STUDY ON DRAWING DIE RADIUS TO LOAD AND THINNING PATTERN OF ALUMINIUM ALLOY

By

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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ABSTRAK

Proses penarikan yang melibatkan bentuk segi empat sama sangat kompleks dan melibatkan banyak berkalunya kecacatan. Kajian ini telah dijalankan bagi mengenalpasti pola thinning dalam proses penarikan yang memfokuskan kepada saiz jejari die. Thinning sesuatu logan adalah corak ketegangan yang berlaku sebelum logam tersebut mengalami kegagalan. Projek ini menunjukkan bahawa sebarang perubahan dalam jejari die akan mempengaruhi aliran bahannya. Dalam kajian ini, corak load dan thinning dalam proses penarikan untuk bentuk segi empat sama dikenalpasti. Ciri-Ciri utama dalam kajian ini adalah jejari sudut die yang mana Aluminium Aloi merupakan bahan yang dikaji. Projek ini adalah suatu kaedah pendekatan yang menggunakan UTM dan juga DIC semasa menjalankan eksperimen dan data dianalisis menggunakan perisian Davis. Keputusan kajian mendapati bahawa bahan dan specimen akan mengalami kegagalan lebih cepat pada jejari sudut die yang kecil. Dapat disimpulkan bahawa formability bahan dalam bentuk segi empat sama semasa proses penarikan bergantung pada geometri die.

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ABSTRACT

Deep drawing in square cup is very complex and associated with many defects. This is a study where the thinning pattern in the square deep drawing process by focusing on the effect of size at die corner radius was carried out. Thinning of metal is a strain pattern that takes place prior to sheet metal failure. This project shows the variation in die corner radius have an influences on the material flow. Here the load and thinning pattern on square cup drawn by deep drawing process is observed. The main features in this experiment is die corner radius and the studied material is Aluminium alloy. This project is an approach to use Universal Testing Machine (UTM) and Digital Image Correlation (DIC) as apparatus in the experiment and analyze the data using Davis software. Result found that, the material or specimen would undergo the faster deformation at small corner radius. It is concluded that, the formability of material in square corner area depends on the die corner geometry

CHAPTER 1

INTRODUCTION

1.1 Overview

Deep drawing is one of the most common metalworking methods in producing metal parts. This method involves forming flat sheet metal into “cup-shaped”, “box-shape”, or other complex-curved with hollow-shape parts. The process is called deep drawing if the depth of formed cup is equal to or greater than the radius of the cup.(Joshi, Ramesh, & Reddy, 2013) Deep drawing involves placing a sheet metal blank over a shaped die and pressing the metal into die with a punch. Main elements in structural design of tooling in deep drawing is drawing punch (punch), blank holder, drawing ring (die), and ejector.

Deep drawing have been widely used in automotive component, aerospace components, medical components, housing, and other appliances and components. Different application have different product geometries. Common type of geometries in deep drawing is cylindrical object (circular), square, rectangle, conical and more complex geometries. Circular geometries can easily be drawn into 3D circular object with a single drawn ratio. However, complex geometries such as rectangle may create slightly complication due to the unusual metal flow pattern. The forces exerted on the parts during deformation are different along the area of angle. Without the proper optimize range to design parameters, it may lead to different load or excessive localized thinning on drawn parts.

The process in deep drawing involve forming by tensile and compressive forces. Deformation of workpiece can takes place when have complete structural design of tooling. But, drawing operation is the most complex and difficult to control in all the press working operation due to existing variety of variables.

Unsuccessful deep drawing is observe through the existing of defect in drawn parts. Fracture at bottom of redrawn cup, flange of drawn cup, excess material at top of drawn shell are the common problem in deep drawing. Wrinkling in flange, wrinkling in wall, tearing, earing, and surface scratches is some defect that may occur in drawing. All this problem and defect always related to the designing of tooling and it process parameter. Many researchers study the parameter to observed and get the optimized design and value. So that, industries involves in deep drawing process can encounter this problem and defects.

Many research study the effect of process parameter towards the simulation in a circular cup. A researcher discover that the developed Finite Element model can predict the thickness distribution and thinning of the blank with the die design parameters (geometrical and physical parameters)zein. In a recently publish work, coefficient of friction which is one of the most important parameters affects the deep drawing process for flange and radius regions were determined experimentally. (Dilmec & Arap, 2016)

In a previous research on deep drawing process, generally the die design parameter being studied and observed through numerical studies which capable to reveal the deformation pattern of workpiece. Usually, forming parameters are used in finite element simulation and the optimal value can be predicted. Simulation were carried out to determine the optimum range operational parameter in deep drawing. So, this project will performing an experimental works to observed thinning pattern on strain distribution with the changes in die geometries for rectangular forming parts.

1.2 Problem Statement

Deep drawing is one of the sheet metal forming processes widely uses in industries to produce the hollow parts. However, the thinning of sheet metal is the unwanted defect in deep drawing application. Some thinning of sheet metal is unavoidable. Also, the profile of corner radius in square cup is difficult to predict. Many researcher proposed the simulation to discussed and analysed the result. The experimental techniques can be applied as a solution for this problem to observe to evaluate the formability of material flow in square deep drawing. In this project, three different die corner radius are being studied for observing the thinning pattern as well as analysing the load from the material formability.

1.3 Objectives

The objectives of the project are: -

1. To study the effect of die corner radius to the flow of material during square deep drawing.
2. To predict the thinning defect based using Digital Image Correlation (DIC).

1.4 Scope of Project

In this study, the work are focusing on designing, fabricating the specimen, die, blank holder and bottom plate as an experimental test rig. Then, the test rig being tested using Universal Tensile Machine (UTM) and Digital Correlation Image (DIC) to illustrate the load and thinning pattern of aluminium alloy. The data obtained is being studied.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Deep drawing is a process where a flat sheet metal is form into desire shape or cup by forcing a punch against the center of die. Products made by sheet-forming process include a very large variety of different geometrical shapes and sizes, like simple bend to double curvatures even withdeep recesses and very complex shapes.(Angasu & Reddy, 2016) The die may be in circular, rectangular, circular or even more complex outline. Deep drawing is the forming of smooth blanks into hollow parts. It is a process which involves forming by tensile and compressive forces. The deformation takes place using a deep drawing ring, drawing punch and blank holder. In the process, the punch draws the material through the gap formed by the punch and the drawing ring, forming it into a cup.(Tschaetsch & Koth, 2006) The final shape of cup can be reached by more drawing step, this operation is called redrawing

In manufacture rectangular parts, there are unusual metal flow pattern occur during drawing process. Two different deformation involves in rectangular drawn are radial compression and bend and straighten. In circular cup deep drawing, parts being compress radially in simultaneous flow. But in rectangular cup, radial compression causes resistance to flow in corners of drawing. Metal does not flow evenly into the die from all direction. More complex metal part at the corners causes more resistance material movement.

Tangential compression occurs as the material is forced into smaller and smaller diameters. Radial tensile stress occurs due to the tensile force when the blank is drawn into the space between the punch and the die. Compressive stress occurs due to the blank holder force the material is subjected to pressure. Bending stress occurs when the blank is bent over the radius of the die.

2.2 Variables of process parameter

In square shape of component major failures are occurs due to stress concentration at the square shape sharp edges of die and punch.(Yogesh, Deshmukh, Dhembre, Sawant, & Bhosale, 2018) High requirements performance in deep drawing has increases the tendency to allow the defects. Process parameter and another factors affect the product quality. So, products with minimal defect need to be produced. Example of parameter affect the deep drawing process is blank holder pressure, blank holder thickness, punch radius, punch velocity, die radius, material properties, and coefficient of friction(Sezek, Savas, & Aksakal, 2010). All these are classified according to the process parameter as below.

2.2.1 Blank Holder Force

Blank holder force is one of main important elements in the deep drawing process. A lot of research work has been reported to investigate the effect of BHF on product quality, material flow, strain path, stress distribution, thinning and thickening of sheet metal, and defects in product. Demirci, Esner, & Yasar (2008) reported in his work about the influence of aluminium alloy; AA5754-0 blank by the blank holder force. In his experiment, variable forces is applying in computer-controlled manner on blank holder and sheet plate during deep drawing process testing using LS-DYNA. As result, there are no earing and wrinkling occurred at the blank holder force between 1.3-8Mpa. While, tears occurred when forces exceed 18Mpa. The best forming quality is produced at 5Mpa blank holder force.

2.2.2 Punch Force

Behrens, Ruhe, Tetzel, & Vollertsen (2015) carried out micro deep drawing tests to determine the punch forces for a variation of the corner radius and the die radius via experimental and simulation. It demonstrated that an increasing corner radius size leads to an increasing punch force in deep drawing. Enlarging the corner radius from 147 to 250 µm resulted in a 36 % higher punch force. In contrast, an increase of the die radius size results in a decreasing punch force. Here, enlarging the die radius from 76 to 143 µm led to a decrease of the punch force of 26 %.

2.2.3 Die radius

For the die, Hassan, Hezam, El-Sebaie, & Purbolaksono (2014) proposed the deformation characteristics. Finite element analysis was use to study the influences of the main process parameter on draw ability of square cup to optimize the setup dimension and operating condition. They investigated the effects of die fillet radius, die corner radius, die throat length in draw ability of square cup using simulation and experimental. As die corner radius increases, a gradual transition from non-axisymmetric to axisymmetric deformation occurs. During this transition, the deformation resistance reduces as die corner radius increases and Limiting Drawing Ratio (LDR) increases since the flow of metal becomes easier.

2.2.4 Material Properties

Mechanical properties such as stiffness, strength, ductility, hardness, toughness, elastic deformation, plastic deformation, engineering strain, engineering stress, Poisson's ratio, yield strength. Strain, ε is the deformation elongation as result from tensile or comprehensive. When a constant tensile force is apply, the material will break after reaching the tensile strength. The material starts necking, but the stress cannot increase beyond tensile strength. The ratio of the deformation elengation to the initial length is called the engineering stress. If the ratio is to the actual length (that changes with strain), it is true strain.

E, Mizuno, & Li (2008) analyzed only a quarter of the rectangular cup deep drawings and a "three-segment-approach" was adapted. Two straight flange areas and one corner flange area were treated as three independent deformation zones. Theoretical stress distributions on the straight flange areas and corner flange area were obtain. It justified that the most critical location of deep drawing of rectangular cup is upper tangential point of punch shoulder. Pranavi (2014) examined the effect of mechanical properties (strain hardening coefficient and yield strength) on the deep drawing formability. The simulation of tool required for test punch, die, blank holder, draw bead and blank were generated in Solid works and meshed using Delta Mesh facility in PAM STAMP 2G. From the study, as yield strength increases, thickness distribution increases. Also, as strain coefficient increases, there are more formability and less thinning. Takaji (2006) reported the stress distribution in rectangular case drawing along the drawing-in direction of side-wall of straight and curve flanges by means of the simplified method of the equivalent radius to flange curve-edge. The corner drawing-in stress along the die-entrance line is maximal, and the radial stress in straight flange fluctuates above or below zero. It is also pointed out that part regions near the die- entrance line tend to compression deformation in normal direction. Daxin, Mizuno, & Zhiguo (2007) forecast the deformation force and blank-holder force in rectangular drawing effectively by analyzed stress and strain.

2.2.5 Coefficient Friction

In the case of coefficient of friction, Dilmec & Arap (2016) was experimentally studied the effect to the deep drawing process at flange and radius regions of dies through experimental. This study develop the new design test apparatus which can determine the friction coefficients for flange and radius regions. Effect of die radius on dynamic coefficient friction between flange and radius regions of tool and sheet metal were further investigated by using ANOVA. As result, they found that the lubrication condition is a more effective to the flange region compare than the die radius region.

2.3 Failure Criterion

The shape of deep drawing are not limited to circle and square only, the more complex shape are possible. As the complexity of deep drawing increases, manufacturing difficulties increases. In this sheet metal forming process, there are involves complex material flow and force distribution. The factor of die corner radius will change the force distribution and cause metal to flow into die cavity. Tensile stress in material forming of straight wall will cause thinning. Defect occur in deep drawing can be controlled by many parameters factors. In this review, cracking, thinning, wrinkling, earring, fracture, tearing, surface scratch are reviewed and analyzes the effect of process parameter.(Yogesh et al., 2018)

Maximum thinning usually occur near to the base. Tearing may cause by excessive force. When tearing occur at the corner of wall, it may indicate a problem with blank’s geometry. Wrinkling occur if blank holder force is too low. Then, earing is the wavy edges at the open end of drawn cup. Younis, Jabber, & Abdulrazaq (2018) reported that square cup forming process is complicated. The deformation states vary along the square die cavity, the flow of metal at the corner is less uniform and more complex. Also, the cup height is very affect by radial clearance between punch and die, decreasing in radial clearance will increasing the height of the cup. They found that, the increases blank size will increase the height of cup. Mostly thinning appear in corner cup due to excessive stretching occur. Increasing in die profile radius and blank size will reduce the thinning in the cup square cup drawn. Refer figure below for more detail.

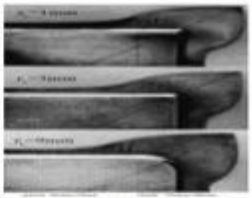
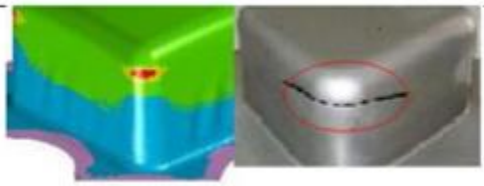
Sr. No.	Name of Defects	Pictures of Defects	Causes
1	Wrinkling	 Fig 2- Wrinkling Defect	Occurs in the areas where is excessive material flow
2	Earring	 Fig 3- Earring	Occurs when the material is anisotropic and has varying properties in different directions.
3	Fracture	 Fig 4- Fracture	Occurs in the areas subjected to high tensile stresses
4	Tearing	 Fig 5- Tearing	In numerical Damage prediction and Experiments in Deep Drawing of Irregular Square Cup they are explained how to effect of blank holding force on tearing

Figure 2. 1: Major Defect in square deep drawing and its causes (Yogesh et al., 2018)

Research stated that during cup drawing, material near the punch radius is subjected to maximum thinning and therefore, the bottom of the cup gets separated. By providing large radius on the punch or reducing the punch load may eliminate this defect.(Chandramouli, n.d.)

CHAPTER 3

METHODOLOGY

3.1 Overview of the Project

This project developed the rectangular design of test set regarding the study of drawing die radius to thinning pattern. Test set consist of die, blank holder, bottom plate, and screw. The designing part was fabricated using machine available in Universiti Sains Malaysia, Mechanical school's workshop. The testing were performed using Universal Testing Machine (UTM); Instron 3367 and Lavision Digital Image Correlation (DIC); Anna-Vandenhoeck-Ring 19 37081 Goettingen/Germany. Appendix 1 show the result obtained.

3.2 Concept Description

Usually, deep drawing consist of punch force gravitationally into the die to form a shape. In this project, the deep drawing in test set will experimentally on the other way around. There are a pull load or forces using UTM to form a shape without using a punch set. New methodologies to measure the strain properties of material were executed. DIC is used to capture the image in every micro second to see the thinning pattern and the flow of material. The results were simulate and analyzes.

3.2.1 Universal Testing Machine

Figure 3.1 shown the UTM setup during experimental testing.

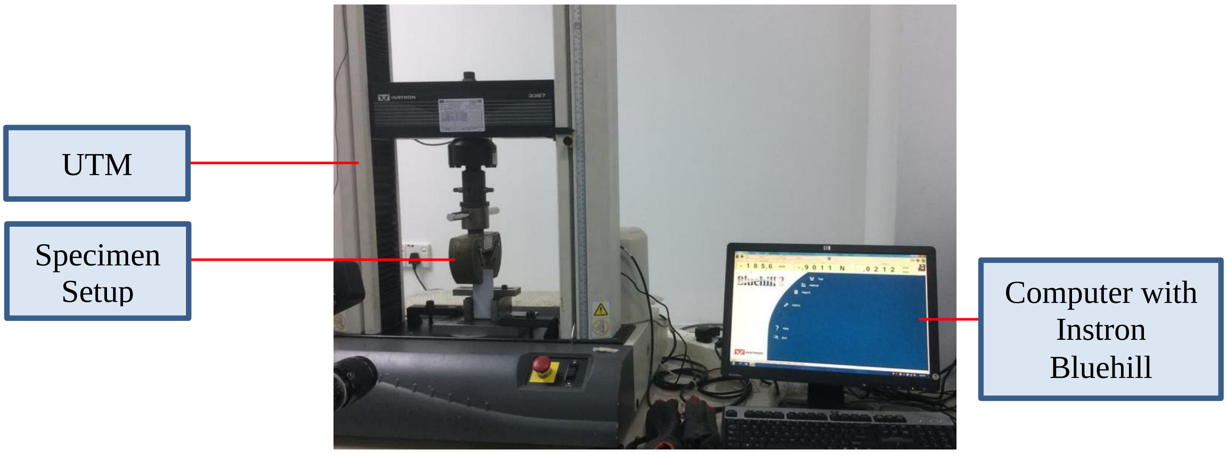


Figure 3. 1: UTM setup in this project

Universal testing machine (UTM) use the tensile concept to pull the aluminium metal plate at controlled test speed, 5mm/s. UTM used to evaluate the load or force applied in kilo Newton, kN to the specimen at different extension of metal plate in milimeter,mm.

3.2.2 Digital Image Correlation

The Digital Image Correlation (DIC) is a non-contact and considerate as high accuracy for displacement and strain measurement. Also a state of art technique that can be used for accurate strain measurement. DIC tracks the position of the same physical points shown in a reference image and a deformed image. DIC technique is an image identification technique to be applied for measuring the object deformation.(S. Gadhe & Navthar, 2016) Figure 3.2 shows the setup for DIC.

Figure 3. 2: DIC setup in this project

To achieve this, a square subset of pixels are identified on the speckle pattern around point of interest on a reference image and their corresponding location determined on the deformed image. Figure 3.3 shows the example of the same position and pixels identified on speckle pattern between reference image and deform image. The digital images are recorded and processed using an image correlation algorithm. With the calibration data, DIC system can translate the image coordinate to geometric coordinate.

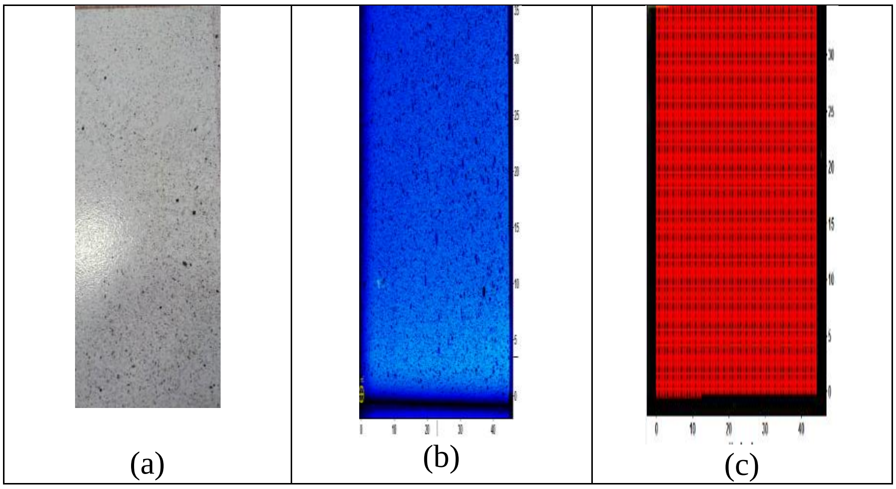


Figure 3. 3: (a) The speckle pattern on reference image. (b) The digital image capture by the camera. (c) The grid identified in deform image based on speckle pattern

3.3 Design and Part Modelling

Figure 3.4 shows the full test rig assembly using Solidwords. The experimental rig consist of Die, Bottom Plate, Blank Holder, and Screw as shown in Figure 3.5. The rig were created, edited, and visualized to 3D models and detailed model drawing by using Solidwork 2018. Detail drawing are attached in Appendix 2.

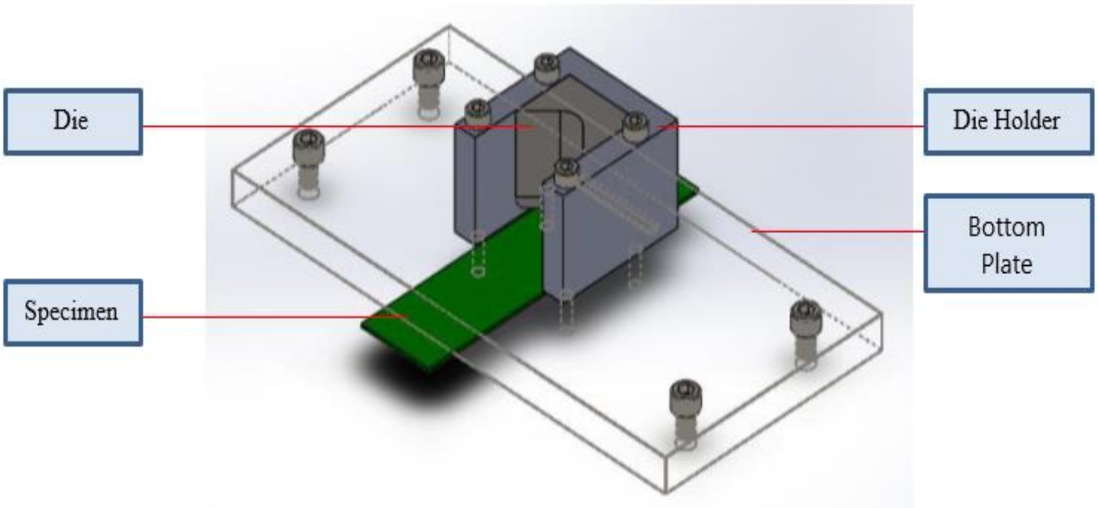


Figure 3. 4: Test rig assembly

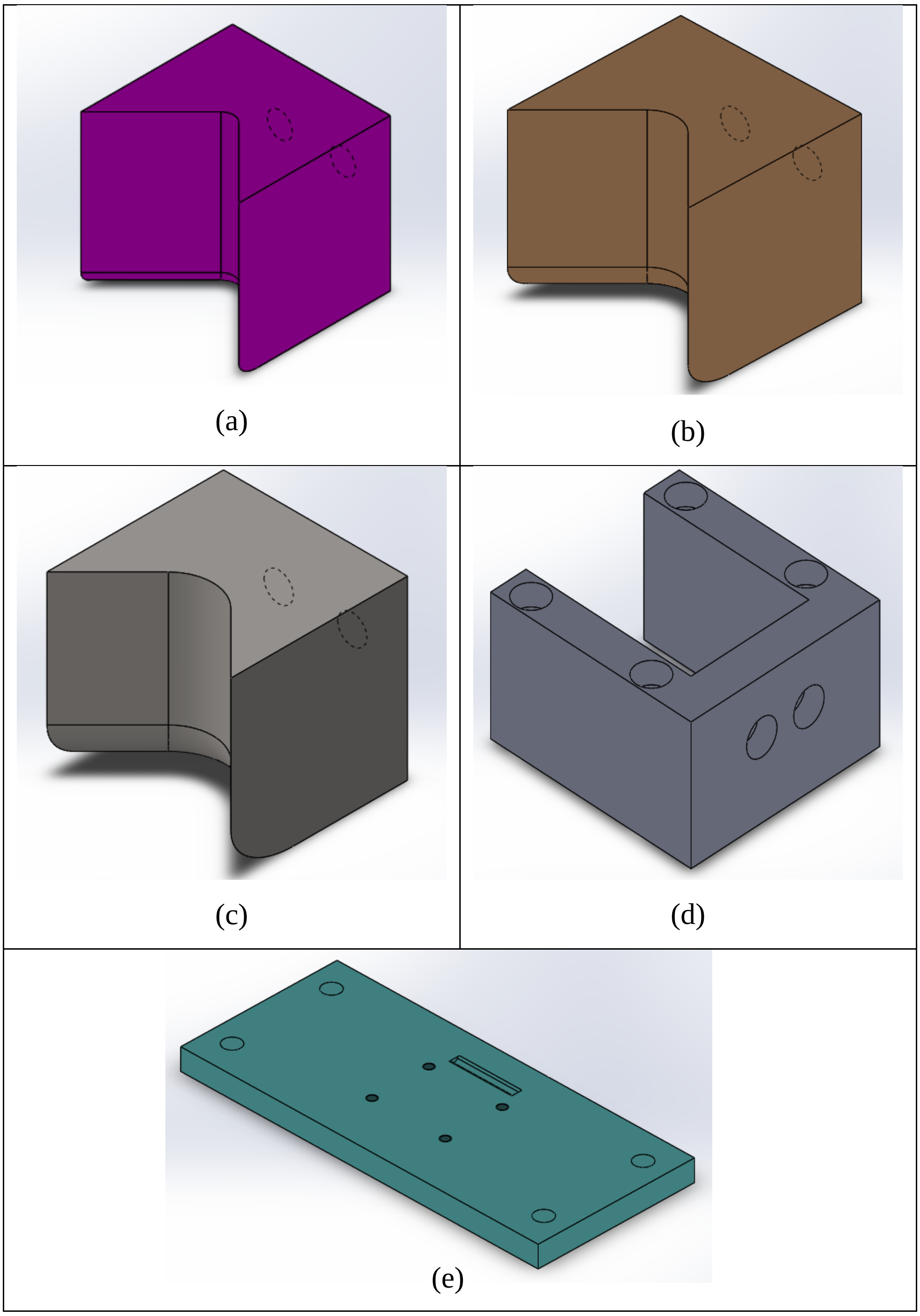


Figure 3. 5: (a) Die with Radius 4mm, (b) Die with Radius 8mm, (c) Die with Radius 12mm, (d) Die holder and (e) Bottom Plate

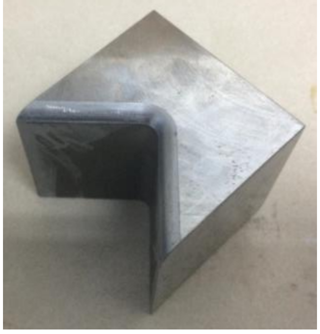
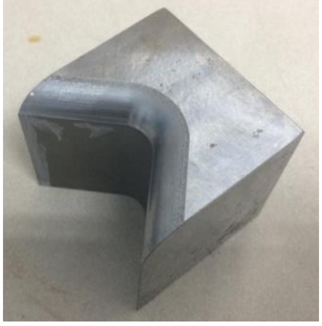
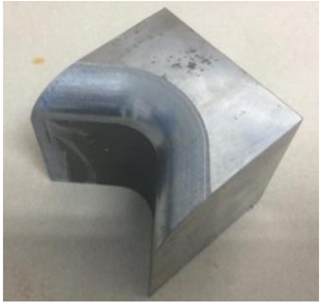
3.4 Fabrication

Once the detail drawings were done, this project were proceeded with the fabrication of parts. The necessary information such as machine selection and fabrication methods were determined. All the parts undergoes internal fabrication. The detail is shown in Table 3.1. The fabrication result can be refer to the Table 3.2.

Table 3. 1: Fabrication execution and processes involved

Part	**Detail Drawing**	**Material**	**Description of Machining Process**	
			Machine Used	**Process**
Die R4 Die R8 Die R12	Appendix	Tool Steel	- Horizontal band saw - Milling machine - 5-axis CNC Machine - Wire Cut EDM - Hand Tapping	- Cutting - Facing - Drilling - Tapping
Die Holder	Appendix	Mild Steel	- Oxy fuel Welding - Milling machine - 5-axis CNC Machine - Wire Cut EDM	- Cutting - Facing - Shaping
Bottom Plate	Appendix	Mild Steel	- Oxy fuel Welding - Milling machine - Hand Tapping	- Cutting - Facing - Drilling - Tapping
Specimen	Appendix	Aluminium	- Manual Cutter - Bending Machine	- Cutting
Screw	N/A	N/A	N/A	N/A

Table 3. 2: Photo of fabricated parts

No	Part	Photo
1	Die R4	 Die set with Radius 4mm
2	Die R8	 Die set with Radius 8mm
3	Die R12	 Die set with Radius 12mm
4	Blank Holder	 Die holder set