A STUDY ON EFFECT OF PROCESS PARAMETERS IN SHEET METAL FORMING SIMULATION OF AA5052

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A report submitted
in fulfillment of the requirements for the degree of
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DECLARATION

I declare that this project report entitled "A Study on Effect of Process Parameters In Sheet Metal Forming Simulation of AA5052" is the result of my own work except as cited in the references.

Signature : ....

Name : Tee Shaw Ting

Date : ....

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Structure & Materials).

Signature : ....

Name : Dr. Sivakumar A/L Dhar Malingam

Date : ....

DEDICATION

To my beloved mother and father

ABSTRACT

Deep drawing is an important process in metal forming and manufacturing. Attaining a defect free product with desired mechanical properties is always intense in market. This research will focus in studying the effect of process parameters in AA 5052-O sheet metal forming by finite element method. All simulations were done in LS DYNA 9.71, model surface were meshed in Hypermesh and the result plotted in LS PrePost. The numerical simulation provides a good qualitative coincidence with experimental result under similar conditions. Mesh refinement, coefficient of friction and material properties exhibit great influences in optimizing the verification result. The effect of blank thickness, blank holder force and punch velocity were studied in forming a circular cup for AA5052-O sheet metal. The results reveal that, 1.5mm thickness of blank implied greater drawability with acceptable thinning and higher punch velocity is desirable in industry. However, there is no significant effect in blank holder forces under this condition.

ABSTRAK

Proses pembentukan merupakan satu proses yang amat penting di industri pembuatan. Kajian ini dijalankan untuk mempelajari implikasi proses parameter AA 5052-O dalam proses pembentukan. Kajian ini dijalankan dengan menggunakan cara simulasi. Perisian LS DYNA 9.71 telah digunakan untuk mensimulasikan seluruh proses. Pengesahan keputusan simulasi telah berjaya dengan membandingkan dengan keputusan eksperimen dalam situasi yang sama. Perbaikan mesh, pekali geseran, dan maklumat bahan merupakan khuatir yang penting dalam pengesahan keputusan simulasi. Hasil eksperimen menunjukkan kepingan logam AA 5052-O dengan ketebalan 1.5mm adalah lebih sesuai dalam proses pembentukan. Selain itu, halaju yang tinggi adalan lebih sesuai dalam industri pembentukan.

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FEA	Finite Element Analysis
AL	Aluminium
BHF	Blank Holder Force
ASM	American Society for Materials
FML	Fiber–Metal Laminates
PDE	Partial Differentiate Equation
LDR	Limiting Drawing Ratio
CAD	Computer-Aided Design
FE	Finite Element

CHAPTER 1

INTRODUCTION

1.1 Background of study

Metal stamping is a technique that widely used to manufacture sheet metal. Stamping process uses punches and dies to transform flat metal sheets to desired shape. Sheet metal forming, or stamping, is a process where a material, referred to as the blank, is formed by stretching it between a punch and a die (Abdulla, S. and Tippa, B., 2013). This process produce high volume metal parts therefore the product produced by metal stamping can be seen from household appliances to automotive industries. Also, metal stamping use in producing large machinery parts particularly in automotive industries such as roof header, bonnets, and vehicle door.

Metal stamping involves punching, cutting and shaping processes. To produce a three dimensional shapes, a flat sheet metal is grip by blank holder and a die is inserted then a mechanical press is initiated to form the object. Basically, metal stamping machine is drive by mechanical press and hydraulic press. Hydraulic presses utilize piston with ease of lubricant oil to drive the punch and die. In this case, the force over the length of the stroke will remain constant. Mechanical press operated by stored energy in flywheel. The flywheel running continually until a clutch is betrothed. The driving force produced in mechanical press may vary with the length of stroke. Still many industries used high-speed mechanical press for operation due to the efficiency.

Traditionally, all the metal stamping process need to be tested experimentally using empirical methods, which are costly and time consuming as dies, blank holders and punches need to be manufactured. Finite element analysis (FEA) is the most common technique of simulating sheet metal forming processes to define whether a proposed design will produce parts free from defects such as fracture or wrinkle moreover this is a cost effective way to produce better quality product in a shorter production time (Zein, H. et al. 2014). In addition, it also helps engineers respond to market changes in a faster line of attack and provide simple way to help engineers understand interaction between materials with different surfaces.

Finite element analysis is a numerical method used to solve multiphysics problems. Finite element analysis offers a mean to find the approximate solution for the engineering and mathematical physic problems. The general procedure of finite element can be categorized to three major steps which is preprocessing, solving and post processing. Preprocessing process involve discretize of geometry, define material properties and apply boundary condition. In solving process, each interval divided will be assigned simple approximate functions, and the suitable linear equations are formulated and finally the equation is solved. The result is then obtains and visualize in post-processing step. Figure 1.1 shows the cup forming in finite element simulation and empirical method.

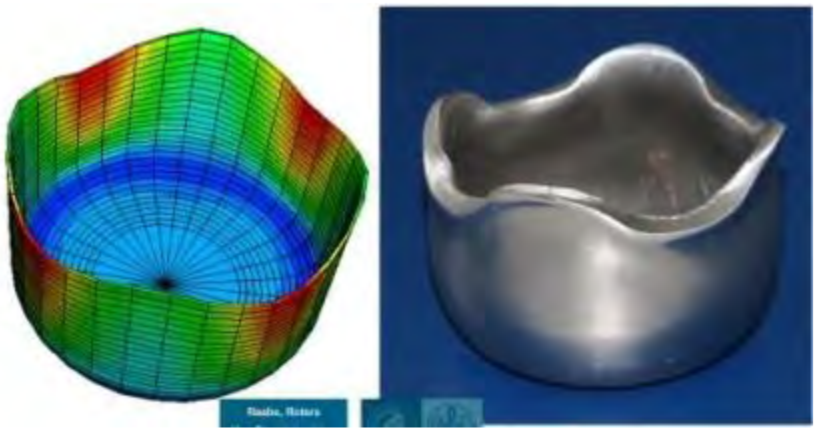


Figure 1.1: Sheet forming in finite element simulation and empirical method.

(Raabe, n.d.)

Experimental design is an important aspect in metal stamping process; it used to identify important factors that affect the process. Design of experiment show the variant information under hypothesized conditions to reflect the variation. The effect of variations can cause large influence to the quality of final stamping. Formability plot shows the wrinkles, cracks, unpredictable spring back of the sheet and other important aspects for the metal thinning after it is formed. This research embodies on the effect of material and process variation for circular cup metal forming process. There are many causes that may lead to occurrence of defects in metal stamping process, however this project only emphasize the thickness of the blank, variation of blank holder force and variation of ram velocities.

1.2 Problem statement

Sheet metal forming is among the most imperative metalworking processes in industries. The products produced under sheet metal forming are variety which did not constraint by shapes and sizes, it can range from simple bending to double curvatures, deep drawing and high complexity geometry designs. In past decade, metal forming tools are designed fully depend on experiences gained through acquaintance, and often needs a protracted and expensive trial and error process. This method leads to high cost of production, which cut down the profit of manufacturers. Consequently, simulations become the current trend to simulate the forming process in finite element method. Simulation makes it conceivable to spot errors and problems, such as wrinkles or splits in parts, on the computer at preliminary stage in forming processes. Thus, the production of real tools to run practical tests is not necessary.

1.3 Objectives

The objectives of this research are:

I. To validate sheet metal forming simulation;

II. To investigate the effect of process parameters in forming process.

1.4 Scope of project

The scopes of this research are:

I. The research is focus on the formability of AA5052-O as blank material;

II. A deep drawing simulation for circular cup is conducted using finite element method;

III. All the simulations is conducted using Explicit Dynamic Software;

IV. The effect of blank thickness, blank holder force and punch velocity in the deep drawing process is discussed.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Literature review shows critical and comprehensive review which relate to topic of project report. In research project, literature must be analyzed in sequence and synthesized logically. All information used must be up to date and related to the topic of interest. Literature not only just summarizes all the related previous research individually but should compare and relate all theories and findings.

2.2 Metal forming

Metal forming process defines as one of the most important manufacturing process in industry especially in metal working. The basic working principle of metal forming is applying force to deform the raw material. Generally in metal forming process, the stress exerted to the material should be greater than yield stress to let the materials undergoes plastic deformation to permanently deform the shape of the component and transformed into desired shape of the design. However, the stress applied must be controlled to less than ultimate stress of the materials to prevent failure. Therefore, forming process need fine control over material properties, because in order to obtain anticipated shape and size of formed component, the ability of the material to flow plastically in solid state without deterioration of its properties should be controlled (Shah et al., 2014).

There are two major processes comprised in metal forming process which is bulk deformation process, and sheet metal working process. The surface area to volume ratio for bulk deformation is lower compare to sheet metal working that show higher surface area to volume ratio. The most common process that undergoes bulk deformation is forging, rolling, extrusion, and drawing. Conversely, sheet metal working processes include shearing, bending and deep drawing. Shearing usually used for punching hole, it cut the workpiece to desire shape. Basically shearing did not involve plastic deformation of the components but still commonly use in metal forming. Bending process deform workpiece by referring to some desired axis. Bending widely use in metal forming industry to manufacture channel, bracket, V-shape along a straight axis. In deep drawing process, a flat sheet metal is deformed when a punch is forced into a die cavity. The process classify as deep drawing only when the depth of the drawn part is greater than its diameter. Figure 2.1 shows illustration of sheet metal working process.

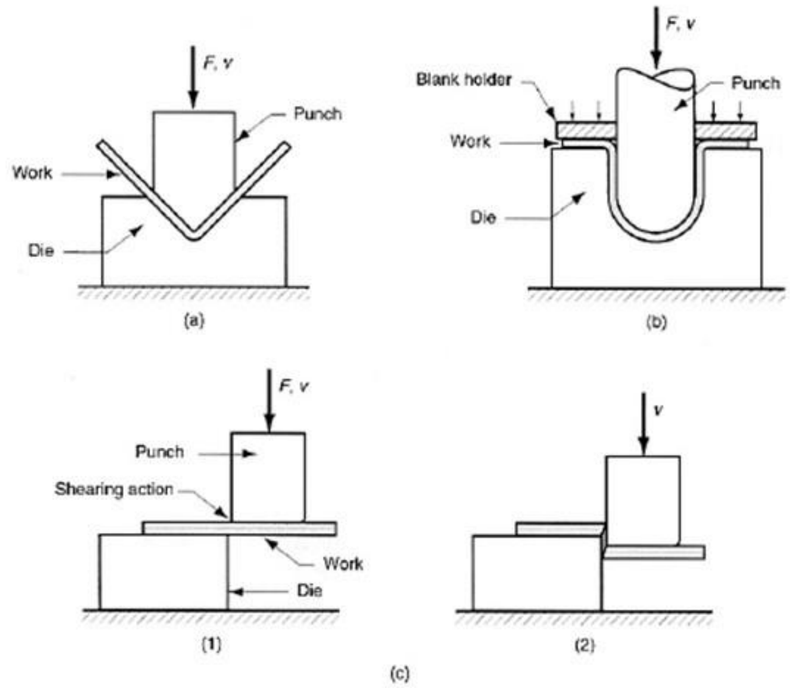


Figure 2.1: Sheet metal working (a) Bending; (b) Drawing; (c) Shearing; (1) as punch first contact sheet and (2) after cutting (Kenzie, 2015).

The deep drawing technology was first developed in 1700s, later numerous relevant studies and researches are done; develop as the commonly used forming process in all industrial applications now. A basic deep drawing process is to transform a flat sheet metal into a three dimensional cup, shell or box shape. However complex contour can be formed in deep drawing process too but as the complexity goes up, and the manufacturing difficulties increase. Sheet metal stamping process may operate by several types of press or machines, but three elementary components are essential: blank, sheet metal from which the part is to be made; punch; and die. Punch is forced to deform the flat sheet metal to anticipated shape for the base of the part then die cavity matches the punch and slightly broader as clearance to allow its passage. In result, the sheet metal is deformed follow the shape designed. A simple deep drawing process is shown in Figure 2.2. Initially, the work piece or blank is placed on the die opening; blank holder is used to surround the blank that applies pressure to the blank ensure it work flat against the die and avoid sticking of blank and punch on return stock. A double action will experience by the equipment which from punch and blank holder.

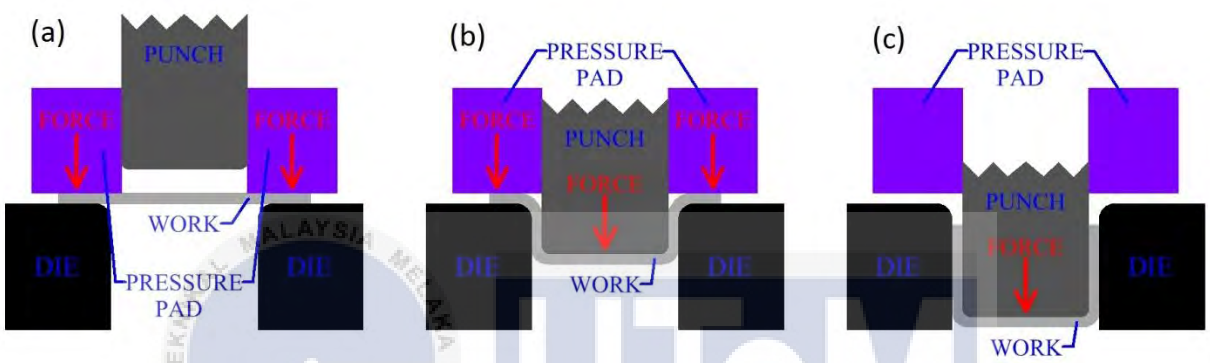


Figure 2.2: Simple Deep Drawing Process (a) Initial position of tools; (b) Punch moving down to deform the work; (c) The work is fully deformed (Sivaraman, 2016).

The basic concept for deep drawing process is that the drawing depth of the cup is higher than half of the cup diameter, if the depth of cup is smaller than the diameter of the cup it can be denoted as shallow drawing (Shah et al., 2014). Tool steels and iron commonly use as materials in making die and punch. However, the materials of making punch and die can also range from plastics to carbide. Engineering processes that prevails every step in deep drawing process are one of the imperative aspects that should be considered. There are several significant procedures during different stages in deep drawing process as reported by Johnson and Mellor (1962):

1. Radial drawing between die and blank holder;

2. Bending and sliding over the die corner;

3. Broadening between die wall and punch;

4. Bending and sliding over the punch corner;

5. Elongation and sliding over the punch nose.

In metal forming process the mechanical properties of materials such as flow stress and anisotropic describe the ability of the sheet materials to deform to produce desired shape. Anisotropic describe that when the properties of a material differ with different crystallographic orientations. Cold rolled sheet metal show crystallographic texture experienced in the process. After rolling process, the grains are usually distorted and elongated in one or more direction. Therefore sheet metal poses significant anisotropy mechanical behavior. In particular, plastic anisotropic give substantial effect in deep drawing process since large deformation will take place. Anisotropy coefficient, or Lankford coefficient R, are common parameter used to describe the anisotropy behavior. Equation (2.1) shows Lankford coefficient R, can be defined through uniaxial tensile test on rectangular sheet specimens.

$$R = \frac{\varepsilon_w}{\varepsilon_t} \tag{2.1}$$

where $\varepsilon_w$and ε_t are the plastic strain along the width direction and the thickness direction of the specimen respectively (Iordache et al., 2009). Limiting Drawing Ratio (LDR) is used to express the deep drawn formability, which is the largest value of the ratio between initial blank diameters and punch diameter with no necking and failure occur in the process. LDR can be related to the fundamental properties of the material drawn through normal or plastic anisotropy.

Basically there are two common theories to describe the yielding of materials. Tresca yield criterion from Henry Tresca, 1868. Tresca theory implies that the material start plastically deform as the shear stress applied higher than the maximum shear stress of the materials. Equation (2.2) describes the Tresca principle.

$$\tau_{max} = \frac{|\sigma_a - \sigma_b|}{2} < \frac{\sigma_y}{2} \tag{2.2}$$

Von Mises Theory (1913) describes the yield criterion based on the total energy distortion. Yielding will start once the root means square of the maximum stress exceeds the yield stress of the material. This criterion can be described in Equation (2.3). The yield locus for plane stress plotted for both Tresca and von mises is shown in Figure 2.3.

$$\sigma_{von\ mises} = \sqrt{{\sigma_a}^2 - \sigma_a\sigma_b + {\sigma_b}^2} \leq \sigma_y \tag{2.3}$$

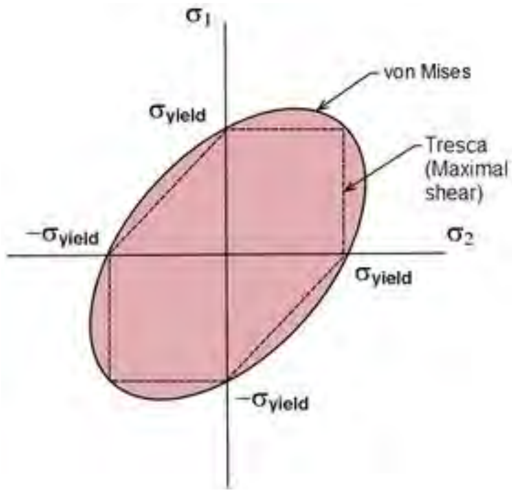


Figure 2.3: Yield locus for plane stress for Tresca and Von Mises (Alan, 2010).

Stress and strain distribution is important to affect the quality and performance of final product in deep drawing process. Stress strain relationship at large plastic deformation will lead to several problems in the process. Therefore it imperative to discovery a mathematical model which can properly analysis forming complications of sheet metal by consider the thickness changes and deformation hardening. However, deformation hardening did not affect the quality of the deformed state but influences the stress rate. Distribution of strain is essential for definition of initial sizes of blank and optimization of process parameter (Arab and Nazaryan, 2013).

2.2.1 Sheet metal forming defects

Basically, deep drawing process is a metal flow process then the drawability can be limited by the initiation of process failures like draw in failures and fracture failure. Consequently, suspend the begin of process failures help improve the drawability (Patel et al. 2015). Towards this end, many concerns need to take into account in drawing process to avoid failure. A number of defects may occur in deep-drawn parts. Figure 2.4 shows the defects frequently occur in deep drawing of cup. Defects in sheet metal lead to a crucial problem in forming industries, particularly in mass production.

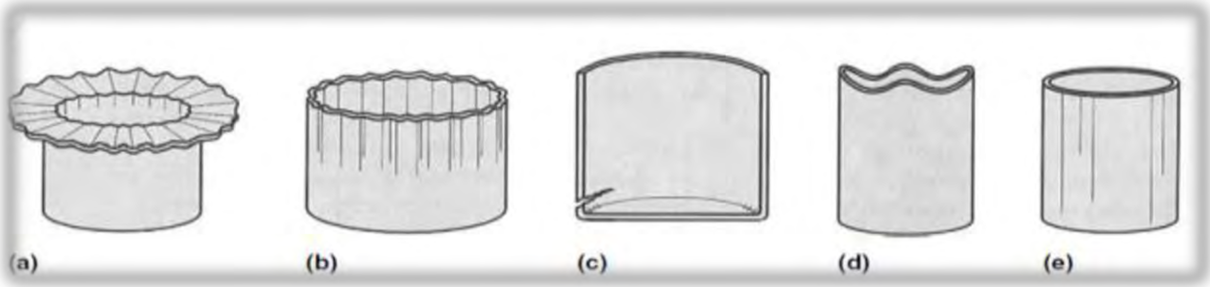


Figure 2.4: Defects in deep drawn cylindrical cup. (a) Flange wrinkling. (b) Wall wrinkling. (c) Tearing. (d) Earing. (e) Surface scratches (Joshi et al., 2013).

Wrinkling is one of the most common defects in deep drawn products. Minimization of compressive stress in drawing process creates wavy surface result to wrinkling. Flange and cup wall are the location that wrinkling frequently take place. Wrinkling may often occur due to the low blank holder forces applied. Therefore optimize the blank holder force will probably eliminate the wrinkling in flange. Yet, for side wall wrinkling many parameters need to be set which include bifurcation method and energy method. High blank holder force is desired to eradicate wrinkling; too high blank holder forces will cause excess friction. Reddy et al. (2012) studied the effect of process parameters on wrinkling for cylindrical cup in deep drawing process. The process parameters considered in the research are die edge radius, punch radius, blank holder forces and coefficient of friction. The experiment is conducted and the mechanism for the initiation and growing of wrinkling is examined in detail. Result show that wrinkling can be avoided by controlling all parameters, which apply right blank holder force, minimize friction, reduce depth of drawing and bigger tool edge radius. Abbasi et al. (2012) has analyzed the behavior of wrinkling for tailor welded blanks under deep drawing process with thickness ratio more than one. The research is run in analytical, numerical and experimental methods. Experimental and analytical results of conical cup wrinkling are compared with bifurcation method. During wrinkling analysis, shear stress showed substantial role if thickness ratio more than one. The experimental obtained punch stroke value and critical strain for initiation of wrinkling are coherent with theoretical values. In brief, formation of wave surface focus on thin section, and wrinkling initiated by extension of three wave surfaces.

Morovvati et al. (2011) compared the wrinkling of circular part for single layer and double layer sheet metals in deep drawing process. Blank holder forces affect the performance in sheet metal forming as insufficient blank holder forces will result to wrinkle on the final products. Findings show that material and arrangements of layers affect the blank holder forces which indirectly may cause formation of wrinkling. Rajabi et al. (2015) analyzed the effect for type of core materials and process parameters in deep drawing for thermoplastic metal composites. The research focus on metal polymer laminates and fiber metal laminates (FMLs). It resolved that wrinkling for both laminate are greatly depend on blank holder force applied while the temperature affect the fiber metal laminates only. Finite element simulation result forecast the force displacement curves and the position of wrinkles on the specimen. Wrinkling formed as low blank holder force applied, whereas temperature poses little effect in deep drawing process of common metals while as temperature increase; the maximum drawing forces will decrease.

Earing is a characteristic problem in deep drawing process which shows crimped edge on the open end in final product in deep drawing. Plastic anisotropy is the major causes of formation for earing. So, the step to predict the deformation behaviors of sheet metal in deep drawing process should undertake to eliminate undesirable ears in drawn cup. Izadpanah et al. (2016), predicted the earing defect in deep drawing of cylindrical cup by BBC2003 yield criterion. This method only focuses in uniaxial and plane strain tension results. Eight constant is derived with non-linear governing equation to forecast anisotropy parameters, normalized uniaxial yield stress and plane stress yield surface. A slight deviation is obtained between experimental result and data from BBC2003 yield criterion which probably because of inaccurate in determining plain strain yield stress. However the accuracy of calibrated BBC2003 yield criterion is proved and accepted in prediction of plastic anisotropy values and yield stress. Yoon et al. (2011) studied the mathematical approach for generation of earing defect which due to anisotropy plasticity. In simple tension, the earing profile is attained from anisotropy plastic properties. The earing mechanism can be expressed in present theory by using explicit formula. An analytical equation was derived to approximate earing profile of ironed and drawn parts. The paper also proves that earing caused by both r value and yields stress directionalities. The theory is then verified with the result from simulation and experiments.

Tearing may due to excessive thinning in critical area of sheet metal. Commonly, tearing localized on the corner of wall on geometry. There are several reasons may be lead to tearing such as too high or improper forces distribution, materials consideration, insufficient blank shape. The surface of the blank is also important, as gouges, and scratches can lead to propagation of crack then lead to tearing on drawn parts.

Son et al. (2015) studied on tearing and delamination for stamping of polymer coated metal sheet. The curve of delamination limit and tearing limit is used to compose the defect diagram to define safe region. Critical minor and major strains are used to build the defect diagram in several deformation modes. Experiments were conducted to create the defect diagram for the polymer coated metal sheet by taking average of limit square cup deep drawing test and dome height test. Result show tearing of coating before fracture of steel. These treatments slacken the mechanical properties of the materials.

Candra et al. (2015) proposed the prediction in both analytical and numerical way to eradicate crack on cup in deep drawing by varying blank holder forces over punch stroke.

The simple analytical method of maximum varying blank holder forces has been directed on each stage of punch stroke under the failure deformation and cracking criteria. The cracking measures refer from maximum strength of materials. The analytical result is similar to the finite element simulation. Findings show that varying blank holder force quite effective to eliminate cracking and achieved higher formability.

2.3 Process Parameter in sheet metal forming

The formability of sheet metals can be affected by many parameters, such as materials parameters, process parameters and strain bounding criteria. These parameters will cause direct effect to the distribution of thickness and feature of the final products. Consequently, optimization of process parameters in sheet metal forming becomes necessary task to reduce direct defects and failures while indirectly reduce cost of manufacturing. There are many defects occur in deep drawing process; it may be caused by several effects such as allowance between matrix and punch, rate of rounding the punch edges, rate of rounding the matrix edges, punch speed, punch forces, blank holder forces lubrication between matrix of the blank and the punch and the thickness of the metal sheet. All these parameters have been studied by various researchers. According to Nguyen et al., 2013, the uncertainty and variation sources in sheet metal process can be synthesized in Figure 2.5.

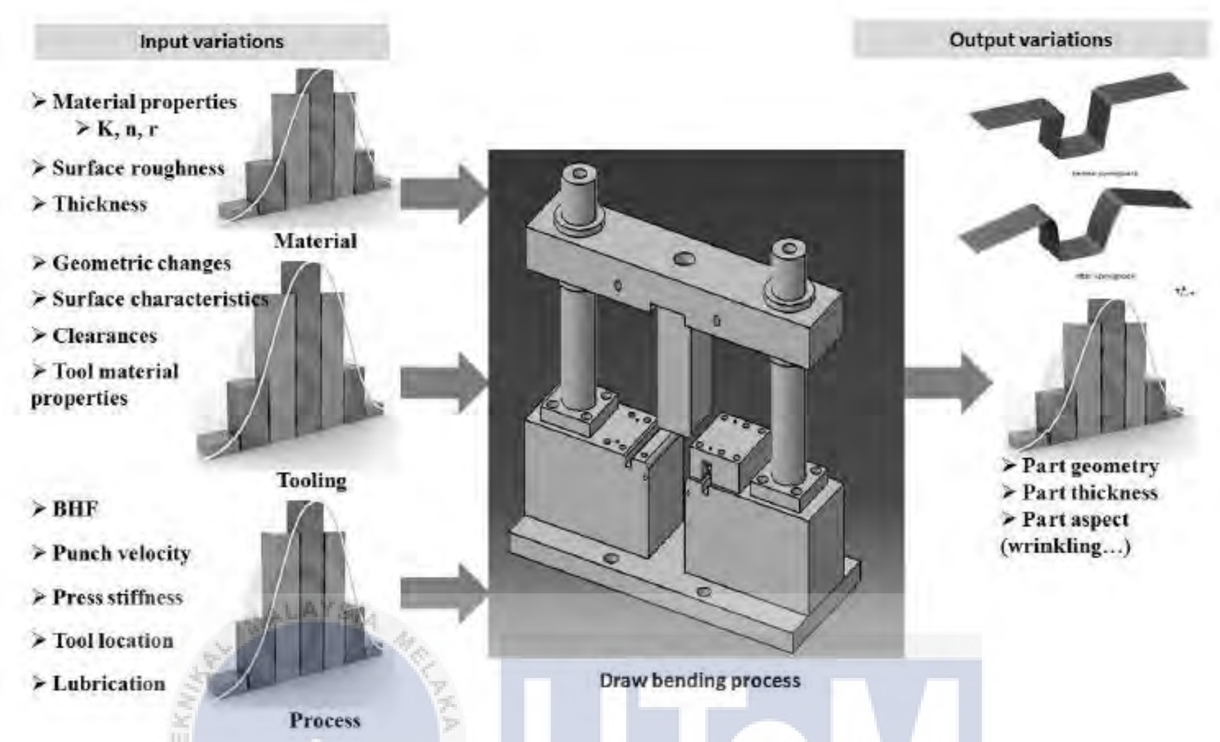


Figure 2.5: Uncertainty and variation sources in the sheet metal forming process(Nguyen et al., 2013)

2.3.1 Effect of blank holder force (BHF)

Blank holder forces act as pressure that applied onto blank in deep drawing operations to elimate the occurance of defects such as wrinkles. Besides, blank holder forces also provide friction at the flange to prevent the blank flow into die. If the friction increase; the radial tension that must be supported by the cup wall increase. Basically, higher blank holder force is desired to prevent wrinkles in deep drawing process though if too much blank holder forces is applied will lead to fracture too. Therefore sufficient blank holder forces should be determined in designing deep drawing process.

Many researches were done to study the effect of blank holder forces on quality of product, flow of material, stess and strain distribution. Tommerup and Endelt (2012) studied the effect of strain path in sheet metal during metal forming process. A tooling system that aim to govern the distribution of blank holder pressure is introduced in this research to study the material flow. Moreover, this tooling system also capable to adjust the process parameters, an actuator scheme to set blank holder force, a tool with implanted hydraulic cavity. This research focus in the drawing of rectangular specimen, then the strain path is checked when different cavity pressure is applied. Tian et al. (2015) carried out the deep drawing process of box parts with finite element simulation to investigate the optimization of process parameter in deep drawing process based on orthogonal experimental method. The research select the most thin and thick location on the blank to show the quality of the final product. The analysis showed that the suitable blank holder thickness need to be applied to prevent wrinkle or sheet metal ripping. Volk et al. (2011) improved blank holder force for an irregular work piece in deep drawing process by using numerical method. This research is focused on minimum wrinkling and higher quality of product by altering the blank holder forces. The result show that little changes in blank holder force can cause failure in the drawing process and these failures can be circumvented by adjusting the blank holder force. However the precise routes need to be chosen.

Consequently, if low blank holder force is applied; occurances of wrinkle in the flange part is high. In contrast, increasing the blank holder force will reduce the wrinkling but will lead to failure in the process before the desired depth reached. Therefore, blank holder force can be calculated to estimate the limit of drawing process. The original Siebel‟s equation is used to determine the specific blank holder pressure to form rotary-symmetric parts (Predrag and Vojislav, 2006). Equation (2.4) shows Siebel‟s equation.

$$P_{bh} = \left(\frac{0.002}{0.003}\right) \cdot \left[\left(\frac{D_o}{d_{in}} - 1\right)^2 + \frac{d_{in}}{200 \cdot s} \right] \cdot R_m \qquad (2.4)$$

where D_o is blank diameter, [mm], d_{in} is inward radius of the part, [mm], s is sheet metal thickness, [mm], R_m is tensile strength of the sheet metal, [N/mm2].

The variance in blank holder pressures is negligible, since in case of Siebel‟s equation application, the mean value of dimensionless coefficient is most frequently adopted, i.e. 0.0025.

2.3.2 Effect of punch velocity

In the deep drawing process, the punch is applied a certain velocity to deform the blank. Punch velocity need to be varied depending on the blank materials, the velocity apply in drawing of stainless steels and heat resistant alloys should be higher than the softer and more ductile metals. According to ASM handbook, if excessive punch velocity is applied when drawing hard and low ductility materials; cracking and wall thining problem will probably be experienced in the final product (Semiatin, 2005). Venkateswarlu et al. (2010) investigate the weightage of importances for process parameters in deep drawing process by finite element simulations with Taguchi strategy of experiments method. This research focus on the effect of die arc radius, blank temperature and punch velocity for deformation of AA7075 sheet metal in deep drawing process. The Taguchi method places a suitable approach of significance on the summarisation in varies products and processes. Enriched toughness can frequently be completed without foremost capital outlay with these practices.The outcome show that the blank temperature achieved 84.4% which show major influences on the deep-drawing process, followed by punch velocity with 9% influences and die arc radius with 6.6%.

Atrian & Fereshteh-Saniee (2013) has examined the effect of process parameters in deep drawing of laminated sheets. The deep drawing operation of steel/brass laminated sheet is preformed in both experimental and numerical way to study the tearing location of bimetal cup. The direct relation between initial blank diameter and the maximum applied force is achieved through this research.

Pop et al. (2015) studied the effect of punch speed in finite element analysis by using Abaqus/Explicit. Their research showed the importance of assigning suitable punch speed since punch speed will result to different inertia force. The simulation is run as quasi-static which concern about the energy variation model. The kinetic energies for various punch speed is considered, it is observed that kinetic energy approaching zero for low punch speed. However, low punch speed will lead to lengthy process which is not pratical. Hence, the punch speed can only be increased artificially without causing effect to inertia force. Kinetics energy performed in a stamping process steps should be less than 10% of domestic energy.

2.3.3 Effect of thickness of blank

Blank is the metal sheet that undergoes large deformation in deep drawing process to form the final products. The shape and thickness of the blank will cause directly influence to the metal flow and forces exerted which effect the quality of the final product. The preferred orientation in plane of sheet metal should be take into account as it may lead to earing defects. Earing defect cause by anisotropy behavior of sheet metal and lead to material wastage in the process. Excessive material used can impede with metal flow and increase forces acting within the blank and cause seriously affects to the process performance. After drawing process, blank is plastically deformed therefore blank‟s behavior can be studied by examining the different proportions of bi-axial straining. Moreover, incorrect blank shape and thickness apply in deep drawing process may cause production problem. The optimal blank shape will vary for different parts and contours in process. Oluwale et al. (2010) studied the effect of sheet thickness and draw ratio in earing and drawability of Al 1200 cups. The findings showed lower draw ratio needed in the drawing process if thicker sheet is used. The higher draw ratio used in same sheet thickness will increase the probability for earing. When constant draw ratio is applied for both thinner sheets (0.6mm-0.9mm) and thicker sheets (1.2mm-1.58mm), the observation showed that in thinner sheet earing become significant as sheet thickness increase within thinner range. In contrast, as sheet thickness increase in thicker sheet range; earing become less significant.

Molotnikov et al. (2012) delibrated a research in the effect of size in micro cup drawing. This research emphasized the effect of size to maximum load and drawing ratio in deep drawing process of copper cup. It use both experimental and numerical method to revise relationship between blank thickness ratio and size of grain of sheet metal. Blank size play a significant influence in deep drawing process when constant grain size and dimension of work piece abridged. This research has proposed the dislodgment density based model to allow for the influence of the work piece dimensions on its mechanical reaction. Hani et al. (2016) proposed a new technique for deep drawing to produce elliptical without blank holder. The research run in simulation way to predict the stress distribution in the deep drawing process when several thickness of plate and clearance is applied. The optimum clearance to thickness is determined to give best result in elliptical deep drawing without blank holder.

2.4 Finite Element Method

In 1960s, the term "finite element" was first created by Clough. Finite element method widely used in solving engineering problems especially for stress analysis, fluid flow, heat transfer, biomechanics and many areas since early 1960s. Finite element method (FEM) is a numerical practice to solve problems which are designated by partial differential equations or can be formulated as functional minimization. Typically partial differential equations use to describe the laws of physics for space and time dependent problem. There are numerous partial differential equations (PDEs) in complex geometry which make it impracticable to predict resolutions in closed form or by purely analytical means. Instead, finite element method is constructed approximately to solve these PDEs. FEM divide structure into numerous elements or small pieces of structures which call discretization then nodes are used to reconnect all the elements in contact. This process generates a set of simultaneous algebraic equations. For a linear problem a scheme of linear algebraic equations need to elucidate. Nodal values use to build up value inside finite element. The solution to the numerical model equations indicates approximation of the real solution to the PDEs. FEM is used to calculate such approximations.

Generally, finite element method can be categorized into three main phase which is preprocessing, solving and post processing. All geometric properties, materials properties and the element type of the model need to be defined in preprocessing. After all the data and basic properties of the model are set, then element connectivity is specifying by using meshing which discretize the structure into small elements connected by nodes. The explanation of mesh involves of numerous arrays which are nodal coordinates and element connectivity. Then interpolation tasks are used to interpose the field variable over the element. Field variables indicate as dependent variable of interest governed by differential equation while boundary condition is the quantified values of the field variable on the boundaries of the field. Frequently, polynomials are designated as interpolation functions. The degree of the polynomial refers to the number of nodes allocated to the element. Then define external loads like forces, moments or others onto particular nodes or elements. Generally many engineering problem can be expressed by governing equation and boundary conditions. Since all nodes in the structure have its own set of governing equation and boundary condition which hard to solve individually. Therefore finite element method defines a set of simultaneous algebraic equations at node to approximate the phenomena. Equation (2.5) shows simple linear equation.

$$\{F\} = [K]\{u\} \tag{2.5}$$

where F is Action, K is Property, u is Behavior.

In solution phase, all element equations are assembled to evaluate the global equation system for the model. This means the combination of all local element equations of all elements form in discretization. Element connectivity is used for the combining procedure. Next, the global equation system is solved by direct and iterative methods. The nodal values of the sought function describe the solution of the result. Lastly in post processing, after solution have been executed all the initial condition, applied load and data will be returned. The result can be viewed through plotting, sorting and printing.

There are two approaches to solve the problem in finite element method which is implicit and explicit. Implicit approach normally use for static analysis which time dependency can be ignored such as static structural, harmonic, modal analysis which using simple linear equation. Conversely, explicit approach is used to solve problem related to large deformation and time dependent like crash, blast, impact, drawing, and stamping. The main difference between implicit and explicit approach is in consideration of velocity or acceleration. For the equation of motion shown in Equation (2.6), „x‟ stand for displacement whereas $\dot{x}$ and $\ddot{x}$ are velocity and acceleration respectively.

$$m\ddot{x} + c\dot{x} + kx = F \tag{2.6}$$

In implicit analysis, displacement is constant therefore zero value for velocity and acceleration then the mass and damping factors can be neglected. After each increment, Newton-Raphson iterations used to impose equilibrium of the internal erection forces with the applied loads whereas in explicit velocity and acceleration is considered, no iteration is requisite as the nodal accelerations are solved directly. Thus, explicit method is suitable to solve dynamic analyses which are computationally intensive while static problem commonly solve with implicit analysis.

Todays, finite element method used in many industrial applications, including aerospace, automobile, fluid mechanics so on. A number of finite element related software are available for industrial user such as IDEAS, NASTRAN, ABAQUS, ANSYS, LS DYNA, MARC, ADINA, HYPERWORK. Many researchers utilize this method and software available to study the forming process in simulation ways.

2.4.1 FEA method in sheet metal forming

FEA technique is widely used in performing stamp forming simulation. Kilpatrick et al. (2015) utilized the finite element method to validate and verify plane stress yield principle in sheet metal forming process. An elastoplastic user material model (UMAT) is employed based on Leacock 2006 yield criterion in finite element method by using PAM-STAMP 2G commercial finite element software. Numerical justification, hemispherical punch testing, material characterization, strips draw friction testing, and deep drawing of cylindrical cup is executed to validate the criterion. Both the numerical prediction and experimental result show good agreement with the criterion.

Kiliclar et al. (2016) studied the formability of forming process in both quasi-static and high speed forming processes through experimental and numerical method. LS DYNA software is used to perform simulation of tensile test and deep drawing of cylindrical cup.

This research introduce a new approach to determine quasi static and high speed forming limit with related strain curves, anisotropic of material that depend on ductile range theory through experimental way. In addition, the forming limit for multifaceted forming operations under fluctuating strain rate is predicted numerically. Consequently, the numerical result for strain curve and critical destruction found is comprehensible with experimental results. This research showed that strain rate effect the formability in forming process.

Cui and Li (2013) focused on the edge based smoothing technique for finite element simulation in metal forming. The work piece is discretized into a set of triangular element, and then edge based smoothing areas extra connected with the element edges as refinement of mesh. Result showed that the strain field is smoothing. In the handling of the contact interface, the basic contact algorithm is activated. Result showed that edge based smoothing work well in problem with large deformation and material distortion.

2.5 Summary

In the current deep drawing process, process parameters play an essential role in producing quality final products. So, this project will focus in the influences of controlled parameter in deep drawing process where various punch velocities, blank holder forces and blank thickness will be studied. In addition, the forming process will be performed under quasi static analysis and explicit dynamic.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes experimental designs and methods used to achieve objectives of the study. A clear and concise description of methodology for the complete simulation process will be discussed in details which allow better understanding. The flow chart of methodology of this project is shown in Figure 3.1.

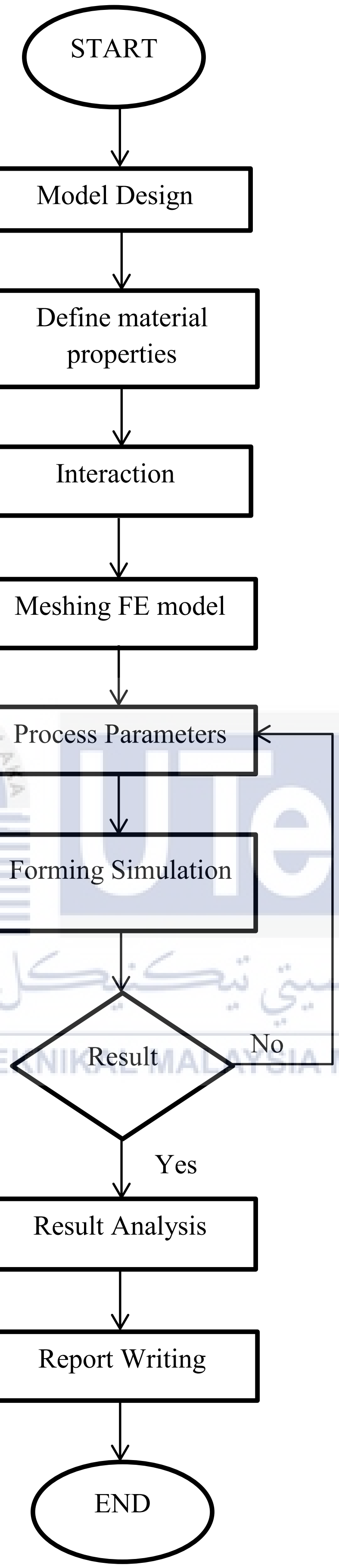


Figure 3.1: Flow chart of the methodology.

3.2 Model design

Punch, die, blank holder and blank are the basic components in metal forming process. The model for all components is drawn in actual dimension to ensure accurate result of simulation. SolidWorks CAD software is used to draw the model. The model is drawn in shell element to reduce the calculation time in simulation. The schematic diagram of tools set in millimeter is shown in Figure 3.2 while Figure 3.3 shows isometric views of the model design.

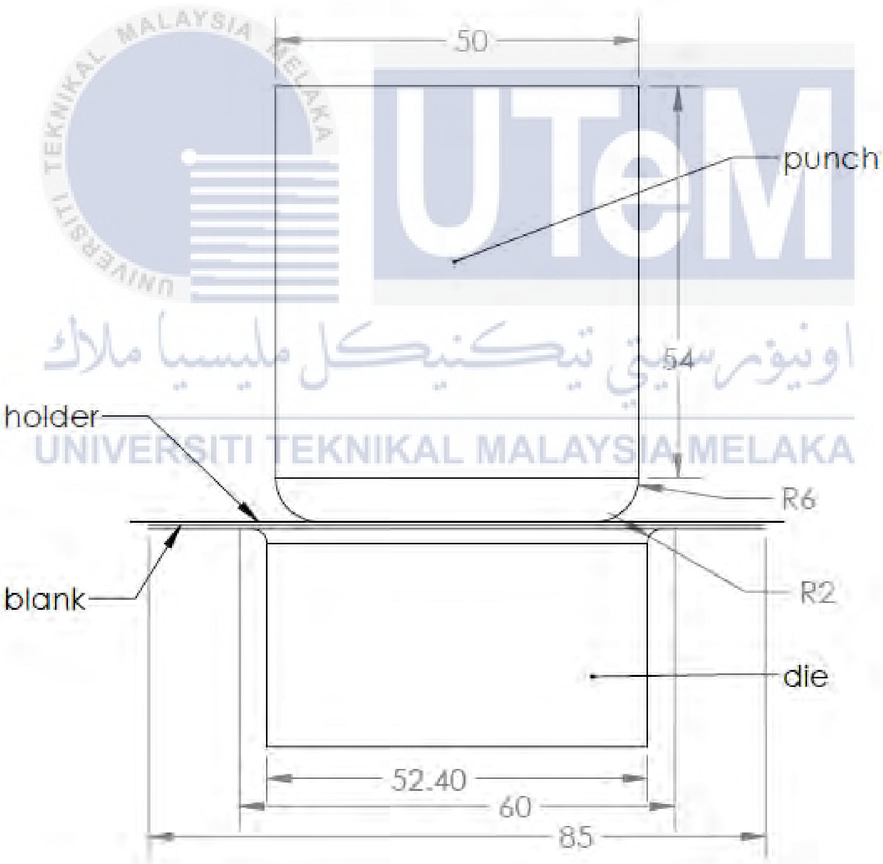


Figure 3.2: Schematic diagram of tools set in millimeter.

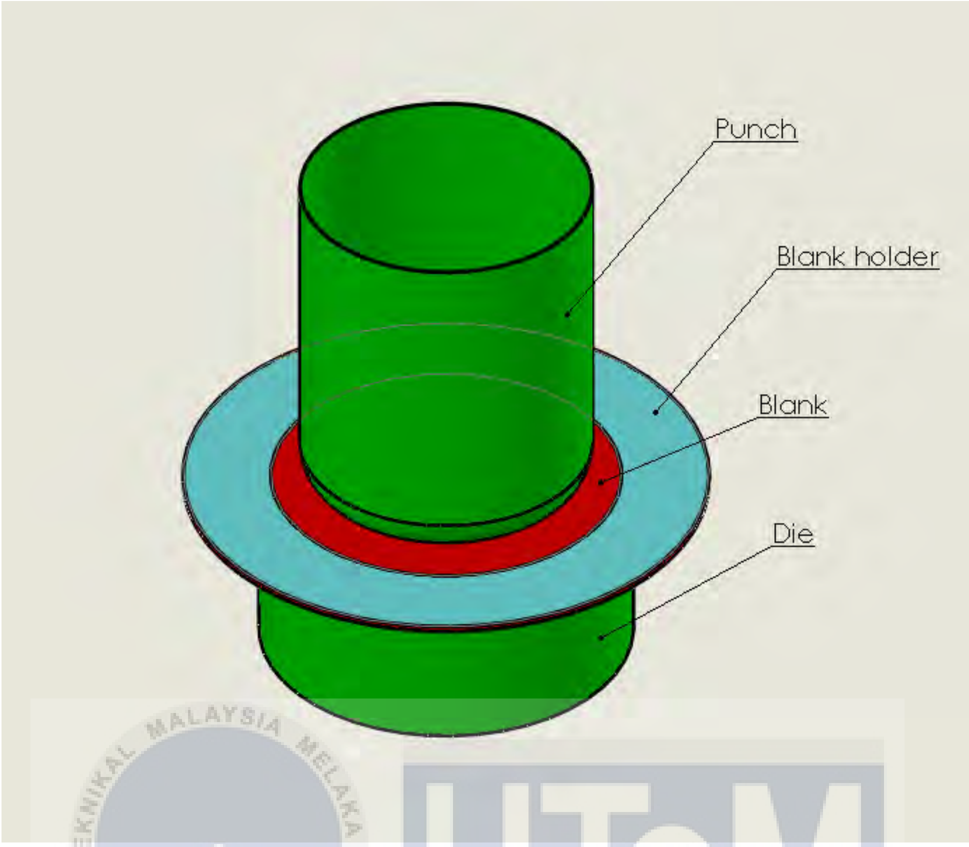


Figure 3.3: Isometric view of model design.

3.3 Simulation

Numerical simulation is a prevailing method for analysis of metal forming processes, including deep drawing. An explicit finite element method is used to simulate deep drawing process of aluminum sheet metal to observe the forming process virtually. In this research, a full 3D model is used in simulation by using LS DYNA.

3.3.1 Properties of Parts

All the stamping tools are set as rigid body, therefore properties assigned is unnecessary. A commercially-available Aluminum 5052-O sheet metal with a thickness of

1.0 mm was used for the blank material and tensile tests were conducted to determine the material properties. However the value of density and Poisson‟s ratio were referred from Metals Handbook. The material properties of the sheet metal are shown in Table 3.1.

Table 3.1: Material properties of Aluminum 5052 from Metals Handbook, Vol.2 and tensile test conducted.

Properties	Value	Sources
Density	2.68 kg/mm^3	Metals Handbook, Vol.2
Poisson‟s ratio	0.33	Metals Handbook, Vol.2
Tensile yield strength	94.980 MPa	Tensile test
Ultimate tensile strength	190.411 MPa	Tensile test
Modulus of elasticity	52.823002 GPa	Tensile test

3.3.2 Interaction

All the tool components are modeled using rigid materials (Material 20 in LS-Dyna) while blank are modeled using Power Law Plasticity materials to better identify its deformation effect later. The simulation of deep drawing process is a contact problem which is highly nonlinear and need substantial computer resources to resolve. It is important to realize the physics of the problem and set up the model to run as competently as possible. Accurate contact interfaces between bodies is decisive to the prediction capability of the finite element analysis. There are numerous contact cards available in LS DYNA sheet metal forming simulation is best described by contact one way surface to surface. One way surface type agrees transferring of compression loads between slave nodes and master segments. This contact type only check penetrations for slave nodes over master surface; consequently only nodal points of the blank is tracked as they move between the disjoint element patches of the tooling surface. Penalty forces are used to limit penetrations. All tooling set were modeled as master while blank is always set as slave part. Then, manual contact between components is applied for simulation test. In this set up, 3 contacts surface is created which are:

a) Frictional contact between blank and blank holder
b) Frictional contact between blank and die
c) Frictional contact between blank and punch

For frictional interaction, a non-zero value will activate Coulomb type friction between bodies.

3.3.3 Meshing of FE model

Another major tasks and difficulties in simulate a forming process is to create a decent mesh for the model. Basically, finer mesh produce higher accuracy of the result, but will lead to amplified computing time. Thus, one need to apply meshes that give accurate result, but still it can compute in reasonable time. In this research, the major focus is on blank therefore finer mesh should apply for blank. This is because all rigid models do not deform however the curvature for punch and die is further refined in order to obtain a smooth curve for the blank in forming simulation. The meshing of the model is created using Altair Hypermesh. All the mesh type is set to quad and since there is large deformation focus on blank therefore finer meshing is defined. Therefore, mass and time scaling was used to decrease the calculation time. Figure 3.4 shows the meshing of model.

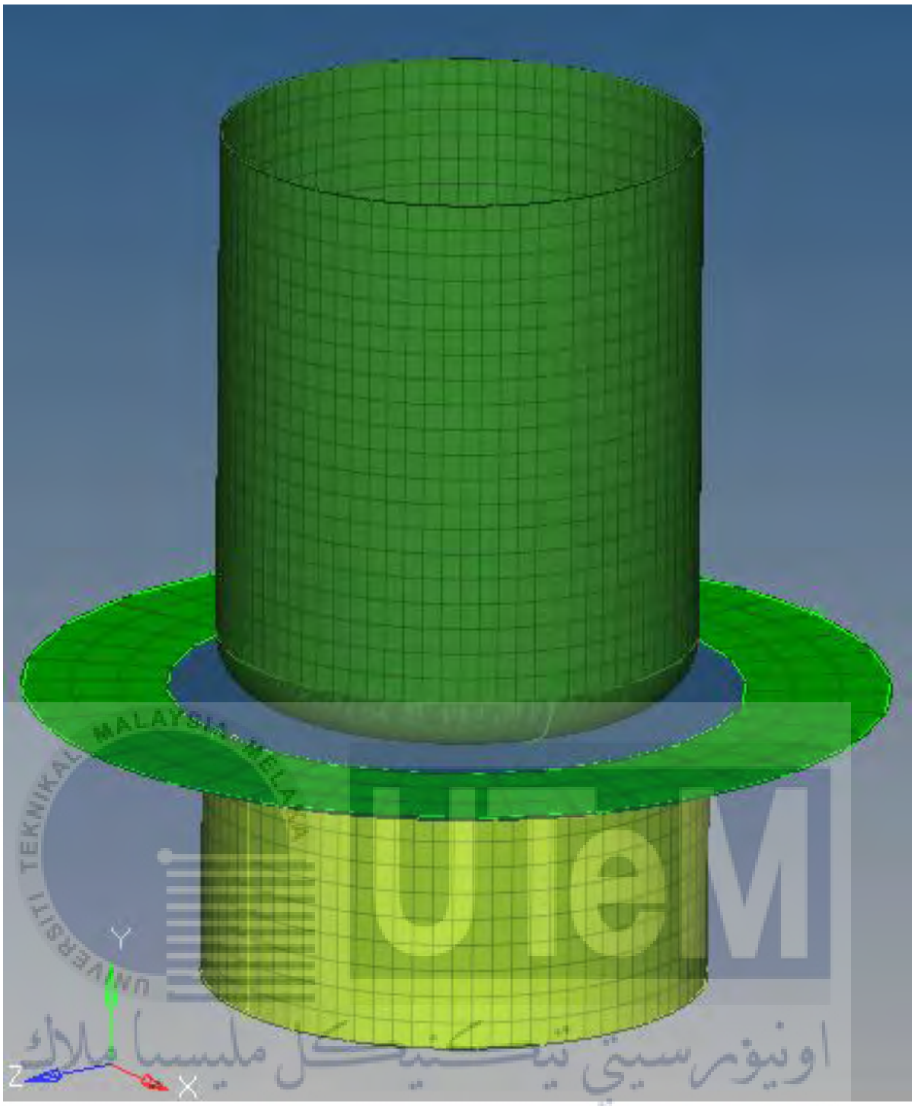


Figure 3.4: Meshing of model.

3.3.4 Process parameter

This research studies the effect of process parameters to the metal forming process. In simulation analysis, the values of process parameter can be altered by the boundary condition assigned at the part of model. Proper constraint and boundary condition is essential in order to get good analysis result. Deep drawing simulation is simulating the actual forming process therefore; proper boundary condition should consider when executing the analysis. So in a way resembling actual process replicate is tried the same in the finite element model by constraining or arresting some degrees of freedom. In this research, punch velocity is applied to the punch to make it move downward to deform the blank; the punch is positioned to displace downward in y-direction only. A load reaction is applied onto blank holder which acts as blank holder force.

Three different parameters is considered with specific combination is carried out in this research to study the effect on deep drawing process. Table 3.2 shows the combination of process parameter values considered in this research.

Table 3.2: Process parameter value considered.

Parameter	Values
Punch velocity (mm/s)	8.333, 100, 200
Blank holder force (kN)	50, 75, 100
Blank thickness (mm)	0.50, 1.00, 1.50

3.3.5 Data and result

Once the simulation is set up, it is the time to run the simulation. The simulation is executed in LS DYNA. All the output and database setting is specified to describe the result computed. The process of simulation will expect to run in few hours. A validation test is run to validate the simulation result by applying same input parameter with experimental result. The simulation test is then further continued with different combination of process parameters to study the effect in sheet metal forming. In post processing stage, all the result evaluated is shown in graphical form and the data value processed is tabulated in table. Force reaction, stress distribution, plastic strain, and thinning are the results emphasize in this research.

3.5 Result analysis

This research is aim to study the effect of process parameters in the deep drawing process. Thus, the result evaluated from the simulation is tabulated and compared. The graph of force displacement, stress distribution, plastic strain and thinning is plotting to compare the effect of process parameters to the process.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter explains the data and results of sheet metal forming using LS DYNA 971. The finite element analysis is validated with experimental work. Then the result is studied and discussed by varying 3 different process parameters which is blank thickness, blank holder force and punch velocity. The data obtained is being tabulated and analyzed in this chapter.

4.2 Validation of the model

In this section, validation between simulation and experimental results has been conducted. A sheet metal forming test is executed in lab and the parameters is tabulated in Table 4.1. Then, the force displacement graph is plotted according to the data collected from the forming test which is shown in Figure 4.1.

Table 4.1: Parameters in forming test

Parameter	Values
Blank thickness (mm)	1.00 mm
Blank holder force (kN)	75 kN
Punch velocity	8.33 mm/s

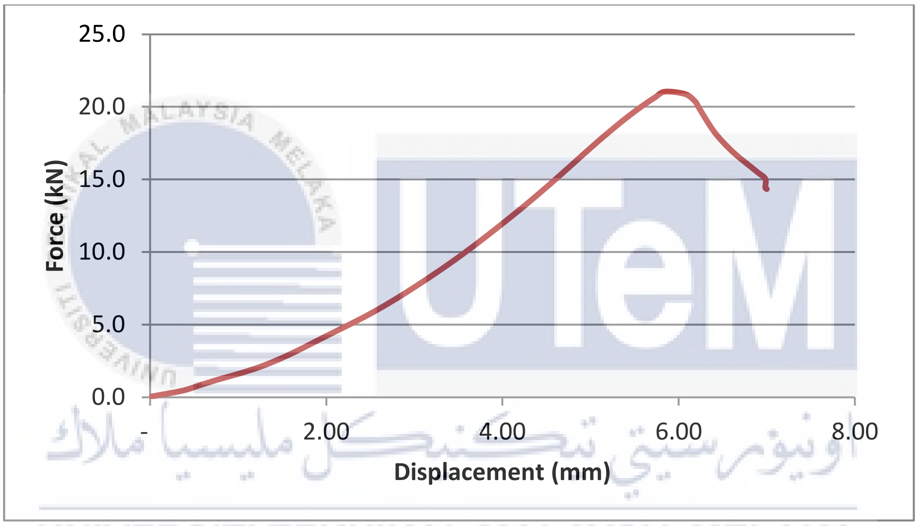


Figure 4.1: Force displacement graph in experiment

Based on Figure 4.1, the maximum reaction force between punch and blank in experiment is 21.17 kN. Therefore different concerns are taken into considerations to optimize the finite element model which is mesh refinement, interaction, material model, and material properties. Figure 4.2 show the process flow for optimization.

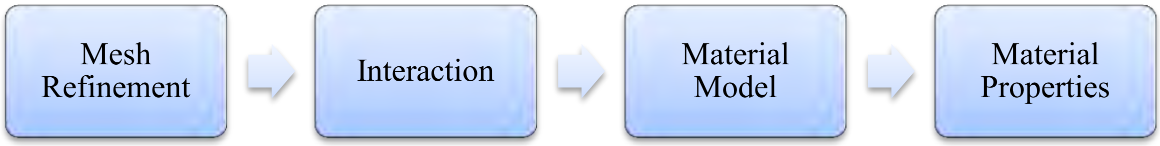
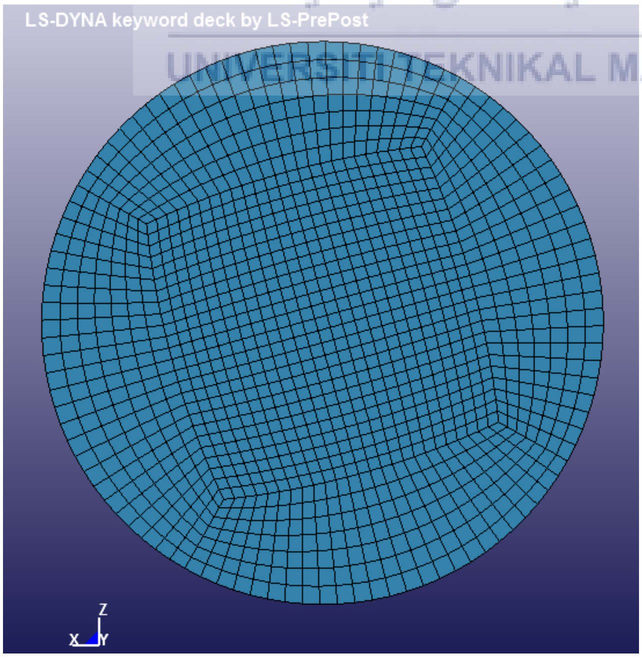


Figure 4.2: Model optimization process.

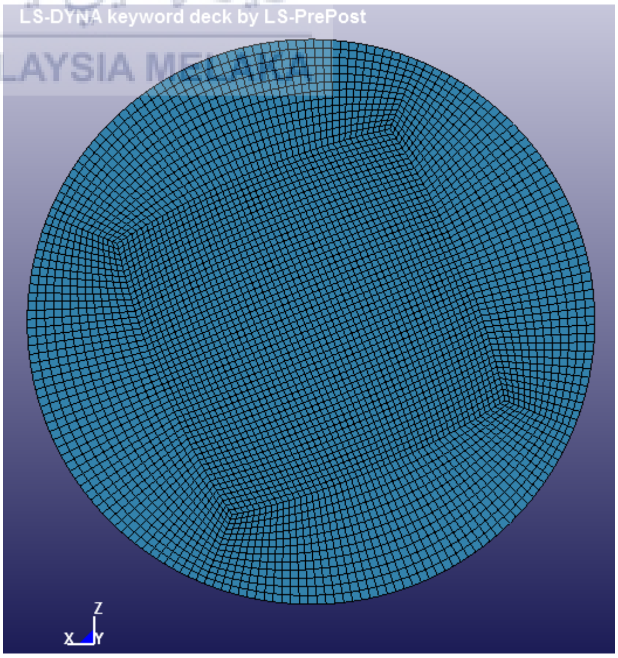
4.2.1 Mesh refinement

In this part the number of elements for blank is compared since blank will undergo large deformation. Figure 4.3 show the blank mesh diagram for respective number of element (NOE) while the relationship between number of elements and the maximum reaction force is recorded in Table 4.2.

NOE: 1325



NOE: 5100



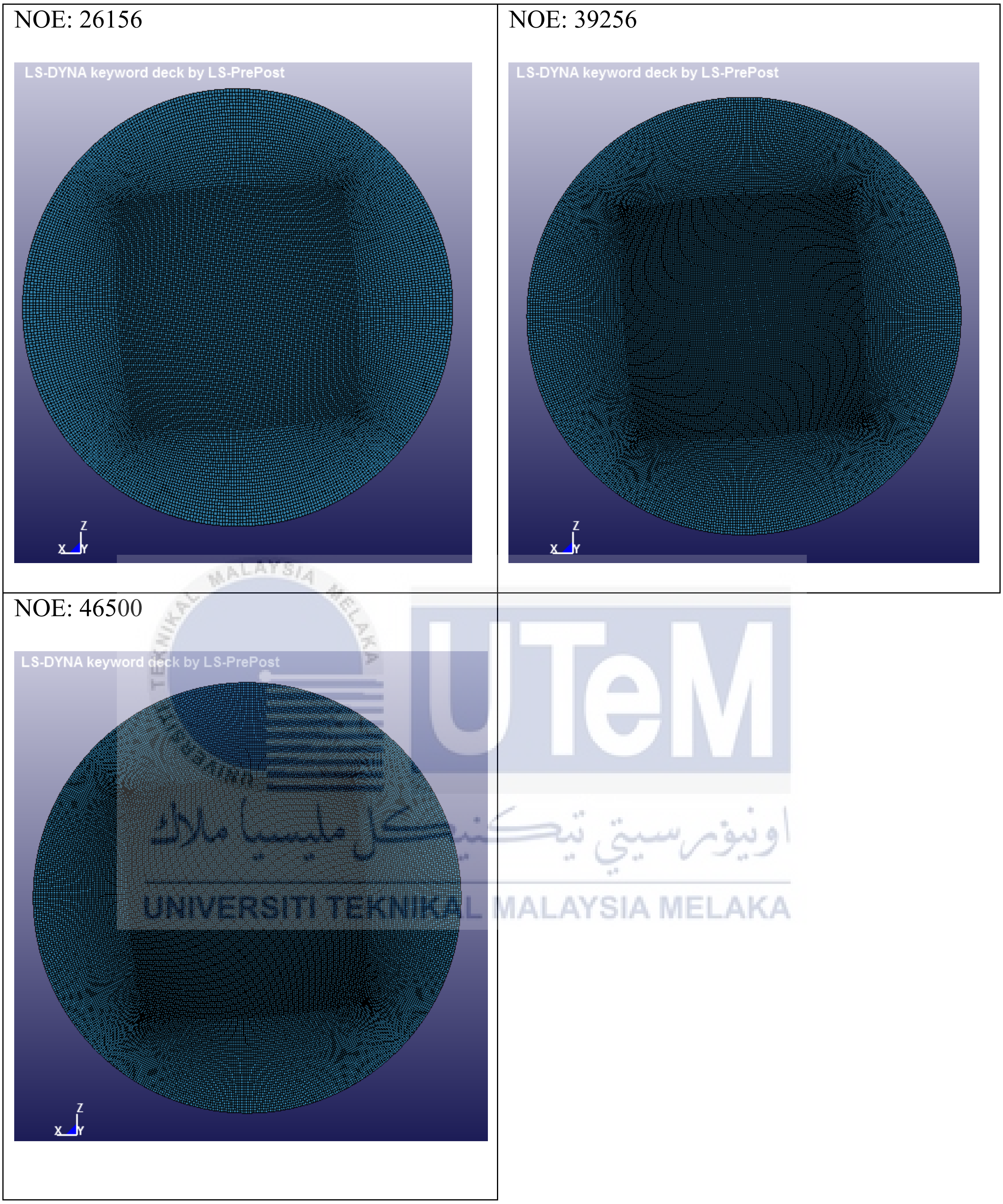


Figure 4.3: Diagram of meshing for respective number of elements.

Table 4.2: Number of element and respective maximum reaction force.

Number of element, (NOE)	Maximum Reaction Force, F_{max} (kN)	Computational time (minutes)
1325	3.60	10
5100	11.10	36
26156	14.70	172
39256	14.73	248
46500	14.75	326

The maximum reaction force between punch and blank in experiment is 21.17 kN. Graph in Figure 4.4 shows the maximum reaction force will become optimum start from number of element 26156. As too high number of element will lengthen the calculation time which is unnecessary. Consequently, number of element 26156 with computational time 172 minutes is chosen for further analysis.

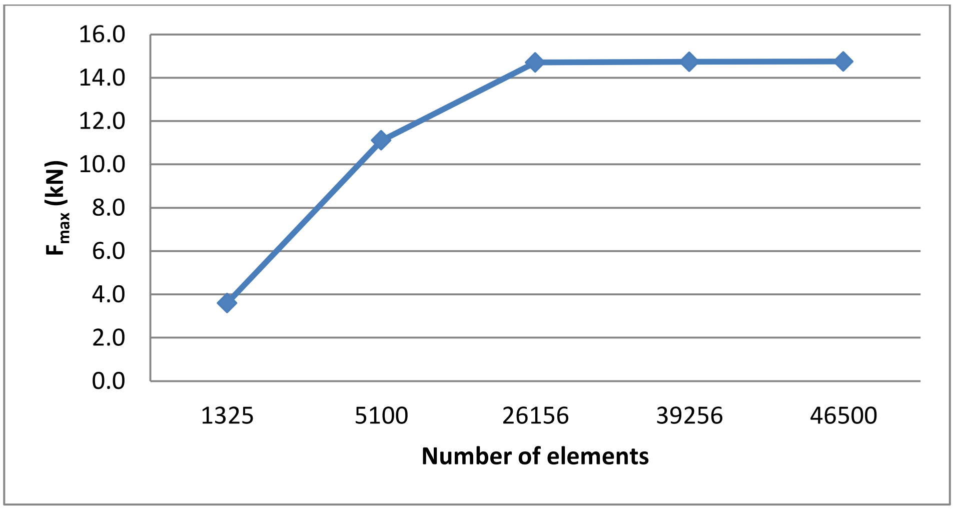


Figure 4.4: Graph of maximum reaction force versus number of elements.

4.2.2 Interaction

As 26156 number of element is chosen for further analysis therefore the same setup is taken into consideration but varying both static and dynamic coefficient between contact of blank and tool components. There are specific ideal solutions to determine the coefficient of friction between different surfaces. Based on the tribology table, static and dynamic coefficient between steel and aluminum is 0.61 and 0.47 respectively (Sullivan 1988). In dry friction for steel on steel the static coefficient of friction is 0.7 and dynamic coefficient of friction is 0.5 (Shridhar Kumar, B. et al. 2015). In addition, according to Atlan, T and Tekkaya (2012), in deep drawing process the value of coefficient of friction are typically in range of 0.04 to 0.10. Several testing is run under different combinations of coefficient of friction. The combination of coefficient of friction and relative maximum reaction force in dry condition is shown in Table 4.3. Also, comparison graph between experimental and simulation result is shown in Figure 4.5.

Table 4.3: Combination of coefficient of friction and relative maximum reaction force in dry condition.

Line	Static coefficient of friction	Dynamic coefficient of friction	Maximum Reaction Force, Fmax (kN)
A	0.15	0.01	21.5
B	0.61	0.01	15.3
C	0.70	0.01	14.7
D	0.71	0.01	14.6
E	0.15	0.47	21.2

F	0.61	0.47	15.2
G	0.70	0.47	14.7
H	0.71	0.47	14.6
I	0.15	0.50	21.2
J	0.61	0.50	15.3
K	0.70	0.50	14.7
L	0.71	0.50	15.3

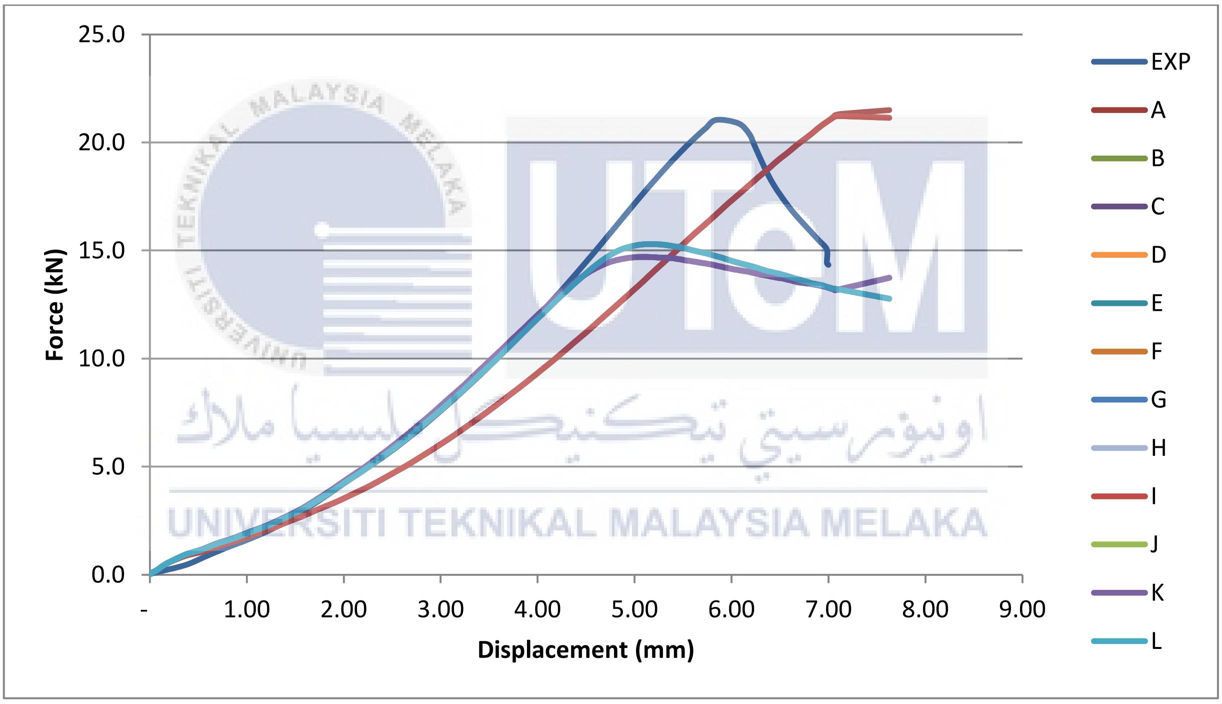


Figure 4.5: Result of variation of coefficient of friction.

The graph in Figure 4.5 shows that the dynamic coefficient of friction bears no effect in the result. So, the graph of varies static coefficient of friction with constant 0.5 dynamic coefficient of friction is plotted in Figure 4.6.

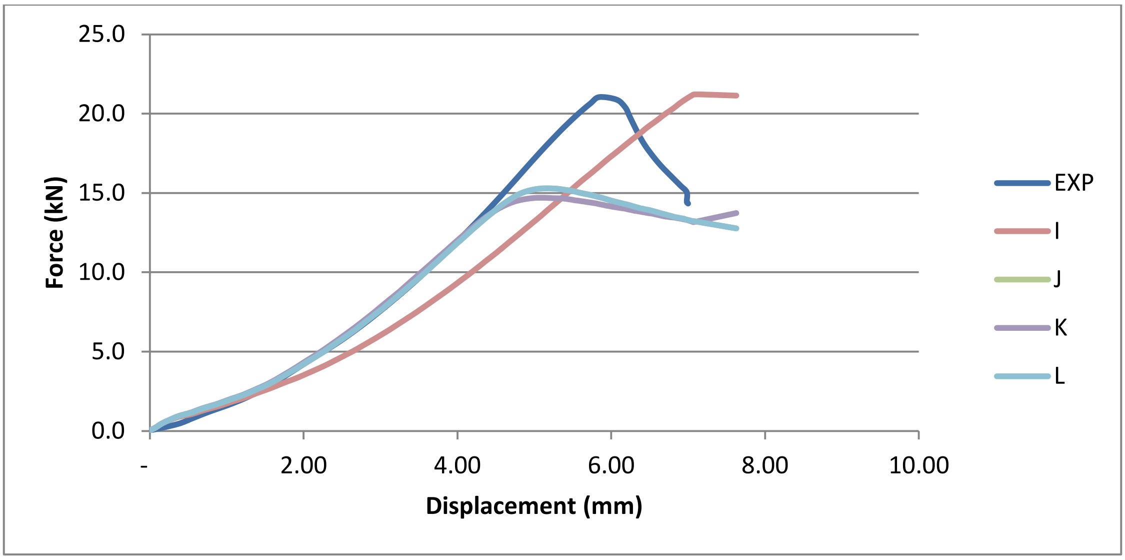


Figure 4.6: 0.5 dynamic coefficients of friction with variation of static coefficient of friction.

In Figure 4.6 line J and K is overlapping while line L shows best fit graph pattern with the experimental result. So, the combination of 0.71 and 0.50 static and dynamic coefficient is used for further analysis.

4.2.3 Material model

There are several materials card usually used for sheet metal forming in LS DYNA keyword manual (Anonymous 2013). Material card that frequently used in simulating sheet metal forming are 003_Plastic Kinematic, 018_Power Law Plasticity and 024_Piecewise Linear Plasticity. The input material properties for 003_Plastic Kinematic, 018_Power Law Plasticity and 024_Piecewise Linear Plasticity are stated in Table 4.4, Table 4.5 and Table 4.6 respectively. Also, the result is tabulated in Table 4.7 while Figure 4.7 shows the graph pattern of force versus displacement recorded from different material card and the results is compared with the experimental result.

Table 4.4: Material properties for 003_Plastic Kinematic material card.

Mass Density	Young‟s modulus	Poisson ratio	Yield stress	Tangent modulus	Hardening parameter
$2.68\text{x}10^{-6}$	52.823002	0.33	0.0949800	1.1869860	0.15

Table 4.5: Material properties for 018_Power Law Plasticity material card.

Mass Density	Young‟s modulus	Poisson ratio	Strength coefficient	Hardening exponent
$2.68\text{x}10^{-6}$	52.823002	0.33	0.2141900	0.15

Table 4.6: Material properties for 024_Piecewise Linear Plasticity material card.

Mass Density	Young‟s modulus	Poisson ratio	Yield stress	Tangent modulus
$2.68\text{x}10^{-6}$	52.823002	0.33	0.0949800	1.1869860

Table 4.7: Maximum reaction force in different material mode.

Material mode	Maximum Reaction Force, Fmax (kN)
003_Plastic Kinematic	7.6
018_Power Law Plasticity	15.3
024_Piecewise Linear Plasticity	63.4

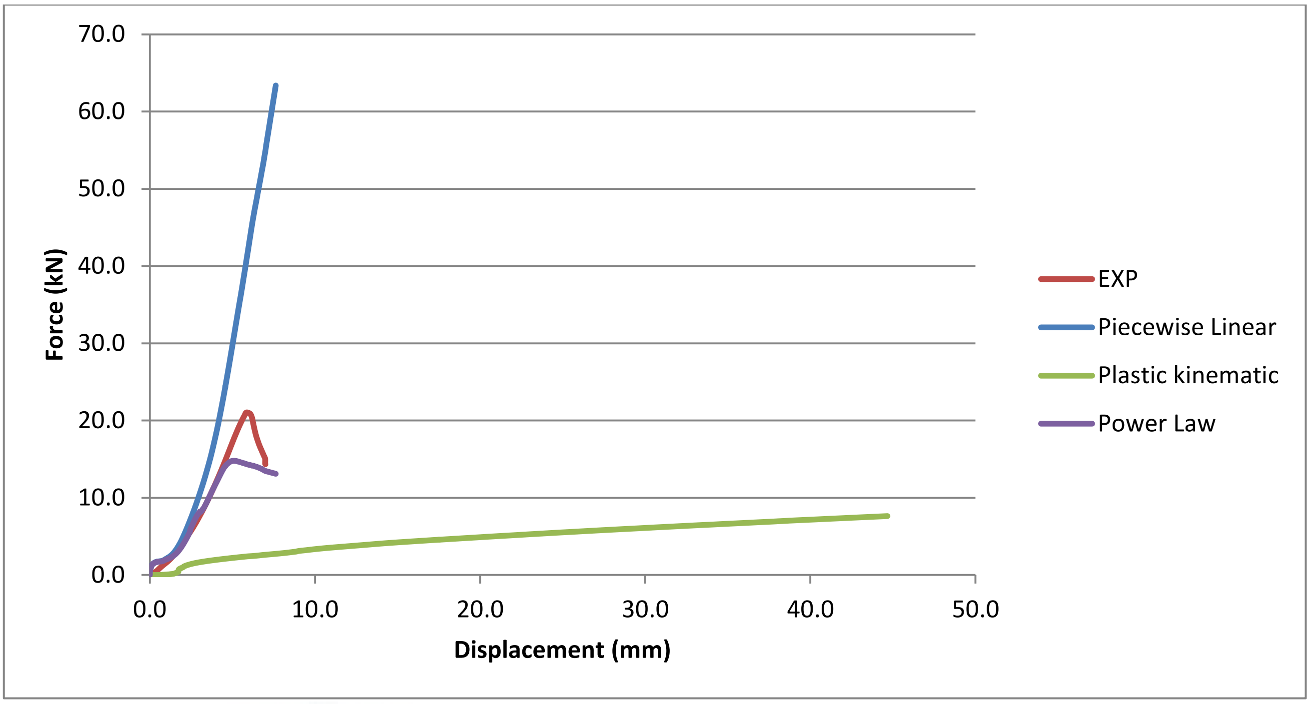


Figure 4.7: Graph of force displacement from different material card.

From the graph shown, Power law plasticity is best describe as the material model used for finite element simulation since it poses almost same graph pattern with the experimental result.

4.2.4 Material Properties

Result shows that 018_Power Law Plasticity is suitable in optimizing the simulation analysis. However, there are still slightly dissimilarities contain between the simulation and experimental result therefore strength coefficient and hardening exponent are varying to obtain the result. According to Yagami, T et al. (2009), the strength coefficient, K for 5052-O aluminum alloy is 430 MPa while the result obtained in the tensile test show that the strength coefficient for the specimen is 214 MPa and the hardening exponent is 0.15. The strain hardening exponent for AA5052-O material sheet is 0.25 (Chun feng, Li et al. 2009). Table 4.8 shows the variation of strength coefficient, K and hardening exponent, n with respective maximum force reaction and Figure 4.8 shows the graph of the result compare with the experimental result.

Table 4.8: Result for variation strength coefficient with respective maximum reaction force.

Strength coefficient (GPa)	Hardening exponent	Maximum Reaction Force, Fmax (kN)
0.21419	0.15	15.3
0.29000	0.15	21.8
0.43000	0.15	32.5
0.21419	0.25	16.2
0.29000	0.25	21.2
0.43000	0.25	33.9

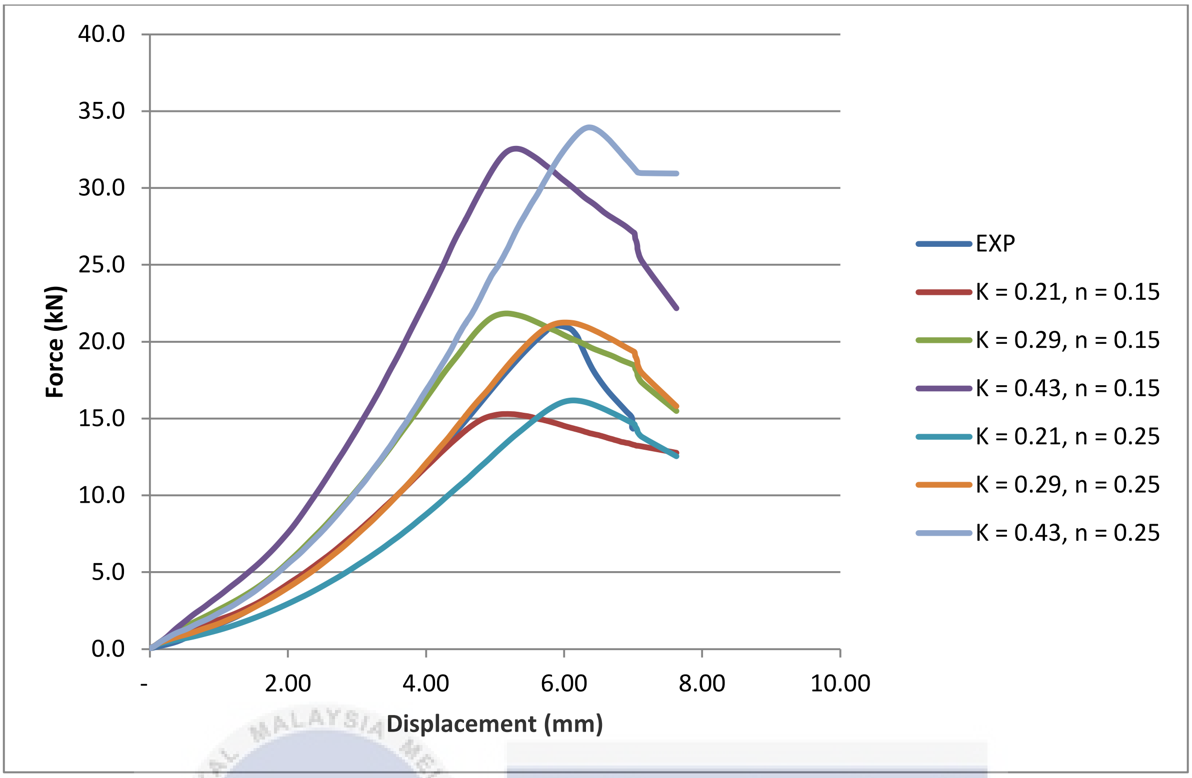


Figure 4.8: Graph of comparison with varies strength coefficient and hardening exponent.

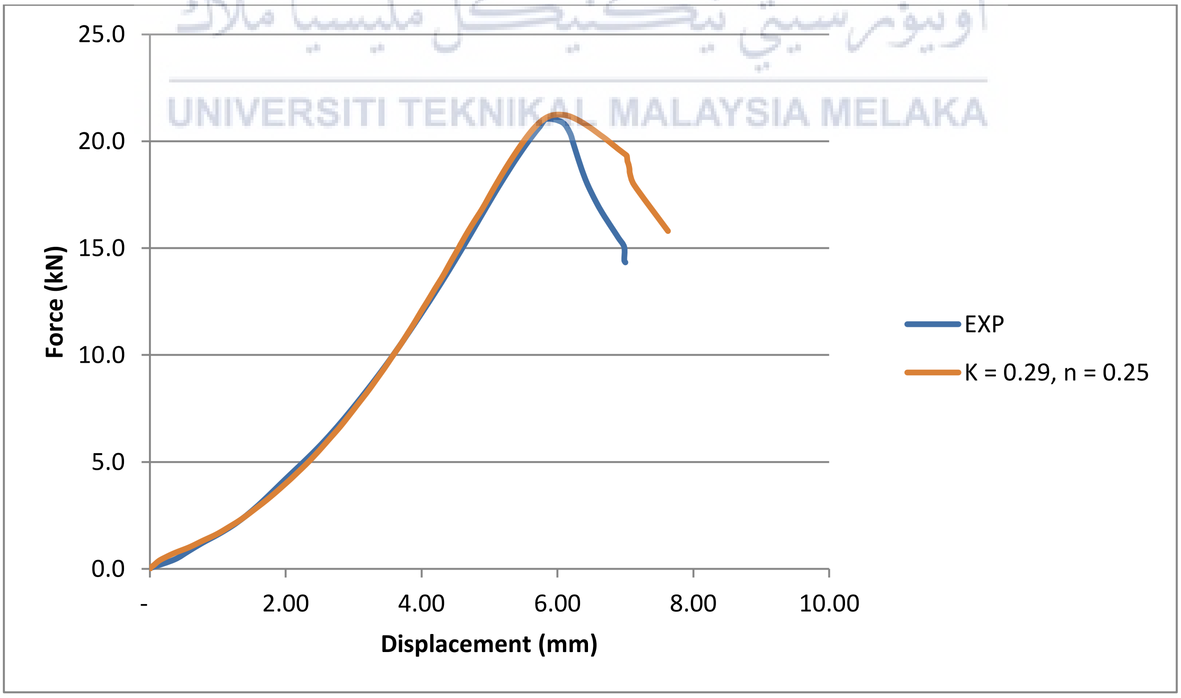


Figure 4.9: The best fits curve between experimental and simulation.

Figure 4.9 shows the best fit curve pattern between experimental and simulation result. Therefore strength coefficient, K is 0.29 and hardening exponent,n with 0.25 is chose. The percentage of error is only 0.14% which is acceptable.

$$percentage\ of\ error = \frac{21.20 - 21.17}{21.20} \times 100 = 0.14\ \%$$

In conclusion, the finite analysis result is been validated. So, the research is further study the effect of process parameters in sheet metal forming.

4.3 Effect of blank thickness

Blank will undergo large deformation during sheet metal forming process, therefore the shape and thickness of blank play an important role in influencing the metal flow and force exerted. Insufficient blank thickness will lead to thinning or fracture while excess blank thickness used will cause wastage of material and indirectly increasing cost of production. The thickness is varying from 0.50 mm to 1.50 mm with increment 0.50 mm. However, the other parameters remain constant when varying thickness. The thickness of the drawn cup is measured in several locations of the circular cup. The respective thickness location in the drawn cup in simulation is shown in Figure 4.10. Apparently, there will be small different between the thickness distribution due to mesh generation, therefore the value used is taking from the closest elements of the corresponding locations for all three blank thickness model. Table 4.9 shows the effect of blank thickness on sheet metal thickness distribution. Figure 4.11 illustrates the distribution of sheet metal thickness with variation of blank thickness.

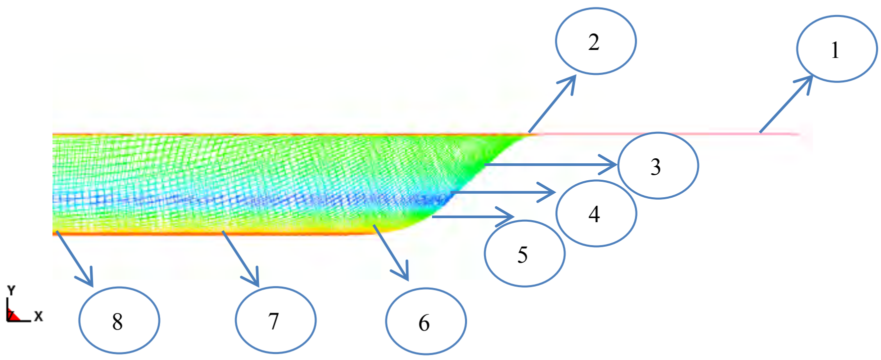


Figure 4.10: Thickness location for the drawn cup in simulation model.

Table 4.9: Effect of blank thickness on sheet metal thickness distribution.

Measured Thickness (mm) at locations	Blank thickness (mm)		
	0.5	1.0	1.5
1	0.502	1.000	1.500
2	0.484	0.933	1.410
3	0.456	0.853	1.310
4	0.431	0.885	1.300
5	0.464	0.939	1.290
6	0.476	0.969	1.400
7	0.488	0.978	1.470
8	0.488	0.978	1.470

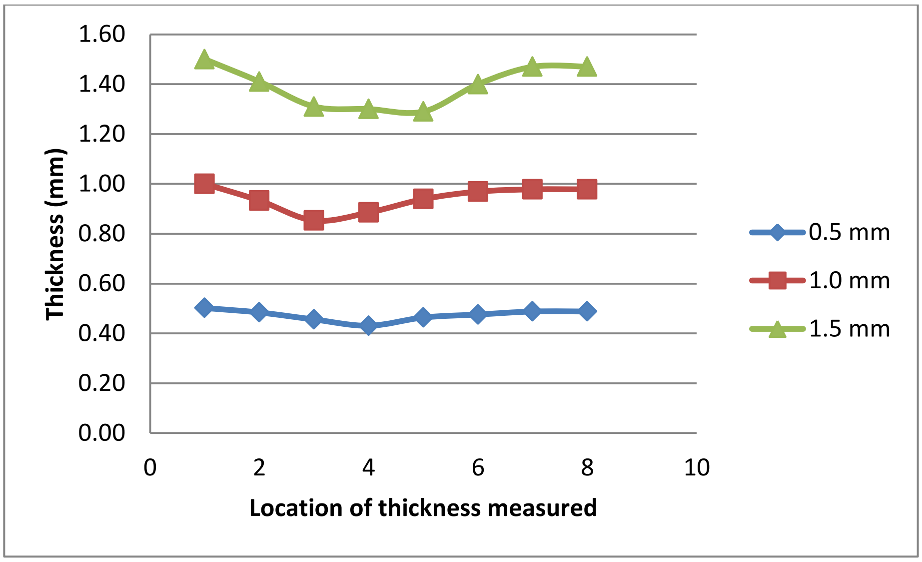
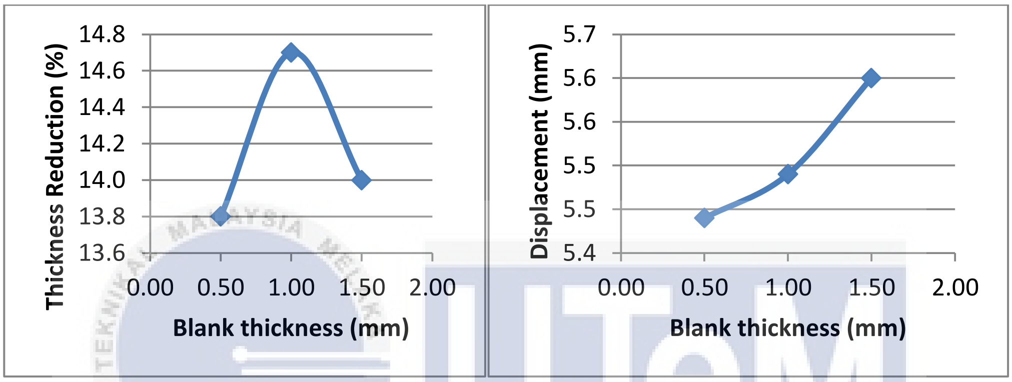


Figure 4.11: Distribution of sheet metal thickness with variation of blank thickness.

In forming process, when a reaction forces is apply on a sheet metal the flat section will undergo deformation therefore it will become thinner due to dimensional changes in width and thickness. Therefore thickness reduction is an important factor to be considered in forming process, as too high thickness reduction will lead to fracture. Table 4.10 tabulated the thickness reduction in respective blank thickness and Figure 4.12 implies the comparative result of thickness reduction with variation of blank thickness. For 1.0mm blank thickness the resulted maximum thickness reduction is 14.70% which shows the highest reduction compare to 0.5mm and 1.5mm with only 13.80% and 14.00% respectively. Generally, the displacement of blank is increase as blank thickness increase which is 5.44mm, 5.49mm and 5.60mm for blank thickness 0.50mm, 1.00mm and 1.50mm respectively. This shows that increasing blank thickness enhances the material"s availability to drawn.

Table 4.10: Comparative result with variation of blank thickness

Blank thickness (mm)	Thickness reduction (%)	Displacement (mm)
0.50	13.80	5.44
1.00	14.70	5.49
1.50	14.00	5.60



(a) (b)

Figure 4.12: Comparative graphical result with variation of the blank thickness where (a) Thickness reduction; (b) Displacement.

The thickness reduction increased as the blank thickness increase from 0.5 mm to 1.0mm. Figure 4.13 show that the blank thickness increase the limiting drawing ratio for Aluminum will increase. Slightly thicker material can be gripped better during the deep drawing process. In addition, thicker blank result to higher volume which can experience higher stretching which show increasing thinning (Zein, H. et al. 2013). However, the thickness reduction show decreasing trends when further increase the blank thickness from 1.0 mm to 1.5 mm. For thicker sheets (1.2-1.58mm) earing was observed to decrease as increasing sheet thickness (Oluwale et al., 2010).

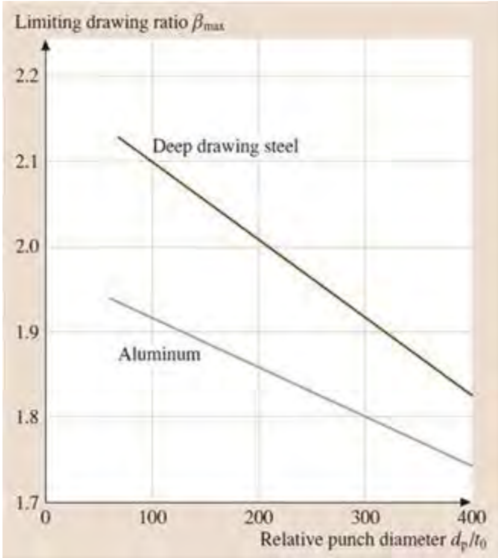
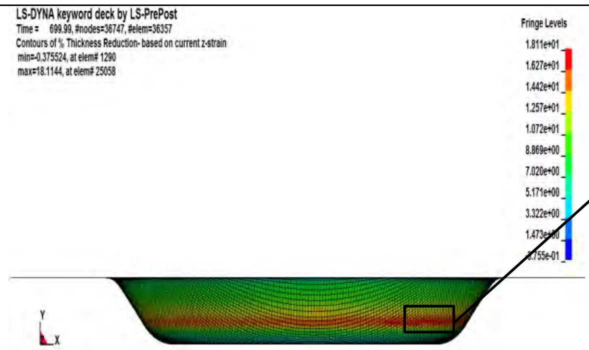
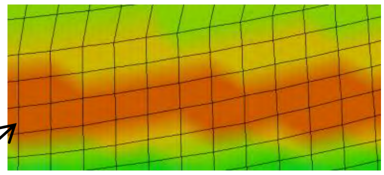
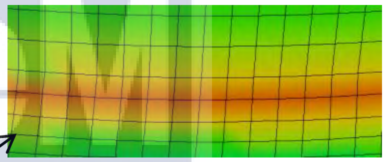
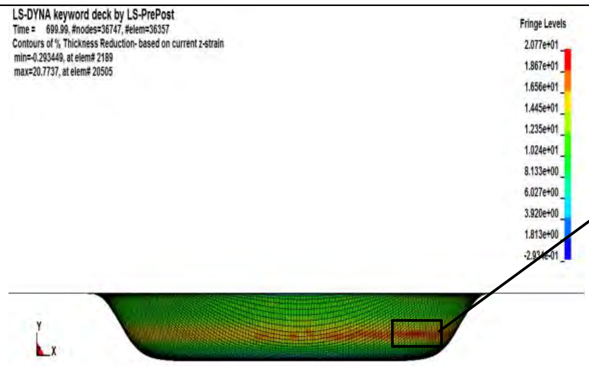
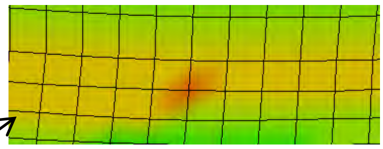


Figure 4.13 Effect of the relative punch diameter on limiting drawing ratio (Grote, K.H. and Antonsson, E.K., 2008).

According to Kalpakjian, S. and Schmid, S. (2008) sheet metal with a reduction of area of about 50% is safe to bend and deform without cracking. In these cases the thickness reductions not exceed 50% which is safe to drawn. Table 4.11 show the maximum reduction happen at the wall section of the cup.

Table 4.11: Thickness reduction for varies blank thickness at different node.

Blank thickness (mm)	Blank	Zoom in at thinning
0.50		 At element 25058
1.00		 At element 24808
1.50		 At element 20505

4.4 Effect of blank holder force

The major function of blank holder in forming process is to prevent wrinkle in final products. Blank holder force exerted pressure onto blank to prevent it to flow into die. Therefore, blank holder force is manipulated to study the effect to the quality of the products. The variation of blank holder forces is 50kN, 75kN and 100kN. The simulation is executed by varying blank holder force while others remain in constant. Table 4.12 shows the comparative result with variation of blank holder force.

Table: 4.12: Comparative result with variation of blank holder force with 1mm blank thickness.

Blank holder force (kN)	Von-mises stress (MPa)	Plastic strain	Thickness Reduction (%)	Displacement
50	232.21	0.41	14.70	5.49
75	232.21	0.41	14.70	5.49
100	232.21	0.41	14.70	5.49

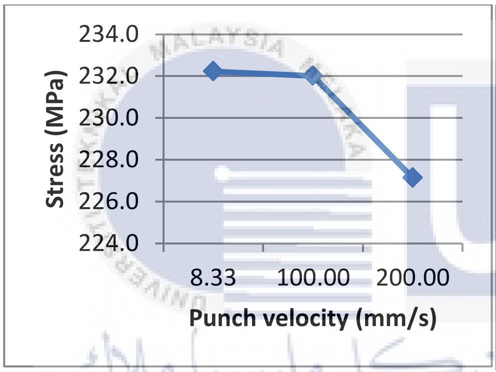
Based on the result obtained in Table 4.12, there are no significant effects of blank holder force as von-mises stresses remain 232.21 MPa, plastic strain is 0.41, thickness reductions remain in 14.70% and displacement is 5.49mm for the forming tests. The clamp holding force bears no effect on the stresses, strains, displacement and pressure (Trivikram et al., 2009). Blank holder force aids to control friction on the flange during sheet metal forming process. In result, insufficient blank holder force will cause wrinkling while increasing blank holder force will eliminate wrinkling problem. Yet, excessive blank holder force applied will lead to fracture. Besides, Kovac and Tittel (2010) had concluded that the safe range for blank holder force in deep drawing process is from 50kN to 125kN. Consequently, the blank holder force applied in this research was in acceptable range therefore no wrinkling and fracture occurred due to variation of blank holder force during the forming processes. In addition, the blank holder force contributes no effect in limiting values of strains when the strain condition in the deep drawing process at the punch corner is nearly equibiaxial (Ravindra, P.V.R. et al.).

4.5 Effect of punch velocity

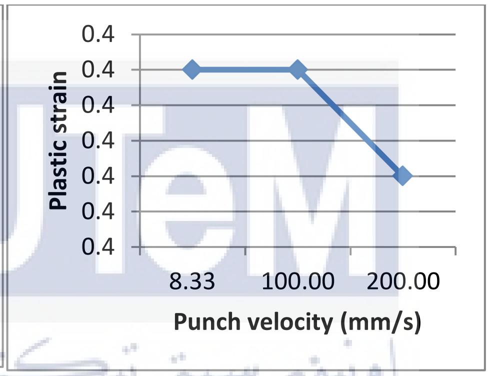
In sheet metal forming process, velocity is applied to the punch to make it displace downward to deform the blank. This research is focus in quasi static sheet metal forming process therefore punch velocity is increase to 100mm/s and 200 mm/s to study the effect of punch velocity while other parameters were remain unchanged. Table 4.13 shows the comparative result with variation of punch velocity while Figure 4.14 shows graphical result with variation punch velocity.

Table: 4.13: Comparative result with variation of punch velocity

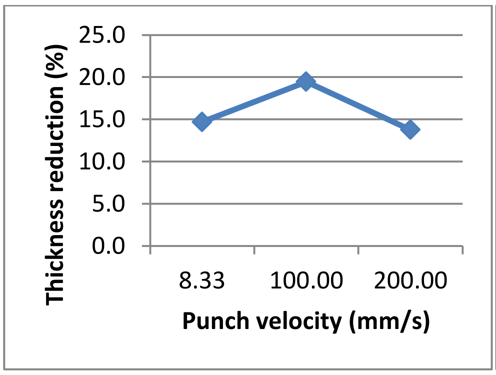
Punch Velocity (mm/s)	Von-mises stress (MPa)	Plastic strain	Thickness Reduction (%)	Displacement
8.33	232.22	0.41	14.70	5.49
100.00	232.01	0.41	18.45	5.68
200.00	227.14	0.38	13.76	5.52



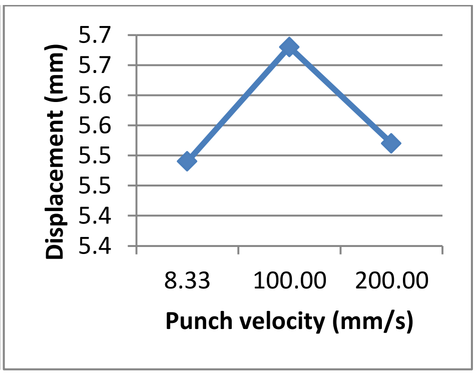
(a)



(b)



(c)



(d)

Figure 4.14: Comparative graphical result with variation of punch velocity where (a) Stress; (b) Plastic strain; (c) Thickness reduction; (d) Displacement.

The validation punch velocity 8.33 mm/s is not practical in industrial process because it lead to lengthy process. Therefore the punch velocity is increase to 100mm/s and 200 mm/s. By referring to Figure 4.14 (a) increasing the punch velocity result to lower von mises stress exerted. For 8.33 mm/s the maximum von mises stress is 232.22MPa which is the highest compare to 100 mm/s with 232.01MPa and 200 mm/s with only 227.14MPa. This shows that 200 mm/s present lowest von mises stress while exhibit excellent formability as compare to remaining set of simulations.

Also, the plastic ratio show decreasing trend as punch velocity increase. Punch velocity 200 mm/s show largest drawability as it achieve the lowest plastic ratio 0.38 compare to 100 mm/s and 8.33mm/s with 0.41. In addition, the thickness reduction of 200mm/s implied the lowest among the three combinations, it show 13.76% as compare to 100 mm/s with 18.45% and 8.33 mm/s with only 14.70%. Figure 4.15 show the thickness reduction with variation of punch velocity. The initial shell thickness of 1.003 mm is reduced to 0.8530mm, 0.8155mm and 0.8624mm for punch velocity 8.33 mm/s, 100mm/s, and 200mm/s respectively. Figure 4.16 show the thickness contour with variation of punch velocity. As the minimum and maximum thickness values in each simulation are checked, it could be stated that the maximum variation in thickness for both 8.33 mm/s, 100mm/s and 200 mm/s is less than 20%.

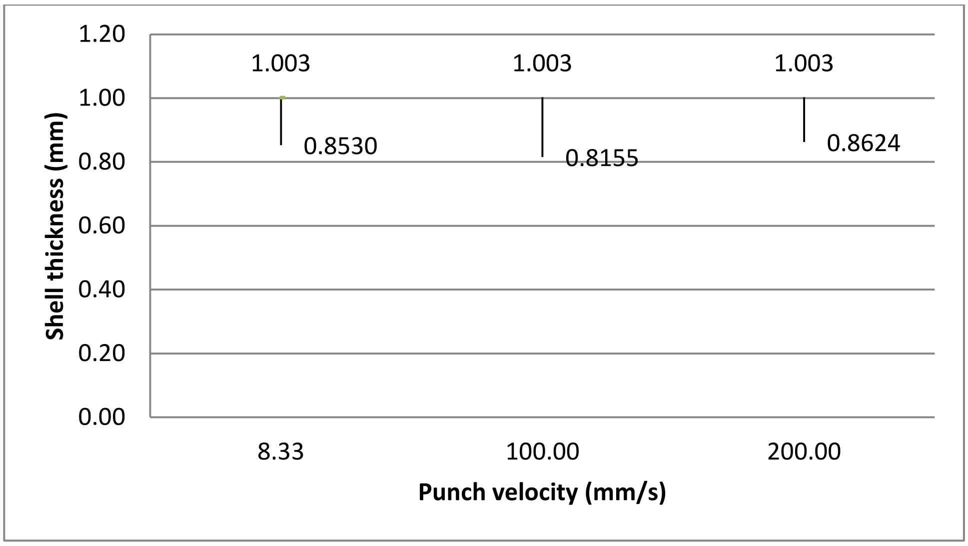
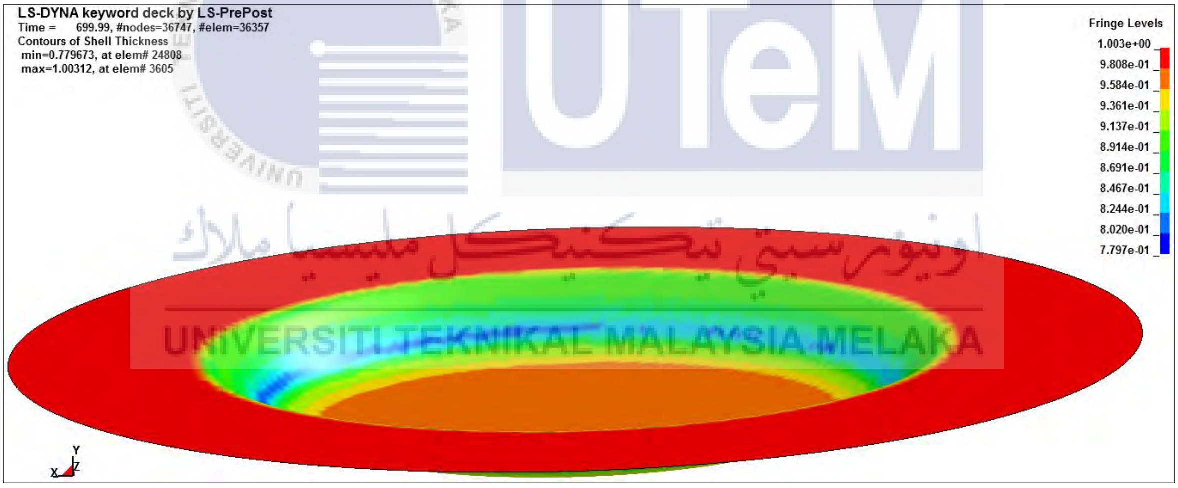
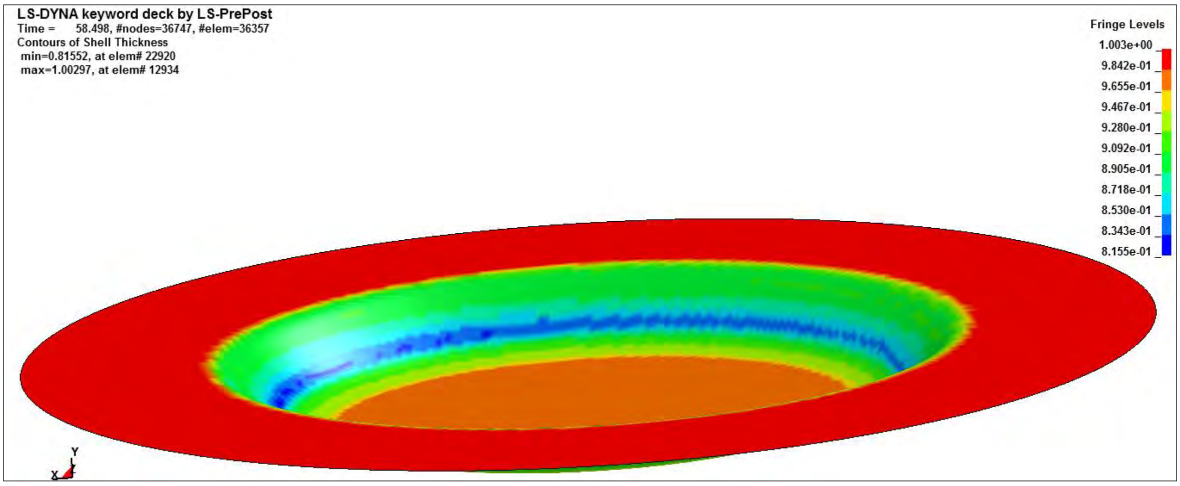


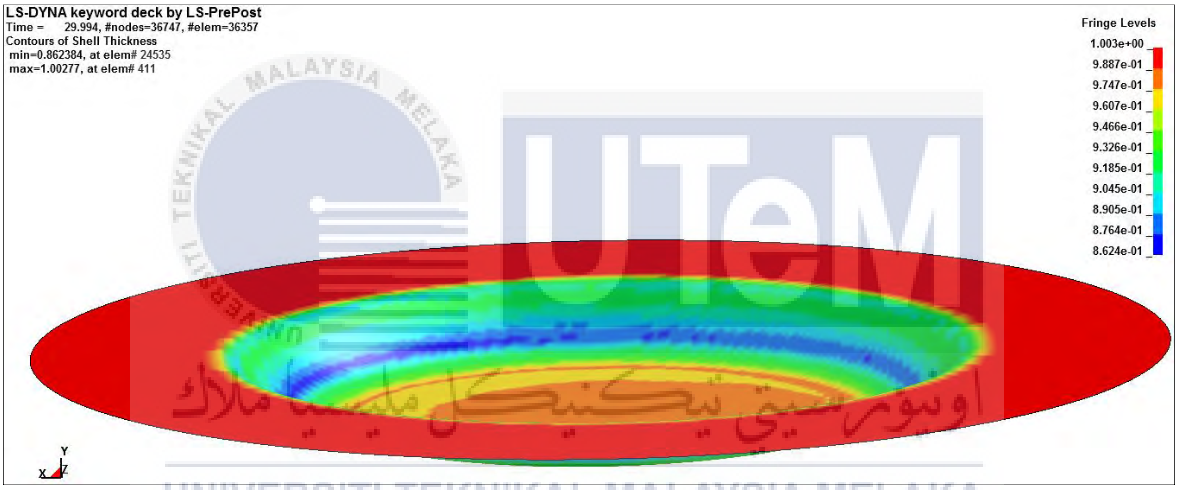
Figure 4.15: Thickness reduction with variation of punch velocity.



(a)



(b)



(c)

Figure 4.16: Thickness contour with variation of punch velocity (a) 8.33 mm/s; (b) 100 mm/s; (c) 200mm/s

The effect of varying punch velocity can also be observed in forming force versus punch progression curves. As shown in Figure 4.17, the result obtained shown insignificant vibration which indicated the punch velocities are in optimum range.

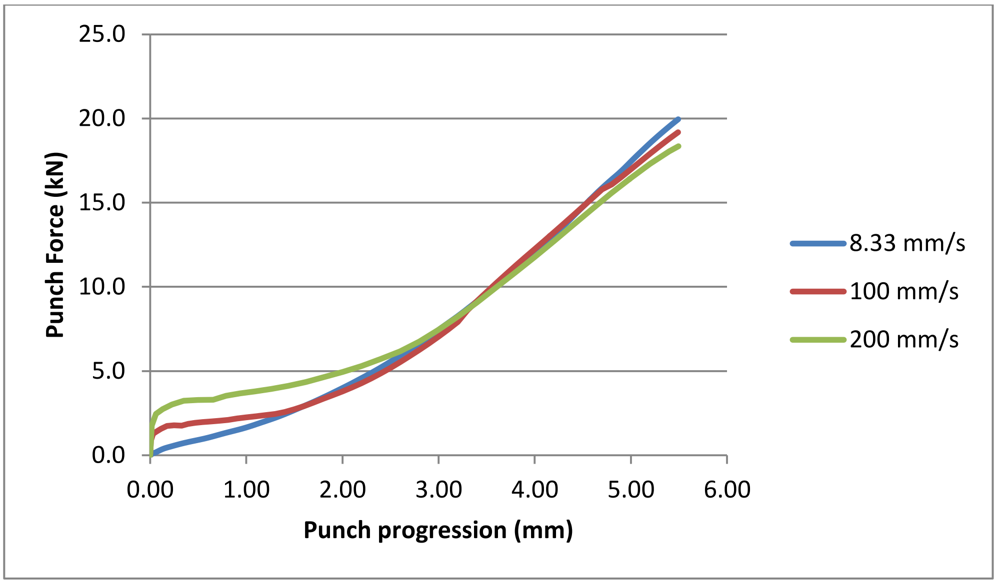


Figure 4.17: Curve between punch force and punch progression with variation punch velocity.

Besides, increase the punch velocity is greatly contributed to reduce the process time. Table 4.14 shows the processing time and respective displacement with variation of punch velocity.

Table 4.14: Processing time and displacement of cup with variation punch velocity.

Punch velocity (mm/s)	Processing time (ms)	Displacement (mm)
8.33	700	5.49
100.00	60	5.68
200.00	30	5.52

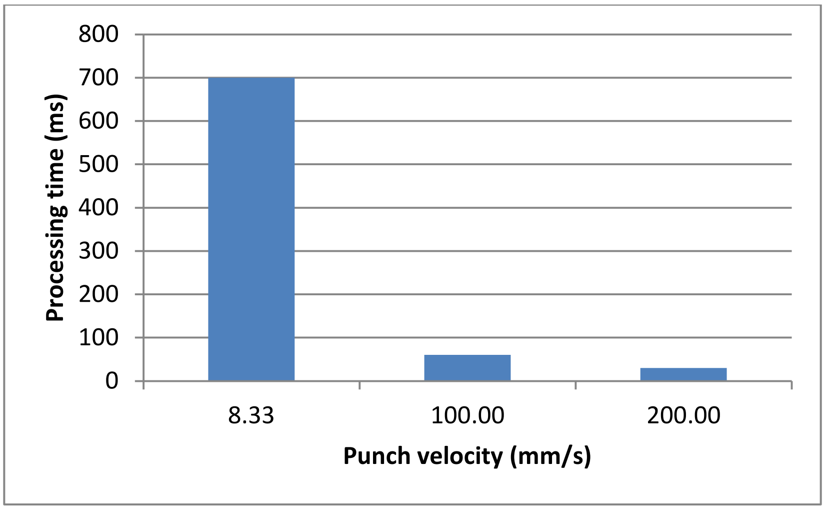


Figure 4.17: Processing time with variation of punch velocity.

Figure 4.17 show the processing time in three different punch velocities. By increasing the punch velocity the processing time is decreased. The percentage of time reduction as the punch velocity increase from 8.33mm/s to 100.00 mm/s is 91.43% while for 200 mm/s is 95.71%. This is very effective in manufacturing process in industrial which will indirectly reduce the cost of production.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this study, the commercial finite element program LS DYNA is used for modeling sheet metal forming process. The material properties are obtained from Metals Handbook and tensile testing. The effect of process parameter and their effects on the result are discussed. The finite element result is compared with experimental findings and the load versus displacement curve is validated.

The effect of blank thickness is discussed by focusing in 0.5 mm, 1.0 mm and 1.5 mm. The variation of blank thickness analysis reveals that blank thickness 1.5 mm implied optimum result compare to 0.5 mm and 1.0 mm because it show greater drawability with acceptable thinning.

The effect of blank holder forces show there is no significant effect in this study. The focused blank holder force is 50kN, 75kN and 100kN. This phenomenon can be explained that all these three blank holder forces show no wrinkling and fracture in the design. Therefore, it is proper to use in sheet metal forming process.

The effect of punch velocity is compared between 8.33 mm/s, 100mm/s and 200mm/s. The result show that 200mm/s exhibit lower computational time which is appropriate to use in industry and increases the production effectively.

As a conclusion, this study is expected to be valuable for understanding sheet metal forming process. The simulations performed clarify effect of blank thickness, blank holder forces and punch velocity in sheet metal forming process.

5.2 Recommendation

The followings are some specific suggestions listed for further investigations on simulation in sheet metal forming analysis:

I. There are still many process parameters need to be considered in sheet metal forming such as clearance between die and punch.

II. Use larger range of blank holder forces to study the effect of wrinkling and fracture which may contributed.

III. Simulation makes it possible to obtain the result that may be hard to measure in real materials. Conduct a study to improve the qualitative analysis by utilizing simulation data for guidance of lab measurement.

IV. Conduct a research to study the spring back effect in sheet metal simulation.

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