ANALYSIS AND OPTIMIZATION MACHINING PARAMETER BASE ON DIFFERENT TYPE OF MATERIAL IN INCREMENTAL FORMING PROCESS (ALGOR SIMULATION)

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for the award of the degree of
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SUPERVISOR'S DECLARATION

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

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

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Dedicated to my beloved father and mother

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ABSTRACT

This research was carried out to develop and analysis of an incremental forming machine controlled by personal computer numerical control (PCNC) and ALGOR software for simulation. Incremental Sheet Forming (ISF) is one kind of sheet metal forming. It is based on using of simple spherical tool, which is moved along personal computer (PC) controlled tool path. Aim of this study is analysis in stepdown for new development of incremental forming. The paper presents the analyses about the implication and justification for forming process. Using FE analysis have been achieved with the purpose to compare between experimental and simulation. The process and analysis have been use to determine the stepdown in the design phase for continuous operation. Additionally, this paper also shows investigate the effect different type of material on yield stress and Springback and investigate the deformation mechanics under an optimization with different type of material.

Keywords: Incremental Forming; ALGOR; Yield Stress; Springback; Process Parameters; PCNC

ABSTRAK

Penyelidikan ini telah dijalankan bagi membangunkan dan analisis satu tokokan membentuk mesin diawasi oleh kawalan komputer peribadi dan perisian ALGOR untuk simulasi. Kepingan Tokokan Membentuk (ISF) adakah satu jenis mesin untuk membentuk kepingan logam. Ini adalah berasaskan pada penggunaan mata alat sphera yang mudah, yang mana digerakan oleh mesin yang dikawal oleh komputer (PC). Matlamat kajian ini ialah analisis dalam langkah turun untuk pembangunan baru tokokan membentuk. Kertas ini menunjukan analisis tentang implikasi dan justifikasi untuk proses membentuk. Menggunakan analisis elemen terhad (FE) telah dicapai dengan tujuan untuk membandingkan antara ekperimen dan simulasi. Proses dan analisis digunakan untuk bagi menentukan langkah turun dalam fasa reka bentuk untuk operasi berterusan. Tambahan pula, kertas ini juga menunjukkan menyiasat kesan mengunakan bahan berbeza pada tegasan alah dan kebolehan logam kembali kebentuk asal dan menyiasat kecacatan mekanik-mekanik dibawah satu pengoptimuman dengan jenis bahan yang berbeza.

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LIST OF ABBREVIATIONS

AISI	American Iron & Steel Institute
ASTM	American Society for Testing and Materials
CAM	Computer Aided Manufacturing
CNC	Computer Numerical Control
FE	Finite Element
FEM	Finite Element Model
FLC	Forming Limit Curve
FLD	Forming Limit Diagram
ISF	Incremental Sheet Forming
IF	Incremental Forming
MES	Mechanical Event Simulation
SMI	Small and Medium Industry
SME	Small and Medium Enterprise
SPIF	Single Point Incremental Forming
TPIF	Two Point Incremental Forming
UTS	Ultimate Tensile Stress
Y	Yield Stress

NOMENCLATURE

A	Area
E	Modulus Elasticity
mm	Millimetre
cm	Centimetre
s	Second
v	Velocity
N	Newton
t	Thickness
MPa	Mega Pascal

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Incremental Sheet Forming (ISF) was first explored at the Institute for Manufacturing in 1990 by Colin Andrew, and then taken up in Japan during the 1990s (Allwood et al., 2005). Allwood also said that, many researcher or studies in ISF to date have been with one indenter only, and based around modified Computer Numerical Control (CNC) milling machines. A new incremental forming machine was commissioned in October 2004 at the Department's Institute for Manufacturing, which is the first dedicated rig to be built outside Japan (Allwood et al., 2005).

Nowadays, have a many new incremental forming machine were develop by the company, university and other institution. Researchers of Faculty of Mechanical Engineering (FKM) from Universiti Malaysia Pahang (UMP) also develop new incremental forming machine controlled by personal computer – numerical control (PC-NC) in March 2008. The incremental forming process which runs without mould can be used to replace stamping applications which is very costly due to the mould application. The application of the machine is for low batch sheet metal manufacturing product. This research will produce a new concept of forming process which is cheaper, efficient and suitable for SMI/SME industry, which will benefit the manufacturing industry in our country.

As a part of graduation requirements, the final year degree students of Faculty of Mechanical Engineering from Universiti Malaysia Pahang (UMP) will have to submit the thesis as a final year project for duration of two semesters. These projects propose to

analysis and optimization machining parameter base on different type of material in incremental forming machine using ALGOR software (simulation).

1.2 OBJECTIVE OF THE STUDY

The objective that must be carried out by this study in order to get the analysis and optimization machining parameter of Incremental Forming (IF):

1.2.1 To study and understanding the concept and principle of Incremental Forming (IF).

1.2.2 To investigate the deformation mechanics under an optimization with different type of material.(stepdown)

1.2.3 To investigate the effect different type of material on Springback in ALGOR Simulation.

1.3 SCOPE

1.3.1 Predictable model will be developed using ALGOR software

1.3.2 This project need to operate the ALGOR software with five of material and different Nodal Prescribed Displacement Z (-ve) = 0.5 mm, 1.0 mm and 1.5 mm. [Aluminum Alloy 5052-O,Titanium Ti-6Al-4V , Steel (ASTM - A572), Zinc and Stainless Steel (AISI 309)]

1.3.3 This project needs use same thickness of material is 0.5 mm.

1.3.4 During the analysis, data must be recorded and the analysis needs to be done on it.

1.3.5 By analyze and comparison of data, suitable parameter can be selected.

1.4 PROBLEM STATEMENT

1.4.1 Springback is a very important factor to influence the quality of sheet metal forming. Springback are main goal that need to be archive in order to get high accuracy, high productivity and cost-effective product in incremental sheet forming (ISF) process. However, as what world cannot deny that, practical is not as perfect as theory which due to large number of variable and the uncertain nature of the process, even highly skilled operator is difficult in archive optimal performance of machining. Springback of the workpiece is one of the main problems to achieve since this characteristic is close relation with accuracy.

1.4.2 ISF not have guideline to form sheet metal especially setting stepdown parameter for different type of material.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Incremental Sheet Forming (ISF) is an alternative to metal stamping or pressing. Pressing requires specialist tooling for each product, which is expensive and difficult to design because pressing requires large batch volumes to offset tooling costs. ISF is a very promising technology to manufacture sheet metal products by the Computer Numerical Control (CNC) controlled movement of a simple forming tool. Incremental forming is one of the technologies that have emerged as an alternative to conventional sheet metal forming processes for mass customization. Conventionally a sheet-metal component is manufactured by using dies and punches that depend on the dimensions of the component. This conventional method is adequate for mass production because the cost of dies and punches can be shared with a large number of products. However, when a short series production is required, the conventional methods based on dies, like stamping or drawing are not usable anymore. Therefore, new production methods have to be developed in order to fulfill the requirements imposed by the low series production industries.

Due to the recent diversification of the customer's demand in this field, new manufacturing methods for a small-size production need to be developed. Among the various methods developed over the past few years (Iseki and Kumon, 1994; Mori et al, 1996; Otsu et al, 2000) the ISF which utilizes a simple tool has been studied with a great attention (Matsubara, 1994; Kim and Yang, 2000). ISF is commonly regarded as a

die-less forming process which can form complex three-dimensional parts using relatively simple tools. It has received increasing attention from the engineering community due to its flexibility and low cost. This unique combination enables the rapid prototyping of functional sheet metal parts before mass production. In addition, it offers a valid manufacturing process to match the need of mass customization. Incremental forming has found numerous applications in automobile, aerospace industries, in biomedical applications, such as customized ankle support and bespoke architectural features.

2.2 CHARACTERISTICS OF FORMABILITY IN THE INCREMENTAL FORMING

In the incremental forming (IF) of sheet metal, a simple-shaped tool imposes deformation locally on the sheet in a consecutive manner. An example of the incremental forming, called the negative forming, is shown in Fig. 2.1. In this example, the ball tool moves on the sheet according to a programmed tool path on an Incremental Forming machine. The sheet is located with the periphery fixed by bolts on a die, which is hollow and square in cross section.

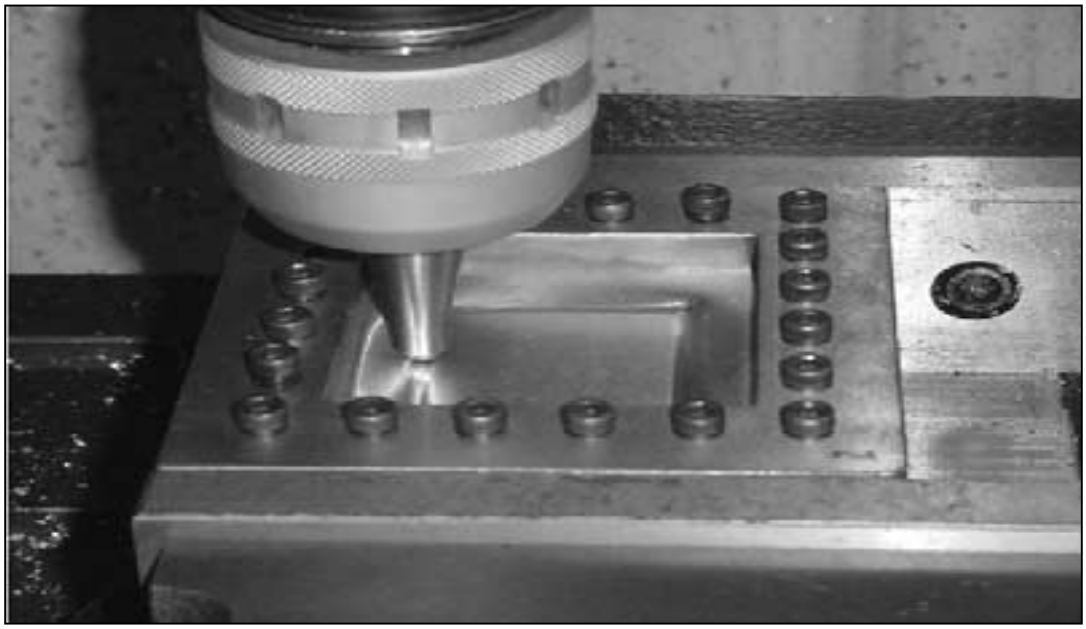


Figure 2.1: Incremental forming of sheet metal on Incremental forming machine.

The tool moves horizontally as well as vertically by a tool-path program, and forms a shape from the sheet. While the tool moves straight on a horizontal plane, the deformation that occurs at the starting and ending points of the straight line is biaxial stretching. The deformation that occurs between these points is plane-strain stretching. Shown in Fig. 2.2, the forming limit curve (FLC) appears to be a straight line with a negative slope in the positive region of the minor strain and thus the formability can be expressed as the value of εmax + εmin (Iseki, 2001). It is noted that the formability is greatly enhanced in the case of plane-strain stretching. Therefore, a greater deformation of a sheet metal can be achieved in the incremental forming. The other characteristic is the formability of the deformation increases as the size of the tool or the magnitude of the vertical feed decreases.

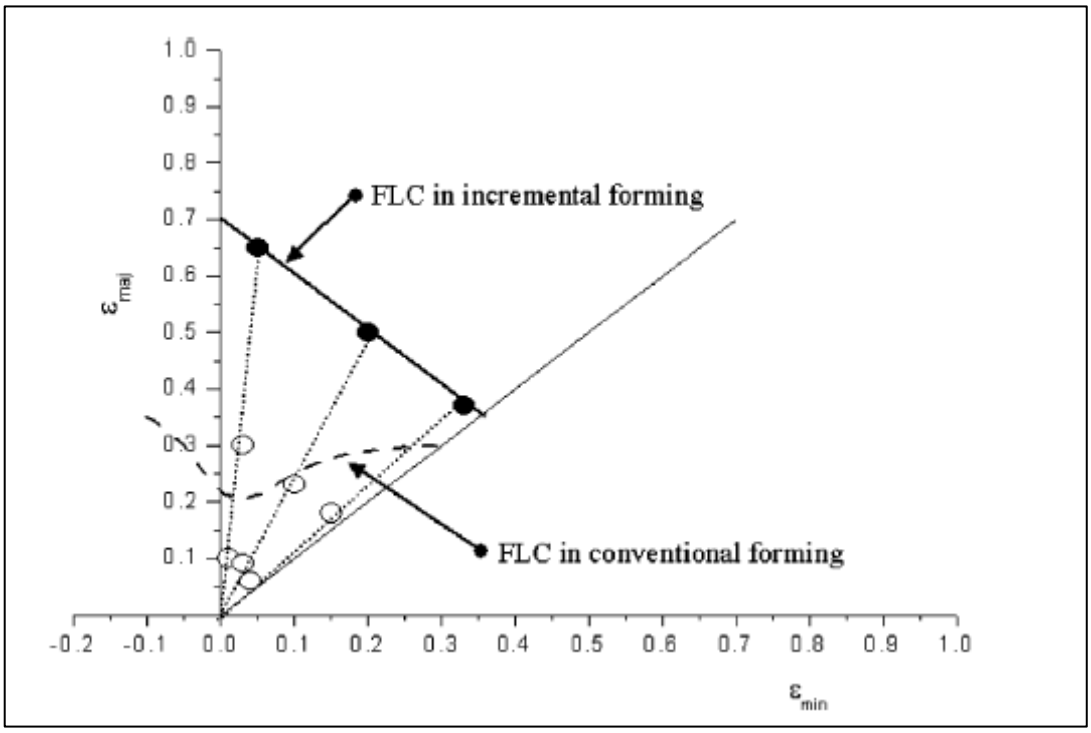


Figure 2.2: Comparison of FLCs in both incremental and conventional forming methods.

In Fig. 2.3 shown the concept of incremental forming by tool is presented schematically. The path of the ball is often a closed or near-closed loop on horizontal plane and the forming depth is controlled by tool depth.

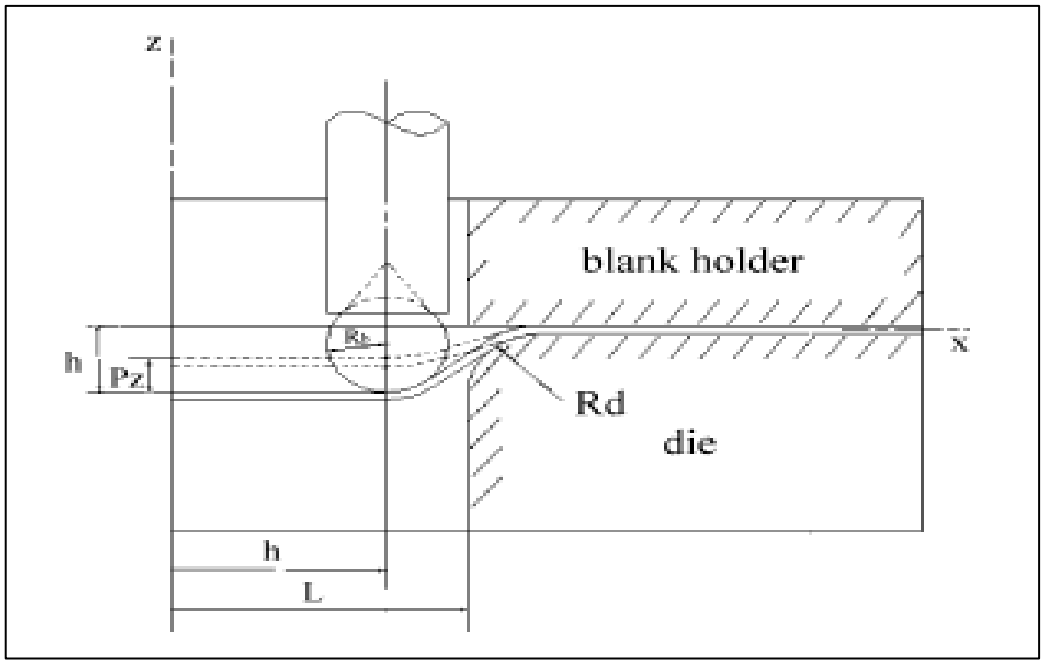


Figure 2.3: Schematic diagram of incremental forming

2.3 TYPES OF INCREMENTAL FORMING

The great interest in this new technique is due to the fact that it allows obtaining complex shapes, only using a simple tool, mounted on dedicated equipment (Lamminen et al, 2003; Shankar et al, 2005) or also on a general purpose 3-Axis CNC machine, which follows a path generated by CAM software. Incremental forming processes can be divided essentially in two families, depending on the number of contact points between sheet, tool and die (when present).Therefore, it is possible to distinguish between single point incremental forming (SPIF), and two point incremental forming (TPIF):

2.3.1 SPIF (Fig. 2.4a) has been investigated by many researchers, who underlined its great flexibility, due to the absence of specific dies. Many studies (Kim and Yang, 2000; Shim and Park, 2001; Jeswiet et al., 2005) report the increased drawing ratio obtainable with this method in comparison with conventional deep drawing processes. SPIF is indicated, and has been studied, above all for the realization of simple, nearly symmetric shapes (Dai et al., 2000; Pohlak et al., 2004a,b; Iseki, 2001; Kim and Park, 2002; Park and Kim, 2003), with few exceptions (Ambrogio et al., 2005; Tanaka et al.,

2005). The limit of this technique is the low geometric accuracy, which often makes the realized objects far from the requested tolerances. Many studies (Hirt et al., 2004, 2003b) have been performed in order to overcome this problem some proposed solutions are, for instance, multistage SIF (Kim and Yang, 2000; Iseki and Naganawa, 2002; Micari and Ambrogio, 2004) or the use of an algorithm (Hirt et al., 2003b) for the tool path correction. These solutions lead to a better dimensional accuracy, but they require longer production time.

2.3.2 TPIF is based on the presence of a partial (Fig. 2.4b) or full die (Fig. 2.4c), which supports the sheet during the deformation. When using TPIF (Jeswiet et al., 2005), the sheet is contemporarily deformed in two points: the contact points between tool and sheet and between sheet and die. This method of sheet defect could cause sheet reduction formability in comparison with SPIF, but it allows increased reachable geometric accuracy within one single pass. Use one TPIF process's detail called asymmetric incremental sheet forming (AISF), it was getting acquire a good for complex dimension accuracy, not axis of symmetry geometries, characterized by depression and convex surfaces. This, together with improve dimensional accuracy able, is great advantage of TPIF in comparison with SPIF, and it makes TPIF more attractive of SPIF for application inside industrial realize complex form prototype.

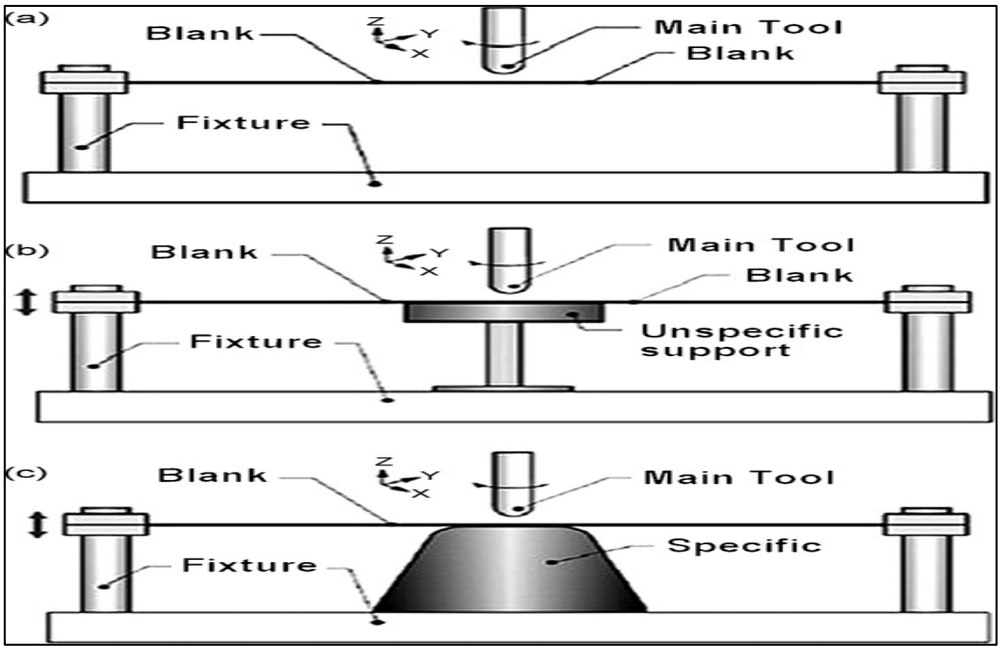


Figure 2.4: (a) SPIF, (b) TPIF with partial die and (c) TPIF with full die (Shankar et al., 2005).

2.4 FORMING TOOL SPINDLE SPEEDS

One major difference between the different sheet incremental forming processes, described by Hagan (Hagan et al., 2003) and other users of the process (Jeswiet et al., 2001; Kim and Yang, 2001; Leach et al.,2001; Filice et al.,2002), is the way the tool moves while deforming the sheet. In the case of SPIF the following have been done:

2.4.1 Move the spindle without rotation.

2.4.2 Move the spindle with the spindle rotating, at different spindle rotating speeds.

In the second case the spindle rotates so that the forming tool rolls over the sheet surface. Controlling this variable controls the heating of the sheet during deformation.

Reduced Friction Heating Speeds

The forming tool has a hemispherical shape, which is pressed into the material to cause deformation as shown in Figure 2.6. The most obvious source of heating is friction. As the tool travels over the surface of the work piece it is also spinning at a certain number of revolutions per minute. If the tool is stopped it will slide along the surface of the material. In all cases heating will occur due to sliding friction. If the tool is rotated at a high speed, the tool surface will slide over the work piece much more often and there will be excessive heating. The relative motion of the surface of the tool, to the surface of the work piece, is directly proportional to the heat generated by sliding friction. If the relative motion between the tool surface and workpiece is small during forming (i.e. all friction is rolling friction, and not sliding friction) the heating is minimized. For the draw angle, φ, there will be a point where the sheet is tangent to the hemisphere. This is the location of the maximum diameter of contact (dmax). From then on the work piece is in contact with the tool down to the very bottom of the sphere, at which point the diameter of contact is zero. This is an assumption. The average diameter of contact is therefore half dmax, see Figure 2.5.

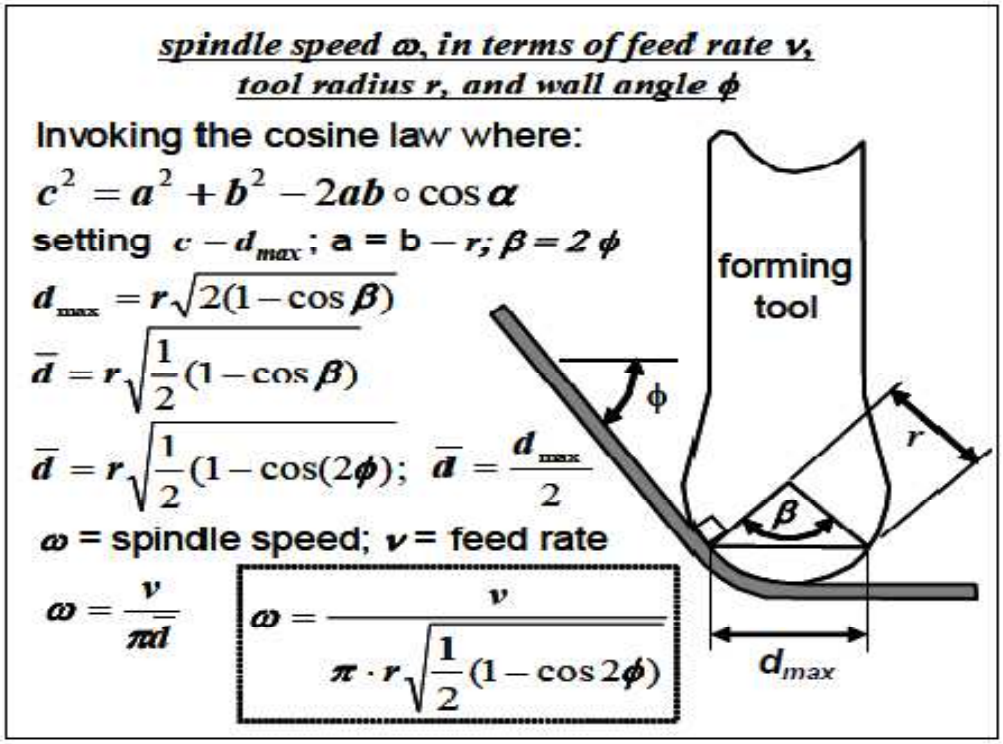


Figure 2.5: Tool geometry and spindle speeds.

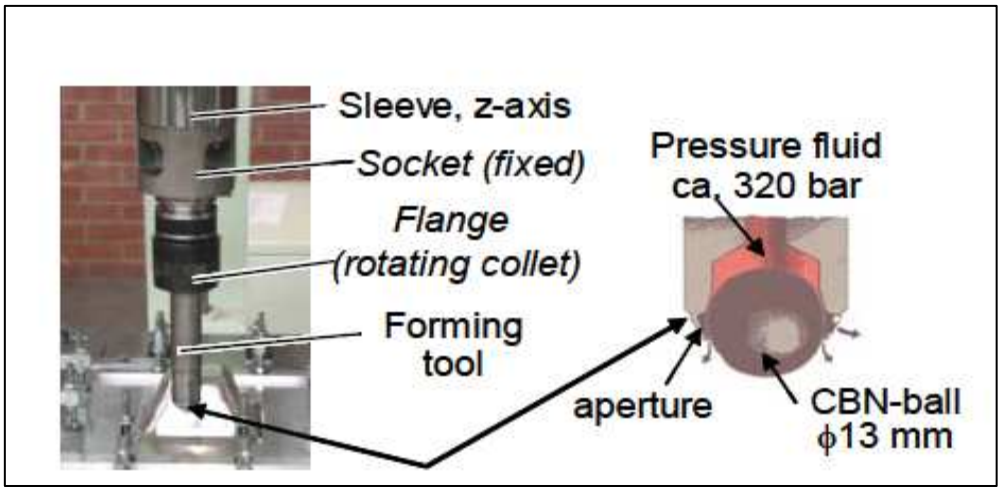


Figure 2.6: A universal tool head (Allwood et al., 2005)

To keep friction heat minimal the tool must roll over the surface of the work piece as it is formed. This result requires that the distance traveled along the work piece (i.e. the feed rate) be equal to the average circumference of the tool in contact with the material multiplied by the spindle speed. The following equation, derived in Figure 4, describes this mathematically. Spindle speed and feed rate are represented by ω and ν respectively and the hemispherical tool radius is *r*.

$$\omega = \frac{v}{\pi \cdot r\sqrt{\frac{1}{2}(1-\cos 2\phi)}} \tag{1}$$

Using Friction Heat

Increased spindle rotational speed is used sometimes to increase Formability (Micari et al., 2004). The Formability increase is due to both a local heating of the sheet and, what is more, a positive reduction of friction effects at the tool-sheet interface.

Spindle, Free Rotation

In a case study of manufacturing a solar oven cavity, the spindle could rotate freely in a CNC mill (Jeswiet et al., 2005). This allowed the friction at the tool/workpiece to cause the tool to rotate at a speed that automatically matched the

spindle surface rotation speed. This method is also used by a machines specially built for Incremental Forming (Hirt and Tools, 2004; Amino et al., 2002; Aoyama et al., 2000; Allwood et al., 2005).

Forming Tool Diameter

The single point incremental forming of a cone, shown in Figures 2.7 and 2.10, illustrates the use of FLD's. An important role is played by the forming tool diameter where a small radius concentrates the strain at the zone of deformation in the sheet under the forming tool, while a larger radius tends to distribute the strains over a more extended area. As the forming tool radius increases the process becomes more similar to traditional stamping, thereby reducing formability limits. Micari (Micari, 2004) found decreasing tool size increased the forming limits; see Figure 2.8. Results found by Hirt (Hirt et al., 2002), see Figure 2.9, and show that as the tool diameter decreases from 30 mm to 6 mm, much higher strains and deformations can be achieved.

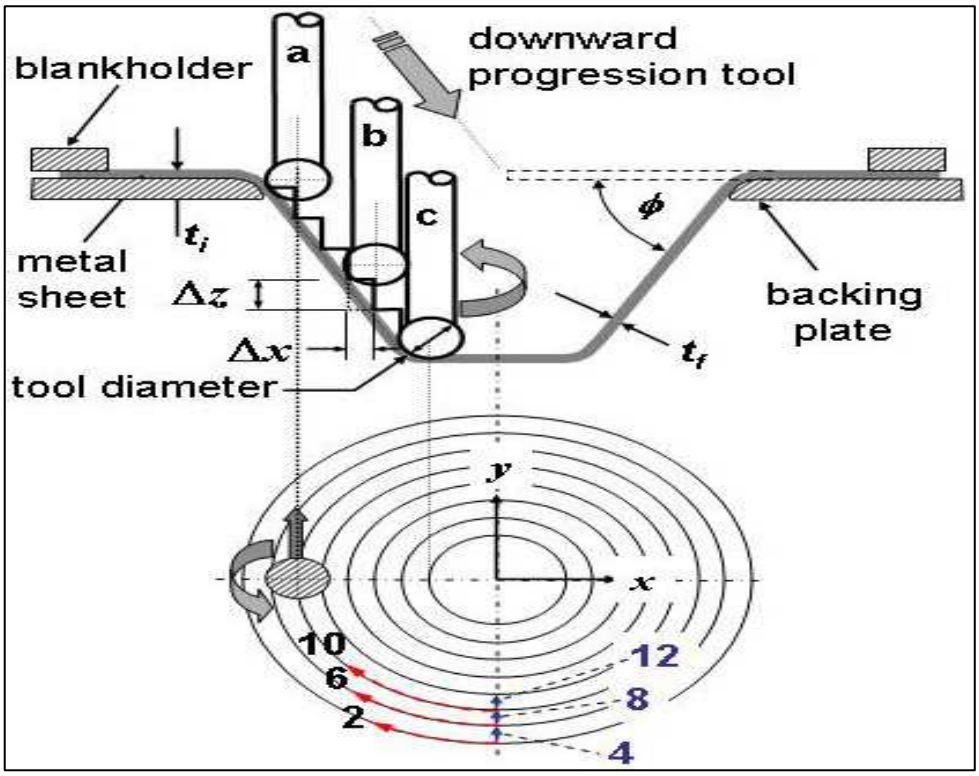


Figure 2.7: Single Point Incremental Forming of a cone.

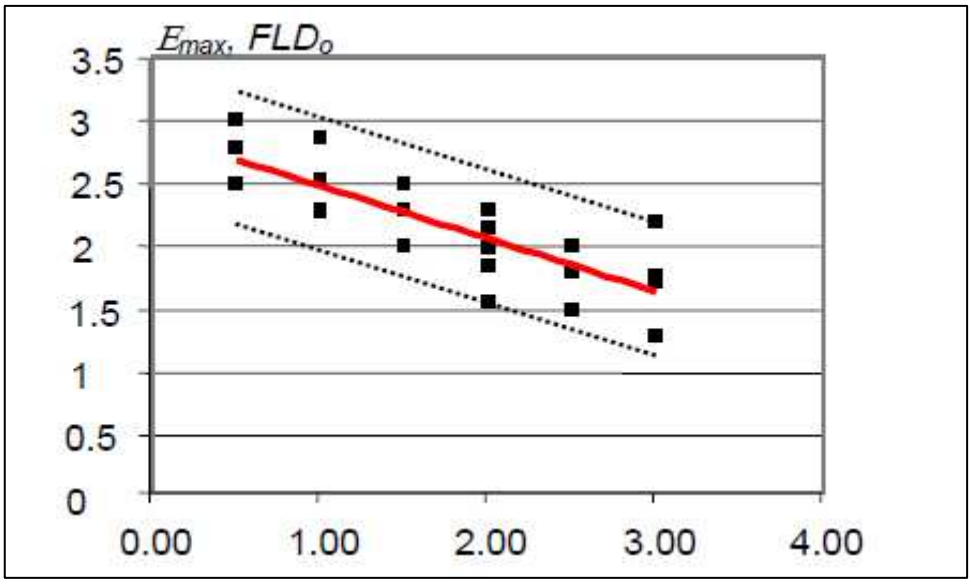


Figure 2.8: FLDo for different step sizes for AA 1050-0, with upper and lower bounds, with a 12 mm diameter tool (Micari, 2004).

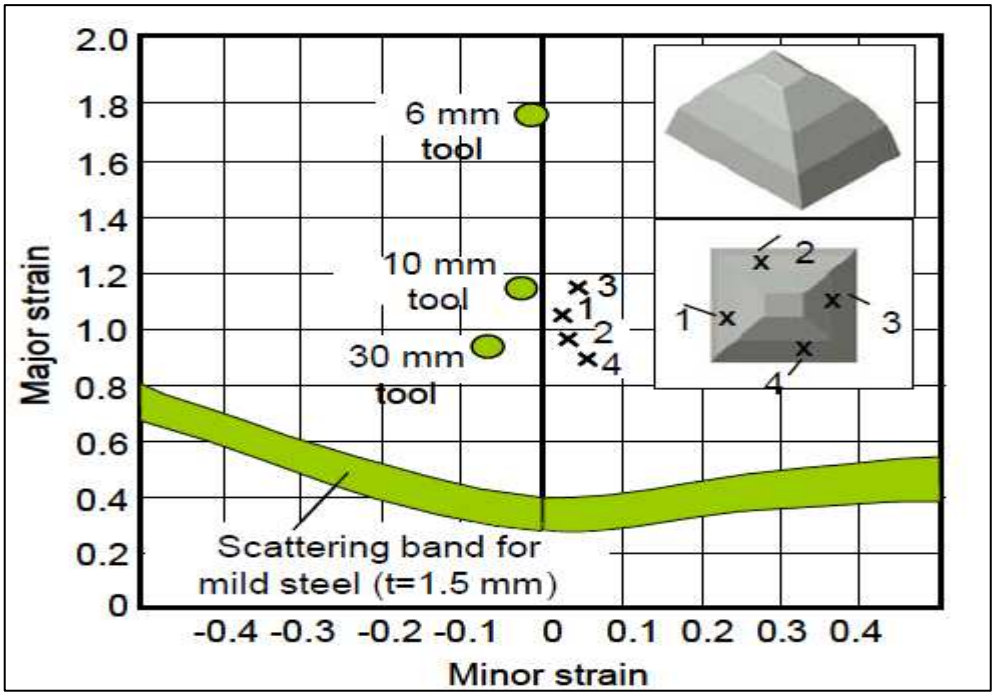


Figure 2.9: FLD for to = 1.5 mm DC04; influence of forming tool size upon forming limits (Hirt et al., 2002). Graph points x1 to x4 correspond to positions on the sheet marked by x.

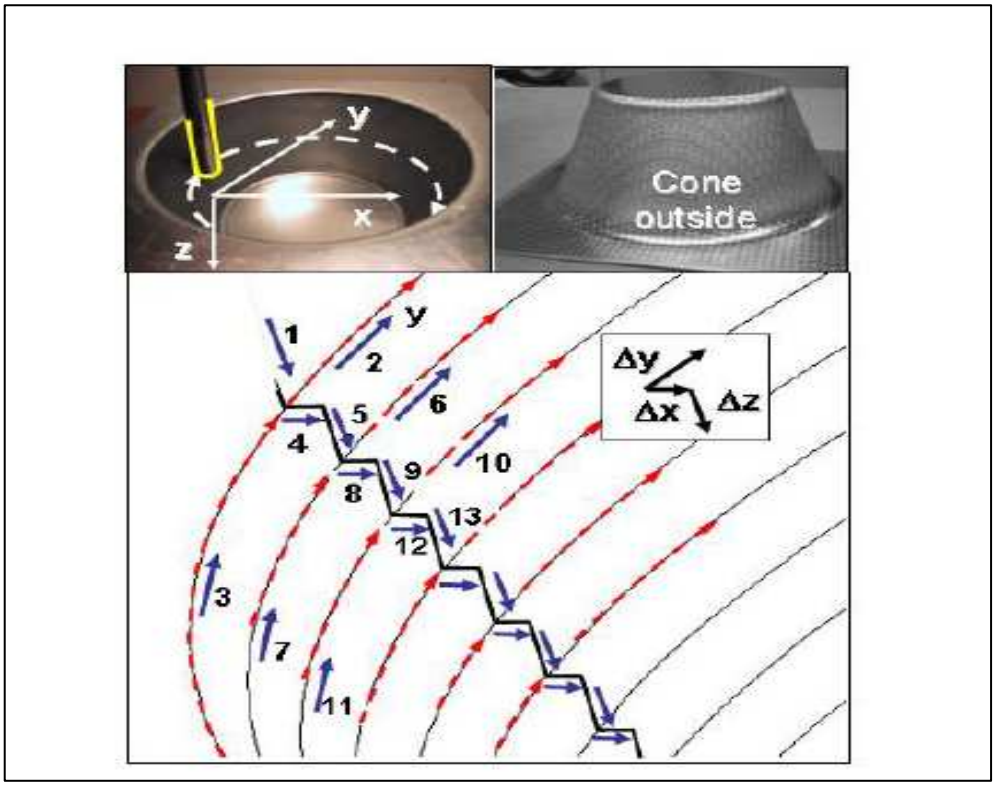


Figure 2.10: Forming of a cone, showing the forming tool inside the cone and the outside surface of the cone. The steps shown are in sequential order and are for incremental, unidirectional steps (Jeswiet and Recent, 2004).

The same model predicted that all components of strain are negligible in the direction parallel to tool travel. However, this is not necessarily a contradiction to the experimental measurements of Allwood et al. (2007) because the tool path used by Bambach et al. (2003) alternated in direction. This would tend to cancel out any shear on successive laps as a result of friction, whereas the tool always moved in the same direction in the experiment by Allwood et al. (2007).

2.5 SPRINGBACK

The name “springback” is original founded in the geometrical difference of sheet metal parts after removing of the tools. But today the word springback is mostly used for all measured geometrical differences after the whole forming process between the ideal geometry and the produced part, even if the used presses do not close fully. An isolated consideration of springback phenomenon is rarely done. Because of this,

springback compensation is today understood in common as a global compensation of all effects that result in geometrical differences of a simulated and a real part and not a consideration of elastic or elastic-plastic springback itself.

In the press forming of a sheet metal, the sheet is often subjected to bending and subsequent unbending or straightening under stretching force when it is drawn over a die corner or through draw beads. After finishing the draw-bending, springback takes place appears in the sheet product. Therefore, it is very important to predict the residual curvature, and also to find techniques for reducing the springback.

Overbending can be successfully applied in forming operations such as deep-drawing and sheet-bending. The main difference between deep-drawing and AISF is that ISF is an incremental forming operation. In ISF a snapshot during forming will show that only a small portion of the workpiece is deformed plastically (Bambach et al., 2003; Bambach et al., 2009).This has important implications on the process mechanics of AISF, giving rise to a special type of springback: the local springback behind the forming tool (Bambach et al., 2003; Bambach et al., 2009), see Fig. 2.11. This type of springback occurs continuously throughout the process. As the tool moves along its trajectory, it pushes the sheet metal in the contact area onto the target geometry. However, as the tool moves, portions of the part are continuously freed from constraints such that they can relax, thus causing a steady local springback in the vicinity of the tool. The inaccuracies due to the local springback contribute to the global deviations of the final part (Bambach, 2008; Bambach et al., 2009).

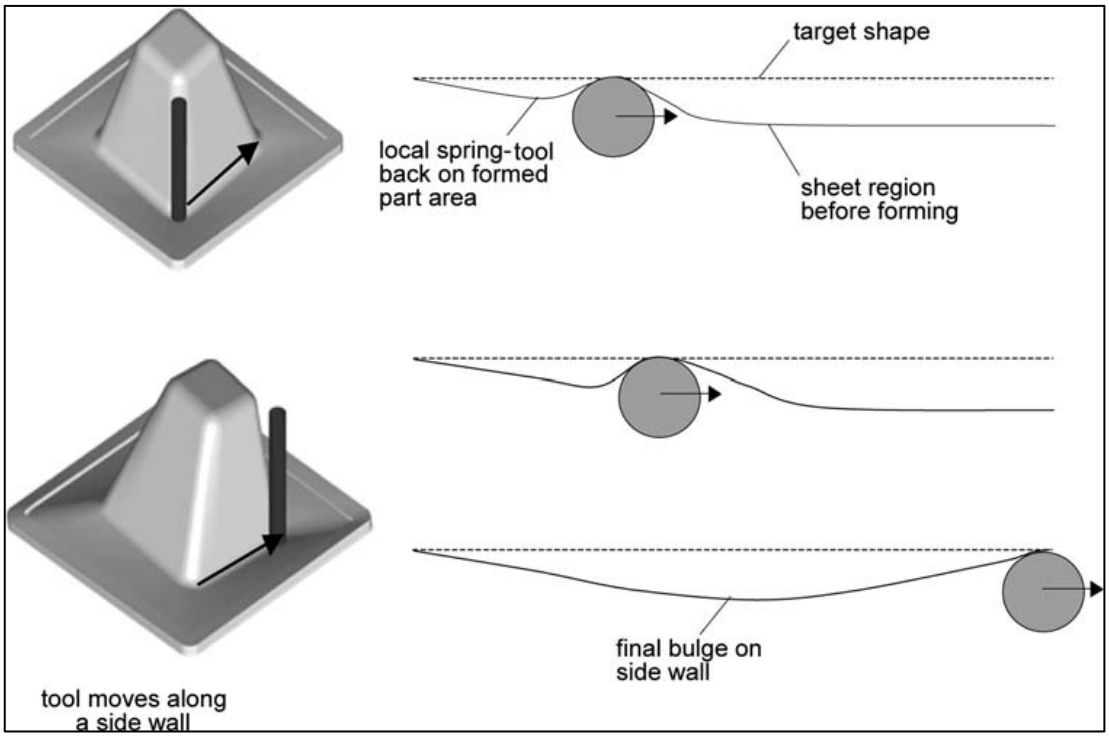


Figure 2.11: Illustration of local springback in ISF (Bambach, 2008; Bambach et al., 2009)

2.6 LIMITS DIAGRAMS

2.6.1 The Stress Strain Curve.

A stress-strain curve is a graph derived from measuring load (stress - σ) versus extension (strain - ε) for a sample of a material. The nature of the curve varies from material to material. The following diagrams illustrate the stress-strain behaviour of typical materials in terms of the engineering stress and engineering strain where the stress and strain are calculated based on the original dimensions of the sample and not the instantaneous values. In each case the samples are loaded in tension although in many cases similar behaviour is observed in compression.

The stress-strain curve characterizes the behaviour of the material tested. It is most often plotted using engineering stress and strain measures, because the reference length and cross-sectional area are easily measured. Stress-strain curves generated from tensile test results help gain insight into

the constitutive relationship between stress and strain for a particular material.

In addition to providing quantitative information that is useful for the constitutive relationship, the stress-strain curve can also be used to qualitatively describe and classify the material. Typical regions that can be observed in a stress-strain curve are: (see Fig. 2.12)

I. Elastic region.
II. Yielding.
III. Strain Hardening.
IV. Necking and Failure

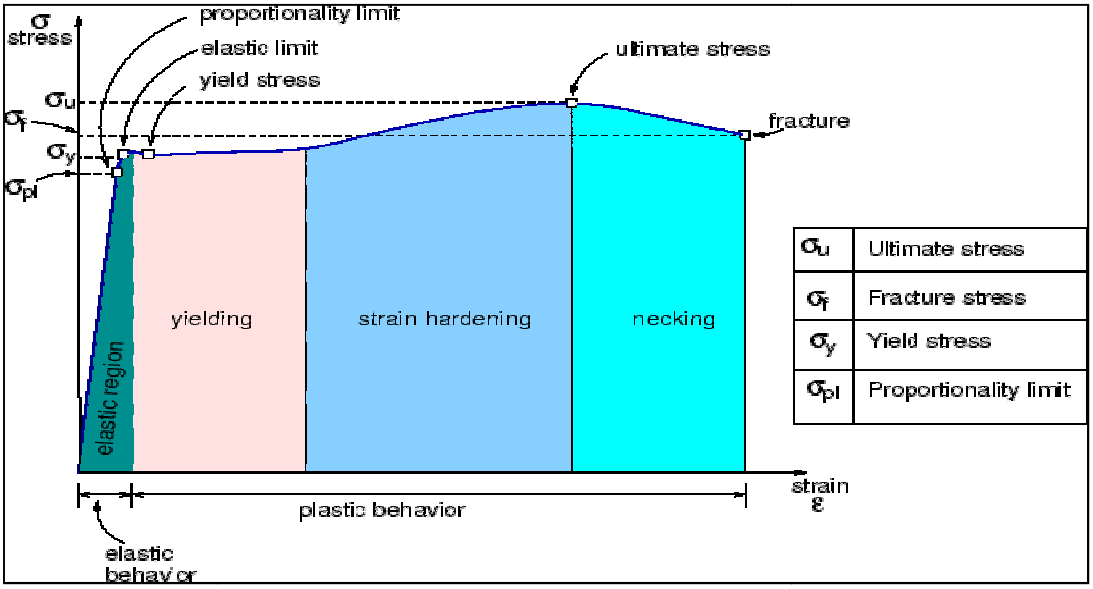


Figure 2.12: Various region and points on the stress-strain curve

2.7 FE ANALYSIS (ALGOR SOFTWARE)

ALGOR is a general purpose multiphysics finite element analysis software package developed by ALGOR Incorporated for use on the Microsoft Windows and Linux computer operating systems. It is distributed in a number of different core packages to cater to specifics applications, such as mechanical event simulation and computational fluid dynamics. ALGOR is used by many scientists and engineers

worldwide. It has found application in aerospace, and it has received many favourable reviews.

This software is always being used for:

I. Bending- analysis for the stress and strain
II. Mechanical contact
III. Thermal- include conduction, convection and radiation
IV. Fluid dynamics
V. Coupled and uncoupled

MES with Nonlinear Material Models analysis is the most common type of FEA used today. Industrial products, manufacturing, consumer products, civil engineering, medical research, power transmission, and electronic design are just a few of the areas in which this type of analysis is often performed. Typical applications for MES with Nonlinear Material Models are;

I. Linkages and mechanisms

II. Press-fit

III. Snap-fits

IV. Multiple body contact and impact

V. Forming and extruding processes

VI. Rubber and foam components

VII. Bellows; Seats

Mechanical Event Simulation (MES) combines large-scale motion and stress analysis including flexible-body motion with nonlinear material models to account for the bending, twisting, stretching, squashing and inertial effects of an FEA model. In addition to rigid-body motion and linear flexible-body motion, MES using nonlinear material models can simulate geometric and material nonlinearities (such as large deformation beyond the material yield point). The combination of motion and stress

analysis considering full inertial effects enables engineers to see motion and its results, such as impact, buckling and permanent deformation. To set up flexible-body motion with nonlinear material models, select a nonlinear material model and supply the needed data. For example, if considering a part comprised of a material with a yield stress, use a material model capable of simulating plasticity. Thus, you will need material properties for both the linear range and for beyond yield, when the strength of the part has been reduced. It should be noted that the former type of material properties coincide with those used by linear static stress analysis. Since the entire MES is displayed on the screen, it will be apparent if yielding or failures occur. The following nonlinear material models are available for models with flexible-body motion:

I. Plastic
II. Variable tangent
III. Curve description
IV. Curve description with cutoff tension
V. Drucker-Prager
VI. von Mises with isotropic hardening
VII. von Mises with kinematic hardening
VIII. von Mises curve with isotropic hardening
IX. von Mises curve with kinematic hardening
X. Thermoplastic
XI. Viscoelastic
XII. Viscoplastic
XIII. Mooney-Rivlin
XIV. Multiple-coefficient (5-constant) Mooney-Rivlin
XV. Multiple-coefficient (9-constant) Mooney-Rivlin
XVI. Ogden

CHAPTER 3

PROJECTS METHODOLOGY

3.1 INTRODUCTION

In this project include many processes such as searching information, design, analysis and validation. Those processes will be described in this chapter according to the flow chart. In this part, every data and information were gathered together and being analyzed according to the objectives and scope of this project. Before starting the experiments, several things needed to be done in order to run the experiments smoothly and accurately. Basically, there are four general steps that had been set so that the utilization of Design of Experiment (DOE) tools can be hold efficiently. The four general steps are:

i. Project Flow Diagram
ii. Plan the experiment
iii. Research Procedure
iv. Conducting the experiment and simulation

3.2 PROJECT FLOW DIAGRAM

In analysis and optimization machining parameter base on different type of material for Incremental Forming machine, there is a planning of the overall progress to assure the project can be finish on schedule. For more detail see Fig. 3.1 and Fig. 3.2.

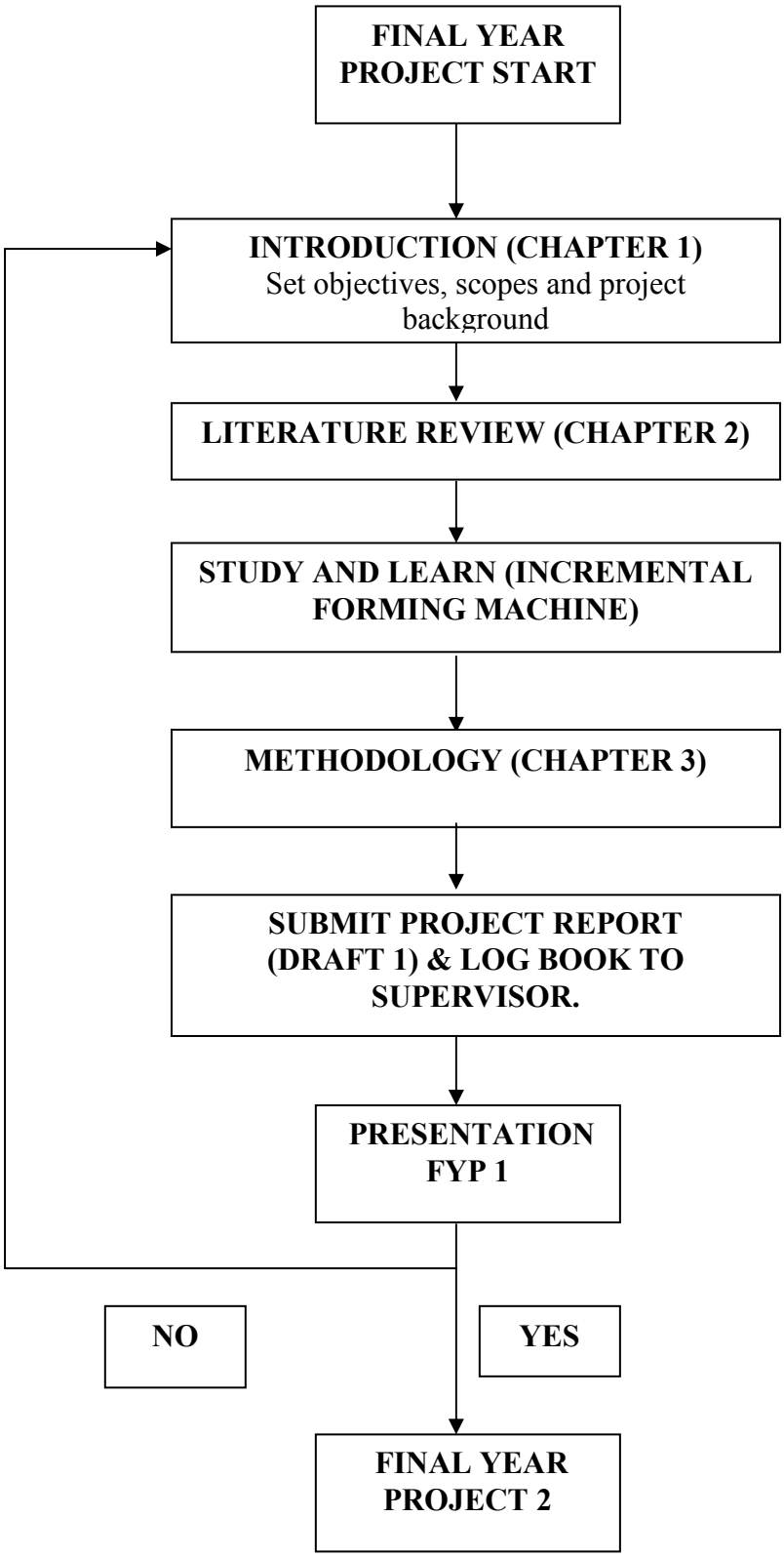


Figure 3.1: Project Flow Chart for FYP 1.

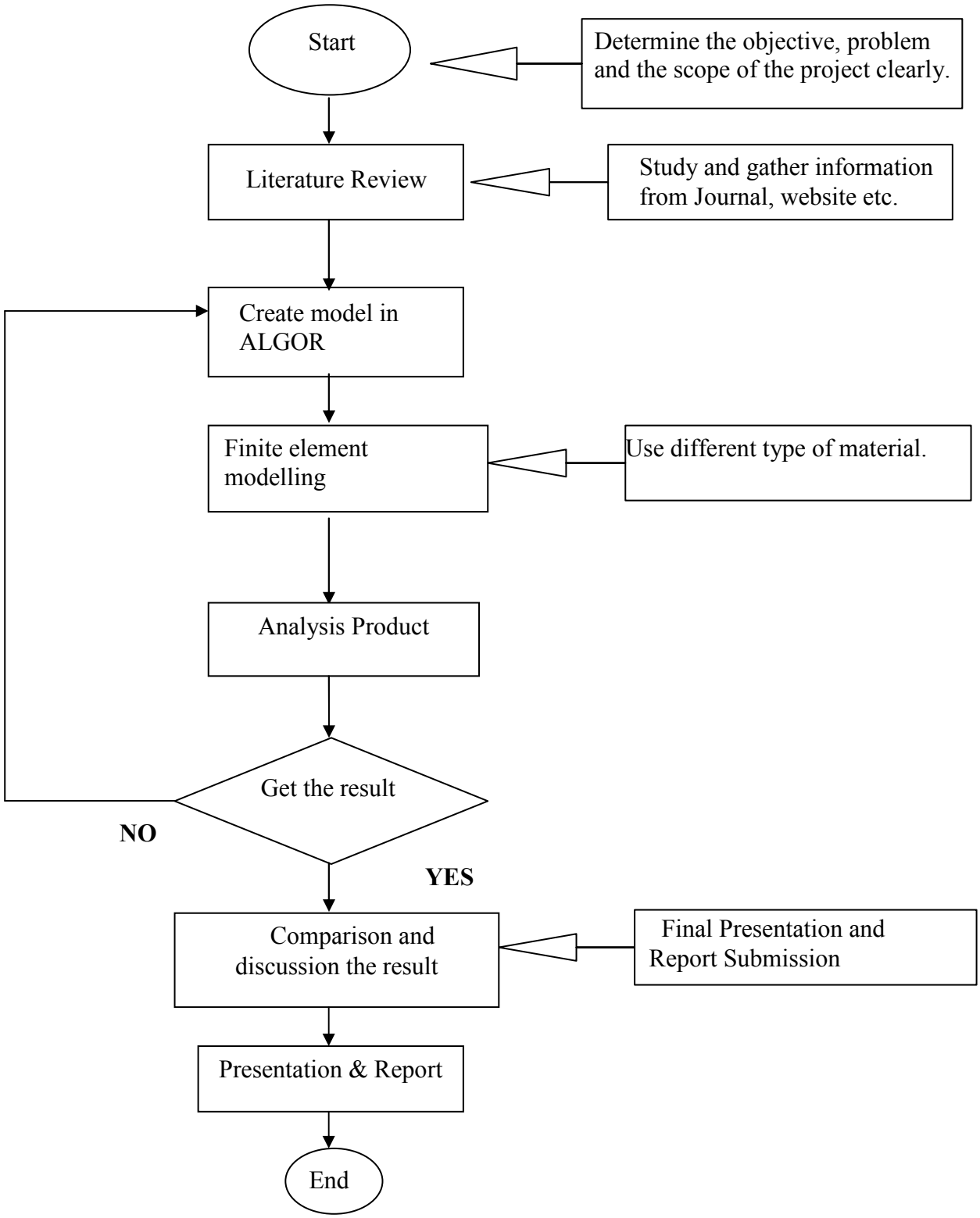


Figure 3.2: Overall Project Flow Chart.

From the flow chart above, this project started with the literature review and research about the title. The main important of the project is determination the objective. The study and make a lot of investigation about ISF. These tasks have been done through research on the journal, books and others sources.

Then the information has been collect and gathers. After that, the project will be continuing with the design process. In this stage, we use software ALGOR FEMPRO V22 to design the model. After that, we need analysis the product with use five different type of material. After finish all process, the product must be compare and analyze. The analysis is to gathered information about the quality of sheet metal forming and the stepdown for ArtCAM software. The lastly, this project must be evaluate and submit the report to supervisor.

3.3 PLAN THE EXPERIMENT

All the experiment need to be planning early to make the project run smoothly and finish on time. Project schedule have been planned by us to decide what to do first. If we get the problem while run this experiment, we renew the project planning so that we finish this project on time. (See appendix A for more detail).

3.4 RESEARCH PROCEDURE

Overall research procedure will be explained in this chapter. For clear and better of view of this whole project procedure, step by step procedure will be explain as illustrated in figure 3.3 . First step is preparation of workpiece and forming tool. The workpiece is plate sheet metal 100mm x 100mm x 0.5mm for each experiment setup that mean five type material is needed. Next is pilot testing of instrument that needs to be using such as IF machine. Until then the actual experiment can be done by replication. Next step is Analysis of variance and compare for optimum parameter result with simulation ALGOR software. As the optimum parameter obtained, confirmation test is compulsory to verify the result. The project is ended by record the final result.

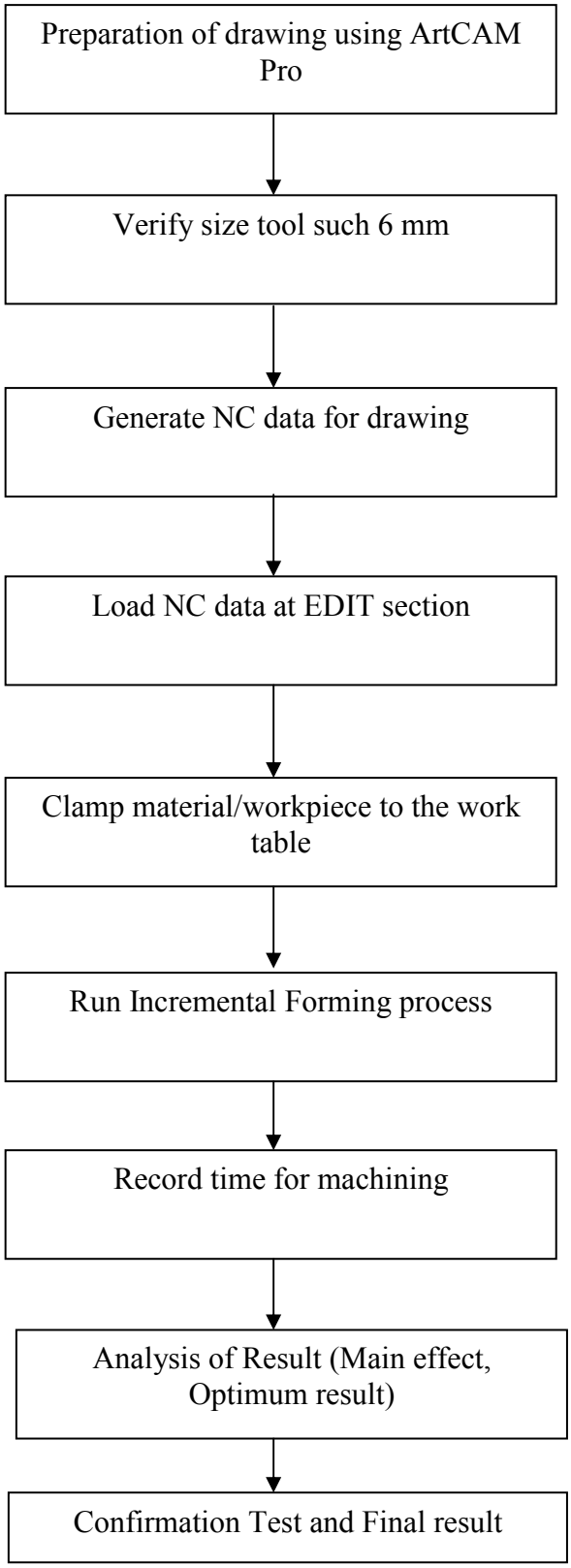


Figure 3.3: Experimental Procedure.

3.5 CONDUCTING THE EXPERIMENT AND SIMULATION

3.5.1 Design product in ArtCAM Pro

Before run IF machine, we must be generate code programming by software ArtCAM Pro. Below is a procedure how to use ArtCAM Pro:

I. Firstly decide what shape want draw and then open ArtCAM Pro.
II. Create new model and click ok. Then zoom in until clear.
III. Click vector tool - create what shape want draw example Create rectangle. Then move to origin and click creates and clicks close.
IV. Next, click 2D toolpath and go to area clearance. Choose final depth and indepent finish. After that, click add tool (size tool) and choose offset, and inside or outside. Then click now.
V. Clicks simulate and go to tool icon and choose toolpath. Next, press save toolpath and press symbol arrow. Then save file, example "name.txt".

After finish draw and simulate, click icon generate code. Then, click open file coding and erase things where not to use. Below is step to erase:

I. Erase line 1, 2 and 3.
II. Erase all word "tool".
III. Lastly erase endmain. Then save file.

When want to run IF machine, we need transfer the coding to IF programming software (Borlan C++ programming). This machine has 3-axis such y-axis, x-axis and z-axis.

3.5.2 Setting Process Parameter

From this experiment, we use same or constant process parameter but different size of forming tool. Below some process parameter we use:

I. Sheet size 100 x 100 mm (0.5mm thickness).
II. Tool was moved along rectangular tool path

III. Put lubricant such as mobilgrease HP222

IV. Setting Stepover

V. Setting Stepdown

VI. Setting Feed rate

VII. Setting Plunge rate

See figure 3.4

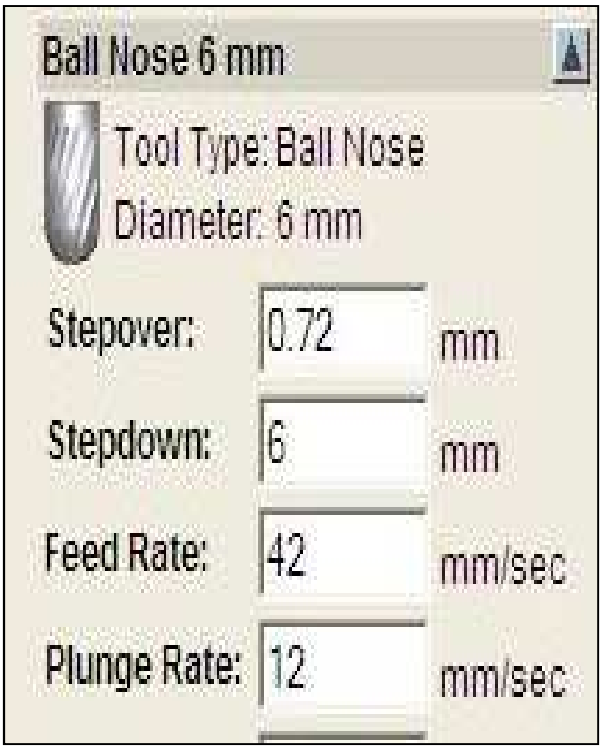


Figure 3.4: Example process Parameter for tool size 6 mm

3.5.3 Design Sample of Incremental Forming Products Analysis in ALGOR software.

Below show four tables for type of material properties for this project analysis. This table we take from ALGOR material library.

Table 3.1: Aluminium Alloy 5052-O

Material Model	**Standard**
Material Source	ALGOR Material Library
Material Source File	C:\Program Files\ALGOR\22.00\matlibs\algormat.mlb
Date Last Updated	2004/09/30-16:00:00
Material Description	None
Mass Density	0.0000000026828 N·s²/mm/mm³
Modulus of Elasticity	70326 N/mm²
Poisson's Ratio	.36
Yield Stress	89.631 N/mm²
Strain Hardening Modulus	415.796 N/mm²

Table 3.2: Zinc

Material Model	**Standard**
Material Source	ALGOR Material Library
Material Source File	C:\Program Files\ALGOR\22.00\matlibs\algormat.mlb
Date Last Updated	2004/09/30-16:00:00
Material Description	Pure Metallic Element
Mass Density	0.0000000071078 N·s²/mm/mm³
Modulus of Elasticity	96526 N/mm²
Poisson's Ratio	.33
Yield Stress	37.025 N/mm²
Strain Hardening Modulus	N/mm²

Table 3.3: Steel (ASTM - A572)

Material Model	**Standard**
Material Source	ALGOR Material Library
Material Source File	C:\Program Files\ALGOR\22.00\matlibs\algormat.mlb
Date Last Updated	2004/09/30-16:00:00
Material Description	High-strength low-alloy
Mass Density	0.0000000078548 $N \cdot s^2/mm/mm^3$
Modulus of Elasticity	199950 N/mm^2
Poisson's Ratio	0.29
Yield Stress	289.58 N/mm^2
Strain Hardening Modulus	520.223 N/mm^2

Table 3.4: Stainless Steel (AISI 309)

Material Model	**Standard**
Material Source	ALGOR Material Library
Material Source File	C:\Program Files\ALGOR\22.00\matlibs\algormat.mlb
Date Last Updated	2004/09/30-16:00:00
Material Description	Annealed
Mass Density	0.000000007993 $N \cdot s^2/mm/mm^3$
Modulus of Elasticity	199950 N/mm^2
Poisson's Ratio	.3
Yield Stress	206.84 N/mm^2
Strain Hardening Modulus	777.661 N/mm^2

Table 3.5: Titanium Ti-6Al-4V (Grade 5), Annealed

Material Model	Standard
Material Source	ALGOR Material Library
Material Source File	C:\Program Files\ALGOR\22.00\matlibs\algormat.mlb
Date Last Updated	2004/10/28-16:02:00
Material Description	None
Mass Density	0.00000000443 $N \cdot s^2/mm/mm^3$
Modulus of Elasticity	113800 N/mm^2
Poisson's Ratio	0.342
Yield Stress	880 N/mm^2
Strain Hardening Modulus	529.232 N/mm^2

3.5.4 FE Analysis

For every study or research we must analyze the design before it is approve as a new invention and being commercialize. The analysis is using finite element analysis (FEA) by ALGOR Software.

Different material test in setting at ALGOR software

For overall test, the same parameters were chosen:

I. The sheet metal was square-chucked with inner sides of the clamping square 250 mm x 200 mm(See Figure 3.5)
II. The sheet-metal plate subjected to forming measured 100 mm × 100 mm
III. The step-over of tool path strategy was 1.5 mm and step-down was 0.5 mm, 1 mm and 1.5 mm for every sheet metal
IV. Diameter of the hemispherical tool is 6 mm
V. Tool path strategy: from outside to inside in measured area

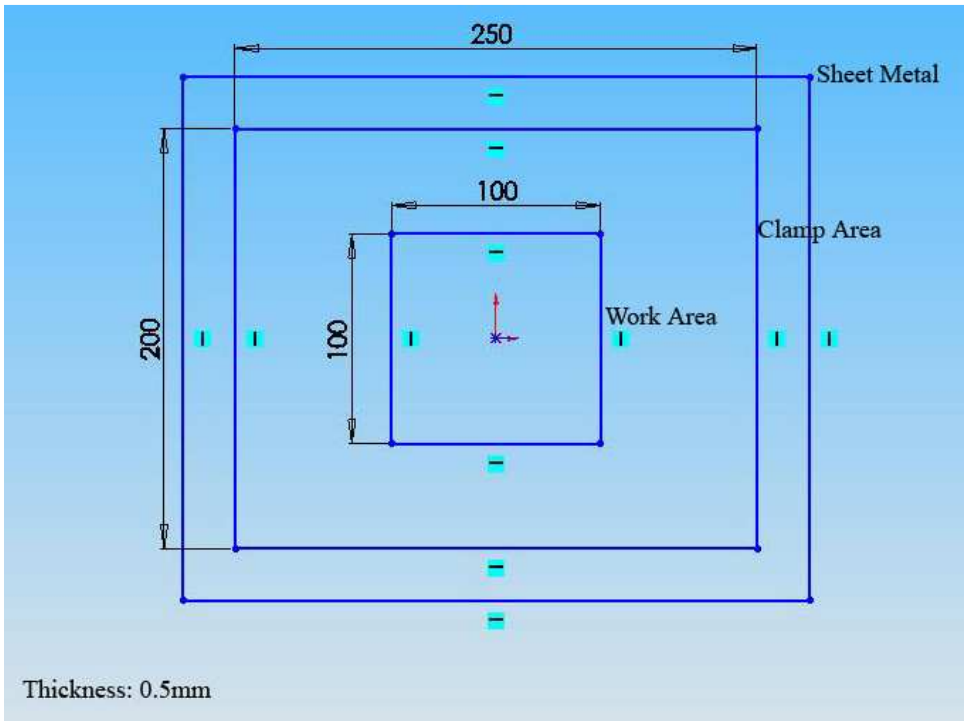


Figure 3.5: Design of sheet metals for incremental forming test

Following are the steps of analysis using finite element analysis methods:

- Analysis Type

  MES with Nonlinear Material Models.

- Meshing the model

  Click on the Open icon in the "What to do" section on the left side of the New dialog. Select the "IGES Files" option in the "File of type" drop-down box. Then select the Tool.IGS file in the "introduction example/input file" directory. Press the "Open" button and click OK. Press the "Mesh Model" button in the "Mesh Model Settings" dialog. Then access the TOOLS pull-down menu and select the "FEA Editor" command to move to the FEA Editor environment and click OK to accept the default "English(in)" system.

- Create Blank (3D)

  Click rectangle icon and draw below tool with size 250 mm x 200 mm. Then, mesh 25 x 20.

- Defining the material data

Right click on the “Material” heading for Part 1(Tool) Brick and in the tree view and select the “Modify Material” command. Select the “Steel (AISI 4130) ” item in the “Select Material” section of the “Element Material Selection” dialog and click Ok to accept that value.

- Processor Information

  Event Duration 220 s and Capture Rate 1 s/

- Nodal Boundary Condition

  Tick tz, ty and tx

- Nodal Prescribed Displacement

  Tick - z(-ve), y(+ve) and x(+ve) such z =-0.5 , y =100 and x =100.

- Built curve for Nodal Prescribed Displacement

Table 3.6: Load Curve Information

Load Curve 1 Type	**Time**
Load Curve 1 Index 1 Time	0
Load Curve 1 Index 1 Multiplier	0
Load Curve 1 Index 2 Time	0.5
Load Curve 1 Index 2 Multiplier	0.95
Load Curve 1 Index 3 Time	1.5
Load Curve 1 Index 3 Multiplier	1.05
Load Curve 1 Index 4 Time	2
Load Curve 1 Index 4 Multiplier	5
Load Curve 1 Index 5 Time	40
Load Curve 1 Index 5 Multiplier	5
Load Curve 1 Index 6 Time	41
Load Curve 1 Index 6 Multiplier	9
Load Curve 1 Index 7 Time	80
Load Curve 1 Index 7 Multiplier	9
Load Curve 1 Index 8 Time	81
Load Curve 1 Index 8 Multiplier	13
Load Curve 1 Index 9 Time	120
Load Curve 1 Index 9 Multiplier	13
Load Curve 1 Index 10 Time	121
Load Curve 1 Index 10 Multiplier	17
Load Curve 1 Index 11 Time	160
Load Curve 1 Index 11 Multiplier	17
Load Curve 1 Index 12 Time	161
Load Curve 1 Index 12 Multiplier	21
Load Curve 1 Index 13 Time	200
Load Curve 1 Index 13 Multiplier	21

Load Curve 1 Index 14 Time	201
Load Curve 1 Index 14 Multiplier	25
Load Curve 1 Index 15 Time	210
Load Curve 1 Index 15 Multiplier	25
Load Curve 1 Index 16 Time	220
Load Curve 1 Index 16 Multiplier	0
Load Curve 2 Type	**Time**
Load Curve 2 Index 1 Time	2
Load Curve 2 Index 1 Multiplier	0
Load Curve 2 Index 2 Time	10
Load Curve 2 Index 2 Multiplier	1
Load Curve 2 Index 3 Time	20
Load Curve 2 Index 3 Multiplier	1
Load Curve 2 Index 4 Time	30
Load Curve 2 Index 4 Multiplier	0
Load Curve 2 Index 5 Time	41
Load Curve 2 Index 5 Multiplier	0
Load Curve 2 Index 6 Time	50
Load Curve 2 Index 6 Multiplier	0.9
Load Curve 2 Index 7 Time	60
Load Curve 2 Index 7 Multiplier	0.9
Load Curve 2 Index 8 Time	70
Load Curve 2 Index 8 Multiplier	0.1
Load Curve 2 Index 9 Time	81
Load Curve 2 Index 9 Multiplier	0.1
Load Curve 2 Index 10 Time	90
Load Curve 2 Index 10 Multiplier	0.8
Load Curve 2 Index 11 Time	100
Load Curve 2 Index 11 Multiplier	0.8
Load Curve 2 Index 12 Time	110
Load Curve 2 Index 12 Multiplier	0.2
Load Curve 2 Index 13 Time	121
Load Curve 2 Index 13 Multiplier	0.2
Load Curve 2 Index 14 Time	130
Load Curve 2 Index 14 Multiplier	0.7
Load Curve 2 Index 15 Time	140
Load Curve 2 Index 15 Multiplier	0.7
Load Curve 2 Index 16 Time	150
Load Curve 2 Index 16 Multiplier	0.3
Load Curve 2 Index 17 Time	161
Load Curve 2 Index 17 Multiplier	0.3
Load Curve 2 Index 18 Time	170
Load Curve 2 Index 18 Multiplier	0.6
Load Curve 2 Index 19 Time	180
Load Curve 2 Index 19 Multiplier	0.6
Load Curve 2 Index 20 Time	190
Load Curve 2 Index 20 Multiplier	0.4
Load Curve 2 Index 21 Time	201
Load Curve 2 Index 21 Multiplier	0.4

Load Curve 2 Index 22 Time	210
Load Curve 2 Index 22 Multiplier	0.5
Load Curve 3 Type	**Time**
Load Curve 3 Index 1 Time	10
Load Curve 3 Index 1 Multiplier	0
Load Curve 3 Index 2 Time	20
Load Curve 3 Index 2 Multiplier	1
Load Curve 3 Index 3 Time	30
Load Curve 3 Index 3 Multiplier	1
Load Curve 3 Index 4 Time	40
Load Curve 3 Index 4 Multiplier	0.1
Load Curve 3 Index 5 Time	50
Load Curve 3 Index 5 Multiplier	0.1
Load Curve 3 Index 6 Time	60
Load Curve 3 Index 6 Multiplier	0.9
Load Curve 3 Index 7 Time	70
Load Curve 3 Index 7 Multiplier	0.9
Load Curve 3 Index 8 Time	80
Load Curve 3 Index 8 Multiplier	0.2
Load Curve 3 Index 9 Time	90
Load Curve 3 Index 9 Multiplier	0.2
Load Curve 3 Index 10 Time	100
Load Curve 3 Index 10 Multiplier	0.8
Load Curve 3 Index 11 Time	110
Load Curve 3 Index 11 Multiplier	0.8
Load Curve 3 Index 12 Time	120
Load Curve 3 Index 12 Multiplier	0.3
Load Curve 3 Index 13 Time	130
Load Curve 3 Index 13 Multiplier	0.3
Load Curve 3 Index 14 Time	140
Load Curve 3 Index 14 Multiplier	0.7
Load Curve 3 Index 15 Time	150
Load Curve 3 Index 15 Multiplier	0.7
Load Curve 3 Index 16 Time	160
Load Curve 3 Index 16 Multiplier	0.4
Load Curve 3 Index 17 Time	170
Load Curve 3 Index 17 Multiplier	0.4
Load Curve 3 Index 18 Time	180
Load Curve 3 Index 18 Multiplier	0.6
Load Curve 3 Index 19 Time	190
Load Curve 3 Index 19 Multiplier	0.6
Load Curve 3 Index 20 Time	200
Load Curve 3 Index 20 Multiplier	0.5

- Running the analysis

  Access the ANALYSIS pull-down menu and select the "Perform Analysis" command to run the analysis.

- Viewing the results

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter shows all the results obtained from this study. Tables of results, graphs, and figures are included. Varying machining parameter has been done in virtual simulation, the result will be displayed and graphs have been interpreted. Detailed explanation of graphs and figures are also provided. The virtual simulation involves in one tool path strategy from outside to inside in measured area of varying machining parameters (stepdown). This analysis used five material for analyze a depth of forming with different stepdown from centre node (sheet metal area). The results from each of stepdown was analyzed and summarized in order to relate between processes parameters involves. This simulation also will consider the Event Duration (time step) and Capture Rate applied.

4.2 DEVELOPMENT OF FE MODEL FOR ISF

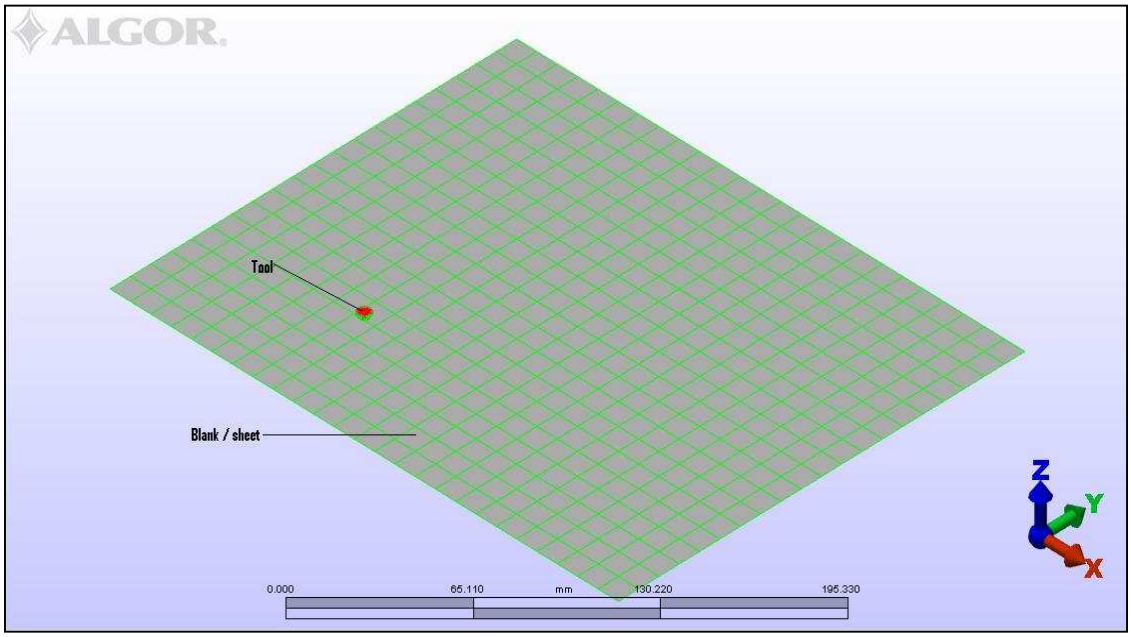


Figure 4.1: Finite elements modelling of ISF

4.2.1 Model Information

In FE analysis for ISF, figure 4.1 shown example models for FE analysis. These project must use analysis type is MES with nonlinear material models and SI unit (N, mm, s, deg C, deg C, V, ohm, A, J). This analysis use mesh is 25 x 20 or 500 node of number element. Table 4.1 shown data for each part must need in FE analysis for this project. The analysis are consists to two partition; a) Sheet Metal Properties, b) Process Parameter (stepdown). Both of this analysis will get the best selection of sheet metal material and will give the absolute data of process parameter for Incremental Forming Process.

Table 4.1: Part Information

Part ID	Part Name	Element Type	Material Name
1	Tool	Brick	Steel (AISI 4130)
2	Blank	Shell	Aluminium Alloy 5052-O
			Zinc
			Steel (ASTM - A572)
			Stainless Steel (AISI 309)
			Titanium Ti-6Al-4V

Table 4.2: Instruction for simulation

Simulation type	Nodal Prescribed Displacement
First Run	Z(-ve) = 0.5 mm
	X(+ve) = 100 mm
	Y(+ve) = 100 mm
Second Run	Z(-ve) = 1 mm
	X(+ve) = 100 mm
	Y(+ve) = 100 mm
Third Run	Z(-ve) = 1.5 mm
	X(+ve) = 100 mm
	Y(+ve) = 100 mm

Before go through ALGOR FE analysis, we must know an instruction or guide for simulation. Therefore, from table 4.2 shows a guideline for this project simulation. This simulation needs three run for each material. This simulation just different at z (-ve) nodal prescribed displacement. Sum from each simulation process is 15 times simulation process for all five materials. Every process considered take time about 16 hours in depends on types of material. Apart from that, time for one complete process also dependent type of computer (processor) applies if using the computer more sophisticated (higher processor) then time used quicker to resolve.

Figure 4.2, 4.3 and 4.4 shows about result simulation for all material. This result shows about axis z displacement or depth after formability. Each different stepdown or nodal prescribed displacement, the result for axis z displacement also different depends on material characteristic.

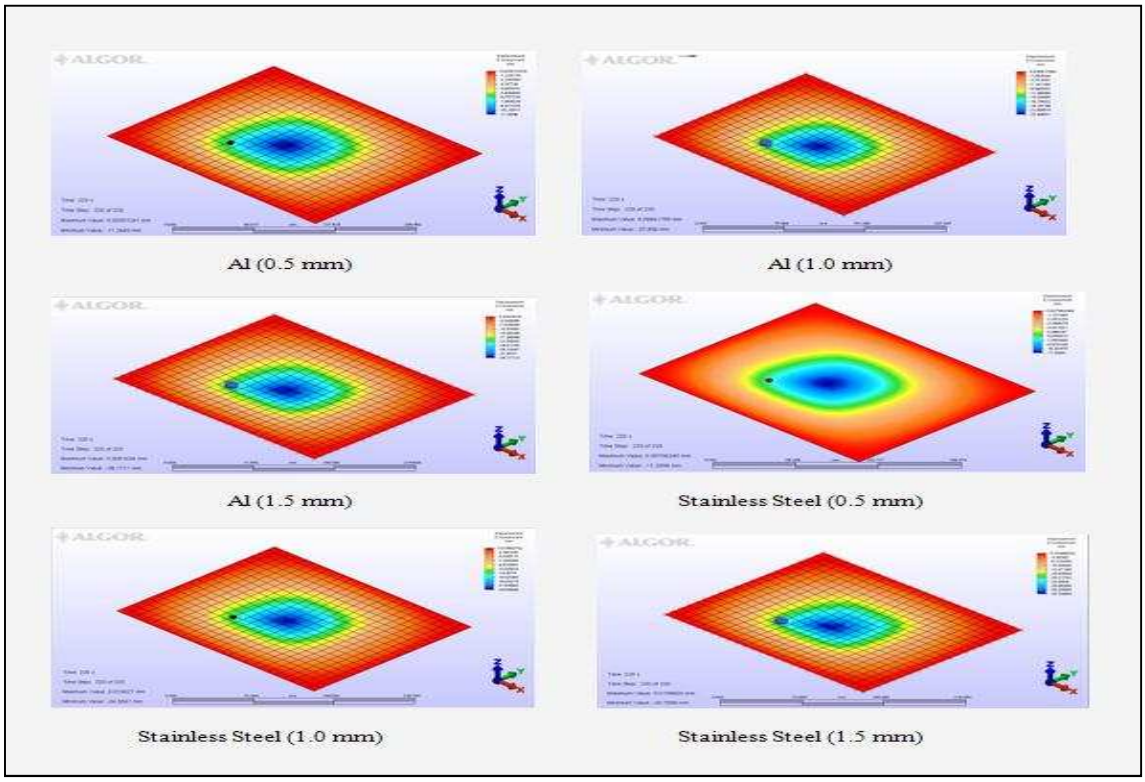


Figure 4.2: Simulation result for Aluminum and Stainless Steel

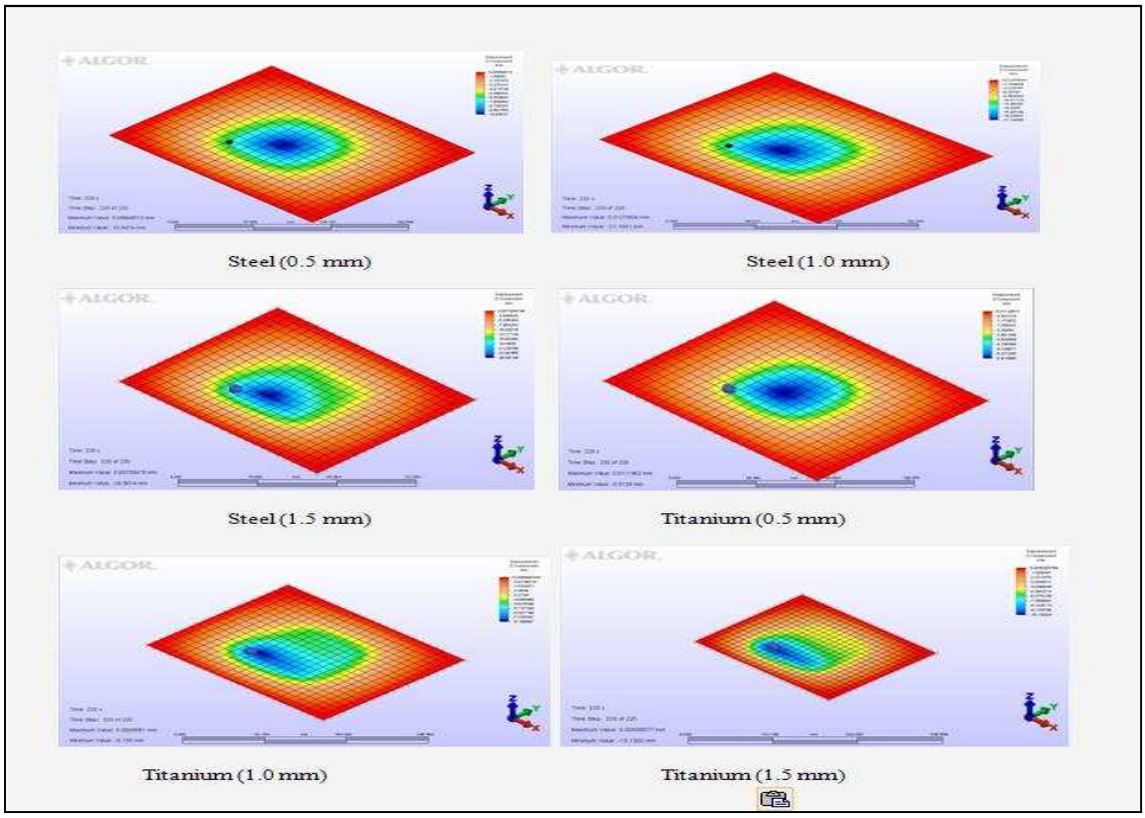


Figure 4.3: Simulation result for Steel and Titanium

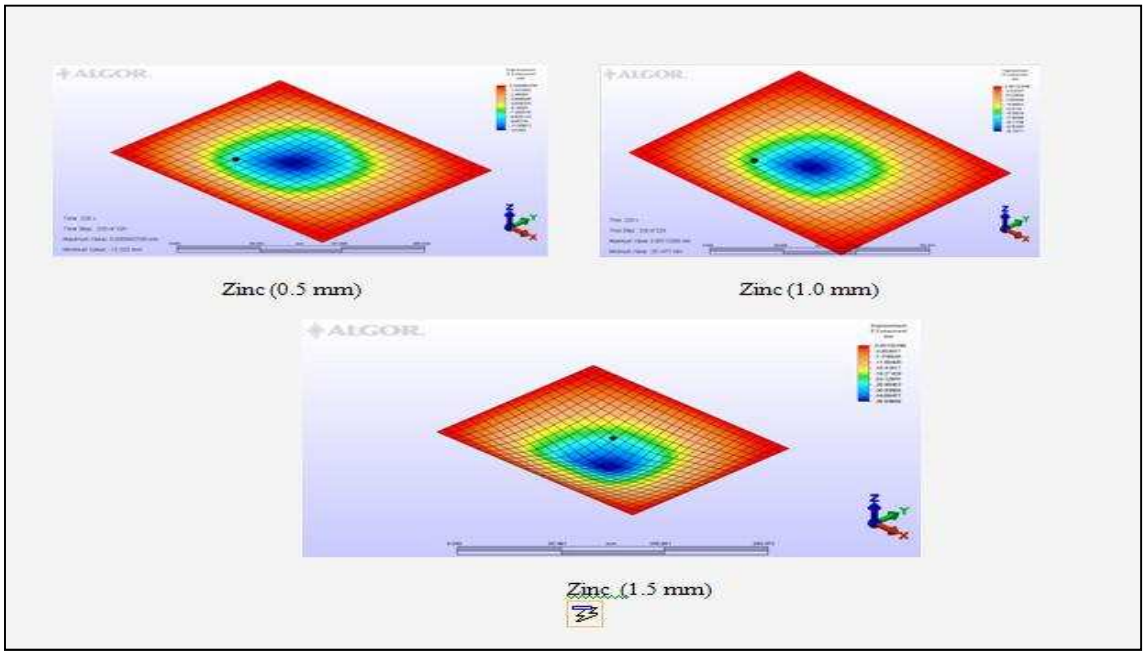


Figure 4.4: Simulation result for Zinc

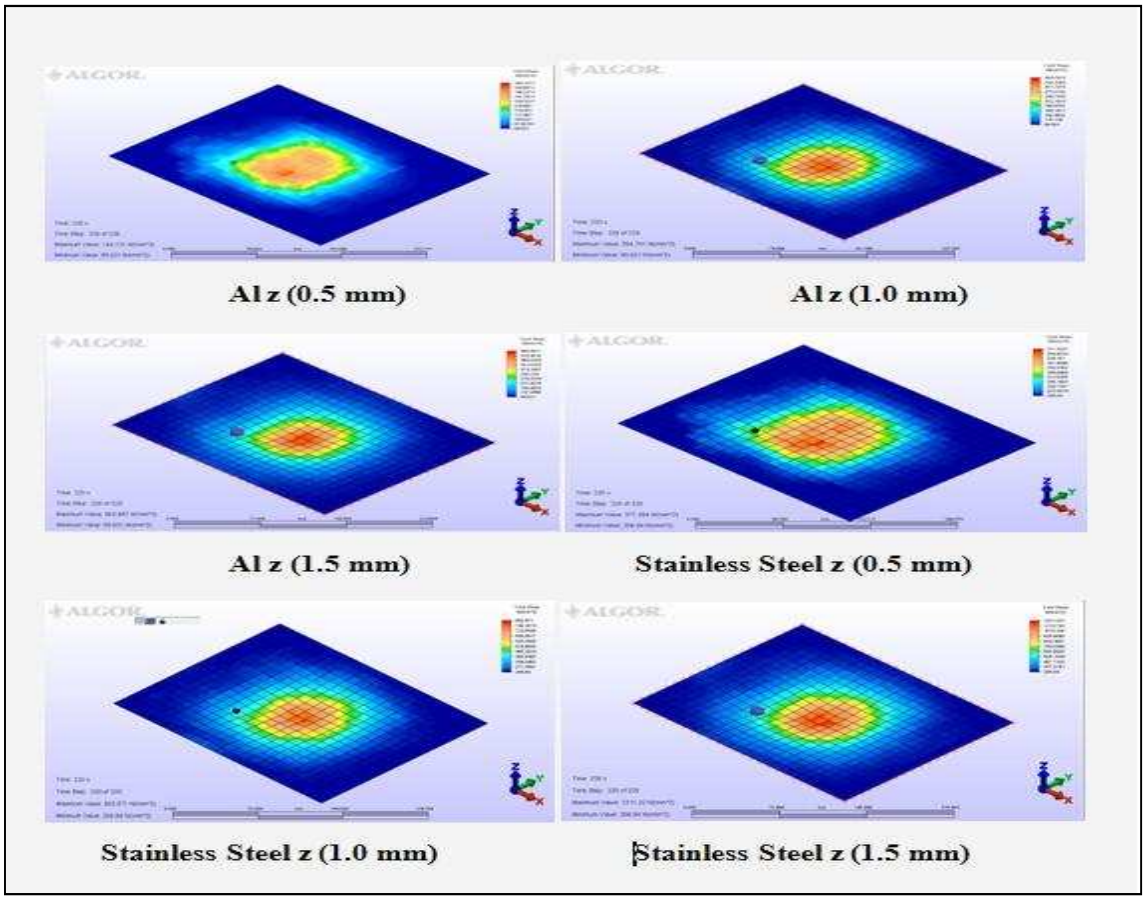


Figure 4.5: Simulation Yield Stress result for Aluminum and Stainless Steel

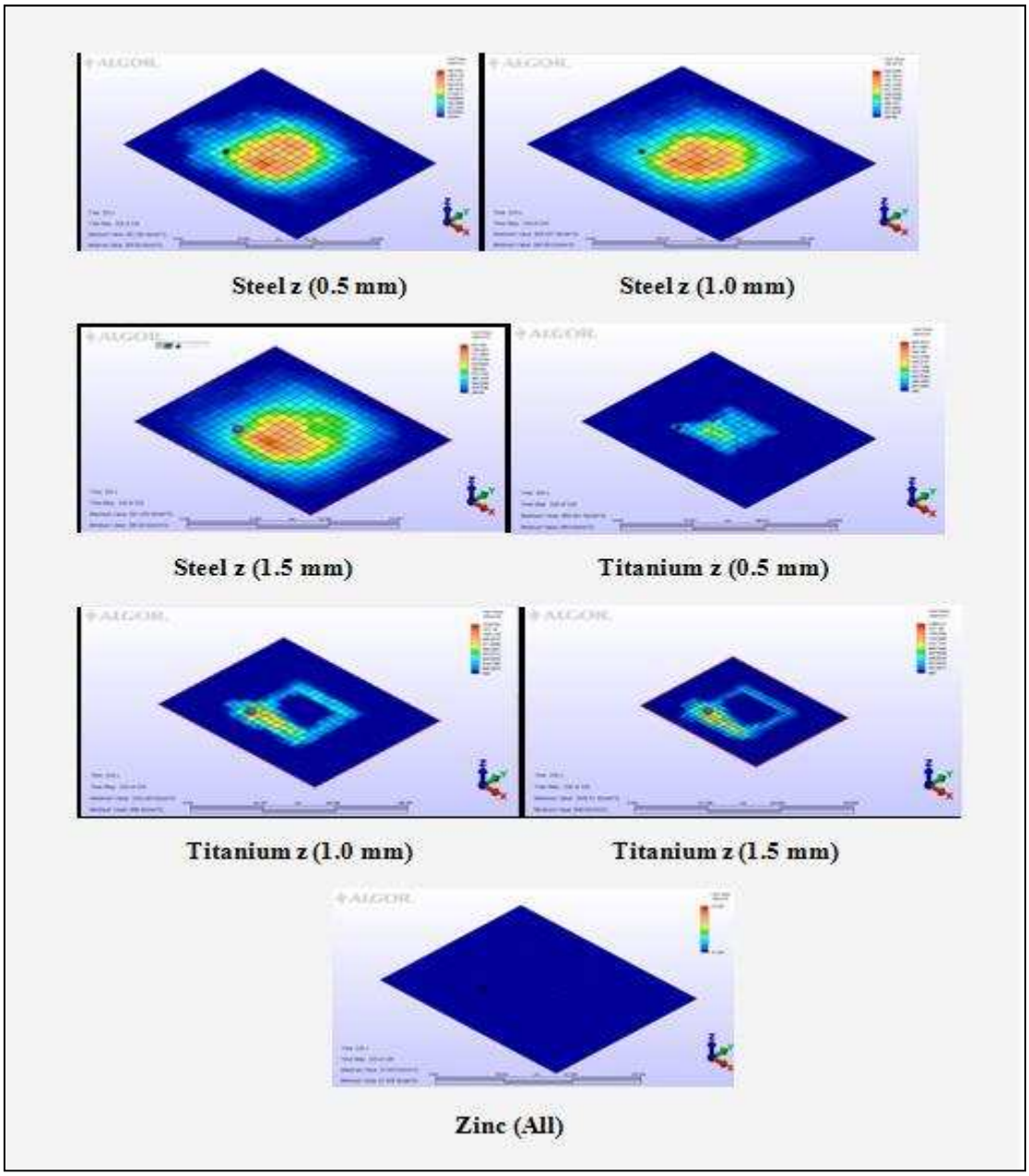


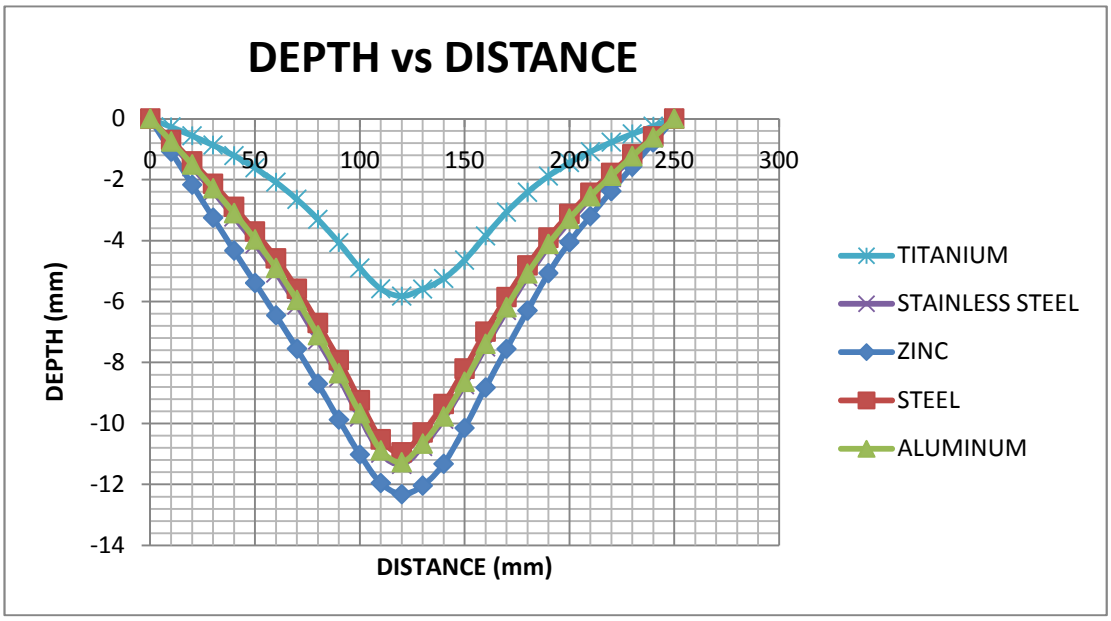
Figure 4.6: Simulation Yield Stress result for Steel, Titanium and Zinc.

Figure 4.5 and 4.6 shows about yield stress result simulation for all material. This result shows about maximum yield stress after formability. Each different stepdown or nodal prescribed displacement, the result for yield stress also different depends on material characteristic. But for material zinc, yield stress have same maximum for all stepdown.

4.3 DATA COLLECTION AND GRAPH

4.3.1 Result simulation ALGOR

From data collection and graph interpret, in terms of depth, and yield stress will show how the formability sheet metal depend to material characteristic when applied stepdown [z(-ve) nodal prescribed displacement].



Graph 4.1: Depth vs Distance for Nodal Prescribed Displacement Z (-ve) = 0.5 mm

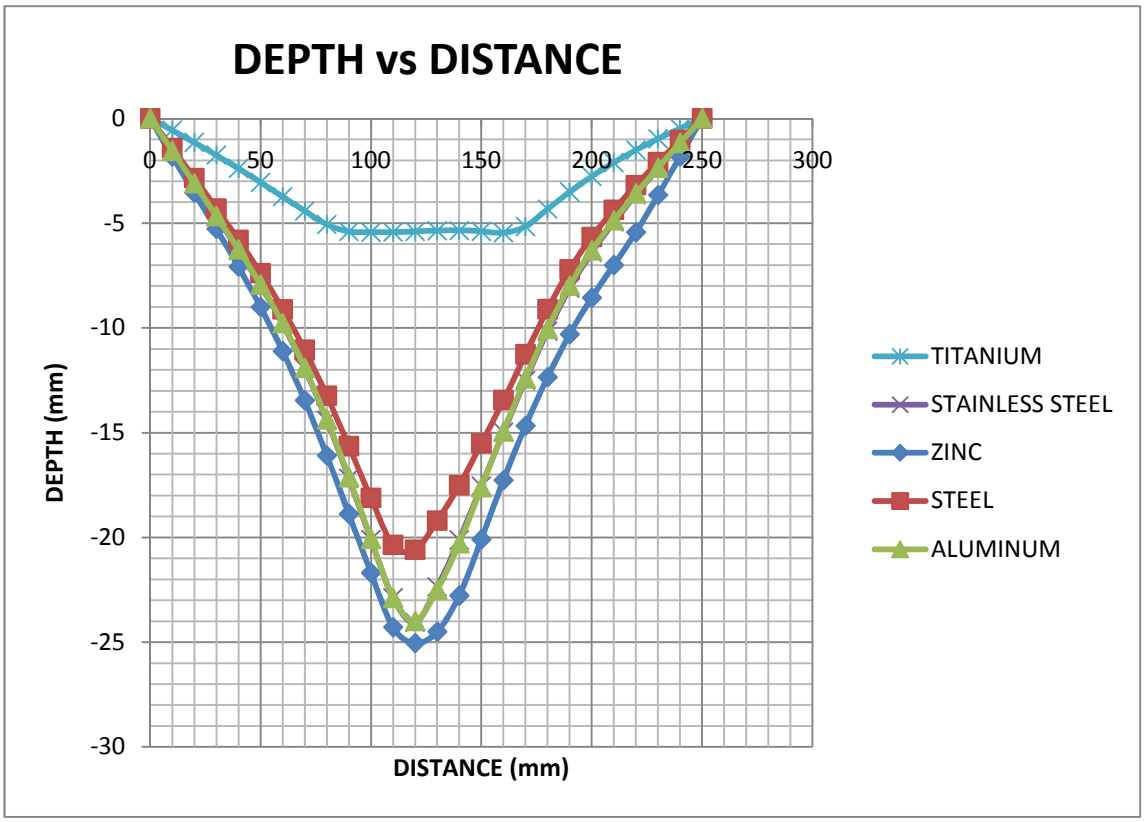
Graph 4.1 show about relationship between depth and distance after given nodal prescribed displacement z (-ve) was 0.5 mm that means stepdown 0.5 in one rotation. From the graph, we see zinc very easy to form than the other material. For titanium no easy to form because this material is a high strength characteristic. The maximum depths for each material are:

- Zinc = 12.322 mm
- Stainless Steel = 11.3394 mm
- Aluminum = 11.2649 mm
- Titanium = 5.81823 mm
- Steel = 10.9474 mm

Table 4.3: Comparison Theory vs ALGOR (z= 0.5 mm)

Type material	**Theory calculation Depth = step down x one rotation (z x 25)**	**ALGOR result (maximum depth)**
Aluminium Alloy 5052-O		11.2649 mm
Zinc		**12.322 mm**
Steel (ASTM - A572)	0.5 x 25 = 12.5 mm	10.9474 mm
Stainless Steel (AISI 309)		11.3394 mm
Titanium Ti-6Al-4V		5.81823 mm

Table 4.3 shows about data comparison theory with ALGOR data. From the table, we can know about data comparisons relationship between depth and stepdown for complete one formability sheet metal. For this analysis, we set to complete form need 25 times from outside to inside or from start till the centre work piece is 25 steps. Therefore, we need multiple stepdown with 25 step for know about theory depth. From the table, we see zinc approximation the theory calculation with 12.322 mm than 12.5 mm for theory. For titanium, the result show very far with theory calculation. This table also show about maximum depth between aluminium and stainless steel having small distinction between this two material namely with value maximum 11.2649 mm and 11.3394 mm.



Graph 4.2: Depth vs Distance for Nodal Prescribed Displacement Z (-ve) = 1 mm

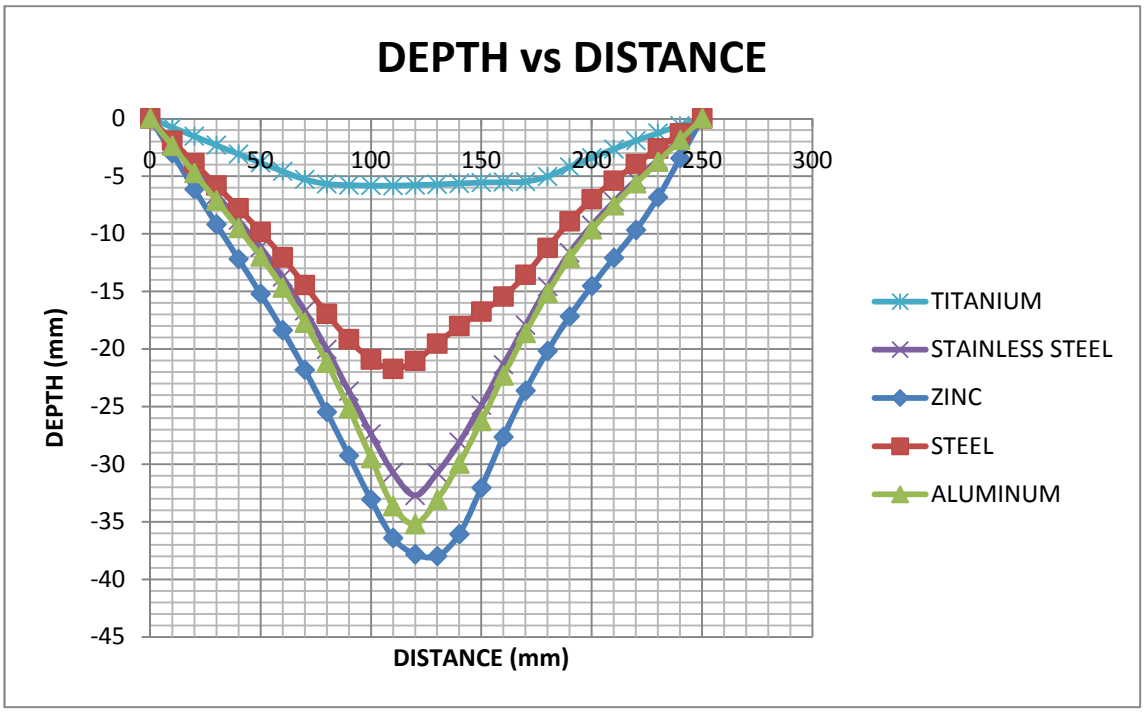
Graph 4.2 show about relationship between depth and distance after given nodal prescribed displacement z (-ve) was 1.0 mm that means stepdown 1.0 in one rotation. From the graph, we see zinc very easy to form than the other material. For titanium no easy to form because this material is a high strength characteristic. While aluminium and stainless steel have small different maximum depth that mean this material have approximate same material characteristics for this phase or stepdown 1.0 mm. The maximum depths for each material are:

- Zinc = 25.0393 mm
- Stainless Steel = 24.0561mm
- Aluminum = 23.986 mm
- Titanium = 5.45709 mm
- Steel = 20.5837 mm

Table 4.4: Comparison Theory vs ALGOR (z= 1 mm)

Type material	**Theory calculation Depth = step down x one rotation (z x 25)**	**ALGOR result (maximum depth)**
Aluminium Alloy 5052-O		23.986 mm
Zinc		**25.0393 mm**
Steel (ASTM - A572)	1 x 25 = 25 mm	20.5837 mm
Stainless Steel (AISI 309)		24.0561mm
Titanium Ti-6Al-4V		5.45709 mm

Table 4.4 shows about data comparison theory with ALGOR data. From the table, we can know about data comparisons relationship between depth and stepdown for complete one formability sheet metal. For this analysis, we set to complete form need 25 times from outside to inside or from start till the centre work piece is 25 steps. Therefore, we need multiple stepdown with 25 step for know about theory depth. From the table, we see zinc approximation the theory calculation with 25.0393 mm than 25 mm for theory. For titanium, the result show very far with theory calculation. This table also show about maximum depth between aluminium and stainless steel having small distinction between this two material namely with value maximum 23.986 mm and 24.0561 mm.



Graph 4.3: Depth vs Distance for Nodal Prescribed Displacement Z (-ve) = 1.5 mm

Graph 4.3 show about relationship between depth and distance after given nodal prescribed displacement z (-ve) was 1.5 mm that means stepdown 1.5 mm in one rotation. From the graph, we see zinc very easy to form than the other material. For titanium and steel no easy to form because this material is a high strength characteristic. The maximum depths for each material are:

- Zinc = 37.9597 mm
- Stainless Steel = 32.699 mm
- Aluminum = 35.1711 mm
- Titanium = 5.8235 mm
- Steel = 21.7167 mm

Table 4.5: Comparison Theory vs ALGOR (z= 1.5 mm)

Type material	**Theory calculation Depth = step down x one rotation (z x 25)**	**ALGOR result (maximum depth)**
Aluminium Alloy 5052-O		35.1711 mm
Zinc		**37.9597 mm**
Steel (ASTM - A572)	1.5 x 25 = 37.5 mm	21.7167 mm
Stainless Steel (AISI 309)		32.699 mm
Titanium Ti-6Al-4V		5.8235 mm

Table 4.5 shows about data comparison theory with ALGOR data. From the table, we need multiple stepdown with the total downward moving distance was 25. From the table, we see zinc approximation the theory calculation with 37.9597 mm than 37.5 mm for theory. For titanium and steel, the result show very far with theory calculation such 5.8235 mm and 21.7167 mm. This table also show about maximum depth for aluminium is 35.1711 mm.

Table 4.6: Comparison and Assumption Data for Experimental

Type of Material	Ultimate Stress(UTS) (MPa)	Min. Yield Stress (Theory) (MPa)	ALGOR max. Yield Stress (MPa)	Sheet metal condition
Aluminium Alloy 5052-O **(z=0.5 mm)**	193	89.6	164.13	OK
Aluminium Alloy 5052-O **(z=1 mm)**	193	89.6	354.75	Fracture
Aluminium Alloy 5052-O **(z=1.5 mm)**	193	89.6	563.89	Fracture
Steel (ASTM - A572) **(z=0.5 mm)**	625	289.58	452.28	OK
Steel (ASTM - A572) **(z=1 mm)**	625	289.58	809.027	Fracture
Steel (ASTM - A572) **(z=1.5 mm)**	625	289.58	841.428	Fracture
Stainless Steel (AISI 309) **(z=0.5 mm)**	621	206.84	371.35	OK
Stainless Steel (AISI 309) **(z=1 mm)**	621	206.84	852.87	Fracture
Stainless Steel (AISI 309) **(z=1.5 mm)**	621	206.84	1211.22	Fracture
Zinc **(z=0.5 mm)**	37	37.025	37.025	Fracture
Zinc **(z=1 mm)**	37	37.025	37.025	Fracture
Zinc **(z=1.5 mm)**	37	37.025	37.025	Fracture
Titanium Ti-6Al-4V **(z=0.5 mm)**	950	880	955.451	Fracture
Titanium Ti-6Al-4V **(z=1 mm)**	950	880	1032.68	Fracture
Titanium Ti-6Al-4V **(z=1.5 mm)**	950	880	1099.51	Fracture

From table 4.6 discuss about condition sheet metal after simulation. For check condition sheet metal, we must know about relationship between stress and strain for all material this project. This is because relationship between Stress and Strain is derived on the basis of the elastic behaviour of material bodies. Elasticity of a body is the property of the body by virtue of which the body regains its original size and shape when the deformation force is removed. Most materials are elastic in nature to a lesser or greater extend, even though perfectly elastic materials are very rare. When a workpiece is press beyond the elastic limit the stress increases and reaches a point at which the material starts yielding this stress is called yield stress. Ultimate stress is defined as maximum load which can be placed prior to the breaking of the workpiece. From UTS for all material, we can check condition workpiece with we look maximum yield stress at ALGOR simulation. Therefore, only three materials not fracture or crack after pressing such as aluminium, steel and stainless steel. But these materials only can use stepdown 0.5 mm and below. Whereas for stepdown 1.0 mm and 1.5 mm, all material have defect or crack because maximum yield stress in ALGOR exceeding UTS.

4.4 DISCUSSION

From simulation of MES with nonlinear material model of five materials, two of material that is not gets suitable parameters such as zinc and titanium because these materials need stepdown below 0.5 and for zinc not suitable for form process. Three of materials get suitable parameters for stepdown are 0.5 and below. This is because the material has a tendency to partially return to its original shape cause of the elastic recovery of the material.

The depth was limit of the flattened sheet metal on 0.5 mm thickness. In the case for different depth analysis, the sheets formed from flattened sheet metal for which the bending direction was arose in second cycle for forming process, a crack occurs at the thickness when the sheet cannot arrested the load of forming process. These results show that the forming limit of aluminium, steel and stainless steel sheet 0.5 mm thickness affected to the incremental depth after stepdown above 0.5 mm.

Additionally, it is possible to note that the values of the stress reach, at the drawing depth where the failure has occurred, the value of the ultimate tensile stress, measured in the tensile tests. The same results can be obtained examining the graph, relevant to the stresses, calculated by the FEA, in the points where the failure has occurred for the sheet formed with the press of 6 mm in diameter.

From table 4.6 shows the result comparison and assumption data for experimental need to approve by experimental. To get more precise result simulation, we must run different type of number FEA. This simulation result can become guideline for experimental especially in decide stepdown at ArtCAM software.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSIONS

The development of simulation model for different material in terms of stepdown during virtual incremental forming was successfully achieved. The simulation in ALGOR package will give more understanding about the characteristic of material in terms of formability and stepdown. Even though more parameter machining will be considered, so it gives more data value to be interpreted in EXCEL package. Here, graphs and tables from various machining parameter were build up in terms of depth result and yield stress result. It can obtain the relationship between yield stress distribution in material formability (depth) and parameters involve such as stepdown and different type of material. It has been noticed, regarding the simulations results, that it is possible to forecast the failure point of the sheet by the simple comparison between the reached stress value and the material ultimate tensile stress.

From this discussion, it show strengthen and weaknesses of machining parameters that applied in material selected. Characteristic of material need to be analysis before determine suitable parameters to apply in experimental. This reason is the material has a tendency to partially return to its original shape because of the elastic recovery of the material. From the results by FE analysis it's possible to determine the limits of formability on the basis of the scheduled tool path. So, this method could be used in order to define the process parameters to obtain a good quality of the product and the optimization of the manufacturing.

5.2 RECOMMENDATIONS FOR FUTURE RESEARCH

Recommendations are need to improve the incremental sheet metal forming whether in virtual or experimental in order to choose more suitable value for optimization machining parameters and further research of this project thesis. The recommendations for the simulation and modelling improvement are stated as below:

a) Simulation should be carry out in different number of finite element and compare with the experimental result
b) Change thickness of material and step size as new parameters to be considered in incremental sheet metal forming process.
c) Build model in another software application package such as ABACUS, LS-DYNA and CATHIA and this simulation can comparing with ALGOR simulation that already have in this project.
d) FE model should better be validated with experimental work rather than published result.

REFERENCES

Allwood, J.M., Shouler, D.R., Tekkaya, A.E., 2007. The increased forming limits of incremental sheet forming processes. In: SheMet ’07 International Conference on Sheet Metal, Palermo,Italy, pp. 621–628

Allwood, J. M., Houghton, N. E., Jackson, K. P. The design of an Incremental Forming machine, 11th Conference on Sheet Metal, Erlangen, 2005; pp 471 -478.

Ambrogio, G., De Napoli, L., Filice, L., Gagliardi, F., Muzzupappa, M., 2005. Application of incremental forming process for high customized medical product manufacturing. J. Mater. Process. Technol. 162–163, 156–162.

Amino, H., Lu, Y., Maki, T., Osawa, S., Fukuda, K. Dieless NC Forming, Prototype of Automotive Service Parts; Proceedings of the 2nd International Conference on Rapid Prototyping and Manufacturing (ICRPM), Beijing, 2002.

Aoyama, S., Amino, H., Lu, Y., Matsubara, S. Apparatus for dieless forming plate materials, Europäisches Patent EP0970764, 2000.

Bambach M (2008) Process strategies and modelling approaches for asymmetric incremental sheet forming. Umformtechnische Schriften Band 139, Shaker Verlag, Aachen

Bambach, M., Hirt, G., Junk, S., 2003. Modeling and experimental evaluation of the incremental CNC sheet metal forming process. In: Proceedings of the VII International Conferenceon Computational Plasticity, Barcelona, pp. 1–17.

Bambach, M., Taleb Araghi , B. , Hirt, G.,2009. Strategies to improve the geometric accuracy in asymmetric single point incremental forming. German Academic Society for Production Engineering (WGP)

Dai, Kun, Wang, Z.R., Fang, Yi, 2000. CNC incremental sheet forming of an axially symmetric specimen and the locus of optimization. J. Mater. Process. Technol. 102, 164–167.

Filice, L., Fantini, L., Micari, F. Analysis of Material Formability in Incremental Forming, Annals of the CIRP, vol. 51/1/2002: 199-202.

Hagan, E. and Jeswiet, J. A review of conventional and modern single point sheet metal forming methods. IMECHE part B, J. of Engineering Manufacture, 2003 vol 217 No B2. Pp 213 - 225.

Hirt, G., Ames, J., Bambach, M., Kopp, R., 2004. Forming strategies and process modeling for CNC incremental sheet forming. Ann. CIRP 53 (1), 203–206.

Hirt, G., Ames, J., Bambach, M., 2003a. Economical and ecological benefits of CNC incremental sheet forming (ISF). In: Proceedings of the First IMEKO TC 19 Conference on Environmental Measurements, Budapest, Hungary.

Hirt, G., Bambach, M., Junk, S., Chouvalova, I., 2003b. FEM modelling and optimisation of geometric accuracy in incremental CNC sheet forming. In: Proceedings of the 10th Saxon Conference on Forming Technology, Chemnitz,Germany.

Hirt, G. Junk, S., Witulski, N. Incremental Sheet Forming: Quality Evaluation and Process Simulation. 7th ICTP International Conference on Technology of Plasticity, October 27-November 1, 2002, Yokohama, Japan, paper no. 343

Hirt, G. Tools and Equipment used in Incremental Forming. 1st Incremental Forming Workshop, University of Saarbrucken, 9 June 2004. On Cdrom.

Iseki, H., Kumon, H., Forming limit of incremental sheet metal stretch forming using spherical rollers, J. JSTP 35 (1994) 1336.

Iseki, H., Naganawa, T., 2002. Vertical wall surface forming of rectangular shell using multistage incremental forming with spherical and cylindrical rollers. J. Mater. Process. Technol. 130–131, 675–679.

Iseki, H., 2001. An approximate deformation analysis and FEM analysis for the incremental bulging of sheet metal using a spherical roller. J. Mater. Process. Technol. 111, 150–154.

Jadhav S., Goebel R., Homberg W., Kleiner M.: Process optimization and control for incremental sheet metal forming, Proceedings of the International Deep Drawing Research Group Conference, IDDRG, Pg. 165-171, Bled, Slovenia, May 2003.

Jeswiet, J., Duflou, J., Szekeres, A., Levebre, P. Custom Manufacture of a Solar Cooker – a case study. *Journal Advanced Materials Research*, Vols. 6- 8, May 2005, pp 487-492.

Jeswiet, J., Hagan, E. Rapid Prototyping Non-uniform Shapes from Sheet Metal Using CNC Single Point Incremental Forming. NAMRI/SME 2003 transactions, vol. XXXI, pp 65 – 69.

Jeswiet, J., Hagan, E. Rapid Proto-typing of a Headlight with Sheet Metal, Proceedings of Shemet, April 2001, pp 165-170.

Jeswiet, J., Micari, F., Hirt, G., Bramely, A., Duflou, J., Allwood, J., 2005. Asymmetric single point incremental forming of sheet metal. Ann. CIRP 54 (2), 623–649.

Jeswiet, J. Recent results for SPIF. Seminar on Incremental Forming, 22 October, 2004, Cambridge University. CdRom.

Kim, T.J., Yang, D.Y. Improvement of formability for the incremental sheet metal forming process. International Journal of Mechanical Sciences, vol. 42, pp. 1271-1286, 2001.

Kim, T.J., Yang, D.Y., 2000. Improvement of formability for the incremental sheet metal forming process. Int. J. Mech. Sci. 42, 1271–1286.

Kim, Y.H., Park, J.J., 2002. Effect of process parameters on formability in incremental forming of sheet metal. J. Mater. Process. Technol. 130–131, 42–46.

Lamminen, L., Tuominen, T., Kivivuori, S., 2003. Incremental sheet forming with an industrial robot. In: Proceedings of the Third International Conference on Advanced Material Processing, Melbourne, Australia, pp. 331–335.

Leach, D., Green, A. J., Bramley, A. N., A new incremental sheet forming process for small batch and prototype parts. 9th International Conference on Sheet Metal, Leuven, pp. 211-218, 2001.

Matsubara, S., Incremental backward bulge forming of a sheet metal with a hemispherical head tool, J. JSTP 35 (1994) 1311.

Micari, F. Single Point Incremental Forming: recent results. Seminar on Incremental Forming, 22 October, 2004, Cambridge University. CdRom.

Micari, F. and Ambrogio, G. A Common shape for conducting Incremental Forming Tests. 1st Incremental Forming Workshop, University of Saarbrucken, 9 June 2004. On Cdrom.

Micari, F., Ambrogio, G., 2004. A common shape for conducting incremental forming tests. In: Proceedings of the First Incremental Forming Workshop, Saarbrucken, Germany.

Mori, K., Yamamoto, M., Osakada, K., Determination of hammering sequence in incremental sheet metal forming using a genetic algorithm, J. Mater. Process. Technol. (1996) 463.

Otsu, M., Osakada, K., Fujii, M., Controlled laser forming of sheet metal with shape measurement and using database, in: Proceedings of the Metal Forming 2000, Rotterdam, 2000, p. 433.

Park, J.J., Kim, Y.H., 2003. Fundamental studies on the incremental sheet metal forming technique. J. Mater. Process. Technol. 140, 447–453.

Pohlak, M., Ku¨ ttner, R., Majak, J., Karjust, K., Sutt, A., 2004b. Simulation of incremental forming of sheet metal products. In: Proceedings of the Fourth International DAAAM Conference, Tallinn, Estonia.

Pohlak, M., Ku¨ ttner, R., Majak, J., Karjust, K., Sutt, A., 2004a. Experimental study of incremental forming of sheet metal products. In: Proceedings of the Fourth International DAAAM Conference, Tallinn, Estonia.

Shankar, R., Jadhav, S., Goebel, R., Homberg, W., Kleiner, M., 2005. Incremental sheet metal forming of preformed sheets. In: Proceedings of the ICTP 2005, Verona, Italy.

Shim, M.-S., Park, J.-J., 2001. The formability of aluminium sheet in incremental forming. J. Mater. Process. Technol. 113, 654–658.

Shim, M.S., Park, J.J., Deformation characteristics in sheet metal forming with small ball, Trans. Mater. Process. J. JSTP 113 (2001) 654.

Sulaiman A. S., Romlay F. R. M., Zakaria M. S., Yusoff W. A.W., Maarof M. R., Yahya N. M.(2008) Experimental Study of Incremental Sheet Forming on Aluminum AA1100-0 , Faculty of Mechanical Engineering, Universiti Malaysia Pahang

Tanaka, S., Nakamura, T., Hayakawa, K., Nakamura, H., Motomura, K., 2005. Incremental sheet metal forming process for pure titanium denture plate. In: Proceedings of the ICTP 2005, Verona, Italy.

APPENDIX A1

Gantt chart for PSM 1

TASK	WEEK													
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
Identify Title														
Discussion with Supervisor														
Introduction, Define Problem Statement, Project Objective, Project scopes														
Literature review														
Methodology • Project Flow Diagram • Plan the experiment • Research Procedure • Conducting the experiment														
Study machine incremental forming.														
Proposal remarks														
Presentation														

APPENDIX A2

Gantt chart for PSM 2

TASK	WEEK													
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
Preparation Study and Observation														
Study ALGOR														
Run ALGOR														
Analyze the model/product														
Collect and compare the Data														
Report remarks														
Final evaluations														

Planning

Actual

APPENDIX B1

Aluminum Properties

Aluminum 5052-O

Categories: Metal; Nonferrous Metal; Aluminum Alloy; 5000 Series Aluminum Alloy

Material Notes: This alloy has good workability, very good corrosion resistance, high fatigue strength, weldability, and moderate strength. This leads to its use in aircraft fuel/oil lines, fuel tanks, other transportation areas, sheet metal work, appliances and lighting, wire, and rivets.

Data points with the AA note have been provided by the Aluminum Association, Inc. and are NOT FOR DESIGN.

Composition Notes:
Composition information provided by the Aluminum Association and is not for design.

Key Words: UNS A95052; ISO AlMg2.5; Aluminium 5052-O; AA5052-O

Vendors: Click here to view all available suppliers for this material.

Please click here if you are a supplier and would like information on how to add your listing to this material.

Physical Properties	Metric	English	Comments
Density	2.68 g/cc	0.0968 lb/in³	AA; Typical

Mechanical Properties	Metric	English	Comments
Hardness, Brinell	47	47	AA; Typical; 500 g load; 10 mm ball
Ultimate Tensile Strength	193 MPa	28.0 ksi	AA; Typical
Tensile Yield Strength	89.6 MPa	13.0 ksi	AA; Typical
Elongation at Break	25.0 % @Thickness 1.59 mm	25.0 % @Thickness 0.0625 in	AA; Typical
	30.0 % @Diameter 12.7 mm	30.0 % @Diameter 0.500 in	AA; Typical
Modulus of Elasticity	70.3 GPa	10200 ksi	AA; Typical; Average of tension and compression. Compression modulus is about 2% greater than tensile modulus.
Ultimate Bearing Strength	345 MPa	50000 psi	Edge distance/pin diameter = 2.0
Bearing Yield Strength	131 MPa	19000 psi	Edge distance/pin diameter = 2.0
Poissons Ratio	0.330	0.330	
Fatigue Strength	110 MPa @# of Cycles 5.00e+8	16000 psi @# of Cycles 5.00e+8	completely reversed stress; RR Moore machine/specimen
Machinability	30 %	30 %	0-100 Scale of Aluminum Alloys
Shear Modulus	25.9 GPa	3760 ksi	
Shear Strength	124 MPa	18000 psi	AA; Typical

Electrical Properties	Metric	English	Comments
Electrical Resistivity	0.00000499 ohm-cm @Temperature 20.0 °C	0.00000499 ohm-cm @Temperature 68.0 °F	AA; Typical

Thermal Properties	Metric	English	Comments
CTE, linear	23.8 µm/m-°C @Temperature 20.0 - 100 °C	13.2 µin/in-°F @Temperature 68.0 - 212 °F	AA; Typical; average over range
	25.7 µm/m-°C @Temperature 20.0 - 300 °C	14.3 µin/in-°F @Temperature 68.0 - 572 °F	average
Specific Heat Capacity	0.880 J/g-°C	0.210 BTU/lb-°F	Estimated from trends in similar Al alloys.
Thermal Conductivity	138 W/m-K	960 BTU-in/hr-ft²-°F	AA; Typical at 77 °F
Melting Point	607.2 - 649 °C	1125 - 1200 °F	AA; Typical range based on typical composition for wrought products 1/4 inch thickness or greater
Solidus	607.2 °C	1125 °F	AA; Typical
Liquidus	649 °C	1200 °F	AA; Typical

Processing Properties	Metric	English	Comments
Annealing Temperature	343 °C	650 °F	holding at temperature not required
Hot-Working Temperature	260 - 510 °C	500 - 950 °F	

Source: http://asm.matweb.com

APPENDIX B2

Zinc Properties

Zinc, Zn

Categories: Metal; Nonferrous Metal; Zinc Alloy; Pure Element

Material Notes: **Applications:** corrosion protection (galvanization), architectural, automotive, batteries, toys.

This entry is for pure Zn. A wide range of alloys is also included in MatWeb.

Many Zn alloys are listed in MatWeb.

Vendors: No vendors are listed for this material. Please click here if you are a supplier and would like information on how to add your listing to this material.

Physical Properties	Metric	English	Comments
Density	7.10 g/cc	0.257 lb/in³	

Chemical Properties	Metric	English	Comments
Atomic Number	30	30	
Thermal Neutron Cross Section	1.06 barns/atom	1.06 barns/atom	
X-ray Absorption Edge	1.283 Å	1.283 Å	K
	10.33 Å	10.33 Å	L_I
	11.8395 Å	11.8395 Å	L_{II}
	12.1055 Å	12.1055 Å	L_{III}
Electrode Potential	-0.760 V	-0.760 V	
Electronegativity	1.65	1.65	Pauling
Ionic Radius	0.740 Å	0.740 Å	Crystal Ionic Radius for Valence +2
	0.880 Å	0.880 Å	Crystal Ionic Radius for Valence +1
Electrochemical Equivalent	1.219 g/A/h	1.219 g/A/h	

Mechanical Properties	Metric	English	Comments
Hardness, Vickers	30	30	
Tensile Strength, Ultimate	37.0 MPa	5370 psi	cast sample
Modulus of Elasticity	96.5 GPa	14000 ksi	

Electrical Properties	Metric	English	Comments
Electrical Resistivity	0.000005916 ohm-cm	0.000005916 ohm-cm	
Magnetic Susceptibility	-1.74e-7	-1.74e-7	cgs/g
Critical Magnetic Field Strength, Oersted	53.97 - 54.03	53.97 - 54.03	
Critical Superconducting Temperature	0.840 - 0.860 K	0.840 - 0.860 K	

Thermal Properties	Metric	English	Comments
Heat of Fusion	110 J/g	47.3 BTU/lb	
Heat of Vaporization	1754 J/g	754.6 BTU/lb	
CTE, linear	31.2 µm/m-°C @Temperature 20.0 - 100 °C	17.3 µin/in-°F @Temperature 68.0 - 212 °F	
Specific Heat Capacity	0.3898 J/g-°C	0.09316 BTU/lb-°F	
Thermal Conductivity	112.2 W/m-K	778.7 BTU-in/hr-ft²-°F	
Melting Point	419.58 °C	787.24 °F	

Optical Properties	Metric	English	Comments
Emissivity (0-1)	0.0500	0.0500	unoxidized or oxidized; 300°C; total

Component Elements Properties	Metric	English	Comments
Zinc, Zn	100 %	100 %	

Descriptive Properties	
CAS Number	7440-66-6

Source: http://asm.matweb.com

APPENDIX B3

General Properties of Steels

The following table lists the typical properties of steels at room temperature (25°C). The wide ranges of ultimate tensile strength, yield strength, and hardness are largely due to different heat treatment conditions.

Properties	Carbon Steels	Alloy Steels	Stainless Steels	Tool Steels
Density (1000 kg/m^3)	7.85	7.85	7.75-8.1	7.72-8.0
Elastic Modulus (GPa)	190-210	190-210	190-210	190-210
Poisson's Ratio	0.27-0.3	0.27-0.3	0.27-0.3	0.27-0.3
Thermal Expansion (10^{-6}/K)	11-16.6	9.0-15	9.0-20.7	9.4-15.1
Melting Point (°C)			1371-1454	
Thermal Conductivity (W/m-K)	24.3-65.2	26-48.6	11.2-36.7	19.9-48.3
Specific Heat (J/kg-K)	450-2081	452-1499	420-500	
Electrical Resistivity (10^{-9} □-m)	130-1250	210-1251	75.7-1020	
Tensile Strength (MPa)	276-1882	758-1882	515-827	640-2000
Yield Strength (MPa)	186-758	366-1793	207-552	380-440
Percent Elongation (%)	10-32	4-31	12-40	5-25
Hardness (Brinell 3000kg)	86-388	149-627	137-595	210-620

Source: http://asm.matweb.com