipse. The circle grid will deform into two types that is major strain (ε_1) and minor strain (ε_2). The example of these two strains is shown in Figure 2.8.

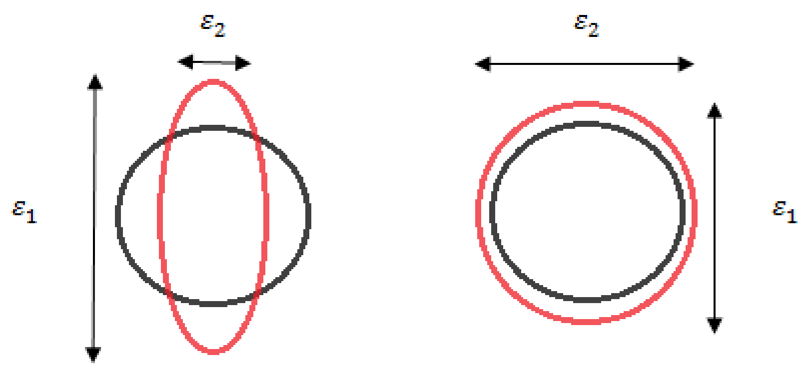


Figure 2.9: Circle grid before and after deformation: (a) Drawing area; (b) Stretch area

Adapted from: Udomphol, 2007

In figure 2.9, the black circle shows the original shape of circle grid before undergo a deformation while red circle shows the new shape of circle grid after undergo the deformation.

The reading of both major and minor strain in the deep drawing process can be recorded on FLD which can be used to predict the formability of sheet metal.

2.7 PUNCH FORCES

The first deep drawing operation is not a steady-state process. The punch force needs to supply the various types of work required in deep drawing, such as the ideal work of deformation, redundant work, friction work and the work required for ironing. The punch forces can be divided between the first drawing operation and the following drawing operations (Boljanovic, 2004).

2.7.1 First Drawing Operation

In deep drawing process, the first drawing process is very important because the force that has been given by punch is difference to following drawing operations. The first drawing punch forces can be calculated by formula as shown in Equation 2.4.

$$F_p = 1.1k \ln \frac{D_1}{d_{s1}} \tag{2.4}$$

Where,

F_p = Punch forces for first drawing $\left({}^{\mathrm{N}}/_{\mathrm{m}^2}\right)$

D_1 = Initial diameter of blank before drawing process (mm)

d_{s1} = Mean diameter of cup after the first drawing (mm)

d_1 = Inside diameter of cup after the first drawing (mm)

2.7.2 Subsequent Drawing Operation

Subsequent drawing operations are different from the first drawing operation because in deep drawing process, the flange diameter will decrease however the zone of plastic deformation does not change due to steady-state process. The punch force for the next drawing operation can be calculated as in Equation 2.5.

$$F_i = \pi d_i t(UTS) \left[\frac{D_1}{d_i} - 0.7\right] \tag{2.5}$$

Where,

F_i = Punch forces for subsequent drawing $({}^{\mathrm{N}}/_{\mathrm{m}^2})$

d_i = Punch diameter (mm)

D_1 = Blank diameter (mm)

t = Material thickness (mm)

2.8 FRACTURE IN DEEP DRAWING

Shell fracture is one of the outcomes commonly observed in deep drawing process. Shell fracture is a fracture that occur on the cup on the sheet metal or blank after through the deep drawing process. Shell fracture in deep drawing is caused by excessive punch load on the blank that has resulted from several factors like excessive punch force (BHF), excessive blank holder force, excessive friction between blank and punch, insufficient clearance between punch and die and insufficient punch or die corner radius. An example of shell fracture is shown in Figure 2.10.

Figure 2.10: Shell fracture of sheet metal after went through deep drawing process.

Source: Yoshihara et al., 2005

Excessive punch force would result in shell fracture directly as it increase the load on the blank, causing the shell to tear or fracture once it exceeds the material plastic limit. Thus, the determination of the suitable punch force is crucial to ensure sufficient force is provided for a given deep drawing operation, and yet not too high to cause fracture. From the previous studies that has been studied by Korhenen (1982), it is can be calculated the maximum drawing force as shown in Equation 2.6. It was observed that for a constant thickness, the required punch force increases when the punch diameter is increase. The punch and die corner radius does not affect the maximum punch force significantly if they are at least 10 times greater than the blank thickness. The fracture toughness and allowable flaw size of materials is decreases with the increases of the materials yield strength (Hertzberg, 1996).

$$F = \left(\frac{1+R}{\sqrt{1+2R}}\right)^{1+n} \times UTS \times \pi D_1 \times t \tag{2.6}$$

Where,

F = Maximum drawing force $\left({}^{\mathrm{N}}/_{\mathrm{m}^2}\right)$

R = Strain ratio

D_1 = Blank diameter before drawing process (m)

n = Strain hardening coefficient

t = Blank thickness (m)

Besides that, excessive BHF will also result in shell fracture as it would result in excessive friction between blank and die, which would increase the punch load causing the shell fracture as it exceeds its plastic limit. Figure 2.11 simplified the effect of BHF in deep drawing process as it is exceeds or insufficient due to displacement of punch.

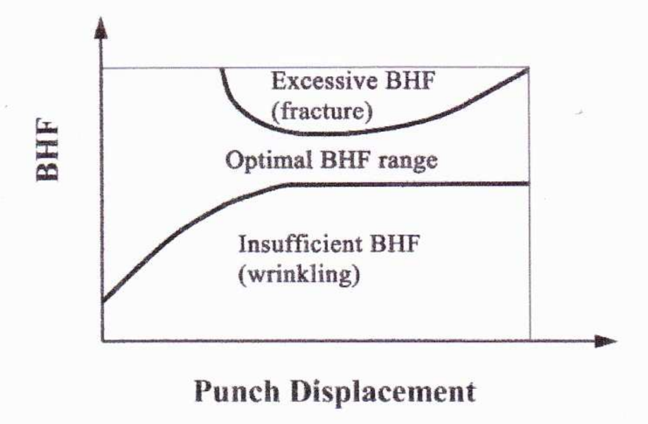


Figure 2.11: Effect of BHF in deep drawing

Source: Obermeyer and Majlessi, 1998

As for the punch and die corner radius, it can be sees that too small of a punch or die corner radius, R_i will cause excessive thinning and tearing at the bottom of the cup (Rao, 1999). If the radii are too small, the required force to draw the blank will be increased. This causes the tensile stresses in the radial direction on the cup wall to increase until a certain extent where it will cause the cup to tear at the critical region, which is at the bottom corner of the cup. Hence, it is customary to provide punch corner radius of 4 – 10 times of blank thickness.

Furthermore, the LDR also one of the main factor that causes the fracture of cup in deep drawing process. This is because of punch-to-blank diameter ratio exceeds the LDR for the material in a single draw. This is due to the fact that deep drawing is independent on the ductility of the blank, which is affected by the amount of strain.

When the fracture of shell happen, the other defects which is occur in deep drawing process also will happen (Moshksar and Zamanian, 1997). The fracture due to excessive drawing speed is caused by inadequate flow of material in the deep drawing pocess. However, too low of a drawing speed will result in reduced the production rate. From previous studies, Browne and Hillary (2003) used drawing speeds of 0.1 – 0.3 m/min for drawing of C.R.1 steel cups of 39.3mm diameter using blanks of 72.28mm diameter and 0.9mm thick.

2.9 DEFECTS IN DEEP DRAWING

In deep drawing process, there are several defects which is occurred after the deep drawing process like wrinkling, earing, excessive thinning of cup and rupture of the blank. The defects usually occur due to unsuitable or non-optimal variables in deep drawing process. Thus, in the designing the deep drawing die and run the experiment, these defects which is occur must be avoided in order to take an ideal result from the experiment.

2.9.1 Wrinkling

Wrinkling is one of the major defects that occur in sheet metal forming by conventional deep drawing process. Wrinkling may be a serious obstacle to a successful forming process and to the assembly of parts, and may also play a significant role in the wear of tool. In order to improve productivity and the quality of products, wrinkling must be avoided. Wrinkling is a kind of buckling phenomenon that prevents from forming of the sheet. If the buckling take place in flange area it is well known as well as it is called puckering if take place on the wall of the cup (Ziaeipoor et al., 2008). The schematic diagram in Figure 2.12 shows the mechanism of wrinkling initiation and growth in the cylindrical cup deep drawing process and Figure 2.13 shows example of wrinkling after deep drawing test.

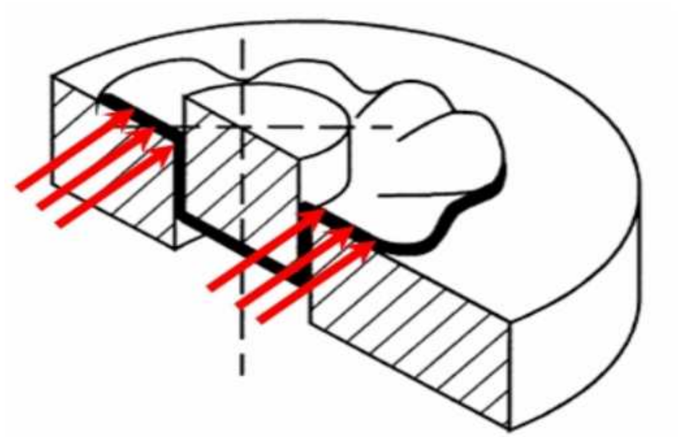


Figure 2.12: The mechanism of wrinkling initiation in the flange area of the cup

Source: Ziaeipoor et al., 2008

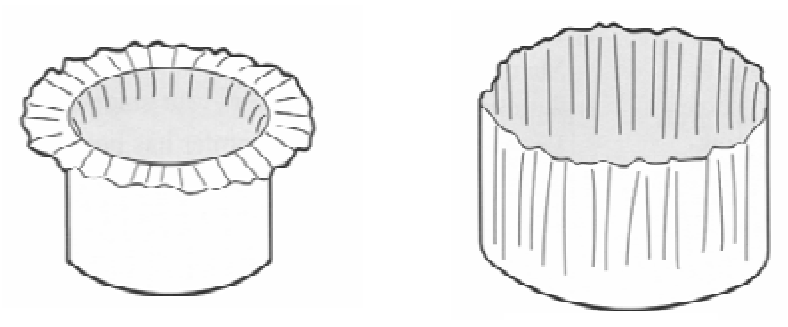
Figure 2.13: Example of wrinkling

Source: Schnakovszky and Ganea, 2007

During the deep drawing process, the sheet under the blank holder is drawn into the deformation zone by the punch. As a result, compressive hoop stress and thus wrinkling can be developed in the sheet metal under the holder (flange wrinkling) as well as those in the side wall, as wrinkling is a phenomenon of compressive instability. The magnitude of the compressive stress necessary to initiate the side- wall wrinkling is usually smaller than that for the flange wrinkling since the wall is relatively unsupported. Hence, the formation of side-wall wrinkles is relatively easier especially when the ratio of the unsupported dimension to sheet thickness is large (Cao and Wang, 1999).

There are several factors that leads to the wrinkling formation like the retaining force of the blank, the geometrical parameters of the die, the frictions that appear during deep-drawing between the blank and the work elements of the die, the material characteristics and anisotropy, the contact conditions, the part geometry, the mechanical properties of the material, the imperfections in the structure and the initial state of internal tensions of the material, etc. (Schnakovszky and Ganea, 2007).

The wrinkling which is occurs in deep drawing process can be divided into two types that is corrugation which is flange instability and bending over that is the instability in the body of the piece. The phenomenon of wrinkling is specific to the process of deep drawing and also depend on the position in the piece in which it occurs.



(a) (b)

Figure 2.14: Wrinkling types: (a) Corrugation; (b) Bending over

Source: Schnakovszky and Ganea, 2007

Usually, the retaining force has to increase along with the increase of the deep drawing depth but it has to take note that if its value is too big it can lead to cracks and even a break of the material. The main geometric parameters of the die which influence the wrinkling is the diameter of the punch. In the case of friction between the piece and the tool, the increase of the coefficient of friction determines the wrinkling to reduce but high value of the coefficient can cause cracks and material breakage (Schnakovszky and Ganea, 2007).

2.9.2 Earing

Earing is one of the defects which is commonly observed in deep drawing process. By definition, earing is uneven height at the edge of a drawn product, forming a series of peak and valleys along its circumference. Kishor and Kumar (2002) defined earing is the formation of waviness on the top of the drawn cup. The numbers of ears formed is commonly four (Hosford and Caddell, 2007), but might also be two, six or eight, depending on thermo-mechanical processing and microstructure of the sheet (Engler and Hirsch, 2007).

Figure 2.15: Earing in deep drawing

Source: Engler and Hirsch, 2007

During deep drawing, the sheet metal is subjected to different amount of plastic strain for each angle relative to rolling direction, which causes different amount of elongation resulting in formation or ears. The difference in amount of elongation resulting in formation of ears. The difference in amount of plastic deformation in different angle is due to anisotropic properties of material. Earing in deep drawing is usually not desirable as the ears serves no purpose and will have to cut off, resulting in loss of material, production rate and increase in production costs (Kishor and Kumar, 2002).

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter describes the methods that will be used in aiding with the research based on the scope that had been given. Other than that, the methodology of the project and the flow chart of the project will be described in this chapter. In deciding the best method to conduct the experiments, a review on the limitations and problematic areas in deep drawing is described and documented. Thus, the review will clarify the problems that will occur during this project. The processes are illustrated in the flow chart in section 3.2.

3.2 PROCEDURES

In Figure 3.1, it is illustrate the flow of this project according to the scope given from it starts until end. This flow chart will determine the method to accomplish the main objectives of this project and will ensure this project is success. The process flow of the project is represented by the flow chart in Figure 3.1. Initially, the first step is to identify the problem statements, objectives and scope of the project. The problem statement will be based on the literature review on the issues concerning the problematic area in deep drawing process. Based on the objectives given the related information will be taken into account and will be analyze to meet the required need of the main objectives of this project. In the flow chart, to determine best parameters that concerning in deep drawing process was mainly based on previous studies.

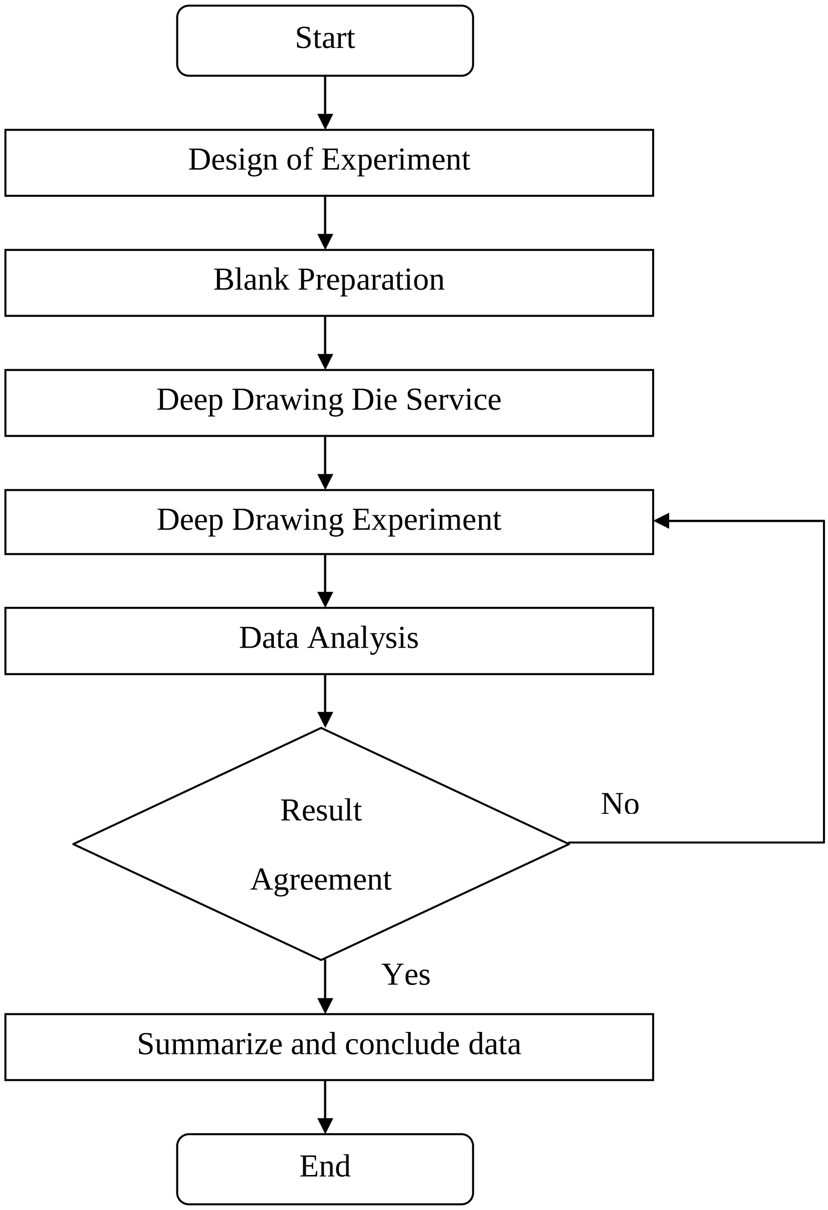


Figure 3.1: Methodology flow chart for the present study

3.3 DESIGN OF EXPERIMENT

In the present study, the test is divided into two tests that is to find the LDR and to predict the deformation of sheet metal in deep drawing process. In LDR test, the aluminium AA1100 and copper is use to investigate the formability in deep drawing process with parameters of blank diameter, lubricant, and blank holder force. While in deformation test, the FLD was used as indicator to predict the sheet metal formability in deep drawing process using aluminium AA1100 as material with thickness and lubricant as parameters.

The tooling dimensions that are used in the present study were similar to Swift flat-bottomed cup test as mentioned in the work of Theis (1999). The schematic drawing of die that is use in the present study is shown in Figure 3.2.

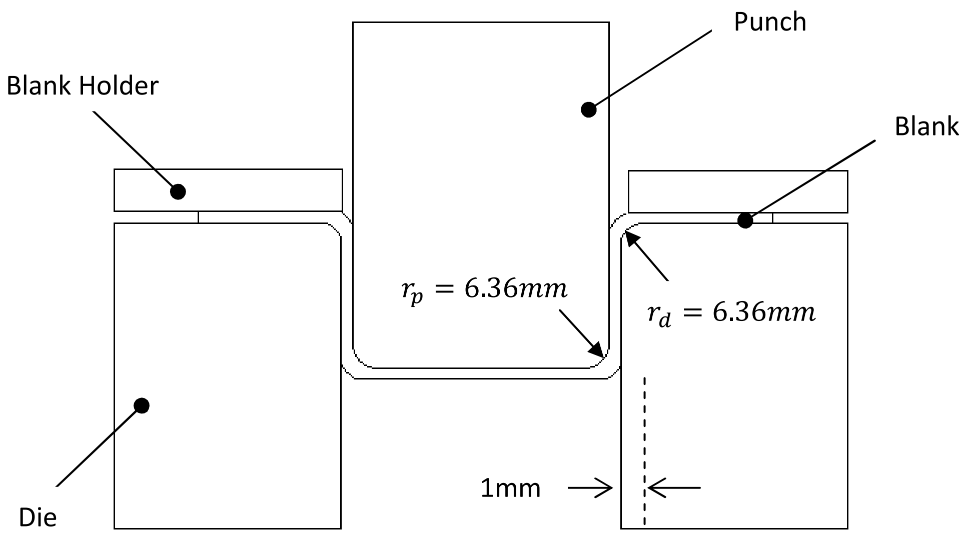


Figure 3.2: The schematic drawing of deep drawing die in the present study

The investigation will be conduct on aluminium AA1100 and copper, where both materials are face-centred cubic (FCC) structure. The compositions for aluminium AA1100 and copper used are given in Table 3.1 and Table 3.2 respectively. The blank thickness that will use in present study is 1mm and 0.6mm.

Table 3.1: Material composition of aluminium AA1100

Material	Aluminium AA1100					
Compositions	**Al**	**Si**	**Fe**	**Cu**	**Mn**	**Mg**
Wt %	99.9	0.0315	0.269	0.104	0.0015	0.0019
Compositions	**Zn**	**Cr**	**Ni**	**Ti**	**Ga**	**V**
Wt %	0.006	< 0.001	< 0.005	< 0.0384	0.0210	0.0147

Table 3.2: Material composition of copper

Material	Copper					
Compositions	**Cu**	**Zn**	**Pb**	**Sn**	**Mn**	**Ni**
Wt %	99.9	< 0.005	0.0232	< 0.005	0.0028	0.0094
Compositions	**As**	**Be**	**Ag**	**Sb**	**Cd**	**Co**
Wt %	0.0021	< 0.005	0.0078	0.0056	0.0013	0.0109

Two sets of blank holder forces is use to study the effect of blank holder force (BHF) in deep drawing process. Each set of blank holder force will utilize four units of coil springs. The type of blank holder that will use is coil springs. The coil springs use in the present study is shown in Figure 3.4 and the force profile illustrated in Figure 3.3. The blank holder or spring is use in present study is yellow spring which consist spring constant, *k* of 10 N/mm and blue spring which consist the *k* value is 16.3 N/mm are set to be in the range of 400 N and 1310.62 respectively.

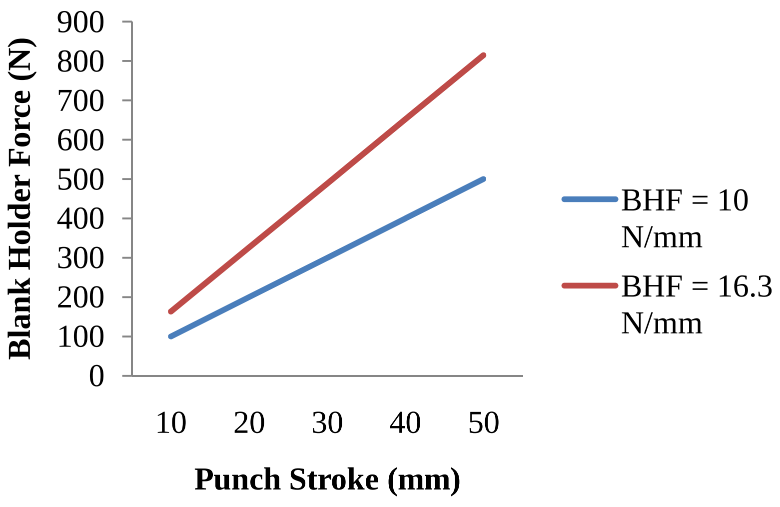


Figure 3.3: Blank holder force in the present study

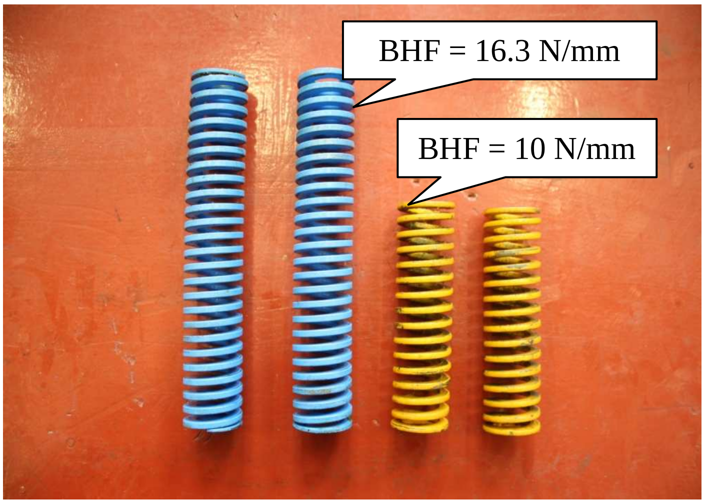


Figure 3.4: Coil springs use in the present study

In the present study, a deep drawing machine that is use in the present study is based on Swift cup test parameter which is widely used nowadays in industry and science. This deep drawing machine is suitable to determine the formability of sheet metal because of the parameter that was set up was according to Swift Cup Test that many researchers and scientists also refer to this Swift Cup Test. This deep drawing machine was design and fabricated from previous students that also has done the deep drawing experiment but with different objectives with the present study. Figure 3.5 shows the example of deep drawing die that was used in present studies.

Figure 3.5: Deep drawing die machine use in the present study

This deep drawing die is supported by a Chung Tie hydraulic press machine model CTO-05. The hydraulic press machine is use to move the deep drawing die machine vertically and punch the blank or sheet metal into cylindrical cup. This hydraulic press machine must be handle very carefully while running the experiment and the condition of this hydraulic press machine also must be in a top condition to avoid an unwanted accident while running the deep drawing experiment like a failure of hydraulic system may caused a serious injured to the user. An example of hydraulic press machine that is use in the present study is shown is Figure 3.6.

Figure 3.6: Hydraulic press machine use in the present study

Table 3.3: Parameter setup for LDR experiment in the present study

Material	Blank Holder Force	Blank Diameters	Blank Thickness
Aluminium AA1100	Yellow Spring (10 N/mm)	80 mm, 85 mm, 90 mm, 95 mm, 100mm	1 mm
	Blue Spring (16.3 N/mm)	80 mm, 85 mm, 90 mm, 95 mm, 100mm	1 mm
Copper	Yellow Spring (10 N/mm)	80 mm, 85 mm, 90 mm, 95 mm, 100mm	1 mm
	Blue Spring (16.3 N/mm)	80 mm, 85 mm, 90 mm, 95 mm, 100mm	1 mm

Table 3.4: Parameter setup for FLD experiment in the present study

Blank Thickness	Blank and Die Condition	Material	Blank Diameter	Blank Holder Force	Diameter of Circle Grid
1 mm	Lubricate (Lithium Grease)	Aluminium AA1100	95 mm	Blue Spring (16.3 N/mm)	2 mm
	Non-lubricate	Aluminium AA1100	95 mm	Blue Spring (16.3 N/mm)	2 mm
0.6 mm	Lubricate (Lithium Grease)	Aluminium AA1100	95 mm	Blue Spring (16.3 N/mm)	2 mm
	Non-lubricate	Aluminium AA1100	95 mm	Blue Spring (16.3 N/mm)	2 mm

3.4 BLANK PREPARATION

Before running the deep drawing experiment, the blank or specimen of the experiment must be prepared in order to achieve the experiment objectives. The material that was selected is aluminium sheet with grade AA1100 and copper sheet. Firstly, the sheet metal of aluminium AA1100 and copper with thickness 1mm was cut into rectangular shape with dimensions of 120mm x 140mm. The blank was cut using LVD hydraulic shear model MVS-C as showing in Figure 3.7.

Figure 3.7: Hydraulic shear machine use in present study to cut a sheet metal.

After the sheet metal was successfully cut according to desired shape (120mm x 140mm), then it is necessary to drill the sheet metal using drill machine or milling machine but in present study, the drilling machine was chosen because it is easy to conduct. The hole is needed to drill because the hole was a path of wire to be thread during cutting process using Electric Discharge Machine (EDM) Wirecut. In the present study, the diameter of drill tools that is used is 4mm. Figure 3.8 shows an example of Sealey Pillar Drill model GDM120BX that was used in the present study while in Figure 3.9 shown the dimension of the blank that was upshot after the drilling operation while Figure 3.10 shows example of blank after went through the drilling process.

Figure 3.8: Drilling machine use in the present study to make a hole on the sheet metal

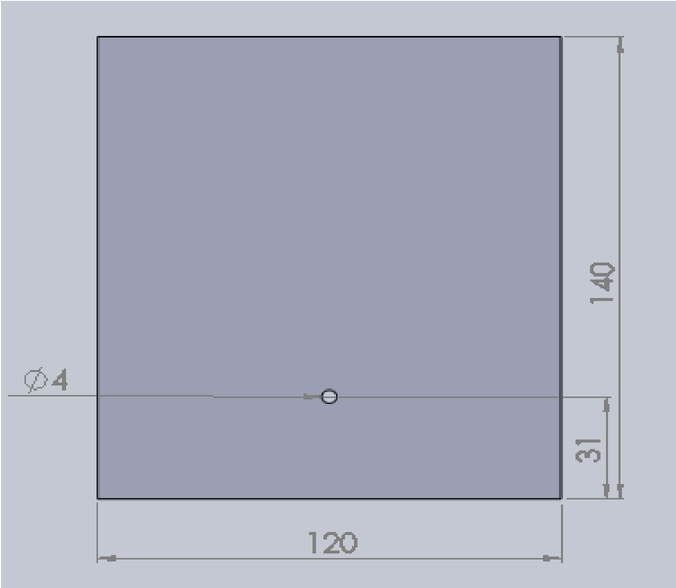


Figure 3.9: Dimension of the specimens after through the drilling operation

Figure 3.10: Example of aluminium AA1100 sheet after went a drilling operation

After the specimen was drilled successfully, the specimen is needed to cut into circular shape using Electric Discharge Machine (EDM) Wirecut. In the present study, the EDM Wirecut is because it will cut the sheet with a precise shape of circular. It is important because in deep drawing process, the diameter of blank will affect the result. Therefore, a precise shape of circular is needed. Figure 3.11 shows the example of

Sodick EDM Wirecut model AQ535L that is in present study to cut the sheet metal into circular shape perfectly.

Figure 3.11: EDM Wirecut use in present study to cut the sheet metal into circular shape

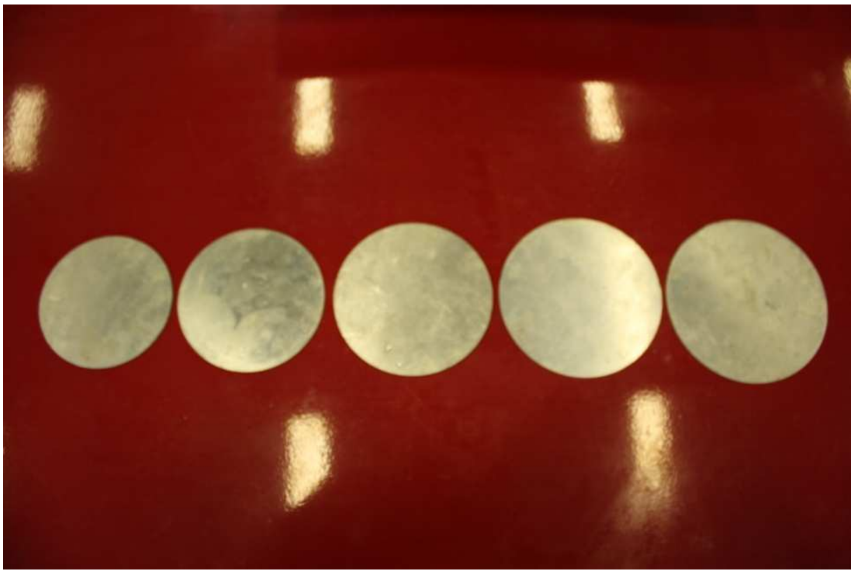


Figure 3.12: Example of aluminium AA1100 specimens. From left: Blank diameter 80, 85, 90, 95 and 100mm

Figure 3.12 shows an example of sheet metal that was successfully cut using EDM Wirecut. It can see that the specimen was cut perfectly and precisely using EDM Wirecut because EDM Wirecut is a Computer Numerical Control (CNC) machine type.

After the blank is successfully cut into circular shape, the experiment of LDR and FLD can be run using a deep drawing machine as shown in Figure 3.5. Note that for FLD experiment, another blank is needed to prepare because of difference of thickness that was used that is 0.6mm for aluminium AA1100.

3.5 DEEP DRAWING DIE SERVICE

Before running a deep drawing experiment, a deep drawing die machine that is in present study is need to services first. The deep drawing die is needed to cleaning using sand paper with grade 1000. Another thing is the deep drawing die is also need to lubricate using Lithium grease lubricant that is widely used in industry nowadays. Figure 3.13 shows some of part in deep drawing die that was clean up using sand paper and some of part that was lubricate using Lithium grease lubricant.

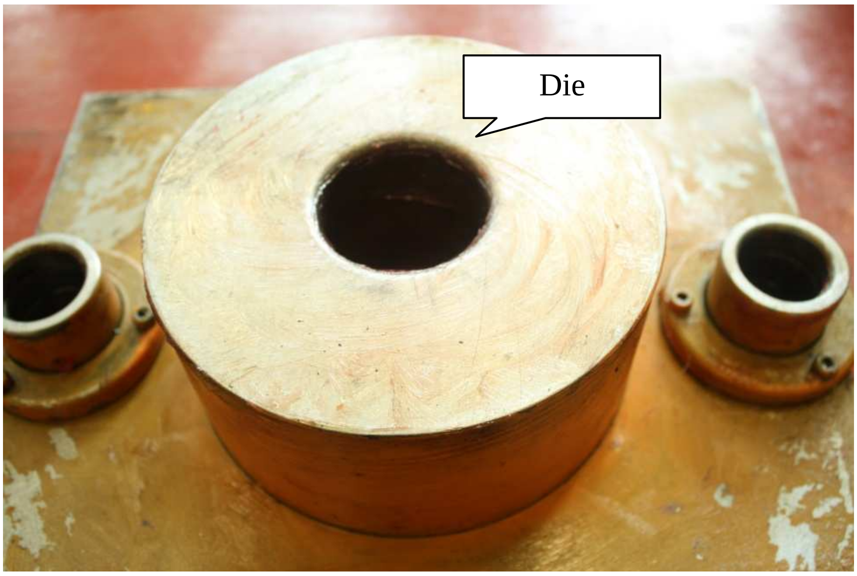


Figure 3.13: Lubricate process for deep drawing die main part

Figure 3.14: Lubricate process for deep drawing punch

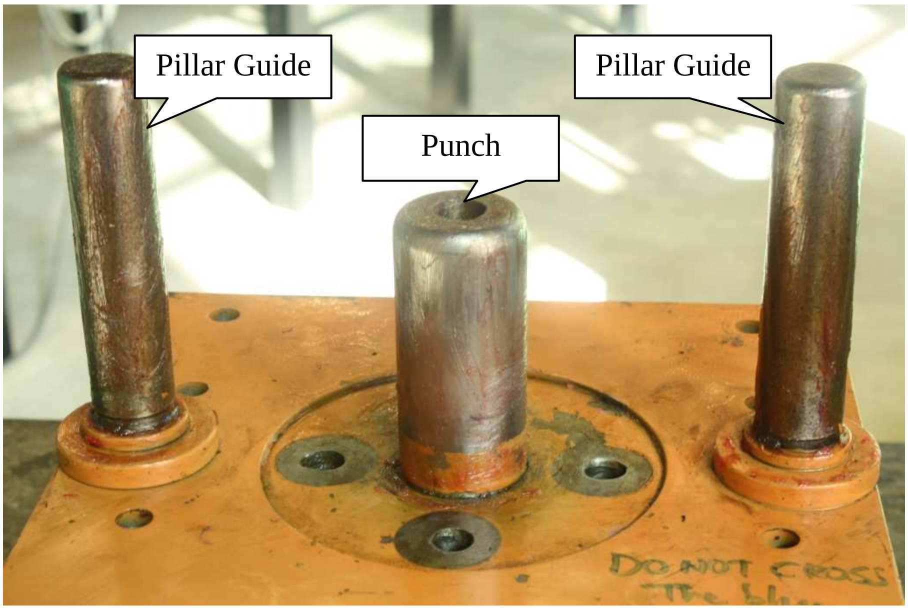


Figure 3.15: Lubricate process for deep drawing punch and guide pillar

While lubricating and cleaning process were done on the deep drawing die machine, it is noted that the pillar of blank holder were bent. The blank holder pillar is one of the most important in deep drawing die machine because this pillar will support the blank holder above the spring coils that is in present study. So a new blank holder pillar is needed to fabricate in order to achieve a better result in the experiment that will be running. Figure 3.16 show example of blank holder pillar that was bent.

Figure 3.16: Blank holder pillar that was bent

First, the material that was selected to fabricate this blank holder pillar is carbon steel with grade AISI 1045. After the material was selected, the material is needed to undergo facing and turning operation using lathe machine. Figure 3.17 show the example Shun Chuan conventional lathe machine model ERL-1330 that is used in the present study to do a facing and turning operations on the carbon steel. The dimension for blank holder pillar is shown in Appendix C1.

Figure 3.17: Lathe machine use in the present study to fabricate the blank holder pillar

When the process of turning and facing is completed, then a thread of hole is needed to make at the above of the blank holder pillar. The purpose was to lock the blank holder pillar with a blank holder using an allen screw with 4mm diameter. A hand tap that is used is M5 x 0.8 as shown in Figure 3.18.

Figure 3.18: Hand tap use in the present study to make a thread in blank holder pillar.

When the thread is done, then the blank holder pillar is ready to install with the deep drawing die that will be used in present study.

3.6 LDR EXPERIMENT

In LDR experiment, the blank material that was used is aluminium AA1100 and copper with same thickness that is 1mm. The diameter for both materials that will be used to investigate in the experiment is 80, 85, 90, 95 and 100mm. For blank holder force, two type of coil springs is used in this experiment that is blue spring (BHF = 16.3 N/mm) and yellow spring (BHF = 10 N/mm).

First, the blank is place on the blank holder. Note that, it is very dangerous to place the blank directly with hand because of a malfunction from the hydraulic press machine may cause the die fall from its original position. So it is recommended to place the blank with wood stick or something that is long. Figure 3.19 show the Aluminium blank with diameter 80mm is placed on the blank holder in the present study.

Figure 3.19: Aluminium AA100 specimen with diameter of 80mm is placed on the blank holder

After the blank is placed at the centre on the blank holder, then a drawing operation can be run. The blank is drawn until the blank is ruptured. Note that in the present study, the maximum punch stroke that is allowed is 55mm. The purpose is to avoid the clash between punch and top die that will cause damages to the punch. After that, all the above step is needed to be done again but this time, the drawing operation must be stop before the blank is ruptured. Let say at first trial, the blank is ruptured when the drawing operation is at 50mm, so for the second trial let the drawing operation stop at 45mm punch stroke.

When the maximum punch stroke is obtained, the cup actually was drawn to its maximum critical diameter. Then the diameter of this cup can be measured using vernier calliper.

All the above steps is need to repeat again with blank diameter of 85, 90, 95 and 100mm and also using copper as blank. After that, the blue spring can be replace by yellow spring and all the procedure as stated in section 3.6 have to repeat again.

3.7 FLD EXPERIMENT

Another test that has been done in the present study is FLD experiment. The purpose of this experiment is to predict the forming behaviour of the material while undergo a drawing process. Unlike LDR experiment, FLD experiment only focus on one material that is aluminium AA1100 with thickness 0.6mm and 1mm in the present study. Also, the blank holder force that is used in the present study also focus on blue spring (BHF = 16.3 N/mm). In addition, the blank diameter that is used also constant that is 95mm. But in this test, the variable that is used is thickness of the blank and lubricant. The thickness that is used in this test is 0.6mm and 1mm while lubricant that is used is Lithium grease.

In FLD experiment, a circle grid has to be made on the blank. The diameter of circle grid that is used in the present study is 2mm. The circle grid was draw using red marker pen. Figure 3.20 shows the circle grid that has been drawn on the blank.

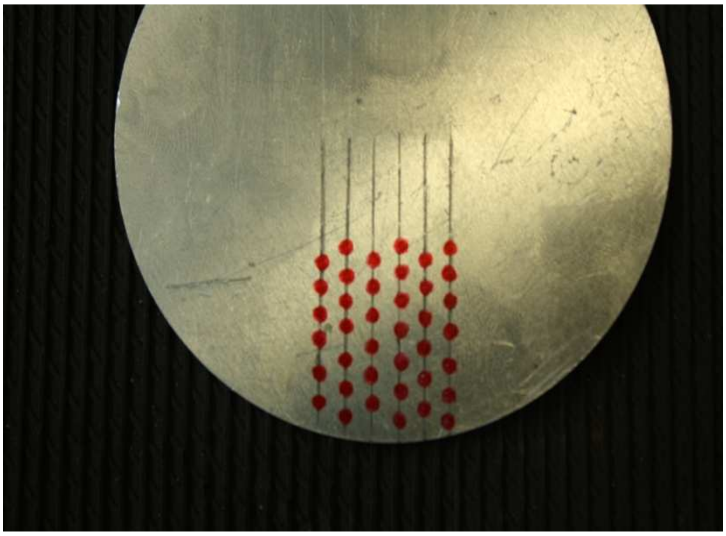


Figure 3.20: Circle grid on the aluminium AA1100 specimens with blank thickness 1mm

After the circle grid was successfully drawn on the blank, the FLD experiment is ready to be running. The indicator was make by drawn it on the paper with increment of 5mm and paste it on the blank holder pillar as shown in Figure 3.21.

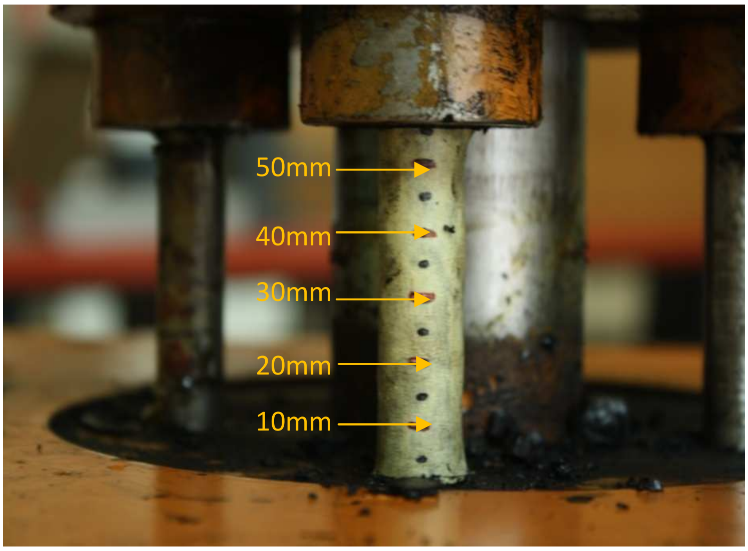


Figure 3.21: Indicator of punch stroke use in the present study

Let say in the trial of FLD test, the blank and die was lubricated using Lithium grease and the thickness of blank that is used is 1mm. Figure 3.22 show an example of

Lithium grease that is used in present study. The FLD experiment can be tested by provide 5 samples of blank. Each blank was drawn for increment of 10mm. For example for the first blank, it is drawn until 10mm and the second blank was drawn until 20mm and so on with other blank until final blank that is drawn to 50mm of draw depth.

Figure 3.22: Lubricant use in the present study

After each drawn is successful, the deformation will occur on the blank and it can see clearly through the deformation of the circle grid. The circle grid will deform into an oval shape and the length for both major and minor in this circle can be measured. After all the 5 blank is successfully drawn, the blank of 1mm thickness is replaced with the blank of 0.6mm thickness. All the above procedures were needed to repeat again. And after that, the deep drawing die is needed to be dried for another test that is to test the effect of presence of lubricant. The material that will be use also same that is aluminium AA1100 with thickness of 1mm and 0.6mm. Note that for blank thickness 0.6mm, the blank was drawn for increment of 5mm. It is because the blank of thickness 0.6mm is easy to rupture compare to blank thickness 1mm.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 OBSERVATIONS

After the sheet metal is successfully deformed (for both LDR and FLD experiment) by a drawing operation, the blank will be deformed into a cylindrical shape same as Swift's cup test. The deformation of the cup is totally depends on the parameter that have been discussed in previous chapter. In this chapter, it will show the result that is obtained from LDR and FLD experiment.

4.2 LDR EXPERIMENT

4.2.1 Cup Observations in LDR Experiment

The deep drawn cup for aluminium AA1100 and copper in LDR test can be divide into two that is using blue spring (BHF = 16.3 N/mm) and yellow spring (BHF = 10 N/mm). Figure 4.1 show some of cup that successfully drawn using the blue spring (BHF = 16.3 N/mm) for Aluminium AA1100 with blank thickness of 1mm.

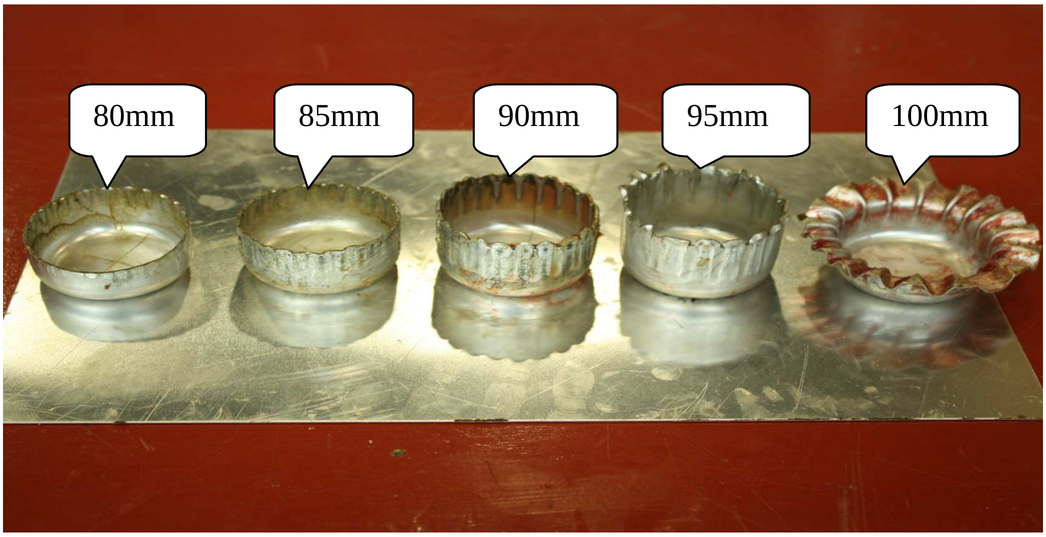


Figure 4.1: Drawn cups for aluminium AA1100 using blue spring (BHF = 16.3 N/mm) as blank holder force. From left: Blank diameter 80, 85, 90, 95 and 100mm

In figure 4.1, it can see that from left to right, the height of cup is increase due to the increasing of blank diameter but for the cup that blank diameter is 100mm, the height of cup is decrease compare to cup that blank diameter is 95mm. It happens because if the blank of 100mm is drawn more than shows in Figure 4.1, the cup will fracture and defect.

For the cup of blank diameter 80mm, it can see that the cup is successfully drawn without wrinkling and earing occur. For the next cup that diameter of cup is 85mm, it can see that an earing is start to occur. And so with cup of blank diameter 90mm, the earing also occurs. For the cup of blank diameter is 95mm, the wrinkling is start to occur. It may because of a lot of surface area that was hold by blank holder or blank holding pressure (BHP) causes the wrinkling. And for the cup of blank diameter is 100mm, the wrinkling is become worst and the height of cup also decrease compare to 95mm diameter blank.

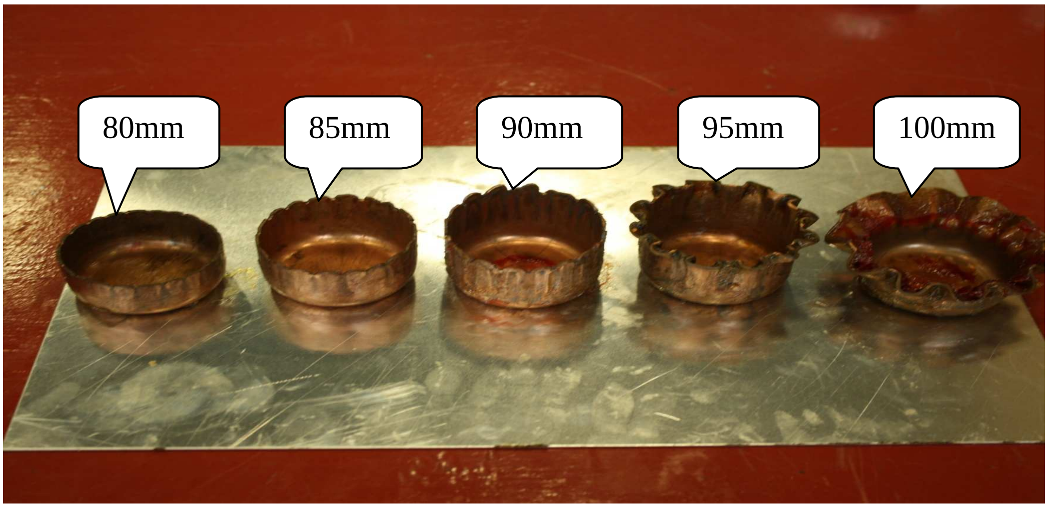


Figure 4.2: Drawn cups for copper using blue spring (BHF = 16.3 N/mm) as blank holder force. From left: Blank Diameter 80, 85, 90, 95, and 100mm

In figure 4.2, it can see that from left to right, the height of cup is increase due to the increasing of blank diameter but for the cup of blank diameter is 100mm, the height of cup is decrease compare to cup of diameter is 95mm. It happens because if the blank of 100mm is drawn more than that shown in Figure 4.2, the cup will fracture and defect.

For the cup of blank diameter 80mm, it can see that the cup is successfully drawn without wrinkling and earing. For the next cup that the blank diameter is 85mm, it can see that a earing is start to occur. And so with the cup of blank diameter 90mm, the earing also occur but it is more worst compare to cup of blank diameter is 85mm. For the cup of diameter 95mm, the wrinkling is start to occur. It may because of a lot of surface area that was hold by blank holder or BHP causes the wrinkling. And for the cup of blank diameter 100mm, the wrinkling is become worst and the height of cup also decrease compare to cup of 95mm diameter blank.

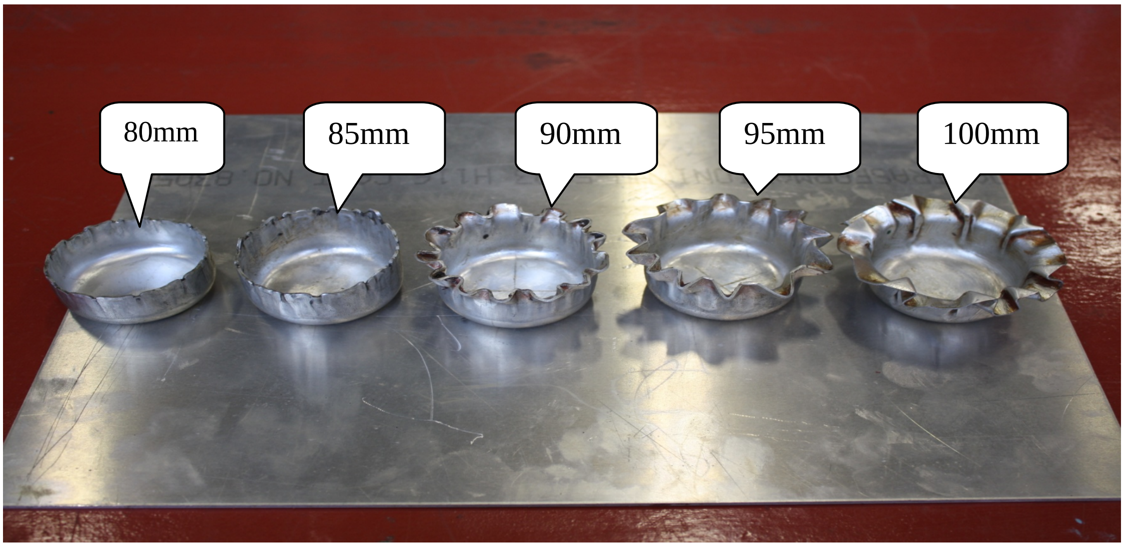


Figure 4.3: Drawn cups for aluminium AA1100 using yellow spring (BHF = 10 N/mm) as blank holder force. From left: Blank Diameter 80, 85, 90, 95, and 100mm

In figure 4.3, it can see that from left to right, the height of cup is increase due to the increased of blank diameter but for the cup of blank diameter 100mm, the height of cup is decrease compare to cup of blank diameter 95mm. It happens because if the blank of 100mm is drawn more than shown in Figure 4.3, the cup will fracture and defect.

For the cup of blank diameter 80mm, unlike the cup that is using blue spring (BHF = 16.3 N/mm) for aluminium AA1100, the cup is already have some defects on it. The earing is already occurs. Also with the cup of blank diameter 85mm, the earing is become worst compare to cup of blank diameter 80mm. But for the cup of blank diameter 90mm, the wrinkling is starts to occur replacing the earing defects. And with another cup of blank diameter 95mm, the wrinkling is much worst compare to of blank diameter 90mm. Like stated on Figure 4.1, the wrinkling might occurred because a lot of surface from the blank that was hold by blank holder or in other words is blank holder pressure (BHP). Thus the wrinkling might occur. And for cup of blank diameter 100mm, the wrinkling is much worst compare to cup of blank diameter 95mm.

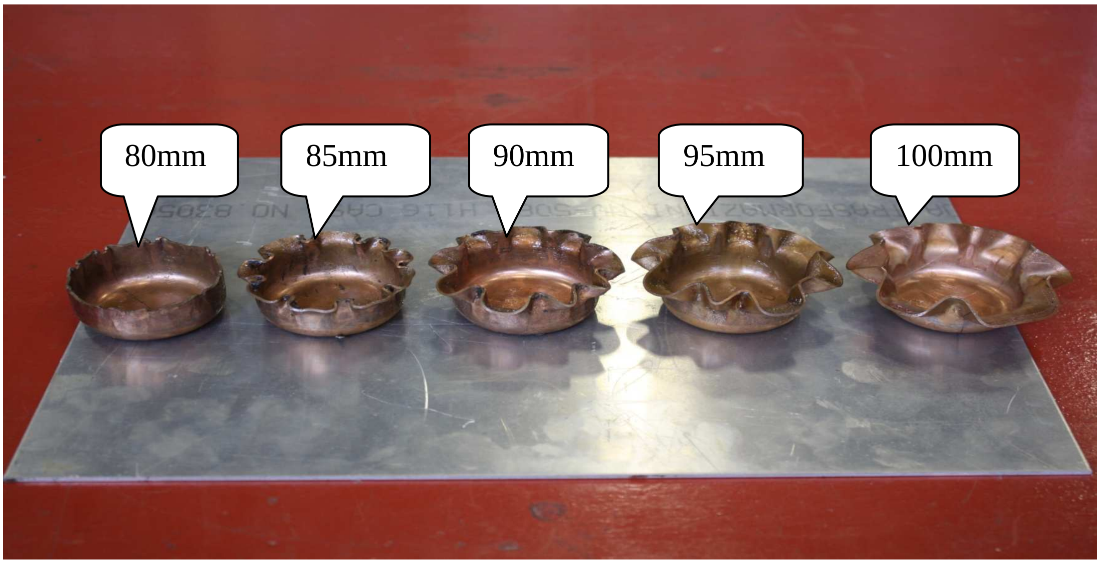


Figure 4.4: Drawn cups for copper using yellow spring (BHF = 10 N/mm) as blank holder force. From left: Blank Diameter 80, 85, 90, 95, and 100mm

In figure 4.4, it can see that from left to right, the height of cup is increase due to the increasing of blank diameter but for the cup of blank diameter 100mm, the height of cup is decrease compare to cup of blank diameter 95mm. It happens because if the blank of 100mm is drawn more than shown in Figure 4.4, the cup will fracture and defect.

For the cup of blank diameter 80mm, unlike the cup that was using blue spring (BHF = 16.3 N/mm) for Copper, the cup is already have some defects on it. The earing is already occurs. Also with the cup of blank diameter 85mm, the earing is become worst compare to cup of blank diameter 80mm. But for the cup of blank diameter 90mm, the wrinkling is starts to occur replacing the earing defects. And with another cup of blank diameter 95mm, the wrinkling is much worst compare to of blank diameter 90mm. Like stated on Figure 4.1, the wrinkling might occurred because a lot of surface from the blank that was hold by blank holder or in other words is BHP. Thus the wrinkling might occur. And for cup of blank diameter 100mm, the wrinkling is much worst compare to cup of blank diameter 95mm.

From literature review, the optimal blank holding pressure (BHP) should be between 0.5% - 1.0% of the yield strength of the material (Hosford and Caddell, 2007).

The BHF is a product of BHP and blank holder contact area, which differs according to blank diameter as shown in Figure 4.5. The calculation of blank holding area is given in Appendix B1. The theoretical BHP and BHF for the present study is as calculated in Table 4.1 and Table 4.2.

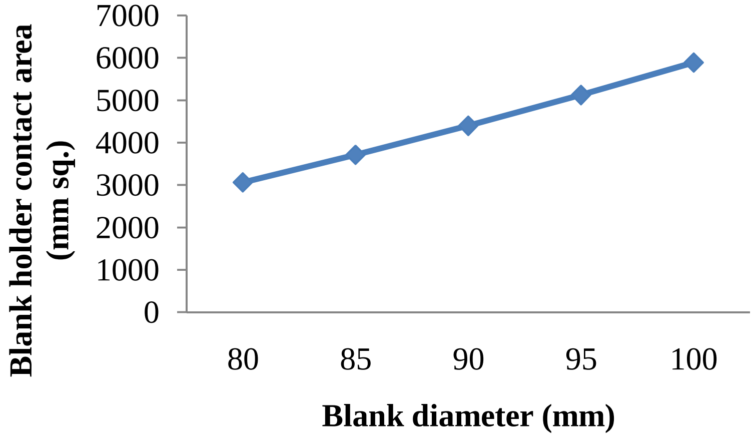


Figure 4.5: Relation between blank holder contact area and blank diameter

Table 4.1: Theoretical blank holding pressure for materials used in present study

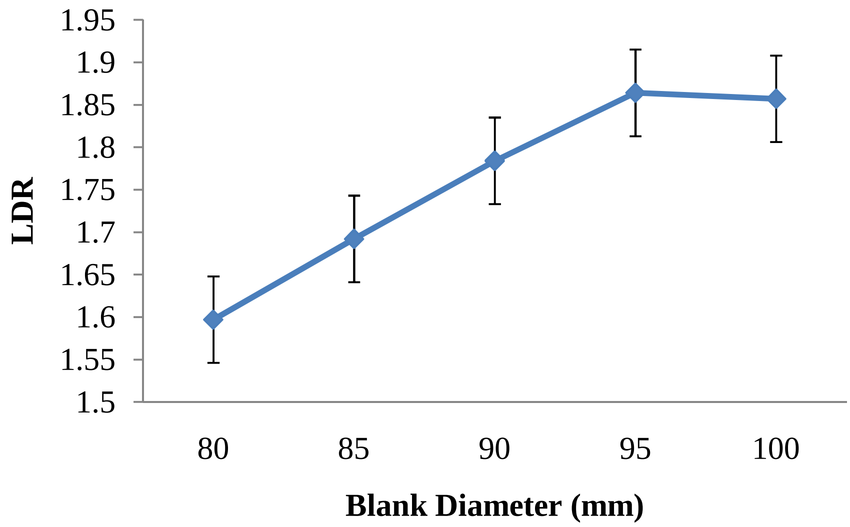
Material	Yield Strength, Y_0 (MPa)	Theoretical BHP (MPa)
Aluminium AA1100	29.9	0.1496-0.2991
Copper	50.0	0.2498-0.4995

Table 4.2: Theoretical and utilized blank-holding force for deep drawing experiment

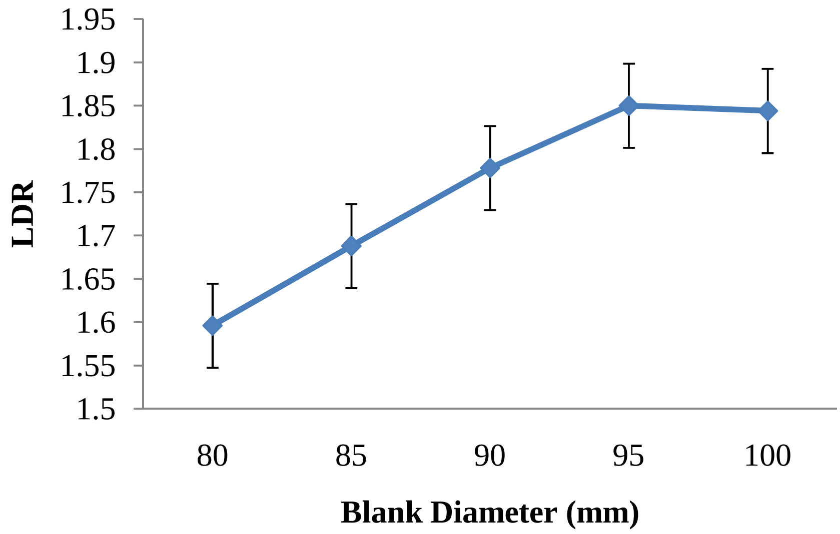
Material	Blank diameter (mm)	Theoretical BHF (N)	Utilized BHF (N)	
			Blue Spring	Yellow Spring
Aluminium AA1100	80	458 - 916	400 - 1000	1311 - 2294
	85	629 - 1110	400 - 1100	1311 - 2497
	90	658 - 1316	400 - 1200	1311 - 2621
	95	767 - 1533	400 - 1300	1311 - 2785
	100	895 - 1762	400 - 1400	1311 - 2949
Copper	80	765 - 1530	400 - 1000	1311 - 2294
	85	927 - 1854	400 - 1100	1311 - 2457
	90	1099 - 2197	400 - 1200	1311 - 2621
	95	1280 - 2560	400 - 1300	1311 - 2785
	100	1471 - 2942	400 - 1400	1311 - 2621

4.2.2 Experimental LDR Profile

From the deep drawing experiment, the LDR values for cup that is drawn without fracture for both materials with variable diameter and blank holder force was taken. All the data of LDR value can be refer in Appendix A1.



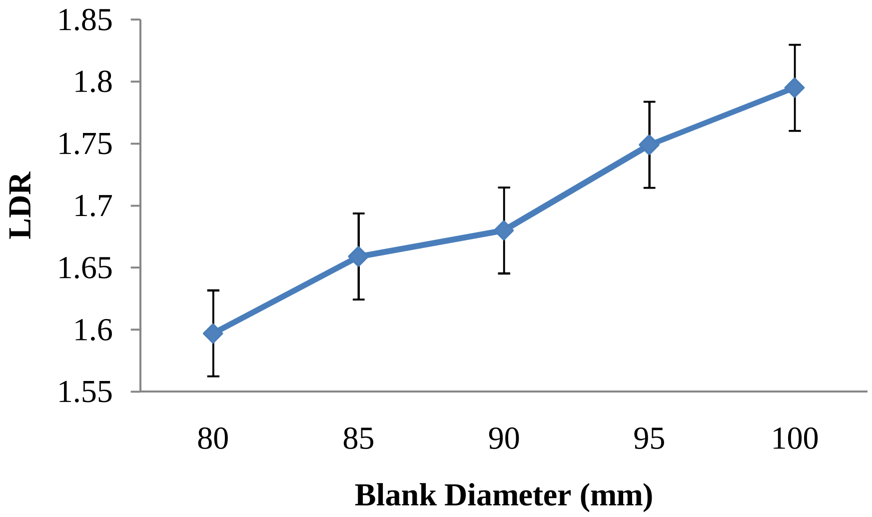
(a)



(b)

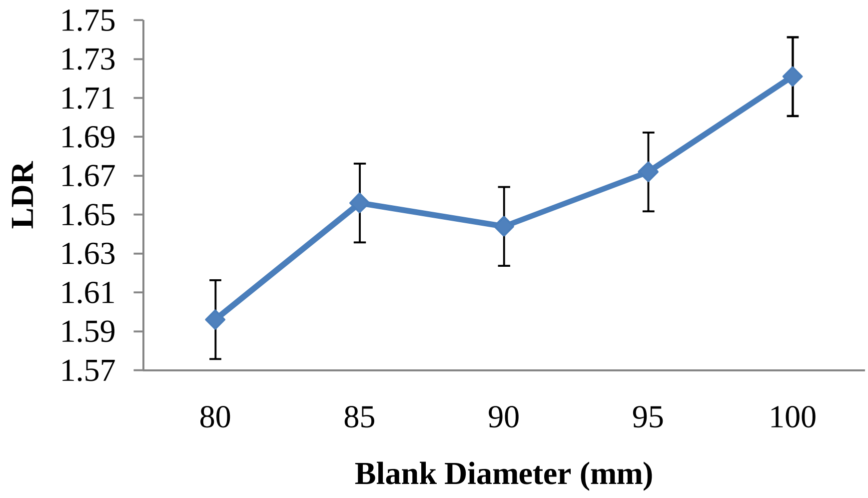
Figure 4.6: LDR profile using blue spring (BHF = 16.3 N/mm) for (a) Aluminium AA1100 and (b) Copper

In Figure 4.6(a), it shows the graph of LDR values for aluminium AA1100 while Figure 4.6(b), it shows the graph of LDR values of copper using blue spring (BHF = 16.3 N/mm) as a blank holder force. Both of the graph shows that the LDR for aluminium AA1100 and copper is increase due to increasing of blank diameter in linear form. But as it reach blank diameter 100mm, it can see that the graph is no longer in linear form. The value of LDR for the blank diameter 100mm is slightly decrease compare to blank diameter 95mm. The decrease of this LDR value may cause from the extremely wrinkling that was occurred when running the experiment for blank diameter 100mm that cause by high BHP. As stated by Verma, 2005, the increasing of blank diameter will cause an increasing of LDR too. Which means with the increasing of blank diameter, the drawability of sheet metal also high.



(a)

Figure 4.7: LDR profile using yellow spring (BHF = 10 N/mm) for (a) Aluminium AA1100 and (b) Copper

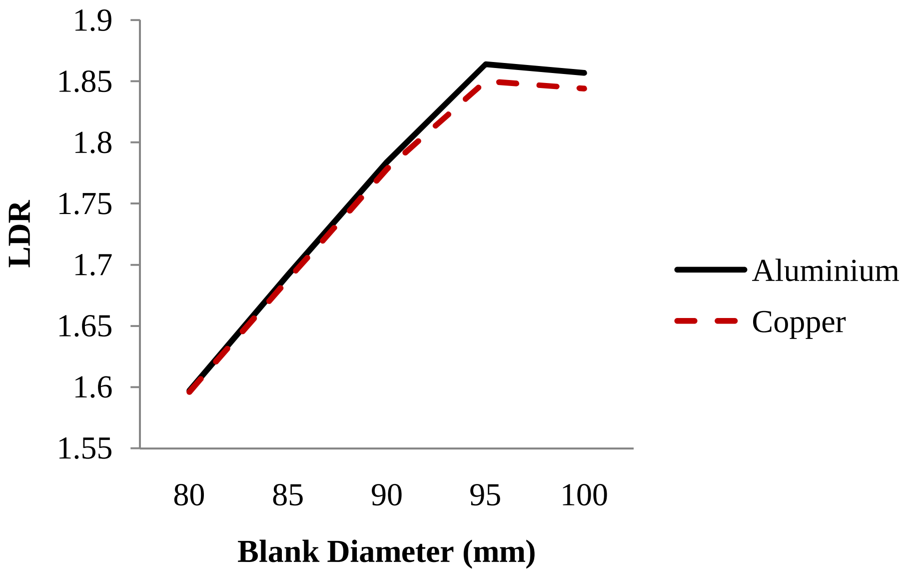


(b)

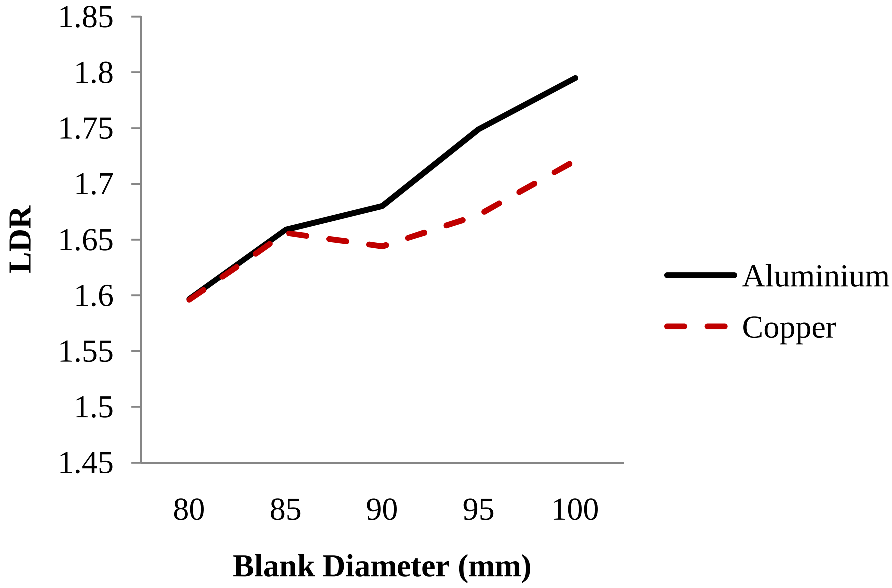
Figure 4.7: Continued.

In Figure 4.7(a), it shows the LDR values for aluminium AA1100 while Figure 4.7(b), it shows the LDR values for copper using yellow spring (BHF = 10 N/mm) as a blank holder force. From the graph it can see that the LDR values also increase same with blue spring (BHF = 16.3 N/mm) for both material. But for copper, it can see that the value of LDR is decrease when it reach blank diameter 90mm. Unlike aluminium AA1100, the value of LDR for copper is increasing with increasing of blank diameter. Both of the graph shows the value of LDR is not decrease when it reach blank diameter 100mm. It may because of the BHP that is used for yellow spring (BHF = 10 N/mm) is significant with the present setup parameter.

So the comparison value of LDR for aluminium AA1100 and copper which is using yellow spring (BHF = 10 N/mm) and blue spring (BHF = 16.3 N/mm) as blank holder force is shows in Figure 4.8.



(a)



(b)

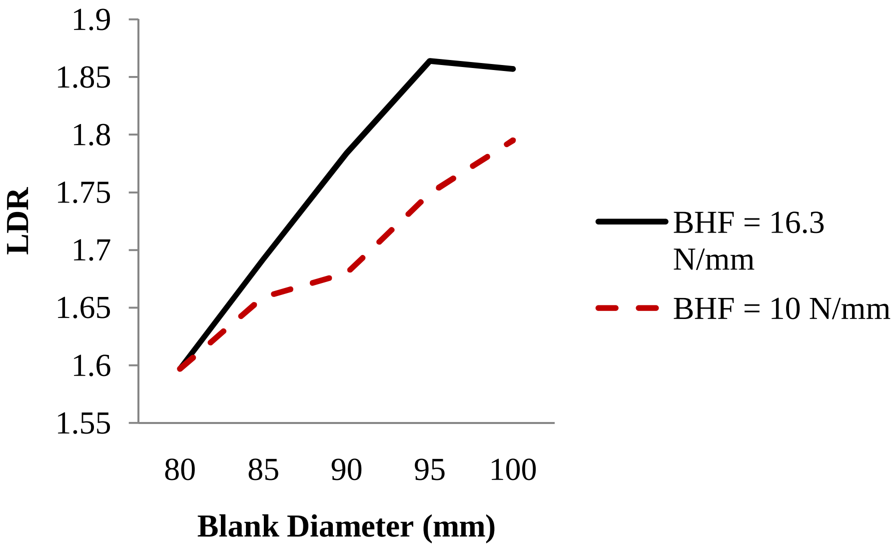
Figure 4.8: Comparison of LDR value between aluminium AA1100 and copper using (a) Blue spring (BHF = 16.3 N/mm) and (b) Yellow spring (BHF = 10 N/mm)

From figure 4.8(a), the graph shows the comparison of aluminium AA1100 and copper by using blue spring (BHF = 16.3 N/mm) as a blank holder force while Figure 4.8(b) shows the comparison of aluminium AA1100 and copper using yellow spring

(BHF = 10N/mm) as a blank holder force. Like discussed before this, the value of LDR is increasing due to increasing of blank diameter.

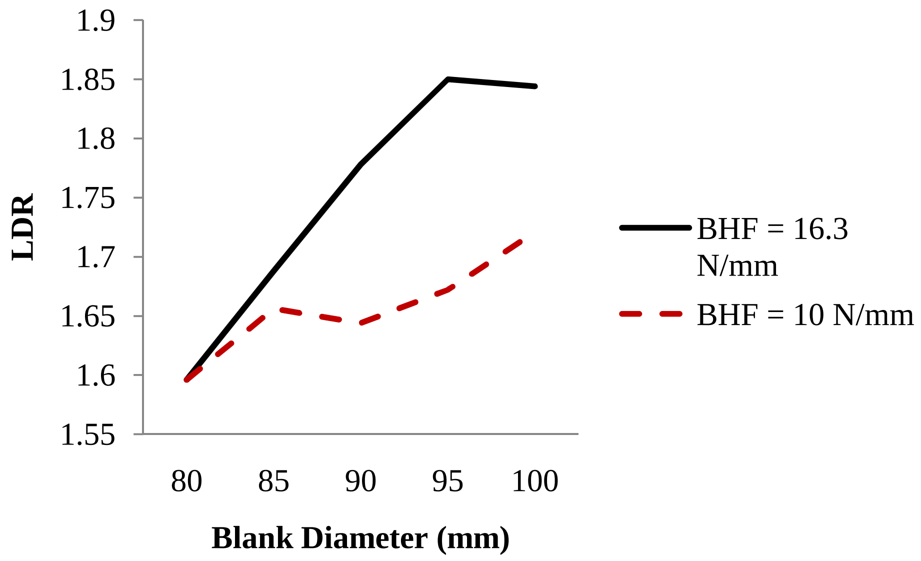
Overall from the Figure 4.8, the value of LDR for aluminium AA1100 is higher compare to copper. It shows that the drawability of aluminium AA1100 is more good compare to copper either using blue spring (BHF = 16.3 N/mm) or yellow spring (BHF = 10 N/mm) as a blank holder forces. From literature review, Whiteley, 1960 stated that the LDR is depends on normal anisotropy, $\bar{R}$ value of the materials. The higher value of $\bar{R}$, the higher value of LDR. So it can conclude that the normal anisotropy, $\bar{R}$ value of aluminium AA1100 is higher compare to copper and thus the drawability of aluminium AA1100 also higher compare to copper.

From all the above statement, it can be discuss briefly how the blank diameter and type of materials can influence the LDR value in deep drawing. Besides blank diameter and type of materials, the BHF also have a big influence in deep drawing.



(a)

Figure 4.9: Comparison of LDR value using different blank holder force for (a) Aluminium AA1100 and (b) Copper



(b)

Figure 4.9: Continued.

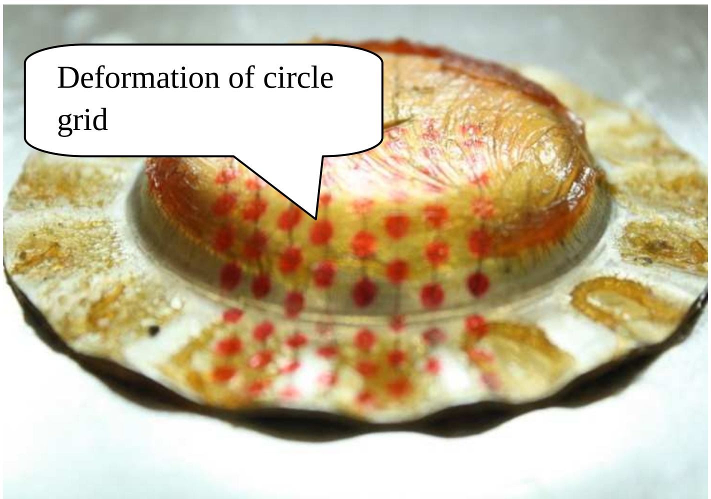
In Figure 4.9(a), the graph shows the value of LDR for aluminium AA1100 with two set of BHF (16.3 N/mm and 10 N/mm) while in Figure 4.9(b), the graph shows the value of LDR for copper with two set of BHF (16.3 N/mm and 10 N/mm). Both materials shows that the value of LDR for blue spring (BHF = 16.3 N/mm) is higher compare to yellow spring (BHF = 10 N/mm).

With this observation, it can be conclude that the drawability of sheet metal (aluminium AA1100 and copper) using blue spring (BHF = 16.3 N/mm) is more good rather than using yellow spring (BHF = 10 N/mm). According to Obermeyer and Majlessi, 1998, an insufficient of BHF may cause a wrinkling in deep drawing. The LDR value also will decrease with the increasing of wrinkling that was occurred because it will affect the diameter of cup after the drawing process. So it is important to use an optimized BHF when conducting the deep drawing experiment to avoid the wrinkling occurred.

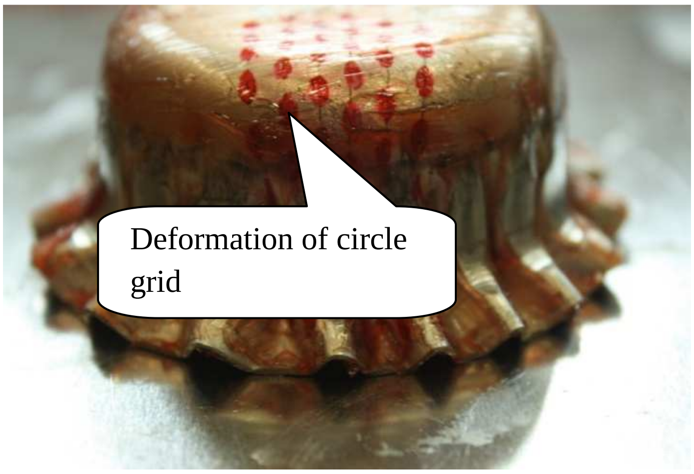
4.3 FLD EXPERIMENT

4.3.1 Cup Observations in FLD Experiment

In FLD experiment, the diameter of circle grid after deformation is taken for every specimens or blank. As stated in chapter 3, the material that is using in present the study is aluminium AA1100 with thickness of 1mm and 0.6mm. A blank diameter and BHF that is used in FLD test is constant which is 95mm and 16.3 N/mm respectively.

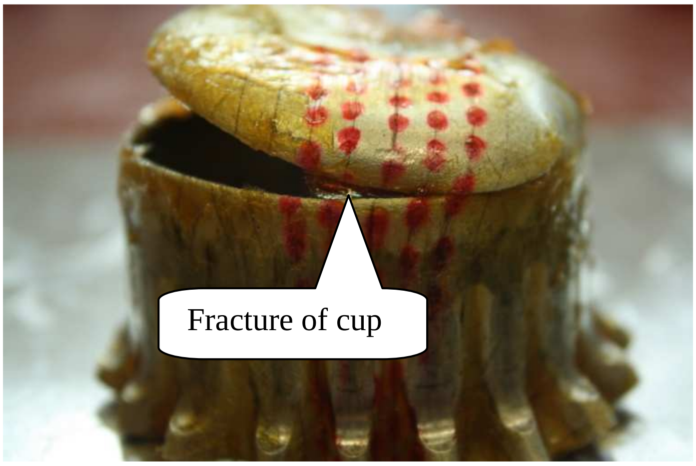


(a)



(b)

Figure 4.10: Example of circle grid deformation on 1mm blank thickness of different punch stroke for (a) 10mm, (b) 50mm and (c) 55mm



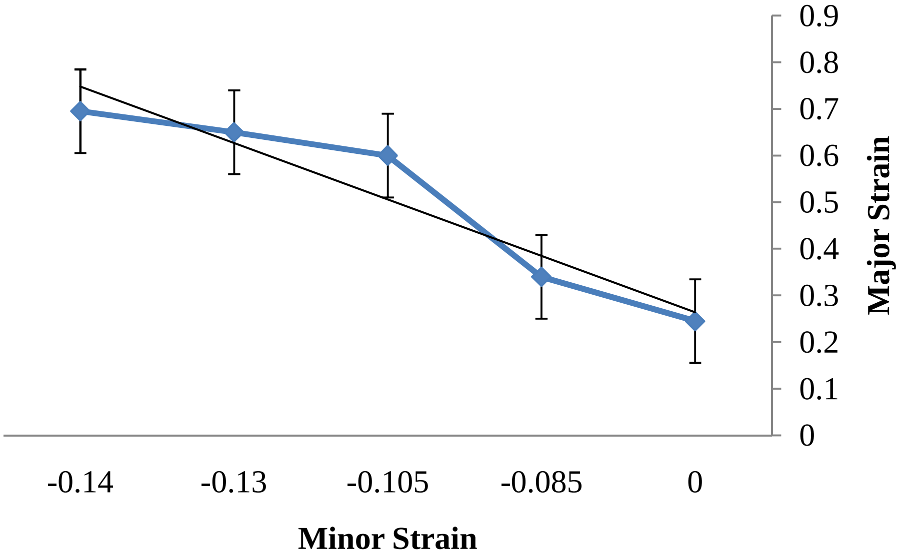
(c)

Figure 4.10: Continued.

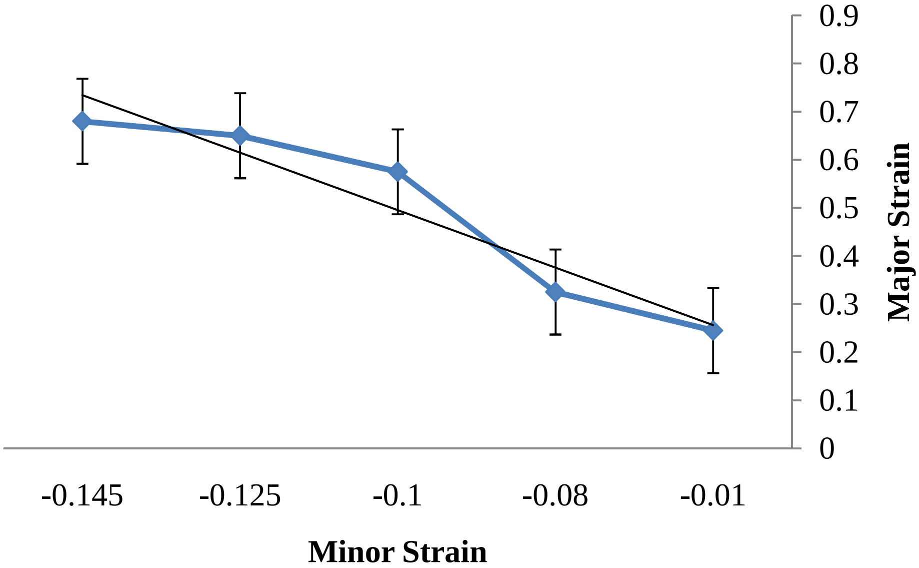
In Figure 4.10, it shows some of circle grid that is deforms from its original shape after undergoes a drawing process. In Figure 4.10(c) the sheet metal was fractured due to excessive BHF exerted on the sheet metal. It can see clearly that the circle grid will deform into ellipse shape after undergoes the deep drawing process.

4.3.2 Experimental FLD Profile

In FLD experiment, the test is divided into two. As stated in objective, the FLD test is conduct to investigate the forming behaviour of aluminium AA1100 with the variable of lubricant and blank thickness. The deformation of circle grid is increasing with the increasing of punch stroke in the deep drawing process. The data of FLD experiment can be refer in Appendix A2.



(a)

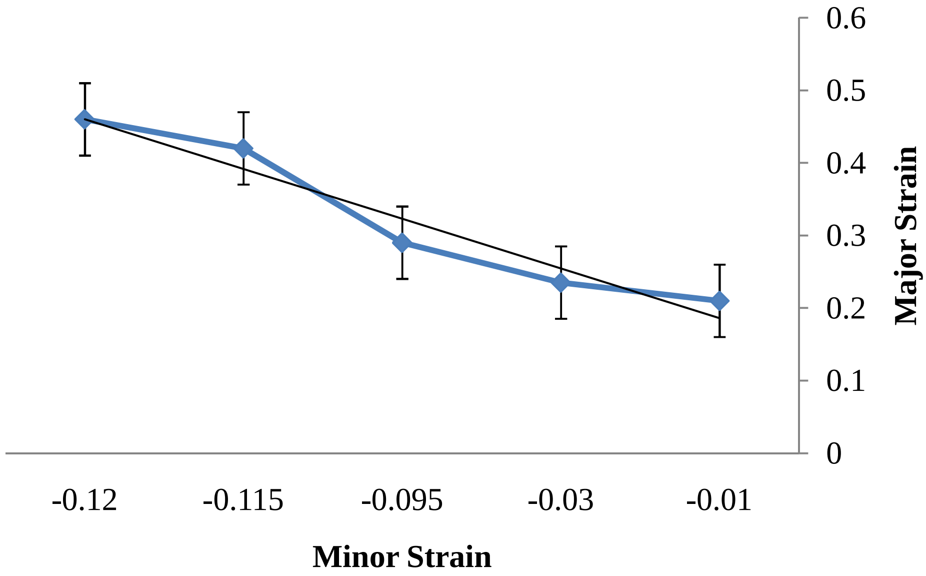


(b)

Figure 4.11: Forming limit diagram of aluminium AA1100 with blank thickness 1mm for condition (a) With lubricant and (b) Without lubricant

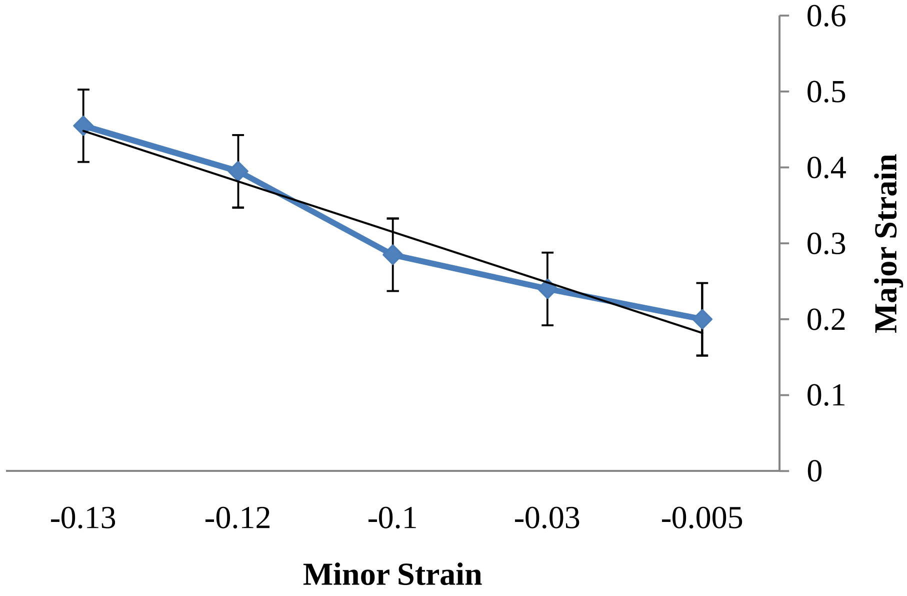
In Figure 4.11(a), it shows the forming limit diagram of aluminium AA1100 for blank thickness 1mm with the present of lubricant while in Figure 4.11(b), it shows the forming limit diagram of aluminium AA1100 for blank thickness 1mm without the present of lubricant. From the diagram, it can see that at major strain or major axis, the value of strain is increasing with the increasing of punch stroke while the value of strain at minor axis is decreasing for both conditions (with and without lubricant).

Theoretically, the shape of FLD for aluminium AA1100 will be in linear shape (black line) but due to limited apparatus in experiment setup like coil springs that was used, the shape of FLD is not in linear line (blue line).



(a)

Figure 4.12: Forming limit diagram of aluminium AA1100 with blank thickness 0.6mm for condition (a) With lubricant and (b) Without lubricant



(b)

Figure 4.12: Continued.

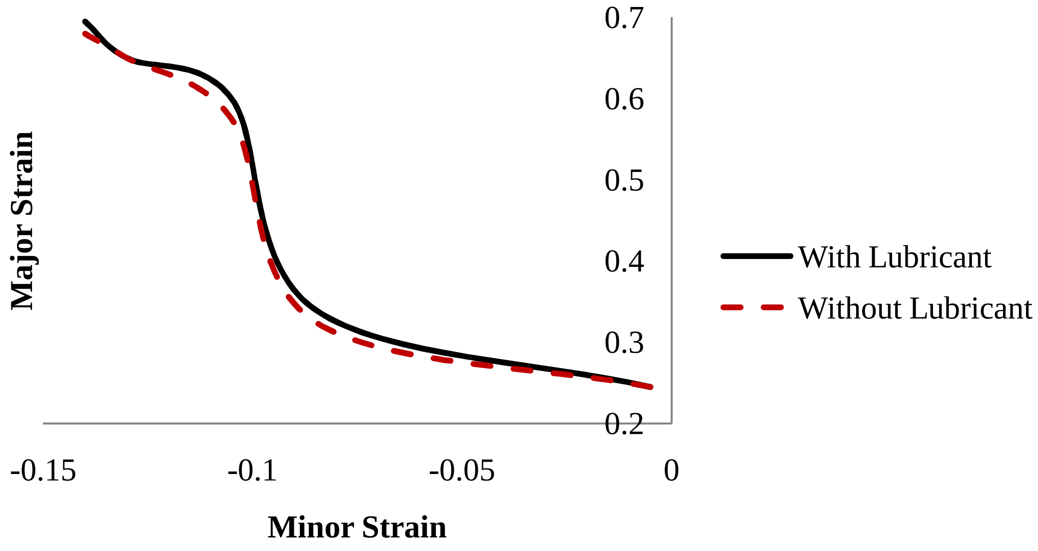
In Figure 4.12(a), it shows the forming limit diagram of aluminium AA1100 for blank thickness 0.6mm with the present of lubricant while Figure 4.12(b), it shows the forming limit diagram of aluminium AA1100 for blank thickness 0.6mm without the present of lubricant. Same with Figure 4.11, the value of strain is increasing at major axis while the value of strain is decreasing at minor axis.

Unlike Figure 4.11, Figure 4.12 shows that the shape of FLD for both conditions (with and without lubricant) is approaching a linear shape. It may because of the setup that was used in the present study is more suitable for blank thickness 0.6mm rather that 1mm in FLD experiment.

In FLD experiment, a prediction of forming limit for aluminium AA1100 can be predict from the Figure 4.11 and Figure 4.12. As mentioned by Goodwin, 1968, the blue line indicated that the blank is deformed to its critical limit. The area below the blue line indicated the failure zone while the area above the blue line indicated the safe zone for aluminium AA1100 that undergoes deep drawing process. It means that the aluminium AA1100 will be ruptured if the value for both strains (major and minor) is below the blue line area or below the critical zone. But if the value of strain (major and minor) is in the safe zone that is above the blue line, the aluminium AA1100 sheet is still in a good condition to be drawn (Banabic, 2000).

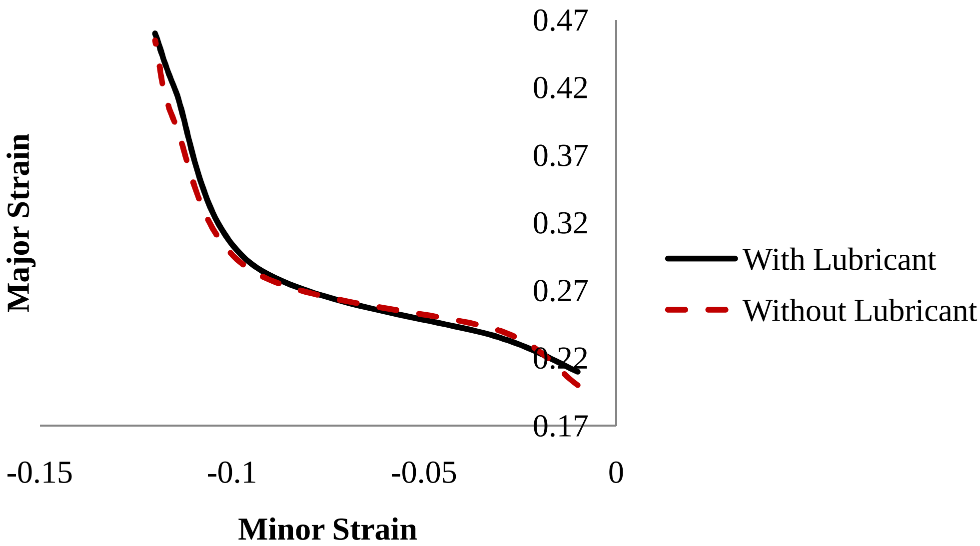
Suppose the FLD will be shape completely as state in literature review like Figure 2.5 and Figure 2.6. But due to limited of tool and equipment in present the study, only drawing area (left side) can be obtain and not the stretching area. Furthermore, the die radius that was used in the present study is cylindrical shape with punch radius is 6.36mm. From the previous studies that have been done by Narayanasamy, 2006, the punch shape that was used is hemispherical shape. With hemispherical punch shape, it is possible to obtain the reading of strain in drawing and stretching area in sheet metal deformation using FLD method.

With the data of strain for both blank thickness (1mm and 0.6mm) and both surface condition (with and without present of lubricant) is obtain, a comparison can be made to see the effect of these variable in deep drawing operations.



(a)

Figure 4.13: Comparison of FLD of aluminium AA1100 in both conditions for blank thickness (a) 1mm and (b) 0.6mm

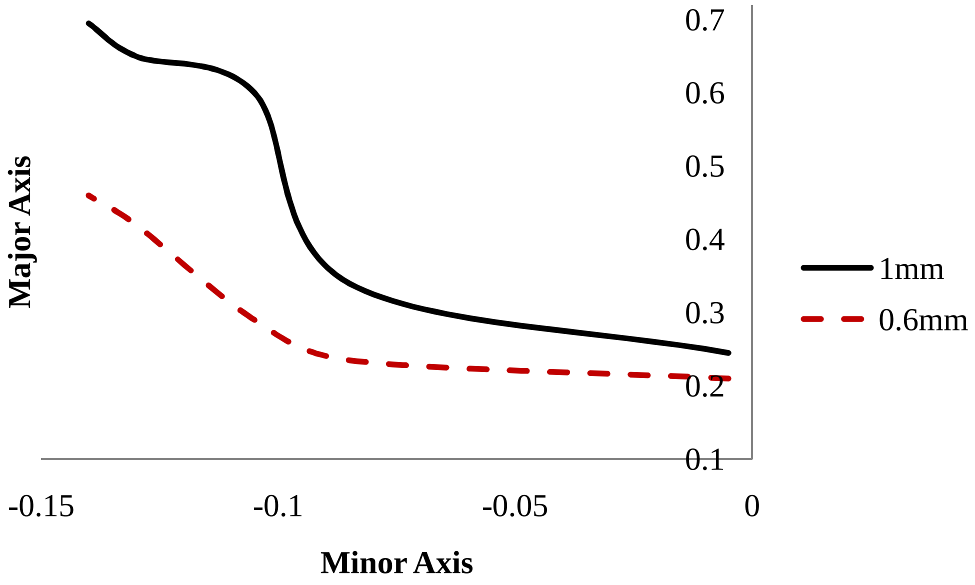


(b)

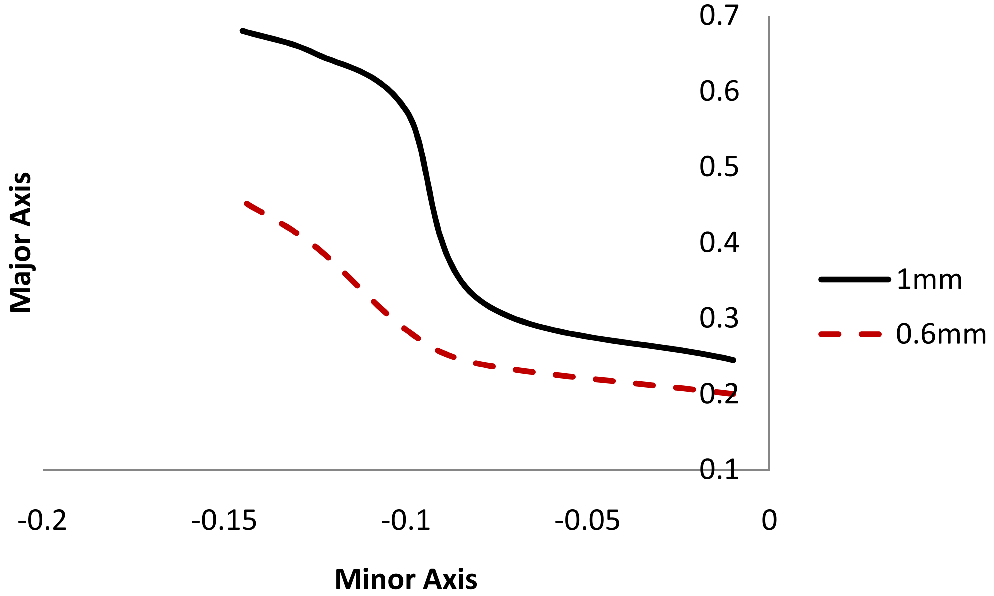
Figure 4.13: Continued.

In Figure 4.13(a), the graph shows a comparison of FLD for both conditions (lubricate and non-lubricate) for blank thickness 1mm while Figure 4.13(b) shows a comparison of FLD for both conditions (lubricate and non-lubricate) for blank thickness 0.6mm using aluminium AA1100 as blank. From both graph, it shows that the level of FLD for both blank thickness (1mm and 0.6mm) with present of lubricant is higher compare to un-present of lubricant. As stated by Elongavan, 2010, the material with higher level of FLD is good material to consider. So with this, it can say that the present of lubricant in deep drawing process is more good compare to un-present of lubricant by referring their FLD level.

Besides that, the blank thickness also one of the main factor that have to consider in deep drawing. With the variable of blank thickness, the normal anisotropy of material, $\bar{R}$ value of the material also change.



(a)



(b)

Figure 4.14: Comparison of FLD of aluminium AA1100 for both blank thickness in conditions of (a) with lubricant and (b) without lubricant

From Figure 4.14(a), it shows a FLD of aluminium AA1100 for both blank thickness (1mm and 0.6mm) with the present of lubricant while Figure 4.14(b) shows the FLD of aluminium AA1100 for both blank thickness (1mm and 0.6mm) without the present of lubricant. Both of the graph shows that the blank thickness of 1mm has a higher level of FLD compare to blank thickness 0.6mm. As mentioned in Figure 4.13, higher level of FLD indicated a good material to consider in deep drawing experiment. It means that in sheet metal forming especially in deep drawing, a sheet metal with higher thickness is good material to consider. It is because of higher thickness of sheet metal have a higher value of material normal anisotropy, $\bar{R}$. As stated by Whiteley, 1960, a material with high value of $\bar{R}$ is a good material to consider in deep drawing process.

CHAPTER 5

CONCLUSION

5.1 CONCLUSION OF EXPERIMENT

In the present study, a deep drawing die that was used is similar to Swift cupping test which was designed to draw a circular blank into cylindrical cup. For both experiment that is LDR and FLD, the purpose of these two experiments is to investigate the formability of sheet metal.

5.1.2 CONCLUSION FOR LDR EXPERIMENT

In LDR experiment, the main objective is to find the value of LDR by using variable of blank diameter, blank holder force and type of material. From literature review, the LDR values indicate the level of its drawability. It can understand that the specimen with high LDR value is good to be drawn in deep drawing operations.

From the experiment, the value of LDR is increasing with increasing of blank diameter and blank holder force. The value of LDR using blue spring (BHF =16.3 N/mm) is higher compare to yellow spring (10 N/mm). Besides that, the blank diameter of 100mm for both materials (aluminium AA1100 and copper) also has a higher LDR values compare to blank diameter of 80mm. It means when running a deep drawing experiment, it is necessary to consider a blank with large diameter and high blank holder force. But for blank holder force, it is necessary to study first an optimal BHF that is needed to drawn the sheet metal. It is because if the BHF that was used is higher than the optimal BHF that is needed, than the sheet metal will be ruptured when the experiment is done. But if the BHF that was used is less than the optimal BHF, a wrinkling may occur and thus the value of LDR also might be effect.

In addition, aluminium AA1100 has higher value of LDR compare to copper by referring their LDR values. It may because of the normal anisotropy, $\bar{R}$ value of aluminium AA1100 is higher than copper. So it can be conclude here, the drawability of aluminium AA1100 is higher than copper by referring their value of LDR.

5.1.3 CONCLUSION FOR FLD EXPERIMENT

As for FLD, the test is use from previous study to predict the formability of sheet metal by finding their value of strains. The FLD is important because it can show the area of the material or blank which is their safe area and failure area. So by construct the FLD, the forming limit of the material of can be predicted by referring their FLD respectively. In the present study, the material that is used is aluminium AA1100 with variable of blank thickness and surface condition of the blank.

From the FLD experiment, it is observed that the level of FLD is higher if the thickness of the blank also high. In the present study, the blank thickness of 1mm has higher level of FLD compare to blank thickness of 0.6mm. It shows if higher thickness of blank is use in deep drawing, the possibility of the blank to rupture is less compare to lower blank thickness. So it can be conclude that higher thickness of sheet metal will raise the level of FLD and thus the material will have a lower tendency to rupture.

As for surface condition of the blank with the punch, the present of lubricant shows that the level of FLD is higher compare to un-present of lubricant. It is because of friction that was exerted between punch and blank is high if there was no lubricant used. So it can be conclude that the present of lubricant (Lithium grease) will raise the level of FLD and thus the material that was used also have lower possibility to rupture compare to material that was not used lubricant.

5.2 RECOMMENDATIONS

From the present study, there are several recommendations which may be use to improve the results for similar studies in the future. The recommendations are listed as follows.

(1) Gas-springs (i.e. nitrogen spring) should be use instead of coil spring to provide higher and constant BHF, especially at lower punch stroke to prevent wrinkling.

(2) For drawing of blanks of variable diameters, the blank holder should have several rings with different blank-slot diameters corresponding to the blank diameter used to allow accurate centering of the blank.

(3) The bottom plate that was used to hold or support the coil springs is need to merge with the deep drawing die as a one system to prevent a non-uniform blank holder force that was exerted on the blank.

(4) To get a full shape of FLD graph, it is suggested to use a hemisphere punch instead of cylindrical punch. It is because it is possible to get a stretch forming area by using the hemisphere punch.

(5) To draw the circle grid, etching process might be use instead of drawing the circle grid by marker pen. It is because if the circle grid is done using etching process, a perfect shape of circle grid will be get and the reading of circle grid deformation also can be taken accurately.

REFERENCES

Assempour, A., Hashemi, R., Abrinia, K., Ganjiani, M. and Masoumi, E. 2009. A methodology for prediction of forming limit stress diagrams considering the strain path effect. *Computational Material Science*. **45:** 195-204.

Banabic, D., Bunge, H.J., Pohlandt, K. and Tekkaya, A.E. (2000). *Formability of Metallic Materials: Plastic Anisotropy, Formability Testing, Forming Limits.* New York: Springer.

Boljanovic, V. (2004). *Sheet Metal Forming Processes and Die Design.* New York: Industrial Press Inc.

Budiansky, B. And Wang, N.M. 1966. On the Swift cup test. *J. Mech. Phys. Solids.* **14:** 357-354.

Bwowne, M.T. and Hillery, M.T. 2003. Optimizing the variables when deep drawing C.R.1 cups. *Journal of Materials Processing Technology.* **136:** 64-71.

Cao, J. and Wang, X. 2000. On the prediction of side-wall wrinkling in sheet metal forming process. *International Journal of Mechanical Sciences.* **42:** 2369-2394

Chinouilh, G., Toscan, F., Leseux, J. and Santacreu, P.-O. Behaviour and forming limit diagram predictions of stainless steels sheets. Technical Report. SAE: 2007-01-0338.

Craig Jr, R.R. (2000). *Mechanics of Materials.* U.S: John Wiley & Sons, Inc.

Elongavan, E. and Narayanan, C.S. 2010. Application of Taguchi approach on investigation of formability for perforated AI 8011 sheets. *International Journal of Engineering, Science and Technology.* **2:** 300-309.

Engler, O. and Hirsch, J. 2007. Polycrystal-plasticity simulation of six and eight ears in deep-drawn aluminium cups. *Material Science and Engineering A.* **452-453:** 640-651.

Gerdeen, J.C. and Daudi, A. 1983. Formability Limits of Relatively Thick Sheet Metal as Determine by the Fukui Conical Cup Test. *Journal of Engineering for Industry.* **105:** 281-286.

Goodwin, G.M. 1968. Application of strain analysis to sheet metal forming problems in the press shop. *Metallic Italiana.* **60:** 764-774.

Hertzberg W.H. (1996). *Deformation and Fracture Mechanics of Engineering Materials.* U.S: John Wiley & Sons, Inc.

Hosford, W.F. and Caddell, R.M. (2007), *Metal Forming: Mechanics and Metallurgy (3rd Edition)*. Cambridge: Cambridge University Press.

Keeler, S.P. 1965. Determination of forming limits in automotive stampings. *Sheet Metal Ind.* **42:** 683-691.

Khoruddin, M.F. 2009. *Finite element modelling Swift sheet metal formability test.* Bachelor Degree. Thesis. Universiti Malaysia Pahang.

Kishor, N. and Kumar, D.R. 2002. Optimization of initial blank size to minimize earing in deep drawing using finite element method. *Journal of Materials Processing Technology.* **130-131:** 20-30.

Korhenen, A.S. 1982. Drawing force in deep drawing of cylindrical cup with flat-nosed punch. *Journal of Engineering for Industry*. **104:** 29-37.

Leu, D.K. 1999. The limiting drawing ratio for plastic instability of the cup-drawing process. *Journals of Materials Processing Technology.* **86:** 168-176.

Miller, W.S., Zhuang, L., Witterbrood, A.J., De Smet, P., Hazler, A. and Vieregge, A. 2000. Recent development in aluminium alloys for the automotive industry. *Material Science and Engineering A.* **280:** 37-49.

Moshksar. M.M. and Zamanian, A. 1997. Optimization of the tool geometry in the deep drawing of aluminium. *Journal of Materials Processing Technology.* **72:** 363-370.

Narayanasamy, R. and Narayanan C.S. 2007. Experimental analysis and evaluation of forming limit diagram for interstitial free steels. *Materials and Design.* **28:** 1490-1512.

Obermeyer, E.J. and Majlessi, S.A. 1998. A review of recent advances in the application of blank-holder force towards improving the forming limits of sheet metal parts. *Journal of Materials Processing Technology.* **72:** 222-234.

Pepelnjak, T. and Kuzman, K. 2007. Numerical determination of the forming limit diagram. *Journal of Achievements in Materials and Manufacturing Engineering.* **20:** 1-2.

Rao, P.N. (1999). *Manufacturing Technology: Foundry, Forming and Welding (2nd Edition).* New Delhi: Tata McGraw-Hill.

Schanakovszky, C. and Ganea, B. 2007. Influence of different factors concerning the wrinkling of cylindrical deep-drawn parts. *Fascicle of Management and Technological Engineering.* **7:** 1266-1269.

Schey J.A. (2000). *Introduction to Manufacturing Processes.* Singapore: McGraw-Hill.

Singh, D.K. (2008). *Fundamental of Manufacturing Engineering.* U.S: CRS Press.

Slota, J. and Spisak, E. 2005. Comparison of the forming limit diagram models for drawing quality steel sheets. *Original Scientific Paper.* **4:** 249-253.

Suchy, I. (2005). *Handbook of Die Design (2nd Edition).* New York: McGraw-Hill.

Theis, H.E. (1999). *Handbook of Metalforming Process.* New York: Marcel Dekker Inc.

Tzou, G.Y., Hwang, Y.m., Hu., H.L., Chien, W.T. and Hu, J.J. 2007. Study on the hemisphere deep drawing process of metal sheet based on FEM simulation. *Proceedings of the 9th International Conference on Numerical Methods in Industrial Forming Process (NUMIFORM '07),* pp. 649-654

Udomphol, T. 2007. *Sheet metal forming.* Slide. Bangkok: Suranaree University of Technology.

Verma, R.K. and Chandra, S. 2006. An improved model for predicting limiting drawing ratio. *Journals of Materials Processing Technology.* **172:** 218-224.

Wagoner, R.H. and Chenot, J.-L. (2001). *Metal Forming Analysis.* U.S: Cambridge University Press.

Wick, W., Raymond, F.V. and John T.B. (1984). *Tool and Manufacturing Engineers Handbook: Forming.* Society of Manufacturing Engineers.

Yoshihara, S., Manabe, K. and Nishimura, H. 2005. Effect of blank holder force control in deep drawing process of magnesium alloy sheet. *Journals of Materials Processing Technology.* **170:** 579-585.

Ziaeipoor, H., Jamshidifard, S., Moosavi, H. and Khademizadeh, H. 2009. Numerical analysis of wrinkling phenomenon in hydroforming deep drawing with hemispherical punch. Technical Report. ISSN: 1792-507X.

APPENDIX A1

DATA OF LDR EXPERIMENT FOR ALUMINIUM AA1100 (BHF = 16.3 N/mm)

Table 6.1: Data of LDR experiment for first drawing operation

Blank diameter (mm)	Critical cup diameter (mm)	LDR
80	50.06	1.598
85	50.30	1.690
90	50.52	1.781
95	50.95	1.865
100	53.88	1.856

Table 6.2: Data of LDR experiment for second drawing operation

Blank diameter (mm)	Critical cup diameter (mm)	LDR
80	50.10	1.597
85	50.18	1.694
90	50.36	1.787
95	50.99	1.863
100	53.84	1.857

Table 6.3: Average data of LDR experiment

Blank diameter (mm)	Critical cup diameter (mm)	LDR
80	50.08	1.597
85	50.24	1.692
90	50.44	1.784
95	50.97	1.864
100	53.86	1.857

DATA OF LDR EXPERIMENT FOR COPPER (BHF = 16.3 N/mm)

Table 6.4: Data of LDR experiment for first drawing operation

Blank diameter (mm)	Critical cup diameter (mm)	LDR
80	50.14	1.596
85	50.32	1.689
90	50.60	1.779
95	51.25	1.854
100	54.08	1.844

Table 6.5: Data of LDR experiment for second drawing operation

Blank diameter (mm)	Critical cup diameter (mm)	LDR
80	50.10	1.597
85	50.40	1.687
90	50.62	1.778
95	51.45	1.846
100	54.40	1.838

Table 6.6: Average data of LDR experiment

Blank diameter (mm)	Critical cup diameter (mm)	LDR
80	50.12	1.596
85	50.36	1.688
90	50.61	1.778
95	51.35	1.850
100	54.24	1.844

DATA OF LDR EXPERIMENT FOR ALUMINIUM AA1100 (BHF = 10 N/mm)

Table 6.7: Data of LDR experiment for first drawing operation

Blank diameter (mm)	Critical cup diameter (mm)	LDR
80	50.08	1.597
85	50.58	1.681
90	53.57	1.680
95	54.27	1.751
100	56.01	1.785

Table 6.8: Data of LDR experiment for second drawing operation

Blank diameter (mm)	Critical cup diameter (mm)	LDR
80	50.12	1.596
85	50.68	1.677
90	53.69	1.676
95	54.35	1.748
100	55.43	1.804

Table 6.9: Average data of LDR experiment

Blank diameter (mm)	Critical cup diameter (mm)	LDR
80	50.10	1.597
85	50.63	1.659
90	53.63	1.680
95	54.31	1.749
100	55.72	1.795

DATA OF LDR EXPERIMENT FOR COPPER (BHF = 10 N/mm)

Table 6.10: Data of LDR experiment for first drawing operation

Blank diameter (mm)	Critical cup diameter (mm)	LDR
80	50.22	1.593
85	51.20	1.660
90	54.65	1.638
95	56.51	1.681
100	57.86	1.728

Table 6.11: Data of LDR experiment for second drawing operation

Blank diameter (mm)	Critical cup diameter (mm)	LDR
80	50.02	1.599
85	51.46	1.652
90	54.38	1.641
95	57.13	1.663
100	58.36	1.714

Table 6.12: Average data of LDR experiment

Blank diameter (mm)	Critical cup diameter (mm)	LDR
80	50.12	1.596
85	51.33	1.656
90	54.74	1.644
95	56.82	1.672
100	58.11	1.721

APPENDIX A2

DATA OF FLD EXPERIMENT FOR ALUMINIUM AA1100 WITH 1mm THICKNESS (WITH LUBRICANT)

Table 6.13: Data of FLD experiment for first drawing operation

Punch stroke (mm)	Diameter of circle grid on major axis (mm)	Diameter of circle grid on minor axis (mm)	Major strain (ε_1)	Minor strain (ε_2)
10	2.46	1.99	0.230	- 0.005
20	2.60	1.84	0.300	- 0.080
30	3.28	1.77	0.640	- 0.115
40	3.33	1.75	0.665	- 0.125
50	3.45	1.73	0.725	- 0.135

Table 6.14: Data of FLD experiment for second drawing operation

Punch stroke (mm)	Diameter of circle grid on major axis (mm)	Diameter of circle grid on minor axis (mm)	Major strain (ε_1)	Minor strain (ε_2)
10	2.52	1.99	0.260	- 0.005
20	2.76	1.82	0.380	- 0.090
30	3.12	1.81	0.560	- .0.095
40	3.27	1.73	0.635	- 0.135
50	3.33	1.71	0.665	- 0.145

Table 6.15: Average data of FLD experiment

Punch stroke (mm)	Diameter of circle grid on major axis (mm)	Diameter of circle grid on minor axis (mm)	Major strain (ε_1)	Minor strain (ε_2)
10	2.49	1.99	0.245	- 0.005
20	2.68	1.83	0.540	- 0.085
30	3.20	1.79	0.600	- 0.105
40	3.30	1.74	0.650	- 0.130
50	3.39	1.72	0.695	- 0.140

DATA OF FLD EXPERIMENT FOR ALUMINIUM AA1100 WITH 1mm THICKNESS (WITHOUT LUBRICANT)

Table 6.16: Data of FLD experiment for first drawing operation

Punch stroke (mm)	Diameter of circle grid on major axis (mm)	Diameter of circle grid on minor axis (mm)	Major strain (ε_1)	Minor strain (ε_2)
10	2.52	1.99	0.260	- 0.005
20	2.67	1.82	0.335	- 0.090
30	3.20	1.79	0.600	- 0.105
40	3.30	1.71	0.650	- 0.145
50	3.31	1.69	0.655	- 0.155

Table 6.17: Data of FLD experiment for second drawing operation

Punch stroke (mm)	Diameter of circle grid on major axis (mm)	Diameter of circle grid on minor axis (mm)	Major strain (ε_1)	Minor strain (ε_2)
10	2.46	1.97	0.230	- 0.015
20	2.63	1.86	0.315	- 0.070
30	3.10	1.81	0.550	- 0.095
40	3.30	1.79	0.650	- 0.105
50	3.41	1.73	0.705	- 0.135

Table 6.18: Average data of FLD experiment

Punch stroke (mm)	Diameter of circle grid on major axis (mm)	Diameter of circle grid on minor axis (mm)	Major strain (ε_1)	Minor strain (ε_2)
10	2.49	1.98	0.245	- 0.010
20	2.65	1.84	0.325	- 0.080
30	3.15	1.80	0.575	- 0.100
40	3.30	1.75	0.650	- 0.125
50	3.36	1.71	0.680	- 0.145

DATA OF FLD EXPERIMENT FOR ALUMINIUM AA1100 WITH 0.6mm THICKNESS (WITH LUBRICANT)

Table 6.19: Data of FLD experiment for first drawing operation

Punch stroke (mm)	Diameter of circle grid on major axis (mm)	Diameter of circle grid on minor axis (mm)	Major strain (ε_1)	Minor strain (ε_2)
10	2.41	1.99	0.205	- 0.005
15	2.42	1.97	0.210	- 0.015
20	2.50	1.84	0.250	- 0.080
25	2.85	1.79	0.425	- 0.105
30	2.99	1.78	0.495	- 0.110

Table 6.20: Data of FLD experiment for second drawing operation

Punch stroke (mm)	Diameter of circle grid on major axis (mm)	Diameter of circle grid on minor axis (mm)	Major strain (ε_1)	Minor strain (ε_2)
10	2.43	1.97	0.215	- 0.015
15	2.52	1.91	0.260	- 0.045
20	2.66	1.78	0.330	0.110
25	2.83	1.75	0.415	- 0.125
30	2.85	1.74	0.425	- 0.130

Table 6.21: Average data of FLD experiment

Punch stroke (mm)	Diameter of circle grid on major axis (mm)	Diameter of circle grid on minor axis (mm)	Major strain (ε_1)	Minor strain (ε_2)
10	2.42	1.98	0.210	- 0.010
15	2.47	1.94	0.235	- 0.030
20	2.58	1.81	0.290	- 0.095
25	2.84	1.77	0.420	- 0.115
30	2.92	1.76	0.460	- 0.120

DATA OF FLD EXPERIMENT FOR ALUMINIUM AA1100 WITH 0.6mm THICKNESS (WITHOUT LUBRICANT)

Table 6.22: Data of FLD experiment for first drawing operation

Punch stroke (mm)	Diameter of circle grid on major axis (mm)	Diameter of circle grid on minor axis (mm)	Major strain (ε_1)	Minor strain (ε_2)
10	2.44	1.99	0.220	- 0.005
15	2.51	1.95	0.255	- 0.025
20	2.65	1.83	0.325	- 0.085
25	2.76	1.79	0.380	- 0.105
30	2.86	1.77	0.430	- 0.115

Table 6.23: Data of FLD experiment for second drawing operation

Punch stroke (mm)	Diameter of circle grid on major axis (mm)	Diameter of circle grid on minor axis (mm)	Major strain (ε_1)	Minor strain (ε_2)
10	2.36	1.99	0.180	- 0.005
15	2.45	1.93	0.225	- 0.035
20	2.48	1.77	0.240	- 0.115
25	2.82	1.73	0.410	- 0.135
30	2.96	1.71	0.480	- 0.145

Table 6.24: Average data of FLD experiment

Punch stroke (mm)	Diameter of circle grid on major axis (mm)	Diameter of circle grid on minor axis (mm)	Major strain (ε_1)	Minor strain (ε_2)
10	2.40	1.99	0.200	- 0.005
15	2.48	1.94	0.240	- 0.030
20	2.57	1.80	0.285	- 0.100
25	2.79	1.76	0.395	- 0.120
30	2.91	1.74	0.455	- 0.130

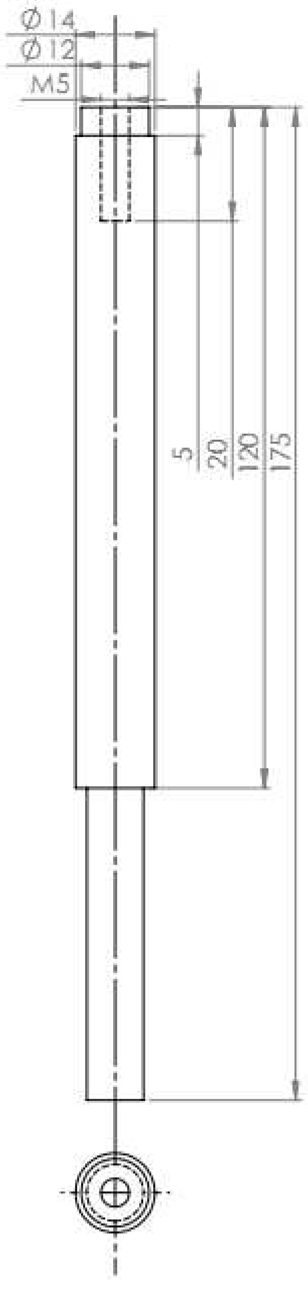
APPENDIX B1

CALCULATION OF BLANK HOLDING CONTACT AREA ACCORDING TO BLANK DIAMETER

Blank diameter, D (mm)	Blank area, A_b (mm^2)	Punch area, A_p (mm^2)	Blank holder contact area, $A_b - A_p$ (mm^2)
80	5026.548	1963.495	3063.053
85	5674.502	1963.495	3711.006
90	6361.725	1963.495	4398.230
95	7088.218	1963.495	5124.723
100	7853.982	1963.495	5890.487

APPENDIX C1

DIMENSIONS OF BLANK HOLDER PILLAR



APPENDIX D1

RECOMMENDED PUNCH AND DIE RADII FOR CERTAIN BLANK THICKNESS

Blank thickness		**Drawing edge radius (punch or die)**	
In.	**mm**	**In.**	**mm**
0.015 – 0.018	0.36 – 0.45	0.156 – 0.250	4.00 – 6.35
0.021 – 0.027	0.50 – 0.70	0.187 – 0.312	4.75 – 7.15
0.031 – 0.046	0.80 – 1.20	0.187 – 0.312	4.75 – 8.00
0.048 – 0.062	1.20 – 1.60	0.250 – 0.375	6.35 – 9.50
0.078 – 0.093	2.00 – 2.25	0.312 – 0.437	8.00 – 11.00
0.109 – 0.125	2.80 – 3.50	0.343 – 0.468	8.70 – 12.00

Source: Suchy (2005)