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JUDUL: EXPERIMENTAL AND FINITE ELEMENT EVALUATION OF BENDING FOR MILD STEEL

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EXPERIMENTAL AND FINITE ELEMENT EVALUATION OF BENDING FOR MILD STEEL

AHMAD AIMAN BIN RAMLAN

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

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

JUNE 2012

UNIVERSITI MALAYSIA PAHANG
FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled "Experimental and Finite Element Evaluation of Bending For Mild Steel" is written by Ahmad Aiman Bin Ramlan. I have examined the final copy of this project and in our opinion, it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering.

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STUDENT’S DECLARATION

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

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Date : 22 JUNE 2012

Dedicated to my father, Mr Ramlan bin Che Ismail, my beloved mother,Mrs Norharsiah binti Said , my brothers Ahmad Nazmi bin Ramlan and Ahmad Fadhil bin Ramlan, my sister Nurul Adillah binti Ramlan, and last but not least to all my fellow friends.

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ABSTRACT

Finite element evaluation is one of the methods in predicting the springback angle in sheet metal bending. Predicting the springback is important since to produce the accuracy part geometry, the design of the die and bending tool must be accurate. This thesis aims to evaluate the reliability of finite element method by comparing the results with experimental results. The effect of parameters such as anisotropy in springback also has been studied. Abaqus software has been used to simulate the bending process and the mechanical properties provided from tensile test will be used to run the simulation. In the U-bending experiment, the die were clamped on stamping machine and the Mild Steel sheets then have been bent before the springback being measured with SolidWorks software. The results from the experiment and simulation is slightly different for the springback angle θ_1 , which the simulation shows increasing the orientation will increase the springback, and for the experimental, the springback higher at 0 degree orientation angle, and lower at 45 degree. For the springback angle θ_2 , the simulation and experimental result show that increasing the orientation angle will increase the amount of springback. Finite element method can be used to predict the springback since the pattern of the graphs are nearly the same and percentages of error are below 10 %. It can be comprehended that the finite element method are suitable method to predict the springback angle of sheet metal bending. The further study on parameters that effected bending process will make the finite element method is important in the future.

ABSTRAK

Kaedah analisis simulasi merupakan salah satu kaedah untuk meramal pembentukan bangkit kembali dalam pembengkokan kepingan logam. Ramalan bangkit kembali amat penting kerana untuk menghasilkan produk yang tepat, reka bentuk alat acuan dan peralatan pembengkokan mestilah tepat. Laporan ini bertujuan untuk menilai kebolehan kaedah simulasi dengan membandingkan keputusan simulasi dengan keputusan eksperimen. Kesan parameter seperti anisotropi dalam bangkit kembali juga dikaji. Perisian Abaqus telah digunakan untuk mensimulasikan proses lenturan dan sifat-sifat mekanik yang disediakan dalam ujian regangan akan digunakan untuk menjalankan simulasi. Dalam eksperimen lenturan-U, alat acuan telah dikapit pada mesin tekanan dan kepingan " Mild Steel " kemudian dibengkokan sebelum nilai bangkit kembali diukur dengan perisian Solidworks. Hasil daripada eksperimen dan simulasi adalah sedikit berbeza untuk sudut bangkit kembali, Θ_1 yang mana simulasi menunjukkan peningkatan sudut orientasi akan meningkatkan bangkit kembali dan untuk eksperimen, bangkit kembali lebih tinggi pada sudut orientatasi 0 darjah dan lebih rendah pada 45 darjah. Bagi sudut bangkit kembali Θ_2 , simulasi dan hasil eksperimen menunjukkan bahawa peningkatan sudut orientasi akan meningkatkan jumlah bangkit kembali. Kaedah simulasi boleh digunakan untuk meramal bangkit kembali kerana corak graf adalah hampir sama dan peratusan ralat di bawah 10 % . Dapat difahami bahawa kaedah simulasi sesuai untuk meramal sudut bangkit kembali bagi pembengkokan kepingan logam. Kajian lanjut mengenai parameter yang mempengaruhi proses pembengkokan adalah penting pada masa akan datang.

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LIST OF SYMBOLS

σ^2	Variance
Fmax	Bending Force
μ	Mean
$\Delta\theta/\theta$	Spring back ratio
n	Strain hardening exponent
R	Normal anisotropic value
v	Poisson’s ratio
E	Young’s modulus
t	Sheet thickness
ρ	Neutral axis
$\Delta\theta$	Spring back angle
I	Inertia moment of cross-section per unit width
$M(\alpha)$	Bending moment along the bending surface
R_n	Neutral layer radius of the sheet
K	Ultimate tensile strength
w	Die gap
t	Sheet thickness
ΔK	Spring back curvature
M	Bending moment
L	Inertia moment of cross-section

LIST OF ABBREVIATIONS

AISI	American Iron and Steel Institute
ASTM	American Society for Testing and Material
TRIP	Transformation Induced Plasticity
CNC	Computer Numerical Control
UTS	Ultimate Tensile Strength
DKL	Daw-Kwei Leu
DFPH	Dongye Fei and Peter Hodgson
FEA	Finite Element Analysis
CRES	Called-Corrosion-Resistant

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

This chapter provides a brief overview of the entire project consists of project background, problem statement, objectives, scopes of the works and organization of the thesis.

1.2 PROJECT BACKGROUND

Bending of sheet metal is one of the widely used processes in manufacturing industries especially in the automobile and aircraft industries. This bending operation is commonly used because the process is simple and final sheet product of desired shape and appearance can be quickly and easily produced with relatively simple tool set. In bending operation, plastic deformation is followed by some elastic recovery when the load is removed due to the finite modulus of elasticity in materials. During the loading and unloading process, elastic strain is released and the residual stresses redistribute through the sheet thickness producing spring-back. Basically, this project deals with experimental and finite element evaluation of bending for mild steel. In this project, bending analysis will take springback as one of the part of bending analysis.

Through this project, bending analysis can be made in term of knowing about spring-back of mild steel material. Many factors affect springback such as types of material, types of bending, and thickness of material and sheet anisotropy.

1.3 PROBLEM STATEMENT

Metal bending is the most common operation to change the shape of material by plastically deforming. Although this process is simple but it has a major problem which is spring-back. Springback can be described as the additional deformation of sheet metal parts after the loading is removed, which can lead to production of unacceptable products with wrinkle, tear, poor dimension precision, and so on.

In the past, sheet metal bending processes are dependent on the designer's experience and involve trials and errors to obtain the desired result, so the study of springback or amount of spring-back that influenced by various factors are really important.

1.4 OBJECTIVES

1. To determine springback angle in sheet metal bending for Mild Steel.
2. To determine the influence of anisotropy,R on springback.
3. To determine reliability of Finite Element Method (FEA) in sheet metal by comparing with the experimental results.

1.5 SCOPE OF WORKS

1. To study the basic understanding of spring-back behaviour from the past researchers (Literature Review).
2. To conduct experiments of tensile test to determine mechanical properties of Mild steel.
3. To perform Finite Element Evaluation analysis of bending for Mild steel.
4. To conduct experiment of sheet metal bending.
5. To analyse and compare the simulation and experimental result.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will discuss about theory of bending, types of bending, materials and parameters involved that causing the bending. This chapter will have all necessary information from journal, book and articles that are related to this project and also about the spring back study. The sources for the literature review are library books, journal from established databases such as Science Direct and Scopus, article and also newspaper article.

2.2 SHEET METAL FORMING

Sheet metal forming processes are those in which force is applied to a piece of sheet metal to modify its geometry rather than remove any material. The applied force stresses the metal beyond its yield strength, causing the material to plastically deform, but not to fail. By doing so, the sheet can be bent or stretched into a variety of complex shapes. There are a few examples of common sheet metal forming such as blanking and piercing, bending, stretching, stamping or draw die forming, Coining and ironing and many more (Marciniak, 2002.)

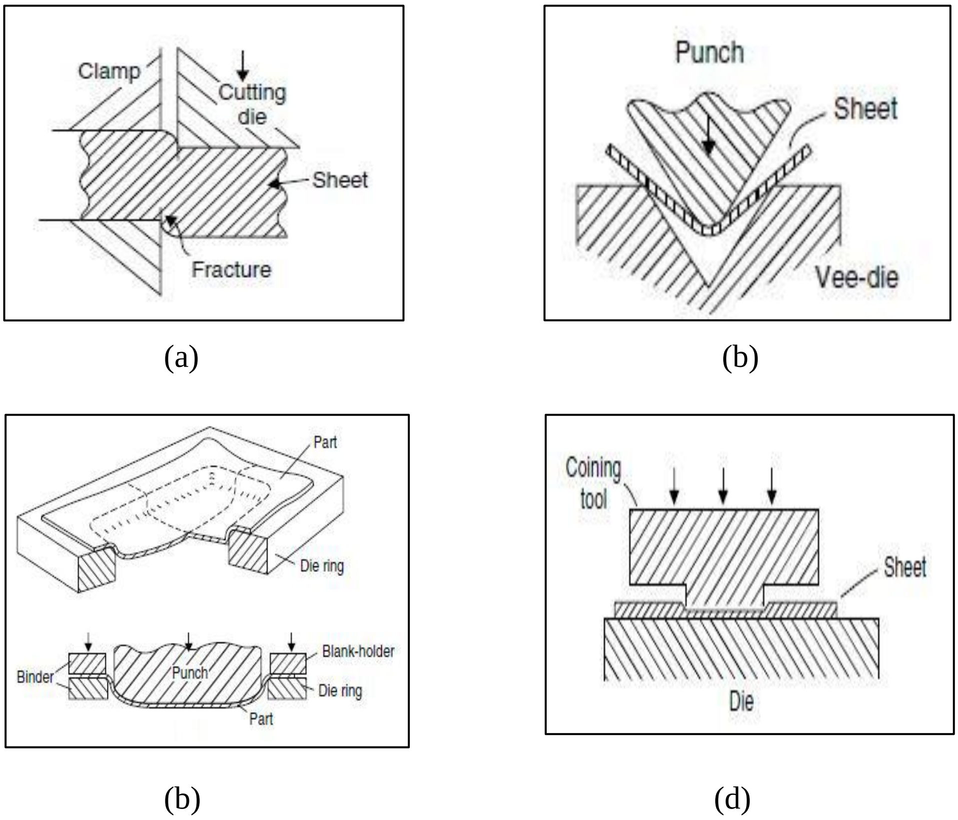

Figure 2.1 : (a) Basic cutting process of blanking an piercing. (b) Example of sheet metal bending process. (c) Typical part formed in a stamping or draw die. (d) Thinning a sheet locally using a coining tool.

Source : (Marciniak, Duncan,Hu, 2002)

In sheet metal forming industry, especially in sheet bending process, spring-back has a very significant role. In this process, the dimension precision is a major concern, due to the considerable elastic recovery during unloading which leads to spring-back. Also, under certain conditions, it is possible for the final bend angle to be smaller than the original angle. Such bend angle is referred to as spring-go or spring-forward. The amount of spring-back/ spring-go is influenced by various process parameters, such as tool shape and dimension, contact friction condition, material properties, sheet anisotropy, and sheet thickness.

2.2.1 Material Properties that affect Sheet Metal Formability

a) **Ductility:** Metal used in the sheet metal work must be ductile. If we use a brittle metal it can easily undergo failure during forming. That's why metal's ductility is very important in sheet metal working.

b) **Yield strength**: Yield strength of a material used in sheet metal forming must be low. High strength metals have reduced stretch distribution characteristic, making them less stretchable and drawable than lower strength metals. Stretch distribution characteristic determines the steel's ability to distribute stretch over a large surface area.

c) **Elastic modulus**: Stretch distribution affects not only stretch ability, but also elastic recovery , or spring back, and the metal's total elongation.

d) **Discontinuously Yielding**: Low carbon show a discontinuous yielding accompanied with the formation of Lǖder bands, which reduces the surface quality of the end product. In order to remove the discontinuous yield point a temper rolling (rolling where a few percent of reduction is applied) can be applied.

e) **Work Hardening Rate (n)**: Work hardening rate is a very important sheet metal forming parameters. When increases material's resistance to necking also increase. The work hardening is the mechanism, which prevents local yielding and increase the uniform elongation.

f) **Anisotropy (Directionality):** Anisotropy is another factor that affect formability. Once consequence of directionality is a change in mechanical properties with direction. When forming sheet metal, practical consequences of directionality include such phenomena as excess wrinkling, puckering, ear-formation, local thinning, or actual rupture.

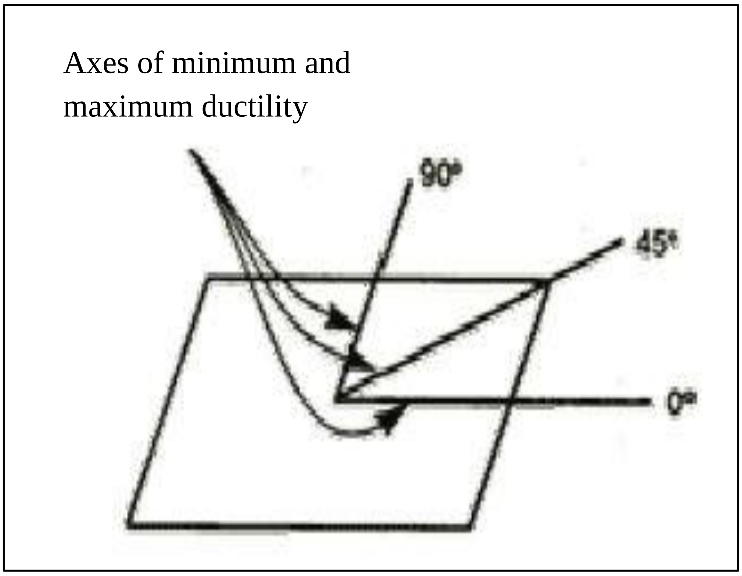

Figure 2.2: Directionality in properties of a Rolled Sheet.
Source: (Chan et al., 2004)

2.3 THEORY OF SHEET METAL BENDING

Bending can be defined as shaping materials without removing any chips around a definite axis through or without heat. Bending is the process of placing a sheet of metal over the matrix on the press bed where the sheet is bent around the tip of the punch as it enters the die. Bending dies are the setup, proper to the required piece shape, consisting of a female die and punch, and making permanent changes on steel sheet material (Tekaslan.O.V, 2007).

(a) (b)

Figure 2.3 : Pictures of V-die bending: a) under load and (b) after unloading.
Source: (Kardes Sever et al., 2011)

Bending along a straight line is the most common of all sheet forming processes as shown in Figure 2.3, it can be done in various ways such as forming along the complete bend in a die, or by wiping, folding or flanging in special machines, or sliding the sheet over a radius in a die. A very large amount of sheet is roll formed where it is bent progressively under shaped rolls. Failure by splitting during a bending process is usually limited to high-strength, less ductile sheet and a more common cause of unsatisfactory bending is lack of dimensional control in terms of springback and thinning. A few among the most common applications of sheet metal parts are as automobile and aircraft panels, housings, cabinets etc. Customization of sheet metal parts to produce parts of varying configurations and sizes is a very common occurrence in a sheet metal fabrication scenario (Diegel, 2002).

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2.4 TYPES OF BENDING

There are several types of bending that commonly used in the industries such as Air bending, Bottoming, Coining, V- bending, and U-bending. A bending tool must be decided depending on the shape and severity of bend (Boljanovic, 2004).

2.4.1 Air Bending

Air bending is a bending process in which the punch touches the work piece and the work piece does not bottom in the lower cavity. As the definition of springback, when the punch is released, the work piece springs back a little and ends up with less bend than that on the punch (greater included angle).There is no need to change any equipment or dies to get different bending angles since the bend angles are determined by the punch stroke.

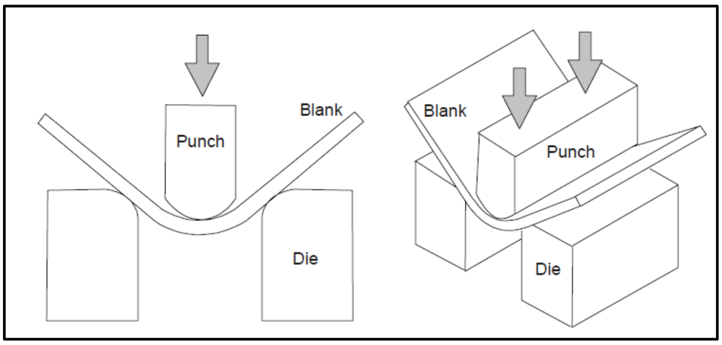


Figure 2.4 : Air bending process

Source : (Diegel, 2002)

2.4.2 Bottoming

Bottoming is a bending process where the punch and the work piece bottom on the die. In bottom bending, spring back is reduced by setting the final position of the punch such as that the clearance between the punch and die surface is less than the blank thickness, the material yields slightly and reduces the spring back.

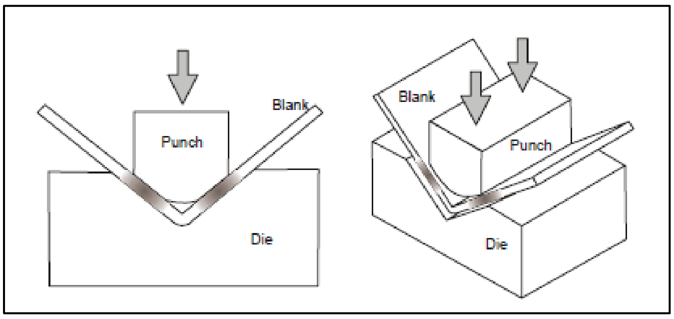


Figure 2.5 : Bottoming process.

Source : (Diegel, 2002)

2.4.3 Coining

Bending process in which the punch and the work piece bottom on the die and compressive stress is applied to the bending region to increase the amount of plastic deformation also can be called as coining

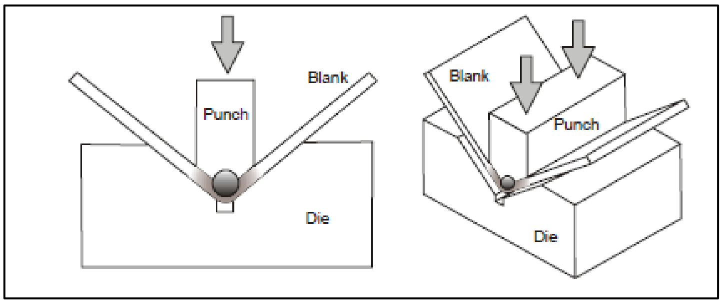


Figure 2.6: Coining process.

Source : (Diegel, 2002)

2.4.4 V-bending

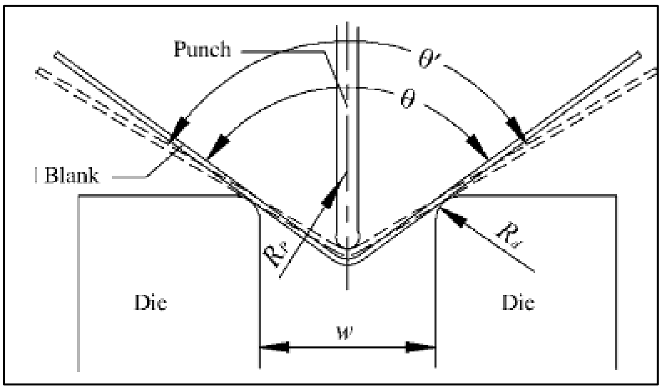


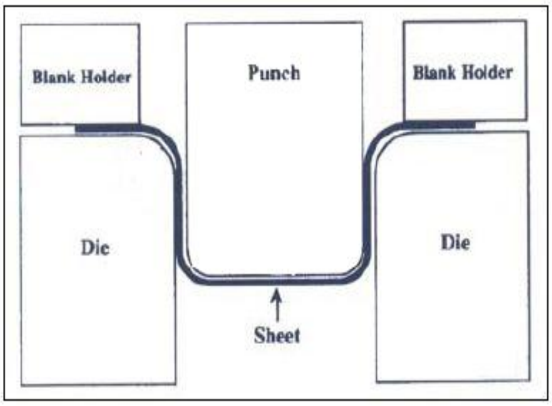
Figure 2.7 : Illustration of V-die bending.

Source : (Esat et al.,2002)

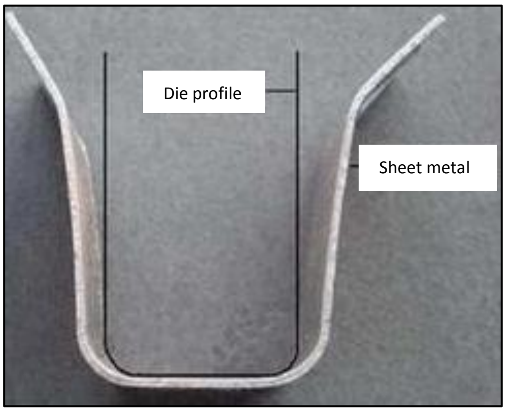
The V-die bending process is the bending of a V-shaped part in a single die. The work piece is bent between a V-shaped punch and die. The force acting on the punch causes punch displacement and then the workpiece is bent. The work piece is initially bent as an elastic deformation. With continued downward motion by the punch, plastic deformation sets in when the stresses exceed the elastic limit. This plastic deformation starts on the outer and inner surfaces directly underneath the punch.

2.4.5 U- bending

U – bending is performed when two parallel bending axes are produced in the same operation. A backing pad is used to forces the sheet contacting with the punch bottom (Marciniak , 2002). Generally U – bending process can be divided into two steps, loading and unloading. In the loading step, the punch will completely moves down and the metal is being bent into the die. During this step, the work piece undergoes elastoplastic deformation and temperature increase under frictional resistance. For the second step which is unloading step, the deformed sheet metal is ejected from the tool set and metal was experiencing the residual stress release and the temperature drop to reach a thermo-mechanical equilibrium state (Cho,2003) .



(a)



(b)

Figure 2.8 : Sheet metal U-bending: (a) Schematic diagram of U – bending process (b) Deformed specimen after unloading.

Source : (Bakhshi-Jooybari et al.,2009)

U-bending process is often used to manufacture sheet parts like channels, beams and frames. In this process, the sheet metal usually undergoes complex deformation history such as stretch–bending, stretch–unbending and reverse bending. When the tools are removed, in addition to springback, sidewall curl often happens, which makes the prediction of springback become more difficult.

Different methods, such as analytical method, semi-analytical method and finite element method (FEM), have been applied to predict the sheet springback of U-bending. Xu (2005) and Samuel (2000), applied FEM to simulate the forming and springback process of sheet U-bending and reviewed the effects of numerical parameters, tools geometry and process parameters on the predicted accuracy of springback. However, FEM is a time-consuming method and also is very sensitive to numerical parameters such as element type and size, algorithms, contact definition and convergence criterion for solution etc . (Zhang, 2007)

2.5 PARAMETERS INVOLVED IN U- BENDING

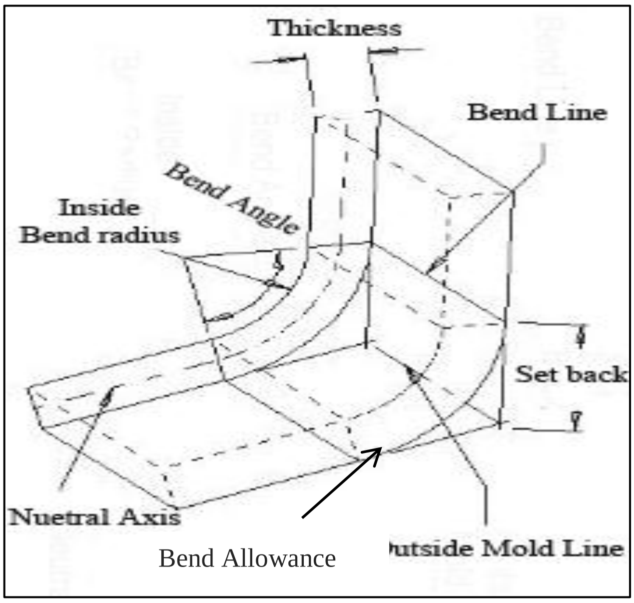


Figure 2.9 : Parameters of U- bending.

Source : (Boljanovic, 2004)

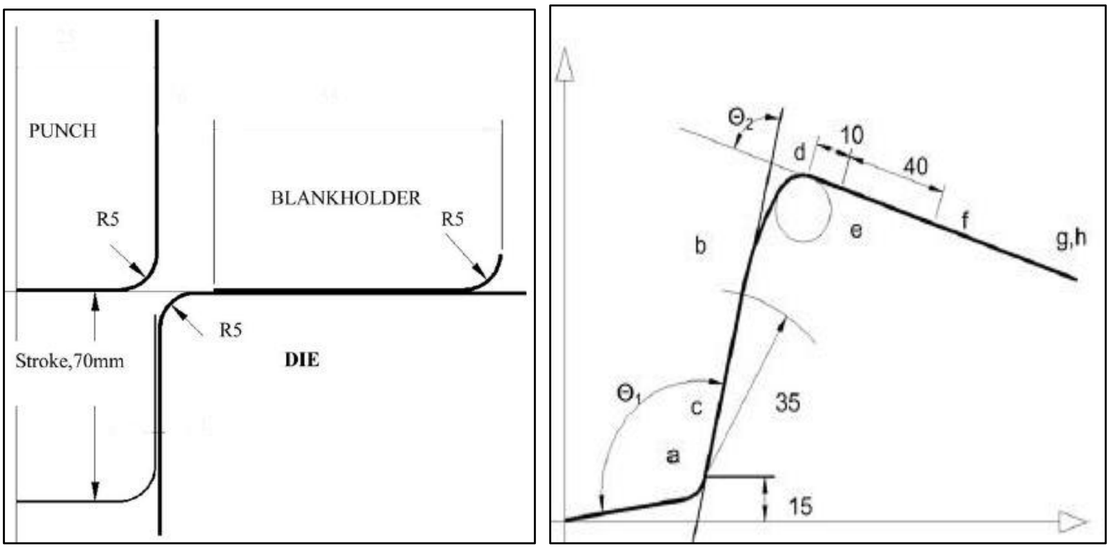
1. **Bend Allowance** – The length of the arc through the bend area at the neutral axis.
2. **Bend Angle** – The included angle of the arc formed by the bending operation.
3. **Bend Compensation** – The amount by which the material is stretched or compressed by the bending operation. All stretch or compression is assumed to occur in the bend area.
4. **Bend Lines** – The straight lines on the inside and outside surfaces of the material where the flange boundary meets the bend area.
5. **Inside Bend Radius** – The radius of the arc on the inside surface of the bend area.
6. **K-factor** – Defines the location of the neutral axis. It is measured as the distance from the inside of the material to the neutral axis divided by the material thickness.

7. **Mold Lines** – For bends of less than 180 degrees, the mold lines are the straight lines where the surfaces of the flange bounding the bend area intersect. This occurs on both the inside and outside surfaces of the bend.
8. **Neutral Axis** – Looking at the cross section of the bend, the neutral axis is the theoretical location at which the material is neither compressed nor stretched.
9. **Set Back -** For bends of less than 180 degrees, the set back is the distance from the bend lines to the mold line. (Boljanovic, 2004).

2.6 SPRING BACK IN U – BENDING

Spring back generally defined as additional deformation of sheet metal parts after the loading is removed (Zhang, 2007). Spring back is a major problem in sheet metal bending technique. Several bending operations done on sheet metal are air bending, V-die bending, rubber die bending and U-bending. In U-bending, the material may exhibit negative and positive spring-back caused by deformation as the punch completes the bending operation(fem of v-bending). The amount of spring-back/ spring-go is influenced by various process parameters, such as tool shape and dimension, contact friction condition, material properties, sheet anisotropy, and sheet thickness (Bakshi,2006).

There are several researchers that have investigated and attempted to obtain a basic understanding of spring back behaviour. The effect of bending angle on spring back of six types of materials with different thicknesses in V-die bending has been studied by Tekiner et al (2001) experimentally showed the effect of combined hot die and cold punch on reduction of spring-back of aluminium sheets. Li et al. (2005) also showed that the accuracy of spring-back simulation is directly affected by the material hardening model.



(a) (b)

Figure 2.10 : (a) U-bending process . (b) Definition of springback in U-bending,

Source : (Firat,2005)

The contact between the tool and the work piece bent during the folding operation extends over a larger area than can be occur when a U-folding or falling edge. The most studied phenomena in the process of formatting is that the spring back appears to be other cases of bending and bending it induces at the walls. I-Nan Chou (Cho-99) used several techniques to reduce spring back in the case of folding a channel U.

The relationship between the evaluation values of spring back and the geometric parameters of formatting is established using a finite element simulation. In this contribution, he developed an optimization algorithm based on the coupling between the finite element code Abaqus / most standard and to minimize the spring back in determining the optimal parameters of the process for each technique.

Xu (2004) studied the sensitivity of spring back to various factors which were introduced during the simulation of the folding process dynamically U explicitly. As example, they analysed the influence of the damping value, the number of points integration through the thickness, the size of items and the speed of the punch the accuracy and efficiency of spring back simulated and reasonable values of parameters are proposed.

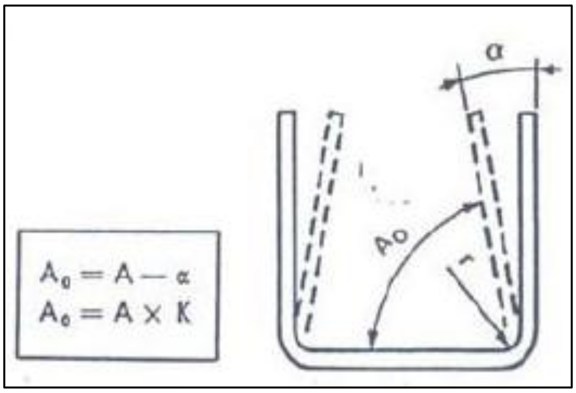


Figure 2.11 : Correction springback based on r / e

Source : (Zhong-qi et al.,2007)

Table 2.1 : List of correction springback on different material.

Metal plates	K Factor r/e =1	r/e = 1.2	r/e = 1.6	r/e = 1.8	r/e = 2	r/e = 2.5	r/e = 3	r/e = 4	r/e = 8	r/e = 10
Aluminium alloy	0.94	0.94	0.94	0.93	0.93	0.93	0.92	0.91	0.86	0.81
Ferritic steel	0.92	0.92	0.91	0.9	0.89	0.88	0.87	0.85	0.79	0.75
Mild steel	0.9	0.88	0.87	0.87	0.86	0.86	0.85	0.84	0.75	0.72

(Wassilieff,2001) proposed a method for correcting spring back given in form of graphs in the case of bending in U. For this he introduced in his study of K correction factors which depend on both the nature of the material and the ratio r / e, where r represents the radius of the matrix and e the thickness of the sheet.

These factors are factors K parameter and effects of major process parameters on the elastic recovery phenomenon have not been sufficiently investigated. However, in practice the understanding of parametric characteristics of the spring-back amount is essential for the systematic tool design.

2.7 MATERIAL

2.7.1 Material Selection

Aluminium Alloy : Aluminium alloys are alloys in which aluminium (Al) is the predominant metal. Aluminium alloys are alloys in which aluminium (Al) is the predominant metal. The typical alloying elements are copper, magnesium, manganese, silicon, and zinc. There are two principal classifications, namely casting alloys and wrought alloys, both of which are further subdivided into the categories heat-treatable and non-heat-treatable. Aluminium alloys are widely used in engineering structures and components where light weight or corrosion resistance is required. (Negi, 2007).

Mild Steel : Mild steel generally refers to low carbon steel; typically the AISI grades 1005 through 1025, which are usually used for structural applications. With too little carbon content to through harden, it is wieldable, which expands the possible applications. Low carbon steel contains approximately 0.05 to 0.25% carbon and mild steel contains 0.16 to 0.29% carbon; therefore, it is neither brittle nor ductile. Mild steel has a relatively low tensile strength, but it is cheap and malleable; surface hardness can be increased through carburizing.

Stainless Steel : Stainless steel also known as corrosion-resistant steel or CRES since does not stain, corrode, or rust as easily as ordinary steel. Stainless steel differs from carbon steel by the amount of chromium present. Unprotected carbon steel rusts readily when exposed to air and moisture.

2.7.2 Material Properties

The most important criteria in selecting a material are related to the function of the part qualities such as strength, density, and stiffness and corrosion resistance. For sheet material, the ability to be shaped in a given process, often called its formability, should also be considered. Whenever there is a stress on a sheet element, there will also be some elastic strain. It is often neglected, but it can have an important effect, for example when a panel is removed from a die and the forming forces are unloaded giving rise to elastic shape changes, or 'springback'.

1. The true stress–strain curve

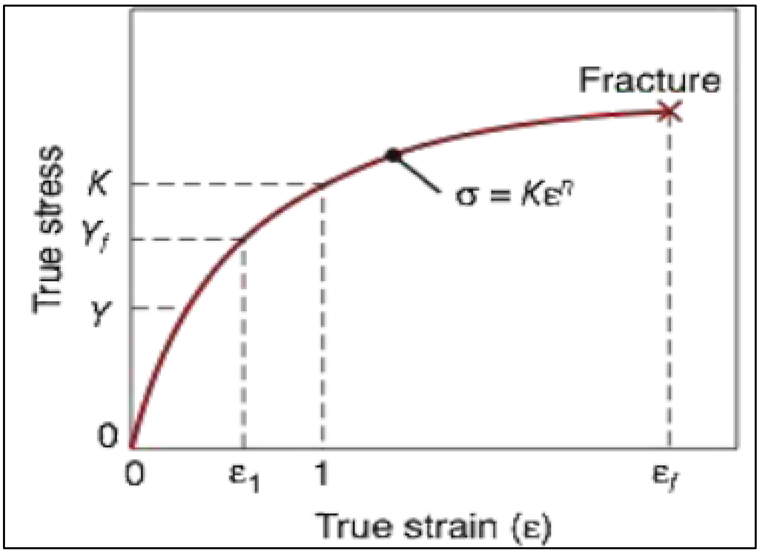


Figure 2.12 : Stress-Strain Curve

Source : (Christensen,2011)

The parameters shown on Figure 2.12 are described as follows :

Y : yield strength
Yf : flow stress is the true stress to complete plastic deformation at a particular true strain ε1. Yf increases with increasing strain .

Stress-strain curves are an extremely important graphical measure of a materis mechanical properties. The yield point is that point when a material subjected to a load, tensile or compression gives and will no longer return to its original length or shape when the load is removed. The yield point is a very important concept because a part is usually useless after the material has reached that point. (Michael F. Ashby, 2005). Ultimate tensile strength (UTS), often shortened to tensile strength (TS) or ultimate strength, is the maximum stress that a material can withstand while being stretched or pulled before necking, which is when the specimen's cross-section starts to significantly contract.

2. Rate sensitivity

For many materials at room temperature, the properties measured will not vary greatly with small changes in the speed at which the test is performed. The property most sensitive to rate of deformation is the lower yield stress and therefore it is customary to specify the cross-head speed of the testing machine – typically about 25 mm/minute. If the cross-head speed, v, is suddenly changed by a factor of 10 or more during the uniform deformation region of a tensile test, a small jump in the load may be observed. This indicates some strain-rate sensitivity in the material.

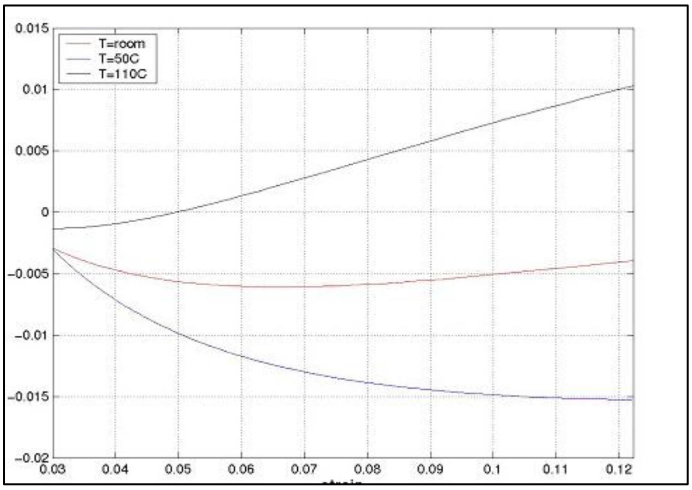


Figure 2.13 : Strain rate sensitivity parameter evaluated from constant strain rate tests at various temperatures

Source : (Christensen,2011)

CHAPTER 3

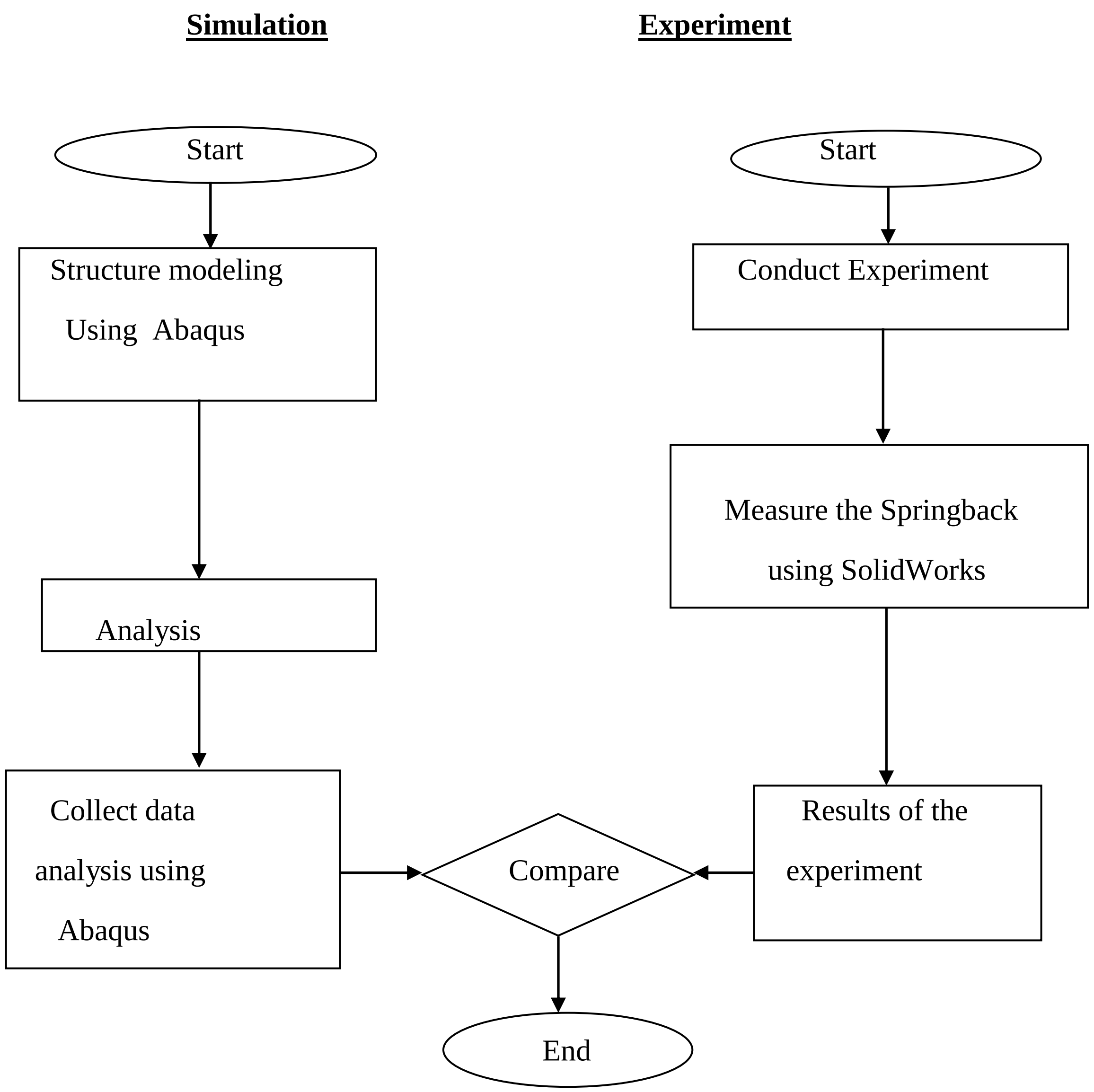
METHODOLOGY

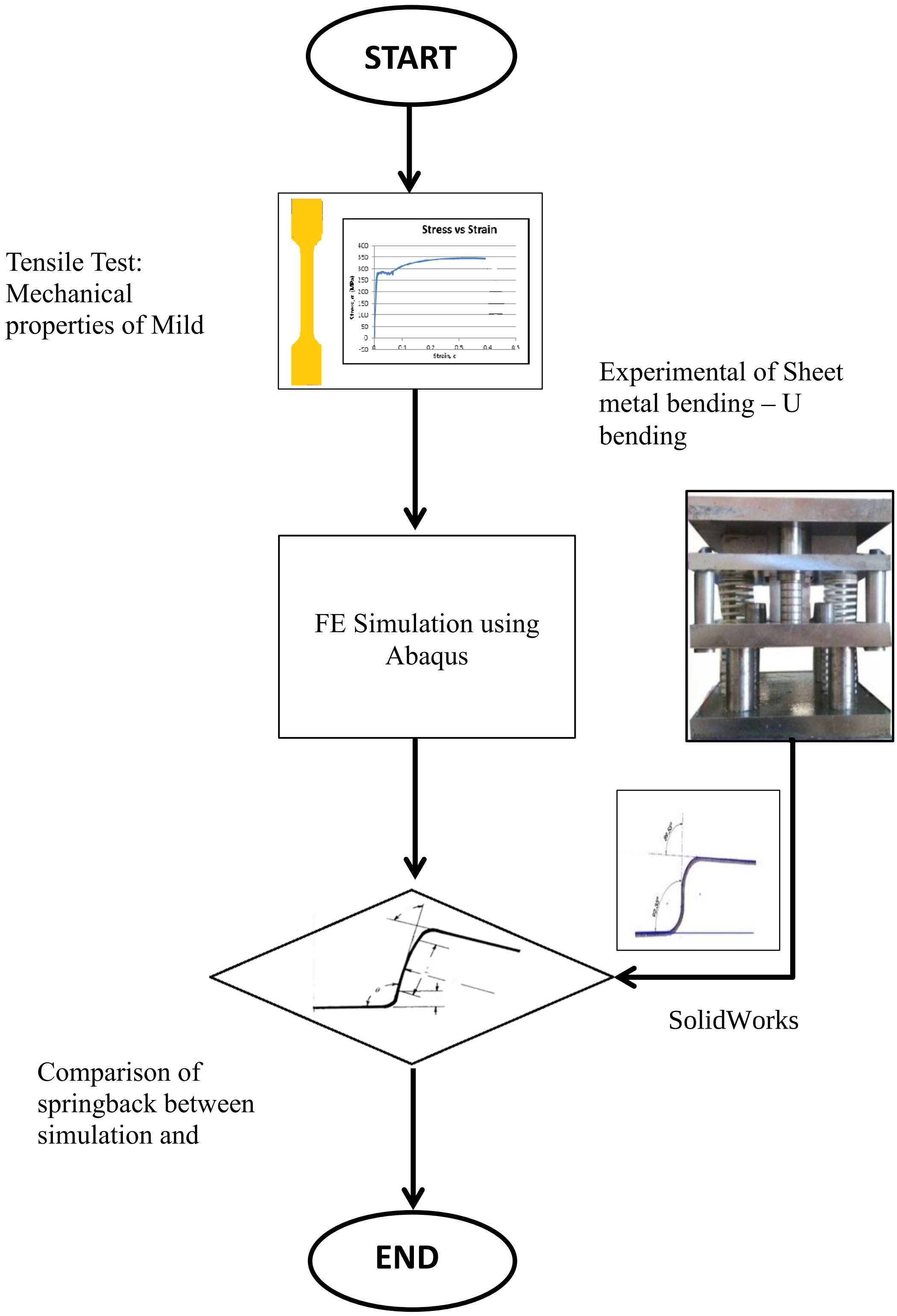
3.1 INTRODUCTION

This chapter is about the method that is used to collect data in completing this study. Explanations for this chapter will be based on several elements that contains in the flow chart of the study. This methodology includes the step to design the product until the steps to develop the simulation using the finite element analysis software. This chapter also deals with procedures and parameters involved in the project.

There are two main methods used in this project which are simulation and experimental method. In the simulation method, the process to predict springback angle starting from the determination of mechanical properties from tensile test. In the experimental method, the methodology of U-bending test will be discussed.

3.2 PROJECT FLOW CHART




START
Tensile Test:
Mechanical
properties of Mild
Stress vs Strain
Experimental of Sheet
metal bending – U
bending
FE Simulation using
Abaqus
SolidWorks
Comparison of
springback between
simulation and
END

3.3 TENSILE TEST METHOD

Tensile test is one of the most commonly used tests for evaluating material properties. Material that has been used in this project is Mild Steel AISI 1010. The tensile test is used to evaluate the strength of metal alloys. In this test a Mild Steel AISI 1010 sample is pulled to failure in a relatively short time at a constant rate. The tensile test is accomplished by gripping opposite ends of a test specimen within the load frame of a test machine. During the tensile test process, force and extension data has been monitored and recorded. The tensile test provides force and extension data that can quantify several important mechanical properties of a Stainless Steel such as elastic deformation properties (Young's modulus and Poisson's ratio), yield strength, ultimate tensile strength, ductile properties (elongation and reduction in area) and strain-hardening characteristics. The mechanical properties that provided from tensile test will be use in the analytical method in solving the spring-back equation.

3.3.1 Tensile test specimen ASTM E8

The Mild Steel AISI 1010 need to be cut into a tensile test specimen which the ASTM Standard as the reference. Regarding to the ASTM standard, the specimen of the tensile test can be divided into three types where it is plate type specimen, sheet type specimen and round type specimen. In this project, the test specimen is sheet metal type.

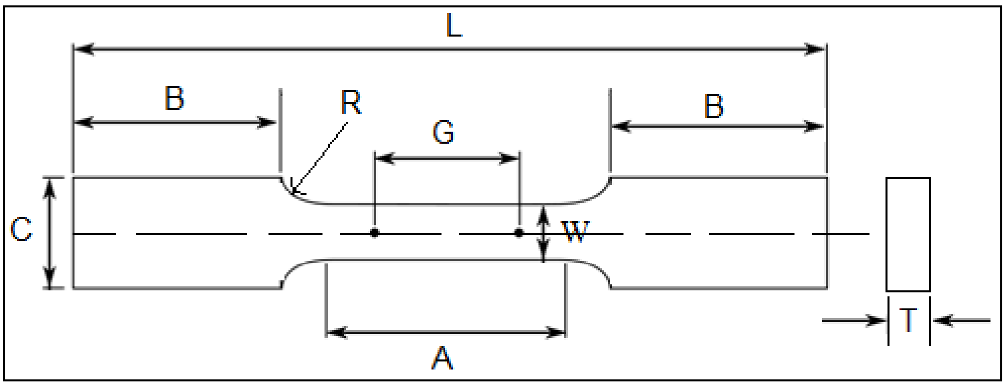


Figure 3.1 : Rectangular (flat) tensile test specimen

Source : (Annual Book of ASTM Standard, Vol 03.01)

This specimen is used for testing metallic materials in the form of sheet, plate, flat wire, strip, band and hoop ranging in nominal thickness from 0.13 to 19mm. The detail dimension and specification of the tensile test specimen is shown in the Figure 3.1 and Table 3.1.

Table 3.1 : Dimension and Specification of The Tensile Test Specimen ASTM E8

	Plate type (1.5 in. wide) mm	**Sheet type (0.5 in. wide) mm**	**Sub-size specimen (0.25 in. wide) mm**
Gage length, (G)	200 ± 0.25	50.0 ± 0.10	25.0 ± 0.08
Width ,(W)	40 + 3 - 6	12.5 ± 0.25	6.25 ± 0.05
Thickness, (T)	Thickness of Material		
Fillet radius (min.), (R)	13	13	6
Overall length (min.), (L)	450	200	100
Length of reduced section (min.),(A)	225	60	32
Length of grip section (min.), (B)	75	50	32
Width of grip section (approx.),(C)	50	20	10

3.3.2 Specimen preparation

In this experiment, two different thickness of Mild Steel AISI 1010 has been used to perform the tensile test. The thickness is 1.5mm and 2mm. Each thickness has been cut in the different orientation angle of 0, 45 and 90 degree and each orientation angle has been cut for 3 specimens. Table 3.2 below shown the total specimens used in this project.

Table 3.2: Total specimens preparation.

Specimen Thickness (mm)	No. of Specimen			
	0°	**45°**	**90°**	**Total Specimen**
1.5	3	3	3	9

3.3.3 Raw material preparation

Mild Steel AISI 1010 sheet metal need to be cut into specimen according to ASTM Standards, which the raw material of sheet metal need to be cut into a rectangular size of 300mm x 50mm by using LVD shearing cutting machine. The material then need to be cut in the direction of 0^o, 45^o and 90^o, which varying with the direction of rolling.

Figure 3.2 : LVD Shearing cutting machine

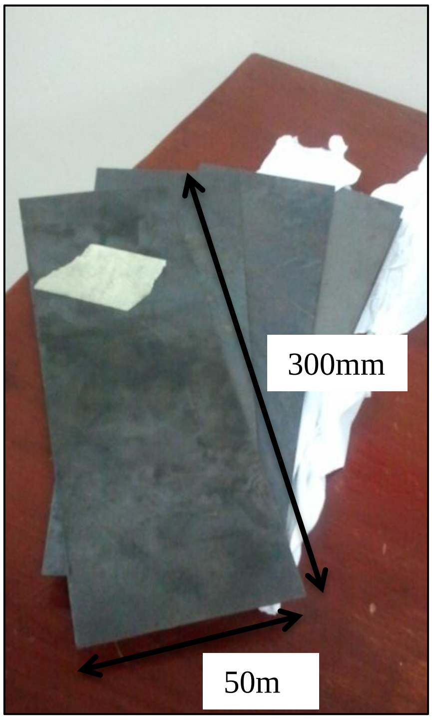


Figure 3.3 : Plates of Mild Steel AISI 1010 (300mm x 50 mm)

3.3.4 CNC Software / Mastercam

The cutting of tensile specimen will be completed by using CNC Machine. Computer Numerical Control which refers to a computer controller that controls the movement of every axis of the machine using G and M codes instructions and drives the spindle or machine tool into a raw material to fabricate or to remove the unwanted material from workpiece more accurately without human intervention.

G codes is a common name in the CNC programming language that begins with the letter G. Basically, the G codes tell the machine tool what type of action need to perform and trigger the CNC machine tools axis movement. M codes use to control the overall machine and use to perform specific action in CNC programs such as to start & stop the machine, turn ON the spindle, turn coolant ON/OFF and etc.

Tensile specimen has been draw using the Mastercam software for generated the G-Code of the CNC milling machine. Mastercam's comprehensive set of predefined tool paths which including contour, drill, pocketing, face, peel mill, engraving, surface high speed, advanced multiaxis, and many more and enable us to cut parts efficiently and accurately. Steps of designing the tensile specimen by using Mastercam software are shown below.

1. First step, the specimen of tensile test should be drawing in this Mastercam software.

2. Then the type of material for specimen should be specifying in the machine group properties toolbar. After that, at the machine group properties toolbar again, set up the raw material size that need to be cut at stock setup.

3. Then, at 2D-toolpaths icon select contour as a toolpaths type. After that, select 16 flat endmill as the tool for this process. 16 flat endmill is a 16mm diameter cutting tool for endmill cutting process type.

4. The next step is setup the feed rate, spindle speed and plunge rate for this process. The feed rate has been set about 40mm/min while the plunge rate is about 10mm/min. The spindle speed is set to be 900rpm.

5. Then, at the linking parameters icon, set up the depth to be cut to the raw material. For example, if the thickness of the material is 2mm, the suitable cutting depth is 2.5mm.

6. After all parameter for this process has been setup in the software, the simulation has been run to check the flow of this process.

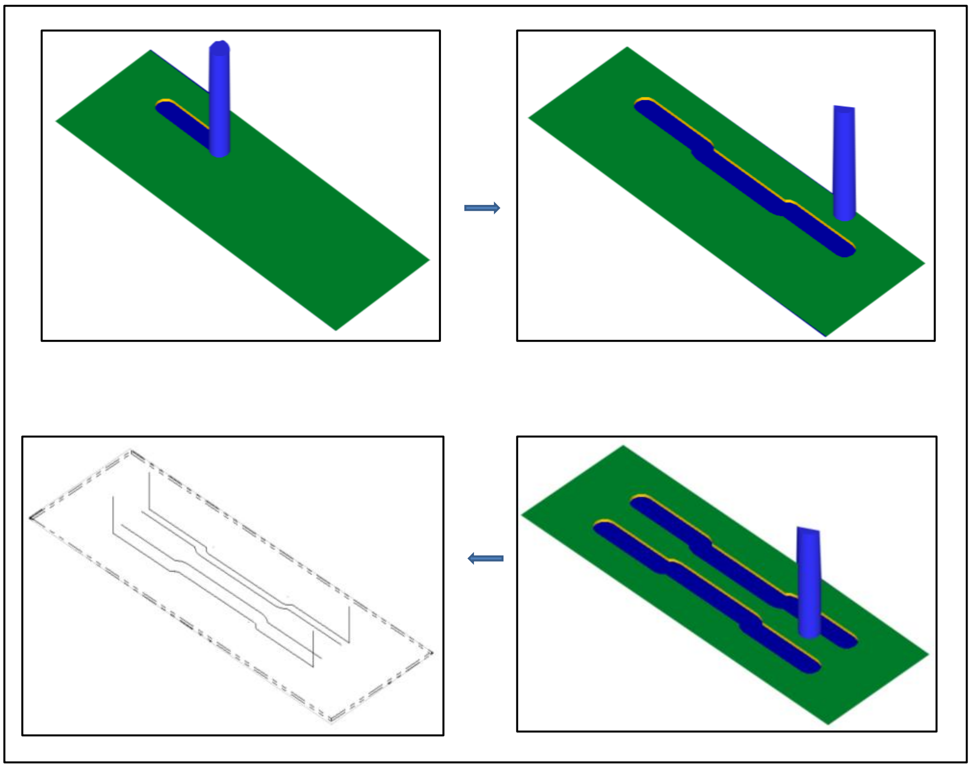


Figure 3.4 : The process flow of tensile test specimen in Mastercam.

7. Finally, ganerate the G-code from the simulation process.

3.3.5 Specimen preparation using CNC Milling Machine

The cutting of tensile specimen will be completed by using Haas CNC Machine. Computer Numerical Control which refers to a computer controller that controls the movement of every axis of the machine using G and M codes instructions and drives the spindle or machine tool into a workpiece to fabricate or to remove the unwanted material from workpiece more accurately without human intervention.

Figure 3.5: Haas CNC Milling Machine

The G-Code that has been generated from Mastercam's than be imported to the CNC milling machine. The scheme below has shown the basic processes to running the milling machine.

The basic processes of how to operate the Haas CNC Milling Machine are shown below :

1. Powering ON The Machine

2. Select And Open The G-Code Programme.

3. Clamping the workpiece.

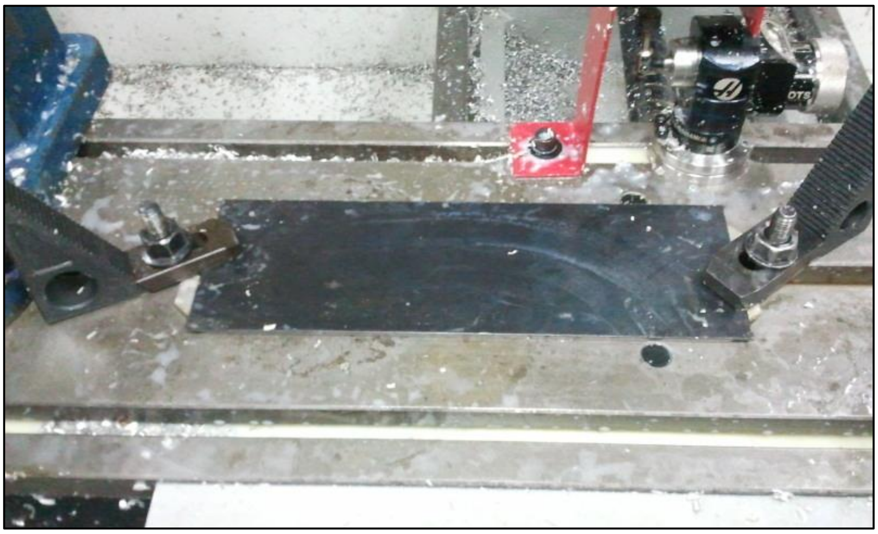


Figure 3.6: Clamping the workpiece

4. Locating X and Y Zero Points of The Part.

5. Loading The Tool into The Tool Carousel.

6. Setting The Tool Offsets.
7. Running The Programme.

Figure 3.7: CNC Milling Machine in process.

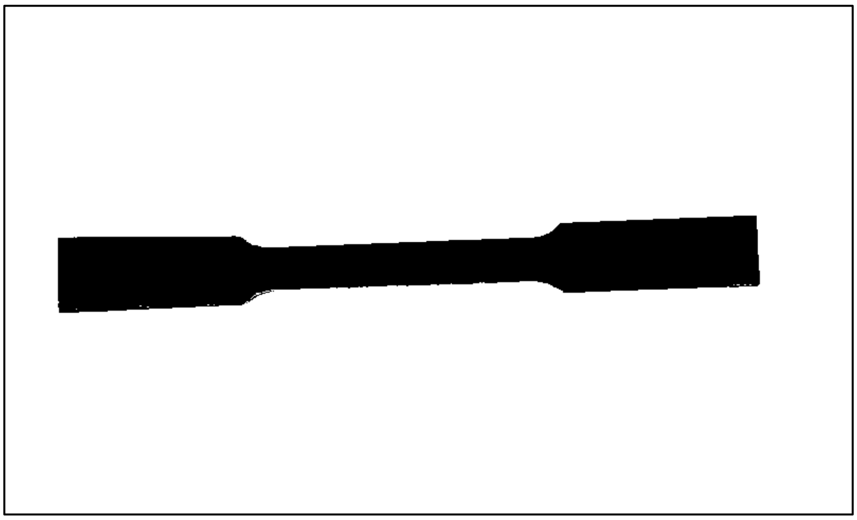


Figure 3.8: The finish product of the specimen.

3.3.6 Tensile Test Experiment

A tensile test is developed to evaluate the strength of metals and alloys. The tensile test is operate with a sample metal is pulled to failure in a relatively short time at a constant rate.

Figure 3.9 : Specimen attached in the tensile Machine during tensile test experiment.

After the sample metal are pulled until reach the yield point of the metal, the metal will start to have necking deformation. The necking deformation will go until the forces attached reach the Ultimate tensile strength of the material.

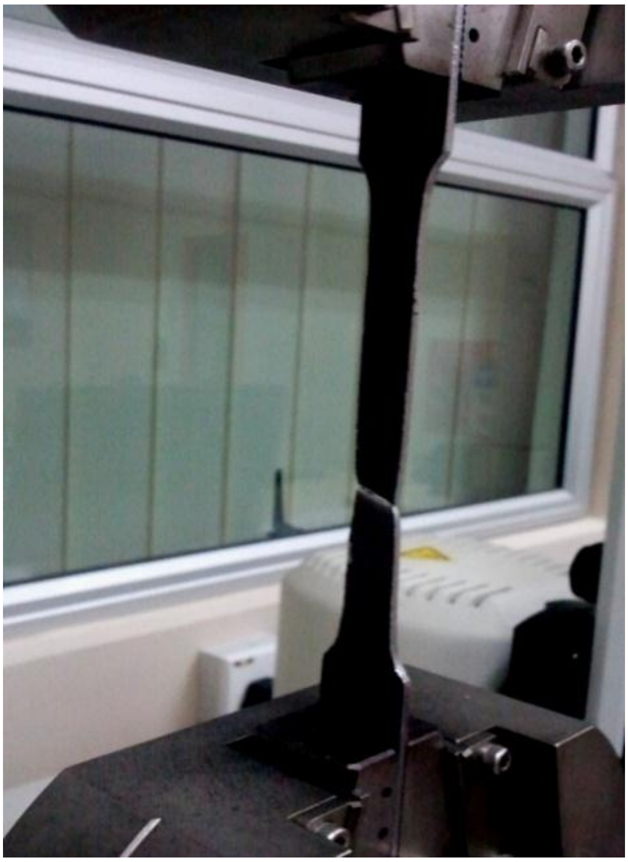


Figure 3.10: Specimen attached starting to necking.

In the end of the tensile test, the sample will break at the necking point which mean the process have reach the ultimate tensile strength of the metal.

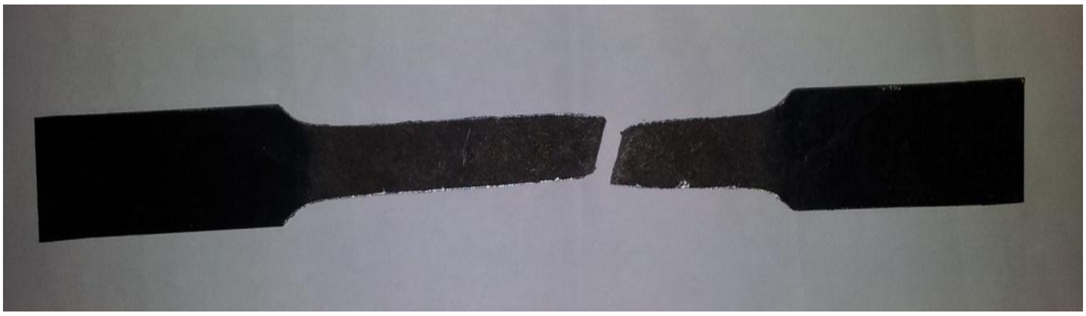
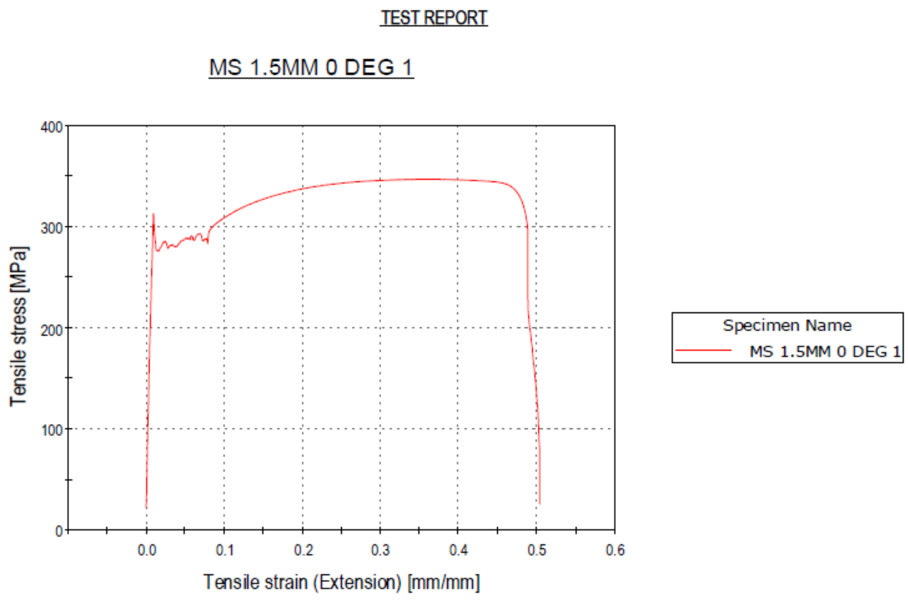


Figure 3.11 : Specimen result in tensile test

The forced data obtained from the chart paper for the tensile test can be converted to the engineering data, and a plot of engineering of engineering stress versus engineering strain can be constructed. Figure 3.12 below shows the first result on tensile test for Mild steel AISI 1010.



	Load at Break (Standard) [kN]	Maximum Load [kN]	Modulus (Automatic) [MPa]	Strain hardening exponent at n-value (Automatic)	Plastic strain ratio at r-value (Automatic)
1	1.23	6.50	38,029	0.27747	-----

Figure 3.12 : Stress-Strain diagram of Mild Steel AISI 1010.

3.4 FINITE ELEMENT SIMULATION

In the finite element model, the workpiece, die, blank holder, and puncha are the main components to be drawn. The punch is moving downward to bend the workpiece. After the bending operation, the workpiece–die contact and workpiece–punch contact definitions are removed. Springback of the metal is then allowed to take place. Throughout the simulation, the top left and bottom left of the workpiece are constrained in the x and y directions. This is to prevent any rigid body motion of the workpiece, which will result in numerical errors during the simulation. Due to plane symmetry, only half of the process was modelled.

3.4.1 Blank

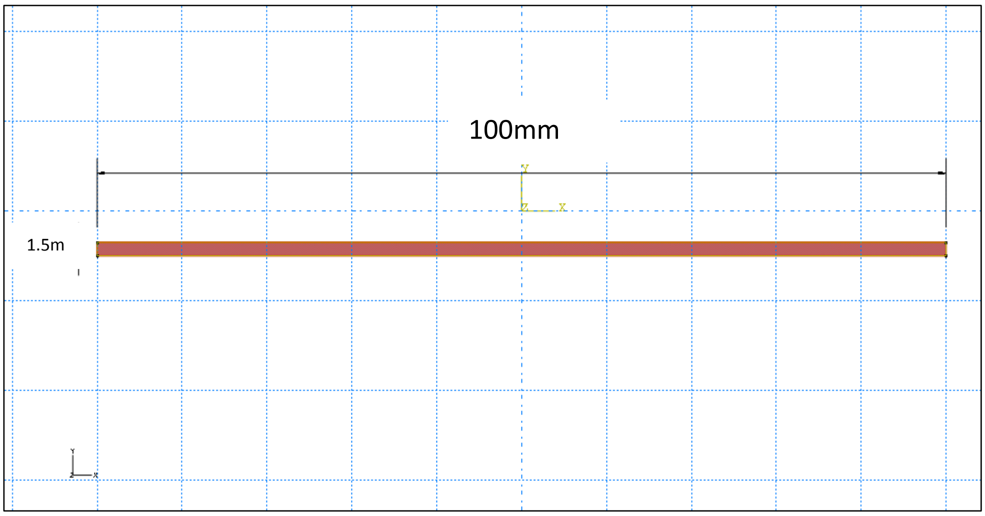


Figure 3.13: Blank

Figure 3.13 shows a drawing of blank. The length of the blank is 100mm while width is 1.5mm. The sheet metal is represented by a deformable body. It is because this particle's part is moving in y and x-direction when the bending process started. The springback value will be calculated based on this part with calculating by the nodes.

3.4.2 Die

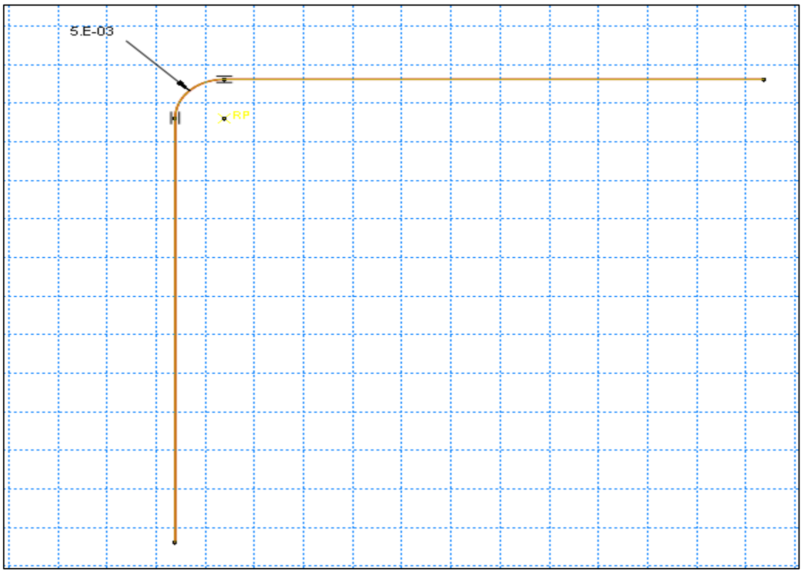


Figure 3.14 : Die

Figure 3.14 shows a drawing of die. The die is defined as rigid body. The sheet metal is placed on the die and will flankaed with blank holder. The workpiece will follow the shape of the die after it bending. The die radius is set by 5 mm.

3.4.3 Blank Holder

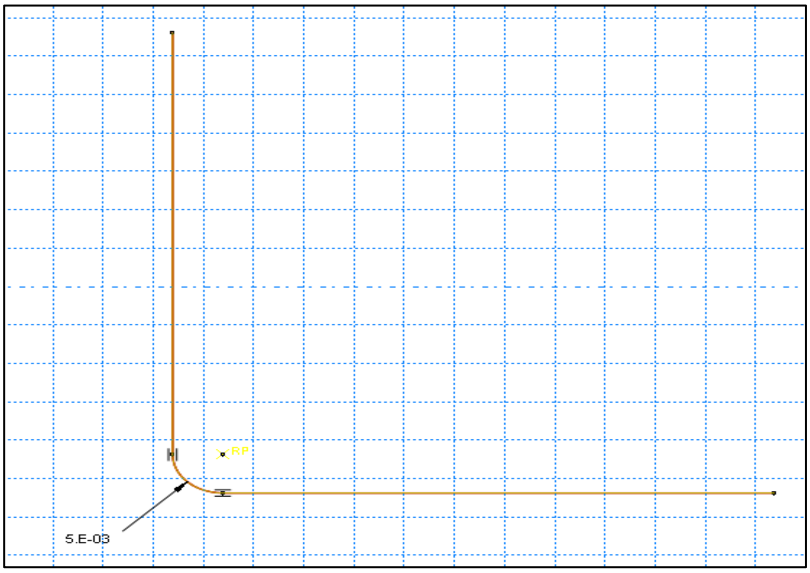


Figure 3.15: Blank holder.

Figure 3.15 shows a drawing of blank holder. The blank holder is also defined by rigid body. The function of blank holder is to clamp the workpiece with the die and to make sure that there is no moving part when the blank is starting to bend. Contact of blank holder and blank must be declared because the blank holder will press the blank when the workpiece is bending.

3.4.4 Punch

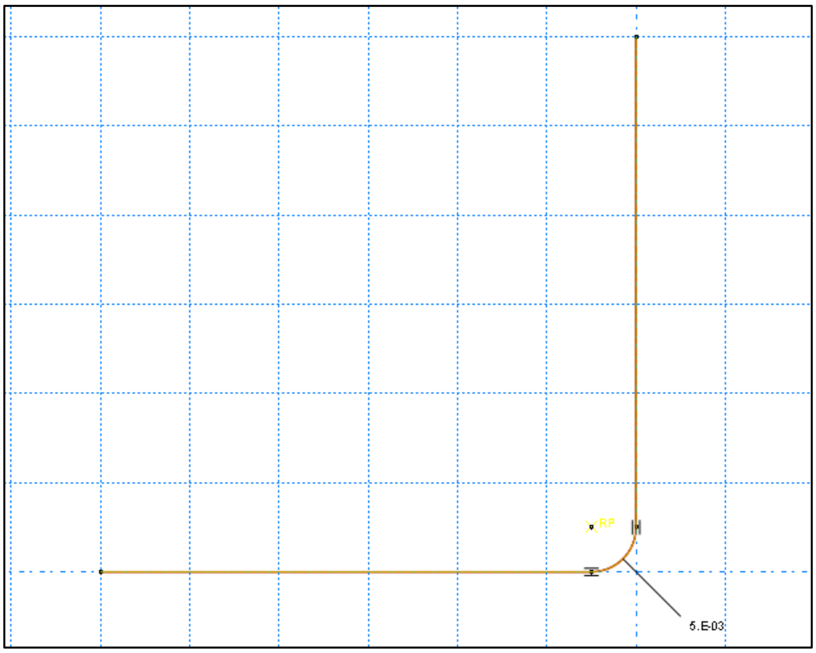


Figure 3.16 : Punch

Figure 3.16 shows a drawing of punch. Punch is modelled as a rigid body since it is functioning to punch the blank. The direction of the punch is in y-direction and it will punch blank downward follows the die shape. Contact of punch and the blank must be declared in the Abaqus software to make sure the punch will bend the blank properly.

3.4.5 Material and properties define

To simulate a finite element model, the elastic and plastic properties must be declared. Elastic and plastic properties data can be obtained from stress-strain diagram of Mild Steel from tensile test experiment. Figure 3.17, Figure 3.18, Figure 3.19 show the selected points in stress-strain diagram for 0 degree, 45 degree and 90 degree of rolling direction. These values then will be used to run the simulation in Abaqus software.

i. Elastic Properties

Elastic properties of a solid are important because they relate to various fundamental solid-state properties. Elastic properties are also linked thermodynamically to the specific heat, thermal expansion, melting point and parameter. So, it is important to know elastic constants of Mild Steel to put into a Abaqus software. Poisson's ratio occurs in some of the more complex stress/strain equations. It sounds complicated, but it is simply a way of saying how much the material (taffy) necks down or gets thinner in the middle when it is stretched.

ii. Plastic Properties

Plastic properties or known as plasticity is a property of solid body whereby it undergoes a permanent changing shape or size when subjected to a stress exceeding a particular value. The yield point is that point when a material subjected to a load, tensile or compression will no longer return to its original length or shape when the load is removed. Some materials break before reaching a yield point.

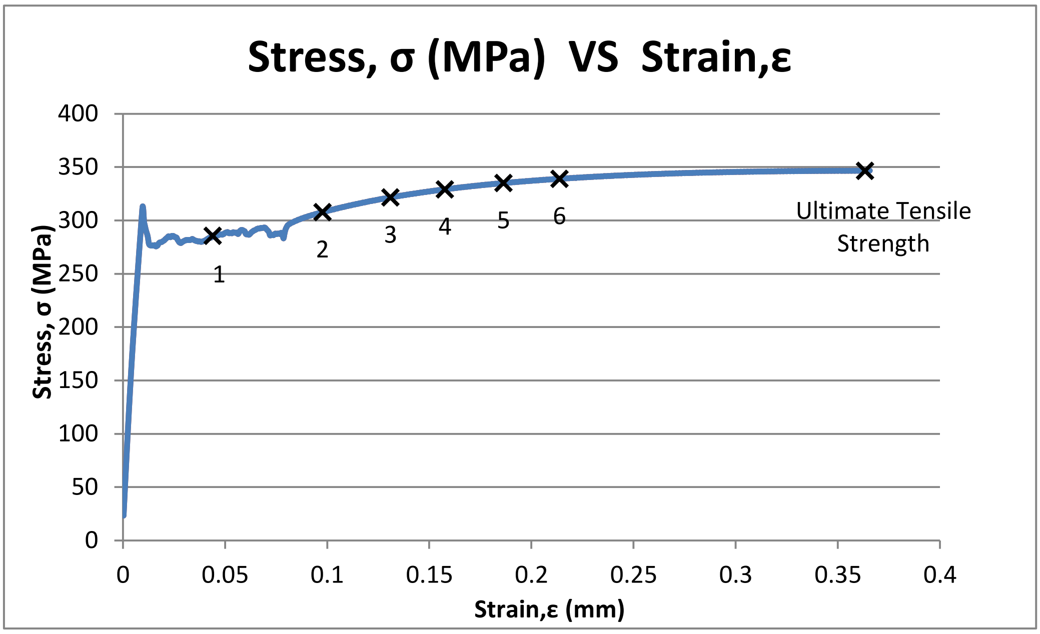


Figure 3.17 : Engineering stress – strain diagram for Mild Steel AS 1010, anisotropy, R = 0 degree.

Yield Strength	=	283.774 Mpa
Ultimate Tensile Strength (UTS)	=	346.5088 Mpa
Poisson's Ratio, v	=	0.3

Table 3.3 : Selected points in stress-strain diagram for 0 degree

Point	Stress, σ (Mpa)	Strain, ε	Strain, ε at 0
1	283.774	0.043	0.00
2	307.749	0.098	0.06
3	321.577	0.131	0.09
4	329.181	0.158	0.12
5	335.073	0.186	0.14
6	339.010	0.214	0.17

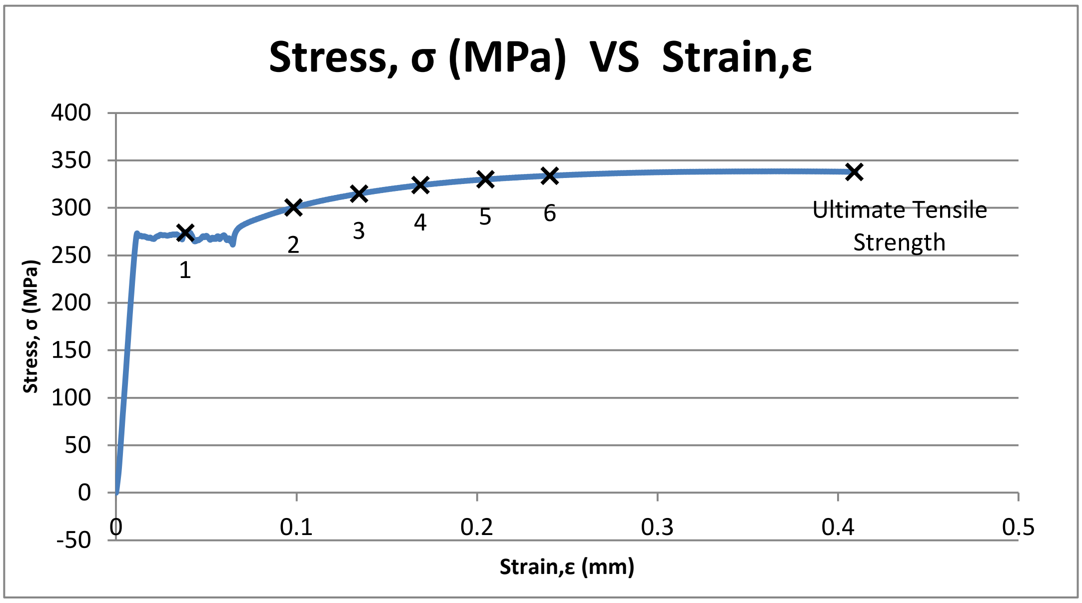


Figure 3.18 : Engineering stress – strain diagram for Mild Steel AS 1010, anisotropy, R = 45 degree.

Yield Strength = 273.887 Mpa

Ultimate Tensile Strength (UTS) = 337.9141333 Mpa

Poisson's Ratio, v = 0.3

Table 3.4 : Selected points in stress-strain diagram for 45 degree.

Point	Stress, σ (Mpa)	Strain, ε	Strain, ε at 0
1	273.887	0.038	0.00
2	300.397	0.098	0.06
3	315.095	0.135	0.10
4	323.938	0.169	0.13
5	330.138	0.205	0.17
6	333.854	0.240	0.20

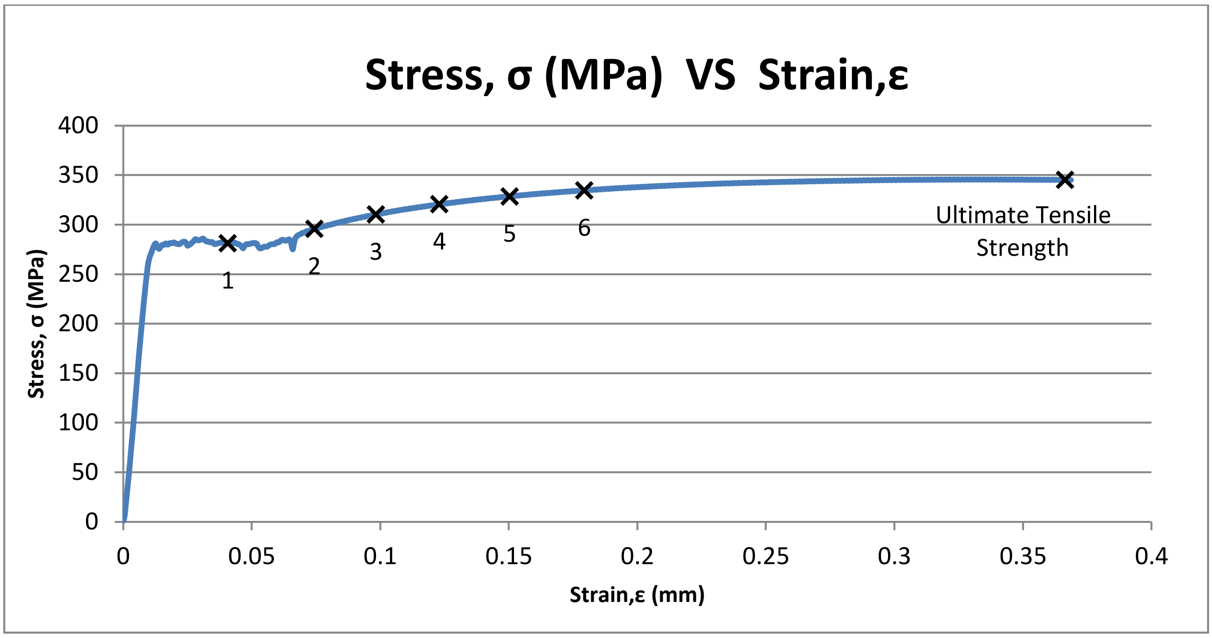


Figure 3.19 : Engineering stress – strain diagram for Mild Steel AS 1010, anisotropy, R = 90 degree.

Yield Strength = 281.3 Mpa

Ultimate Tensile Strength (UTS) = 345.2144 Mpa

Poisson's Ratio, v = 0.3

Table 3.5 : Selected points in stress-strain diagram for 90 degree.

Point	Stress, σ (Mpa)	Strain, ε	Strain, ε at 0
1	281.300	0.041	0
2	295.724	0.074	0.03
3	310.308	0.098	0.06
4	320.714	0.123	0.08
5	328.571	0.15	0.11
6	334.588	0.179	0.14

iii. Mesh Size

The initial geometry used for the simulation with finite element mesh is consists of linear quadrilateral elements. An Abaqus, software was developed to generate the process setup with finite element mesh. The value of 0.5mm mesh is used for this simulation.

iv. Modelling Contact

The simulation of impact and contact among two or more objects of any kind has always been a challenging problem. It is one of the critical elements in successfully simulating the flanging operation. In this simulation the die and blank holder is declared as contact with the blank and is defined a friction with 0.1. The punch is also declared as contact with the blank and it is a frictionless.

v. Analysis and Evaluation

When all the required data has been formed, the simulation need to be calculated to obtain the result and this can be completed by creating a job. The job then will submit the data to be analysed. The result can be analyzed based on different criteria. This can be done by modifying the convergence criteria, re-submit the analysis and the result already can be compared.

3.5 EXPERIMENTAL SETUP

3.5.1 Specimen preparation

The material used is Mild Steel AISI 1010 which will be cut into the size of 25mm x 200mm. Each thickness has been cut in the different orientation angle of 0, 45 and 90 degree and each orientation angle has been cut for 3 specimens. Table 3.6 represent the total specimens used in this project.

Table 3.6 : The total number of specimens used in V bending experimental.

Specimen Thickness(mm)	No. of Specimen			
	0°	**45°**	**90°**	**Total Specimen**
1.5	3	3	3	9

3.5.2 Die

The U-shaping stage, is carried out with the experimental set-up shown in Fig 3.20. Three different anisotropies Mild Steel of 1.5mm thickness were tested which are 0 degree, 45 degree and 90 degree which for every anisotropy there are three specimens. The die travel were stop automatically when there are no clearance between punch and specimen.

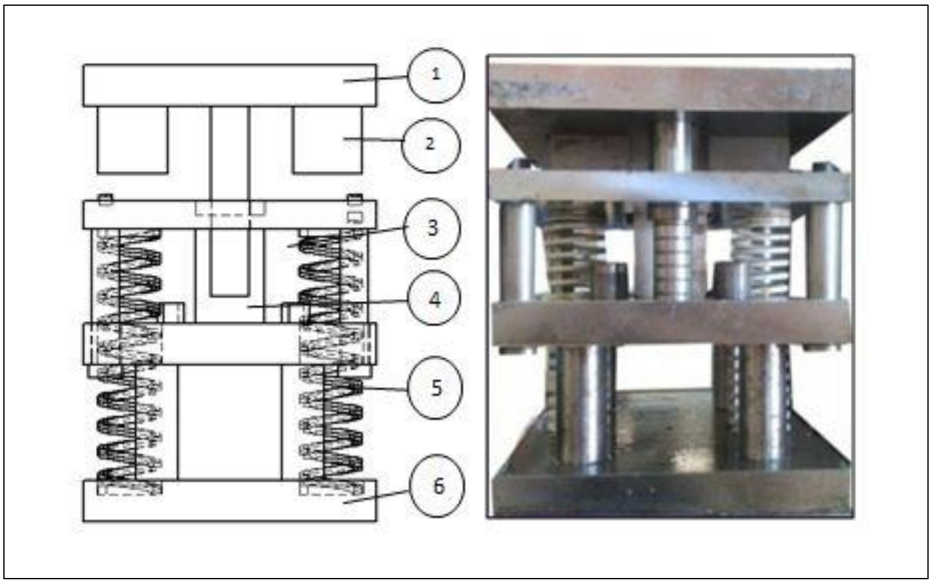
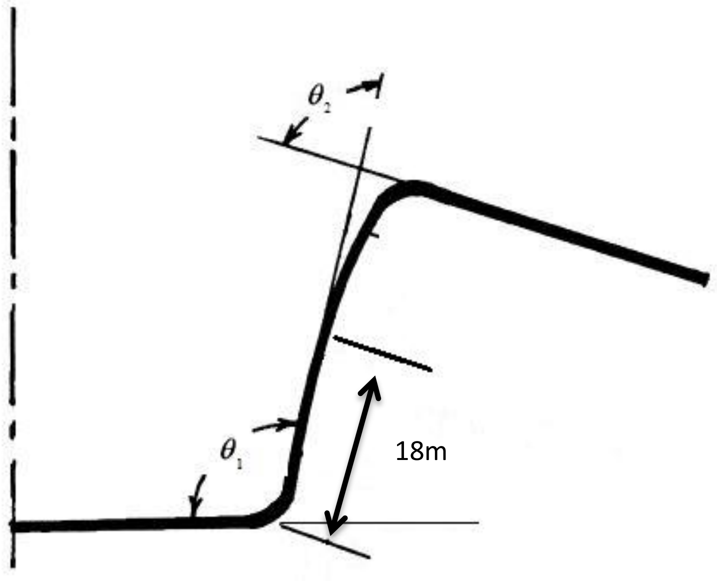


Figure 3.20 : Schematic and photograph for the experimental set-up: 1,upper part , 2, die; 3, blank holder; 4, punch; 5, spring ; 6, lower part.

The die will be clamped on the stamping machine (hydraulic) before the specimen will be placed on the top of the blank holder and punch. When the force applied, die and blank holder will moved downward and hit the specimen while the punch stay still at that position.

3.5.3 Springback measurement



parameters :
Ɵ1 = Springback angle 1 (degree)
Ɵ2 = Springback angle 2 (degree)

Figure 3.21: Parameters for springback in U-bending process.

Source : (Samuel, 2000)

There a few methods that can be used to measure springback angle and one of the method is by measure the nodes of the curve and measure the angle of the curve as shown on the Figure 3.21.

The bending angle of the specimen has been measured using the SolidWork software. After specimen has been bending, it will be scan using Canon Inkjet MP 140 Series. The scanning profile will be save in the picture format.

The bending specimen picture then to be imported in the SolidWorks software and the angle will be measured. The procedures for measuring the springback angle of the specimens are shown below.

Scan specimen using Canon Inkjet MP 140 Series printer

⇩

Save the scanning profile in picute (JPEG Format)

⇩

Open Solidworks software and import the specimen picture using skecth tool toolbar

⇩

Skecth the v-line on the specimen and measure the angle using smart dimension tool

⇩

Save the result

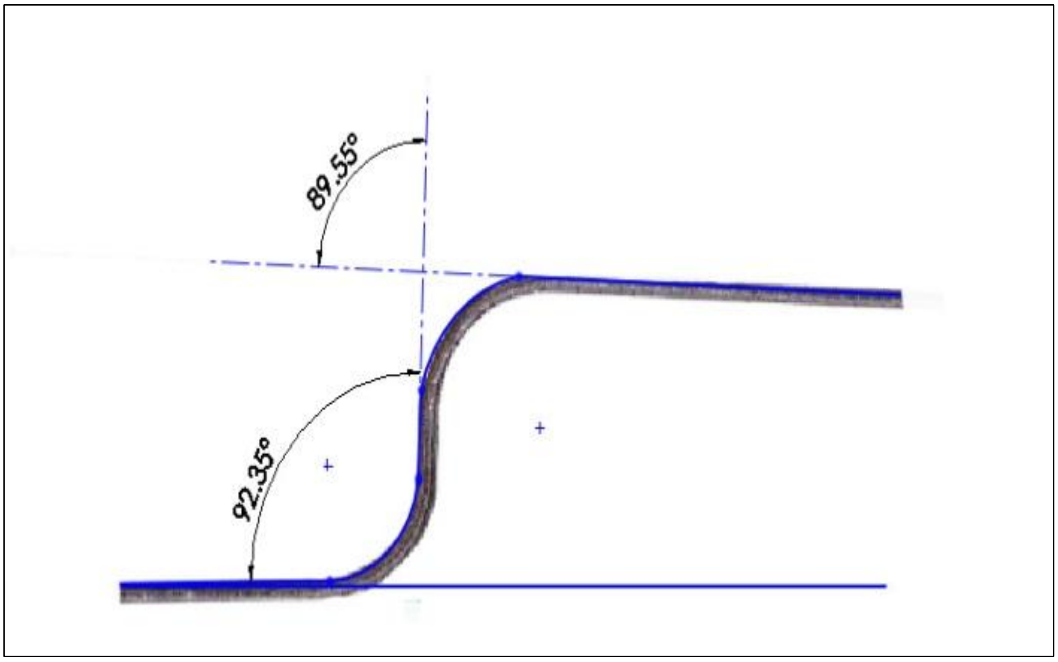


Figure 3.22: Specimen scanning picture

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter is showing the results from the experimental and finite element analysis of springback of Mild Steel AISI 1010. In the experiment, the sheet metal were scan by a scanner and the angle of springback then measured by using SolidWorks 2011 software. For the simulation, Abaqus software were used and springback angle also measured by SolidWorks 2011. Tensile test results were determined and the mechanical properties will be used to run Finite Element Simulation.

4.2 TENSILE TEST RESULT

In the tensile test process, force (load) and extension data has been monitored and recorded. Force (load) and extension data that provided from this test can be use to find several important mechanical properties of a Mild Steel AISI 1010 such as elastic deformation properties (Young's modulus and Poisson's ratio), yield strength, ultimate tensile strength, ductile properties (elongation and reduction in area) and strain-hardening characteristics. But, the machine can also provided directly the mechanical properties value if the method is set up to determined the value. Table 4.1 had shown the mechanical properties value that has been selected in the tensile test method.

Table 4.1: Mechanical Properties from Tensile Test Result

Load at Break (Standard) (KN)	**Maximum Load (KN)**	**Modulus (Automatic) (MPa)**	**Strain hardening exponent at n-value (Automatic)**
1.23	6.50	38,029	0.27747

Using the recorded data (load and extension), the engineering stress is found by dividing the applied load by the specimen original cross sectional area.

$$\sigma_{eng} = \frac{P}{A_0}$$

The engineering strain is found by dividing the change in the specimen gage length by the specimen original gage length.

$$\varepsilon_{eng} = \frac{\delta}{l_0} = \frac{l - l_0}{l_0}$$

The true stress and true strain of Mild Steel AISI 1010 can be found by using the engineering stress and strain value with the equation below:

$$\sigma_{true} = \sigma_{eng}(1 + \varepsilon_{eng})$$

$$\varepsilon_{true} = \ln(1 + \varepsilon_{eng})$$

Table 4.2 below shown the value of engineering stress, true stress, engineering strain and true strain that can be find by using force (load) and extension data from this test. The data in the table below is 10second initial value of the data.

Table 4.2: Tensile Test Result for Mild Steel AISI 1010 1.5mm Thickness

Time(s)	Extension (mm)	Load (kN)	Engineering strain,(mm/mm)	Engineering stress(Mpa)
0	-0.00006	0.43723	0.000334	23.31893
1	0.01669	0.68085	0.000667	36.312
2	0.03337	0.9181	0.000999	48.96533
3	0.04994	1.15709	0.001331	61.71147
4	0.06656	1.39002	0.001665	74.1344
5	0.08325	1.62601	0.002001	86.72053
6	0.10006	1.86144	0.002334	99.2768
7	0.11669	2.08463	0.002665	111.1803
8	0.13325	2.30963	0.002997	123.1803
9	0.14987	2.52741	0.00333	134.7952
10	0.1665	2.74294	0.003667	146.2901

Based on the tensile test result above, the Stress-Strain graph can be plotted. The graph can be plotted by using the engineering stress and strain. Figure 4.1 below shown Stress-Strain graph for Mild Steel AISI 1010 material having a thickness of 1.5mm with different orientation angle (R).

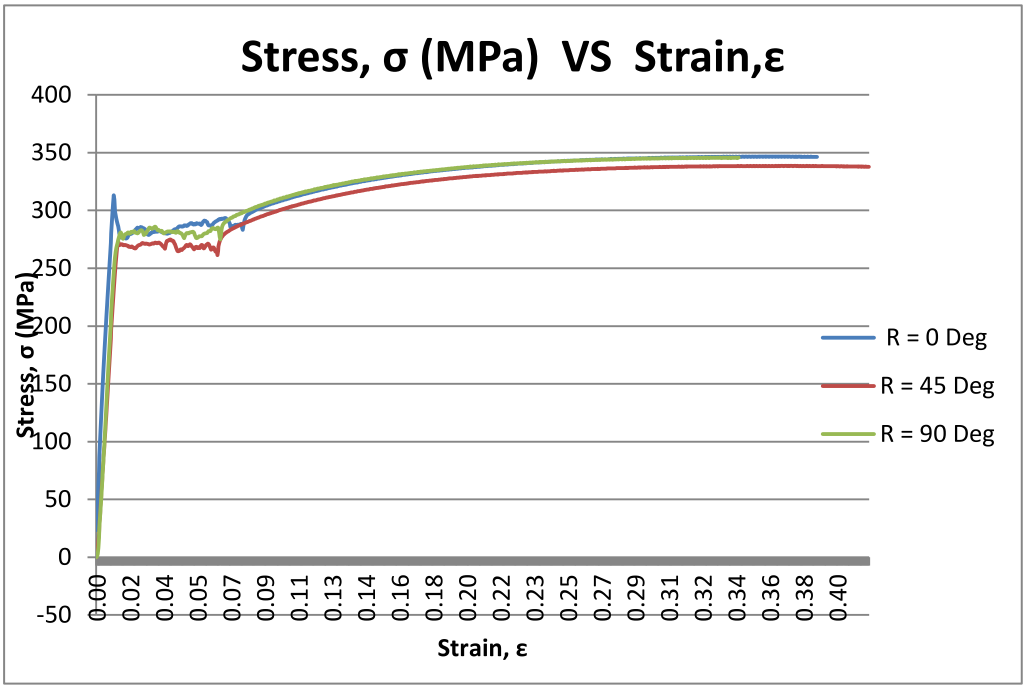


Figure 4.1: Different Orientation Angle of Stress-Strain Graph for Mild Steel 1.5mm Thickness

Another mechanical properties for mild steel such as anisotropy value and poison's ratio can be determined if the final width and length of specimens was measured. Table 4.3 shows the average width and length after the test.

Table 4.3: Final Width and Length of Specimen

Orientation Angle	Final Width,	Final Length,
Average 0	9.29333333	85.13462
Average 45	9.12444444	85.16525
Average 90	9.01222222	81.41844
Average Result For 1.5mm Thickness	9.14333333	83.90610

Anisotropy value, R is defined to express different contractile strain ratio and is generally applied as an index of anisotropy. Due to the difficulty in measuring gage thickness changes with sufficient precision, an equivalent relationship is commonly used, based on length and width strain measurements:

$$R = \frac{\varepsilon_w}{-(\varepsilon_l + \varepsilon_w)} = \frac{\ln(w_0/w_f)}{\ln(l_f w_f / l_0 w_0)}$$

Where ε_w and ε_l are true strains in width and length directions, w_0, w_f, l_0 and l_f are initial and final gage width and length, respectively. With most materials the change of R with strain ε_l is negligible.

The ratio of the two normal strains (lateral and longitudinal) is a material constant called the poison's ratio.

$$v = -\frac{\varepsilon_{lateral}}{\varepsilon_{longitudinal}} = -\frac{(w_f - w_0)/w_0}{(l_f - l_0)/l_0}$$

Wherew_0, w_f, l_0 and l_f are initial and final gage width and length, respectively. Table 4.4 below shows the final summaries for the mechanical properties of Mild Steel AISI 1010.

Table 4.4: Mechanical Properties of Mild Steel AISI 1010

Orientation Angle	Young's Modulus (MPa)	Strain Hardening Exponent, n	Ultimate Tensile Strength, UTS (Mpa)	Anisotropy Value, R	Poisson's Ratio, v
Average 0	32359.843	0.27747	346.7541333	0.26373	0.612382
Average 45	26381.335	0.27838	338.6325333	0.25365	0.643850
Average 90	29002.086	0.26750	345.7738667	0.24181	0.781632
Average Result For 1.5mm Thickness	29247.754	0.27445	343.7201778	0.253063	0.679288

From the tensile test experiment, the value of Young's Modulus is quite low which the average result for Young's Modulus is 29.247 Gpa. The standard value of Young's Modulus for mild steel should be in the range of 190-210 Gpa (M.Samuel,2000). This error happened due to the extensometer which during the tensile experiment, the extensometer cannot be functioned thus error occurred on following the tensile test procedure, but for the sake of the methodology the value of Young's Modulus from the experiment still need to be used. The extensometer is essential in tensile test experiment since it can give more precise result so, the improvement in tensile test is highly recommended.

4.3 FE SIMULATION RESULTS FOR U-BENDING TEST

The elastically - driven change of shape of sheet metal have been simulated with ABAQUS code. Due to plane symmetry, only half of the process was modelled (Figure 4.2). The problem consists of the surface contact between steel blank strip and the tools such as the punch, die and blank holder that is a basic aspect of the stamping operations. The tools can be modelled as rigid surfaces because they are much stiffer than the blank. Figure 4.2 shows the basic arrangement of the components considered in FEM model. The blank strip is squeezed between the blank holder and the die trough a normal load applied on the blank holder while the die remains always unmoving. The contact between the punch and the blank was supposed to be frictionless whereas the contacts between respectively the blank and the die and the blank and the blank holder were supposed to have a coulomb friction law with a friction coefficient of 0.1.

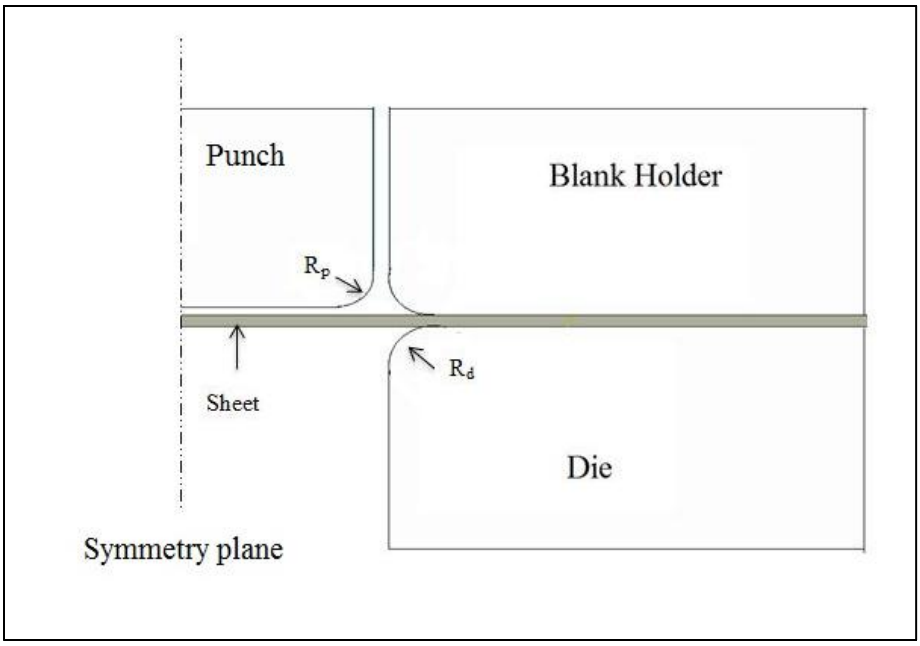


Figure 4.2 : Geometrical description of the simulation model

4.3.1 SIMULATION OF THE SHEET METAL BENDING

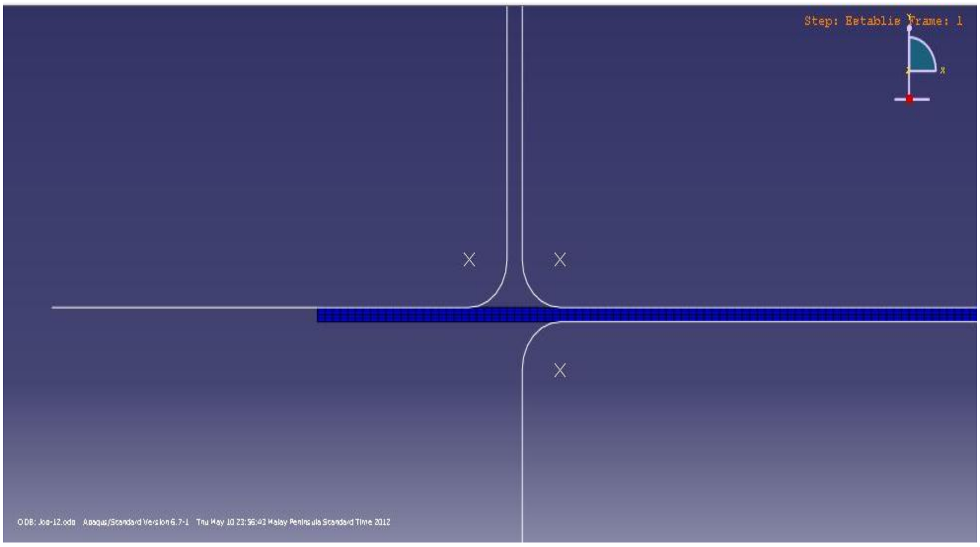


Figure 4.3 : Punch start touching the workpiece

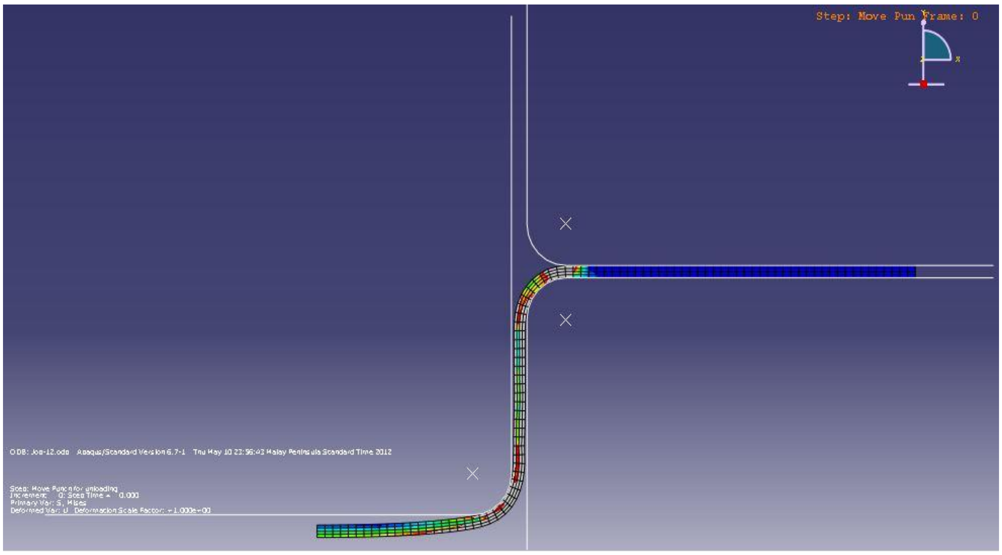


Figure 4.4 : During Bending

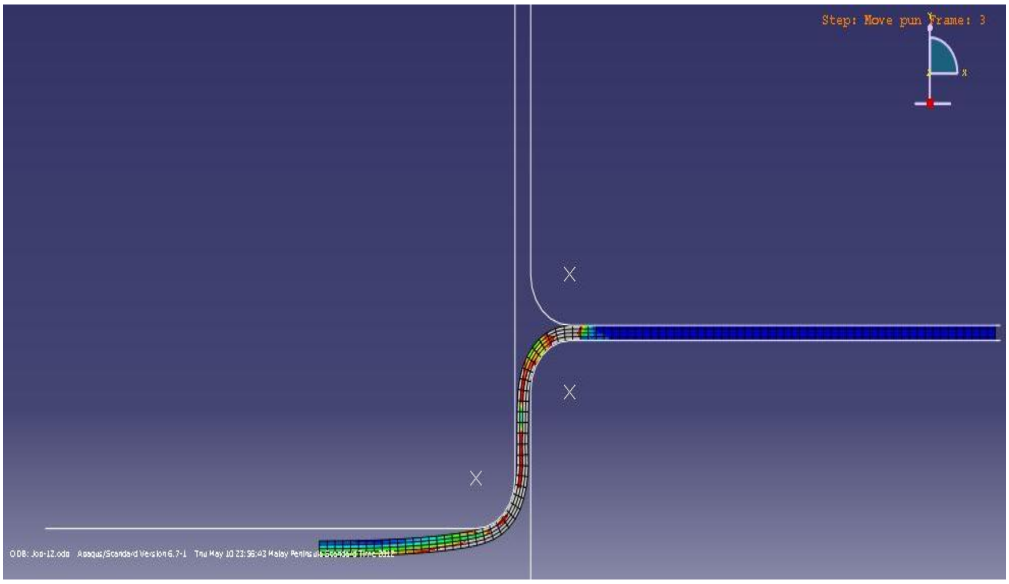


Figure 4.5: Maximum movement of the punch

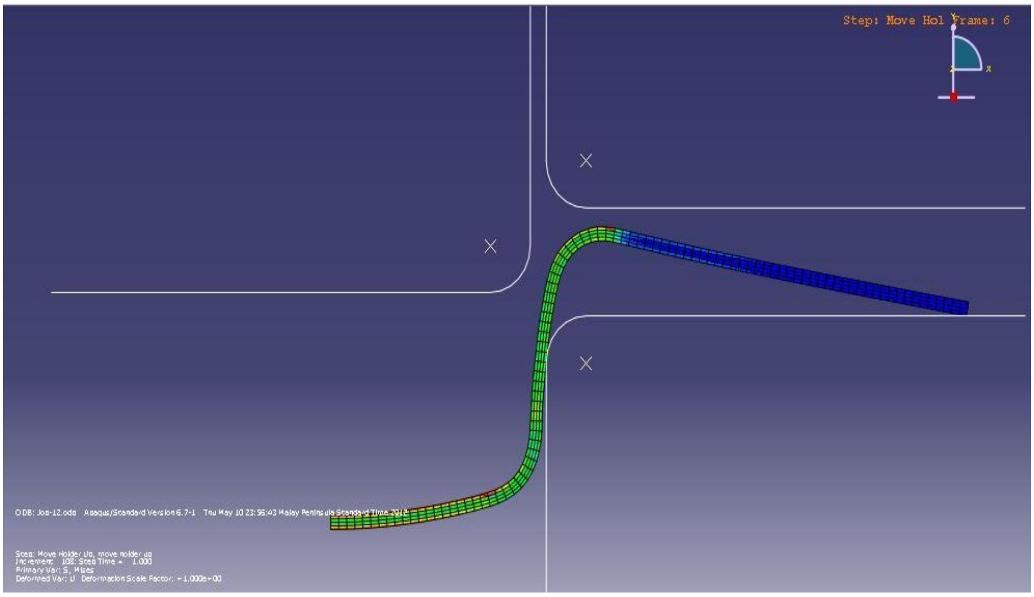
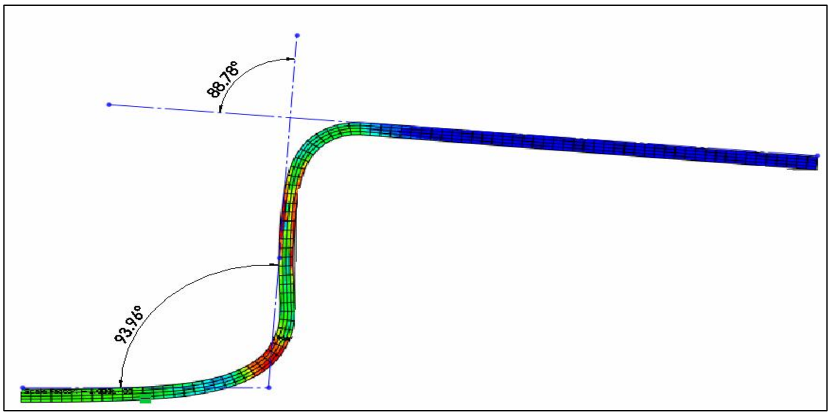


Figure 4.6 : After bending (Punch release)

4.3.2 SPRINGBACK MEASUREMENT FROM SOLIDWORKS



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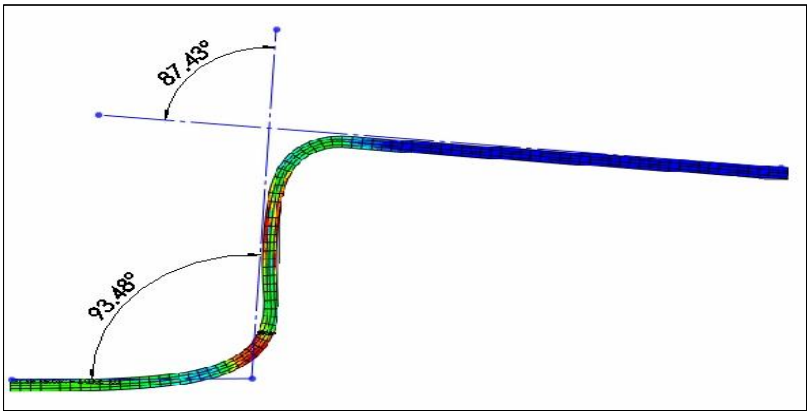
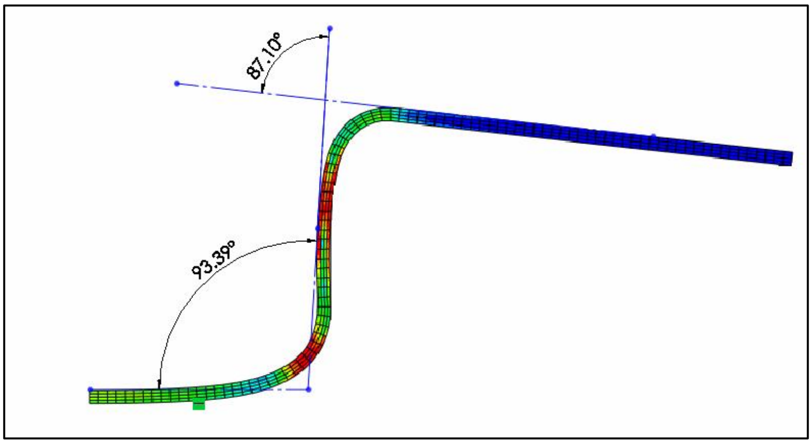


(b)



(c)

Figure 4.7 : (a) 0 degree , (b) 45 degree , (c) 90 degree simulation of rolling direction for Mild Steel 1.5mm thickness

The main objective of FEA is to predict springback for U-bending tests then the results obtained will be validated with experimental values. A 2D numerical analysis of the U-shaped bending process was carried out for comparison with experimental results. In order to truthfully validate materials parameters, both analyses were accomplished with similar operational conditions. This consisted of constant blank holder force of 440 KN. Table 4.5 shows the results of simulation for Mild Steel AS 1010, 1.5mm thickness.

Table 4.5 : Simulation result of springback for Mild Steel.

Rolling direction	0^0	45^0	90^0
Springback angle 1, Θ_1, (^{o})	93.39	93.48	93.96
Springback angle 2, Θ_2, (^{o})	87.10	87.43	88.78

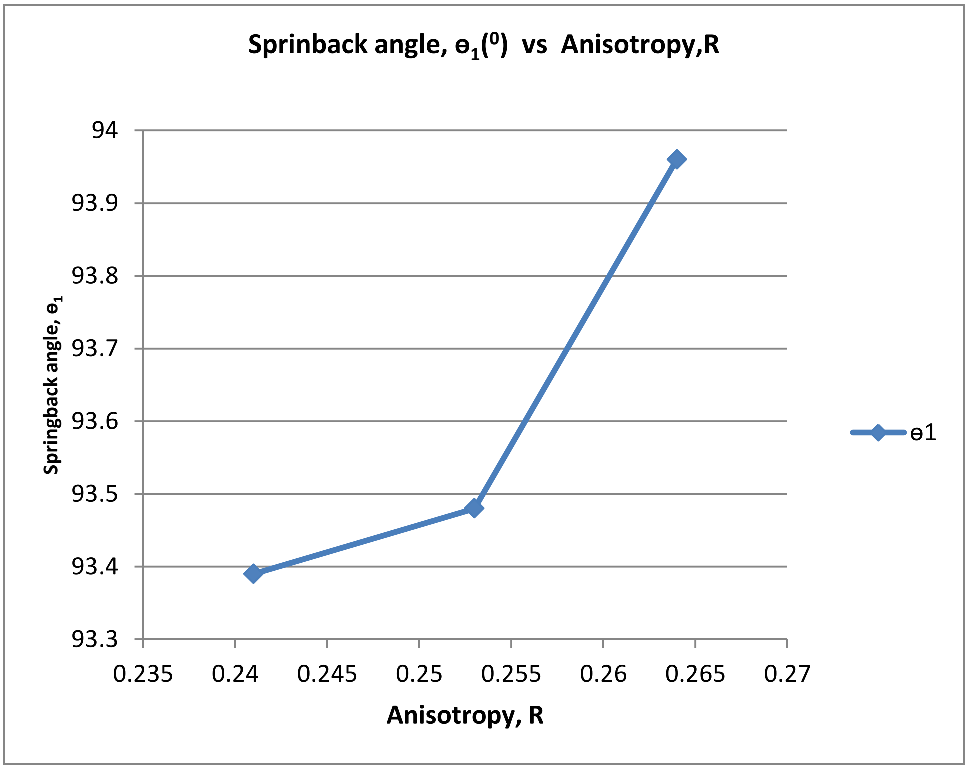


Figure 4.8: Anisotropy effect on amount of springback angle θ_1.

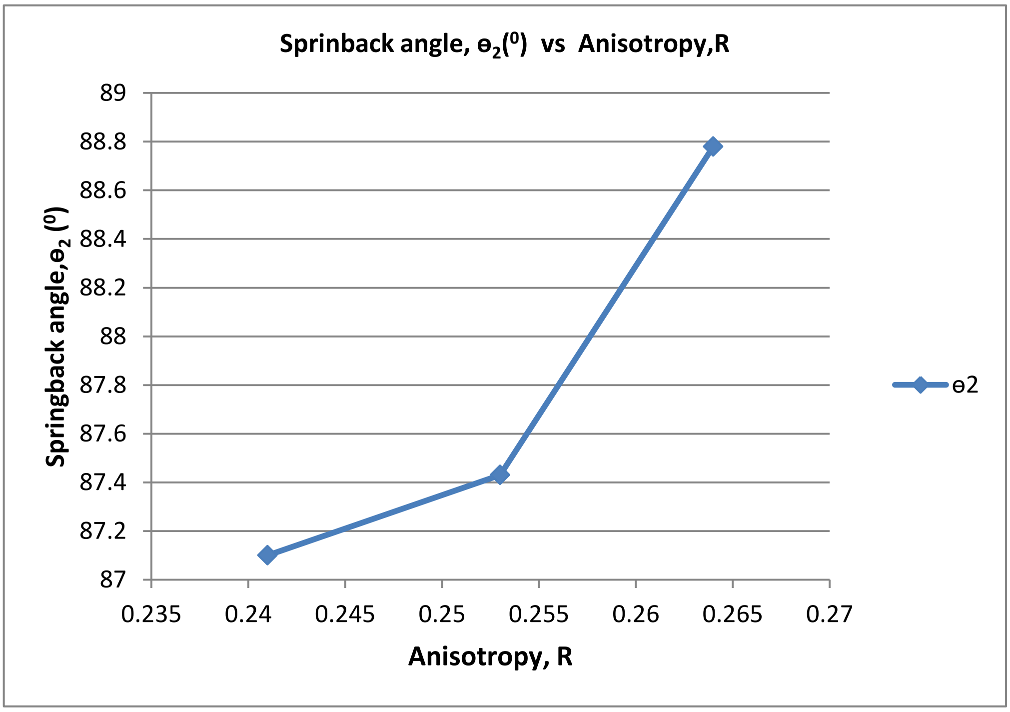


Figure 4.9: Anisotropy effect on amount of springback angle θ_2.

4.3.3 Effect of anisotropy on springback

Figure 4.8 shows that anisotropy effect on the springback , the line indicated that the values of springback angle , Θ_1 are increasing as the anisotropy value, R increasing. It is noted that, for the highest springback, sheet metal with the higher value of anisotropy is not good. Same goes to sspringback angle, Θ_2 , the value will increase as the anisotropy increase and conclude that springback are affected with the anisotropy value.

4.4 EXPERIMENTAL RESULTS

Based on experimental study, springback results were evaluated and these results were used in order to validate the proposed finite element calculation. After the unloading of blank holder section, springback values Θ_1 and Θ_2 were determined. Schematic descriptions of measurement position for springback are given in the Figure 4.10.

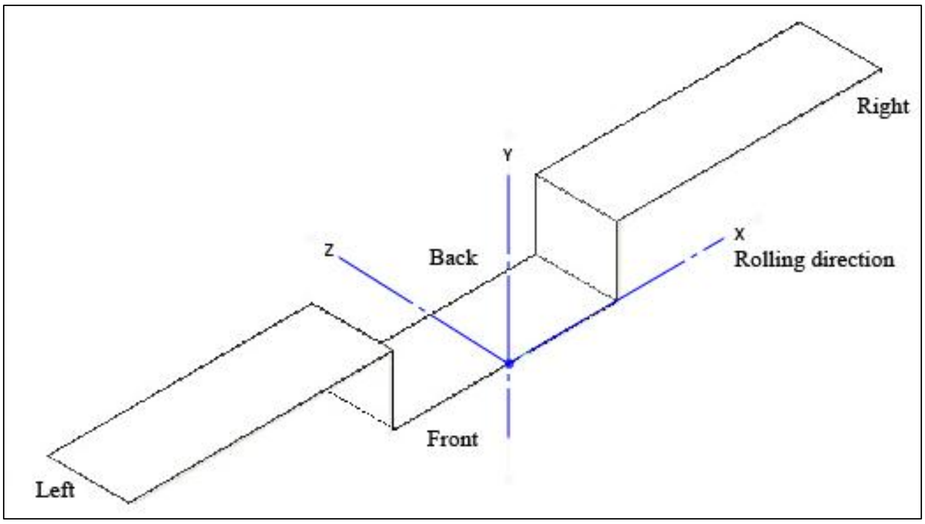


Figure 4.10 : Schematic description of measurement position for springback.

A 2D drawing of Mild Steel AS 1010, 1.5mm thickness after springback were shown on Figure 4.9 below. The 0 degree, 45 degree and 90 degree of Mild Steel specimens after removing from die also shown on Figure 4.11.

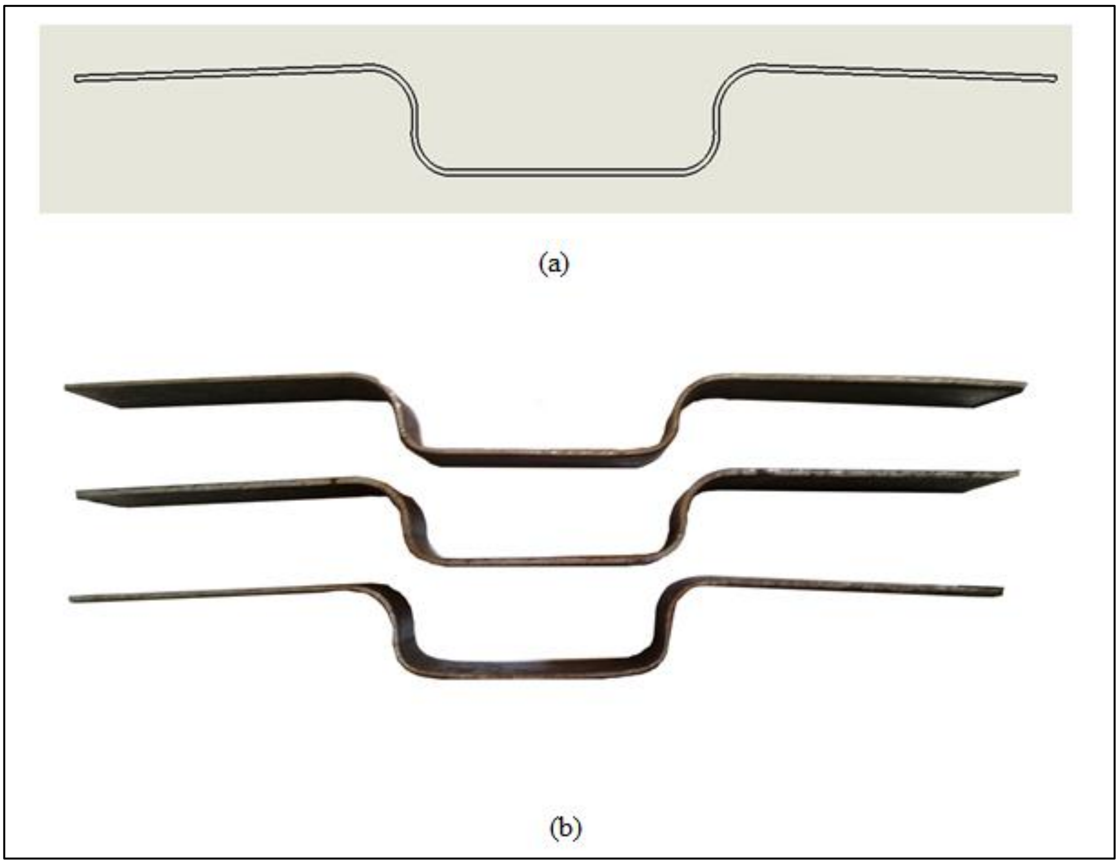
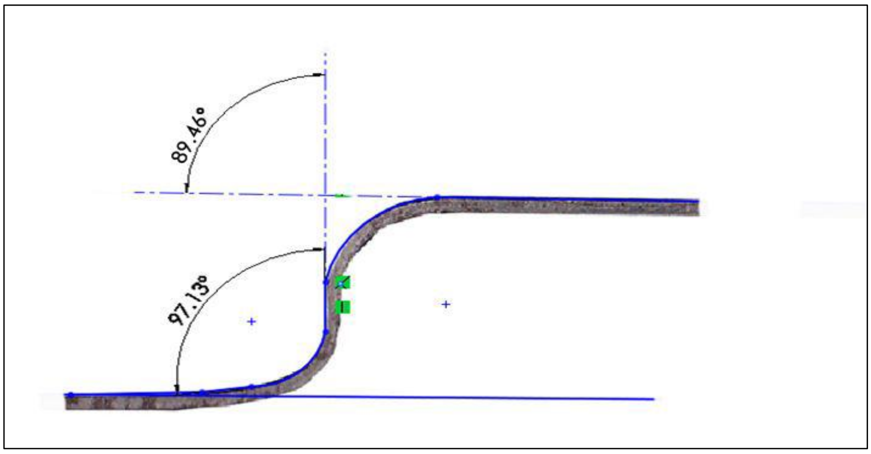


Figure 4.11 : (a) 2D drawing of Mild Steel after bending, (b) Mild Steel specimen after bend

The calculations of springback were performed according to Figure 3.20. The specimen will be scanned by a scanner and the angle, θ_1 and θ_2 then will be measured by using Solidworks software. The springback angle for each specimen then will be compared. There were nine specimens for U-bending test.

4.4.1 Springback measurement using SolidWorks 2011



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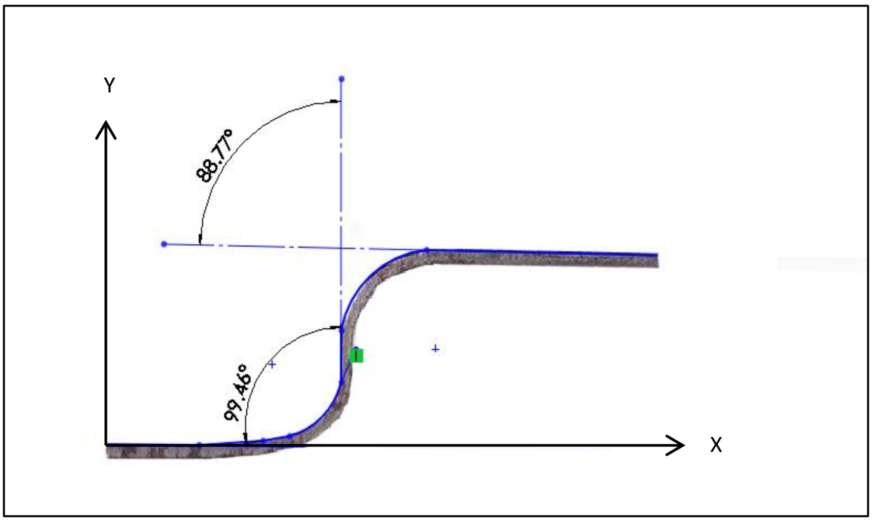

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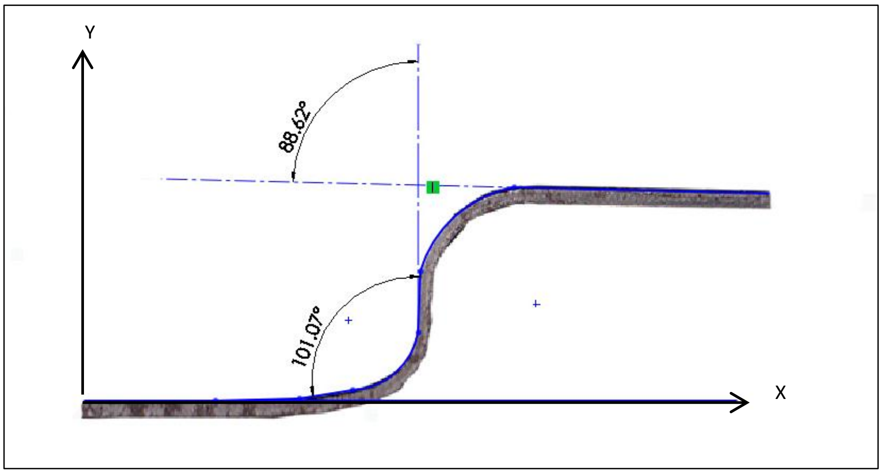
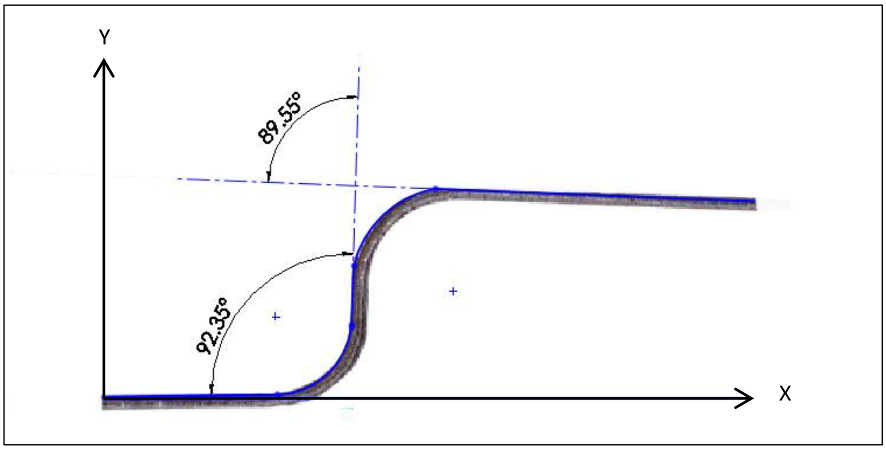
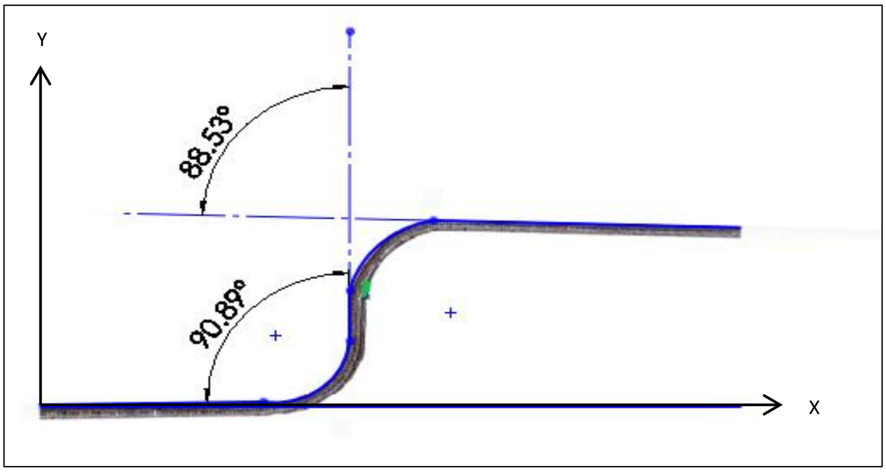


(c)

Figure 4.12 : (a) first specimen, (b) second specimen, (c) third specimen , with rolling direction = 0degree



(a)



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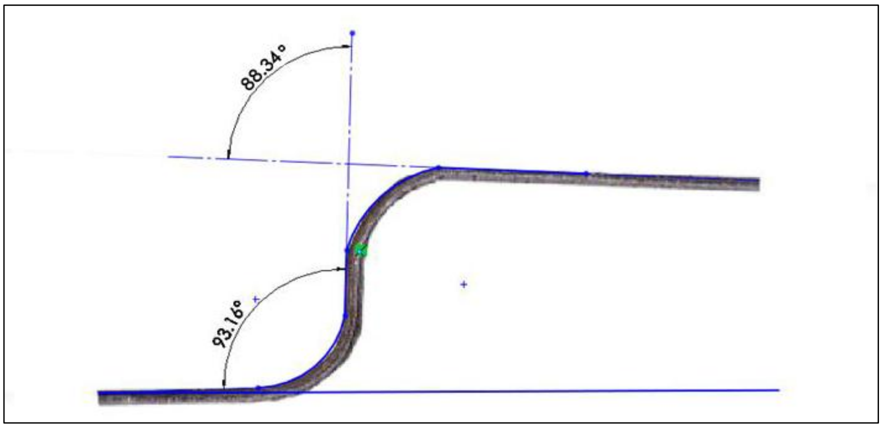
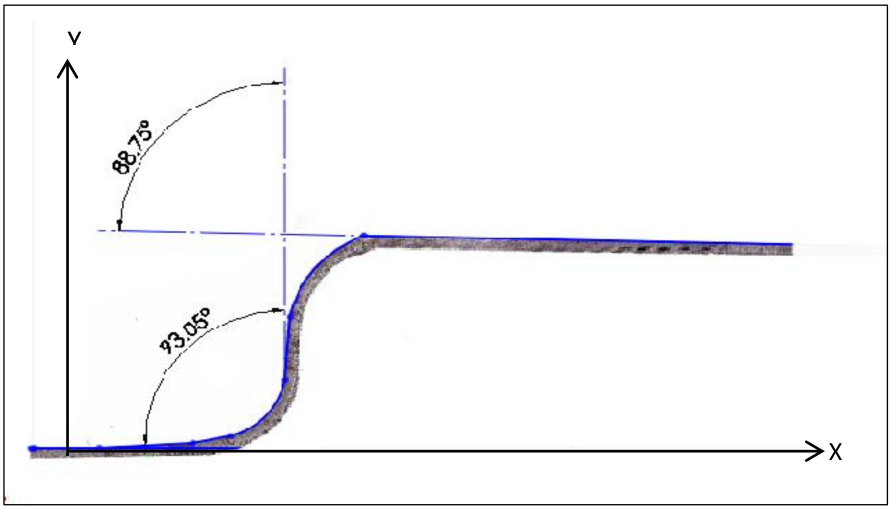
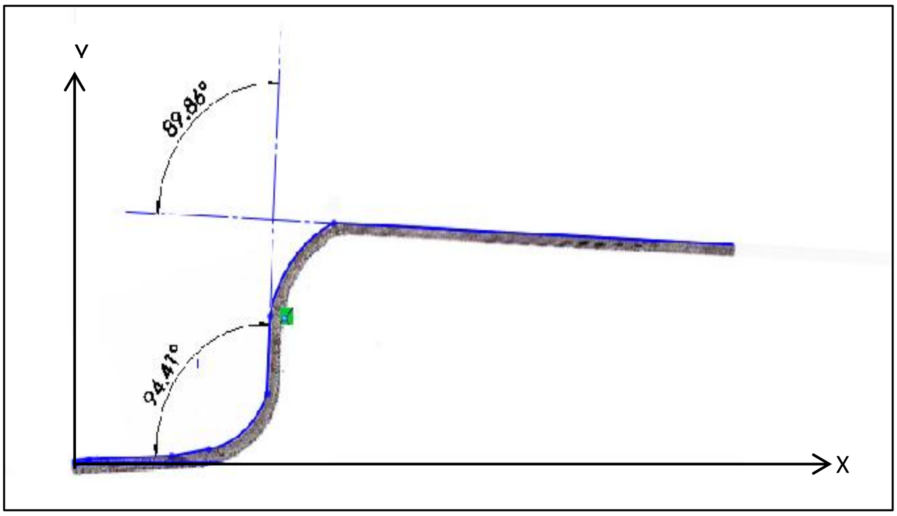


(c)

Figure 4.13 : (a) first specimen, (b) second specimen, (c) third specimen , with rolling direction = 45degree.



(a)



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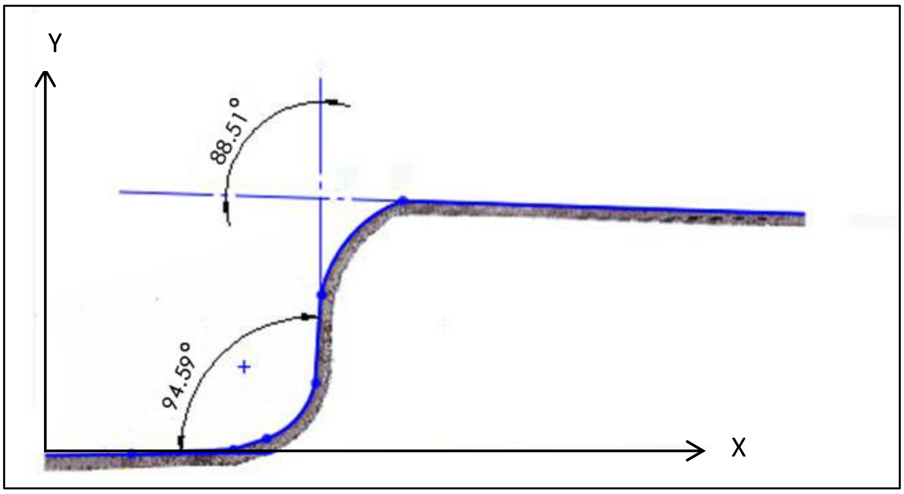

(c)

Figure 4.14 : (a) first specimen, (b) second specimen, (c) third specimen , with rolling direction = 90 degree.

The result obtained for Mild steel plates for rolling direction 0^0 , 45^0 , and 90^0 were given in Table 4.6

Table 4.6: Experimentally measured parameters of springback.

Rolling direction (Degree,)	0^0				45^0				90^0			
	1	2	3	Ave	1	2	3	Ave	1	2	3	Ave
Springback angle 1 ϴ1, (°)	97.13	99.46	101.07	**99.22**	92.35	90.89	93.16	**92.13**	93.05	94.47	94.59	**94.04**
Springback angle 2 (ϴ2),(°)	89.46	88.77	88.62	**88.95**	89.55	88.53	88.34	**88.78**	88.75	89.86	88.51	**89.04**

In this study, the springback variation in the forming of Mild Steel AS 1010 was characterized by investigating the effect of different rolling direction (anisotropy) which were 0, 45 and 90 degree. Their significance parameterson springback angles were investigated to see if they can be used to minimized springback angle.

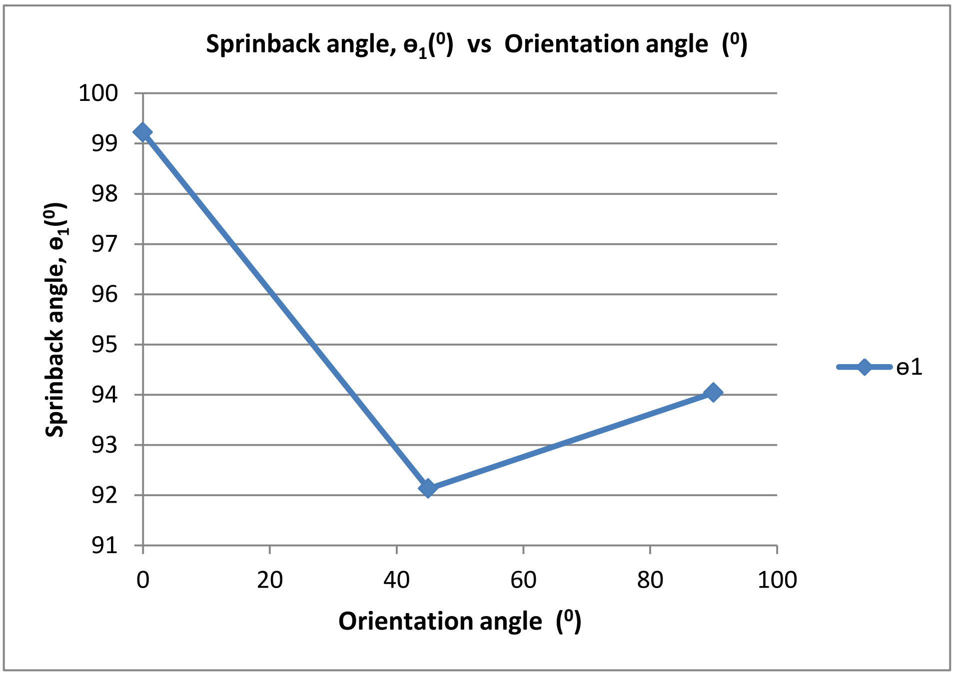

Figure 4.15 : Effect of orientation angle on springback, $ɵ_1$.

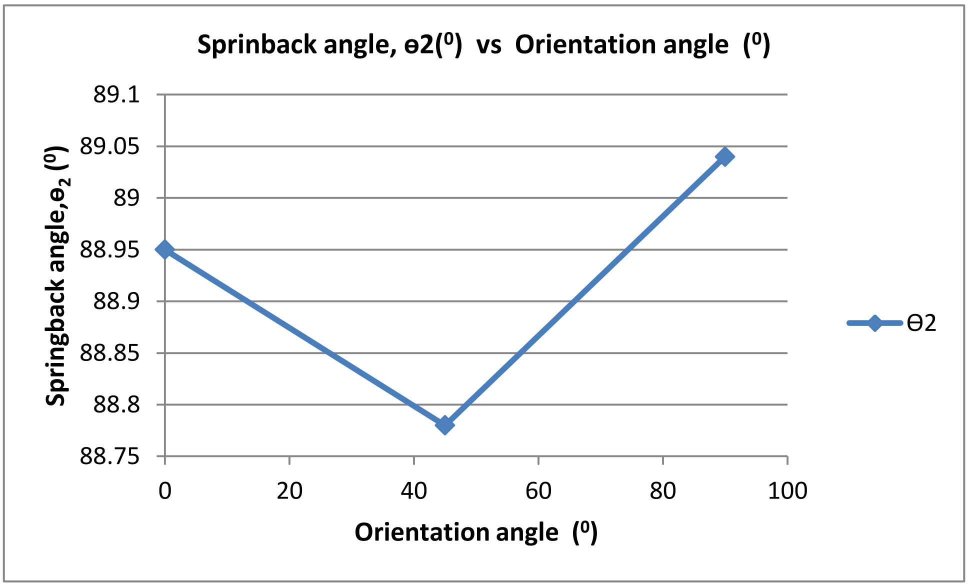

Figure 4.16 : Effect of orientation angle on springback, θ_2 .

4.4.2 Effect of orientation angle on springback

Test were performed under three different orientation angle started from 0 degree, 45 degree and 90 degree. From Figure 4.15 and Figure 4.16, it can be seen that the springback angle decrease as the orientation increase, but for the orientation angle 90 degree, the springback angle is increasing for both springback angle, Θ_1 and Θ_2 . This is because of the experimental error occurred which, after the stamping machine bent the sheet metals for 0 and 45 degree, the machine then stoped operating. For bending sheet metals of 90 degree orientation angle, the loading force used is not the same with the previous experiment , and caused the blank holder force applied is not constant.

4.5 COMPARISON OF FE SIMULATION AND EXPERIMENTAL

Table 4.7 shows the result of springback angle, Θ_1 and springback angle, Θ_2 for both FE Simulation and experimental. Graph shows the comparison of springback angle between experimental and simulation.

Table 4.7 : Springback values for Experimental and Simulation.

Orientation angle	0^0		45^0		90^0	
	Θ1	Θ2	Θ1	Θ2	Θ1	Θ2
Experimental	99.22	88.95	92.13	88.78	94.04	89.04
FE Simulation	93.39	87.10	93.48	87.43	93.96	88.78
Percentage of error POE (%)	5.88	2.08	1.47	1.52	0.09	0.29

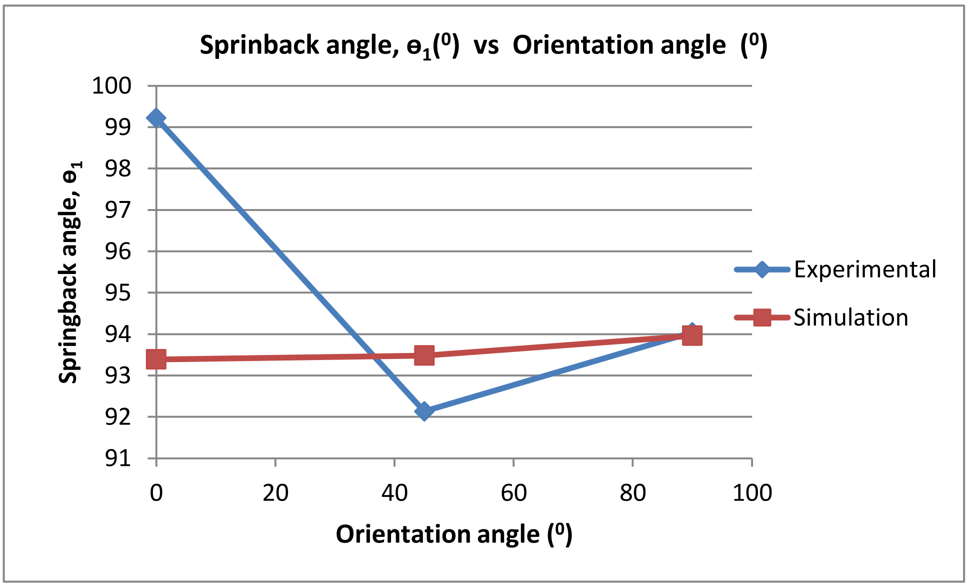

Figure 4.17 : Comparison between simulation and experimental for $ɵ_1$

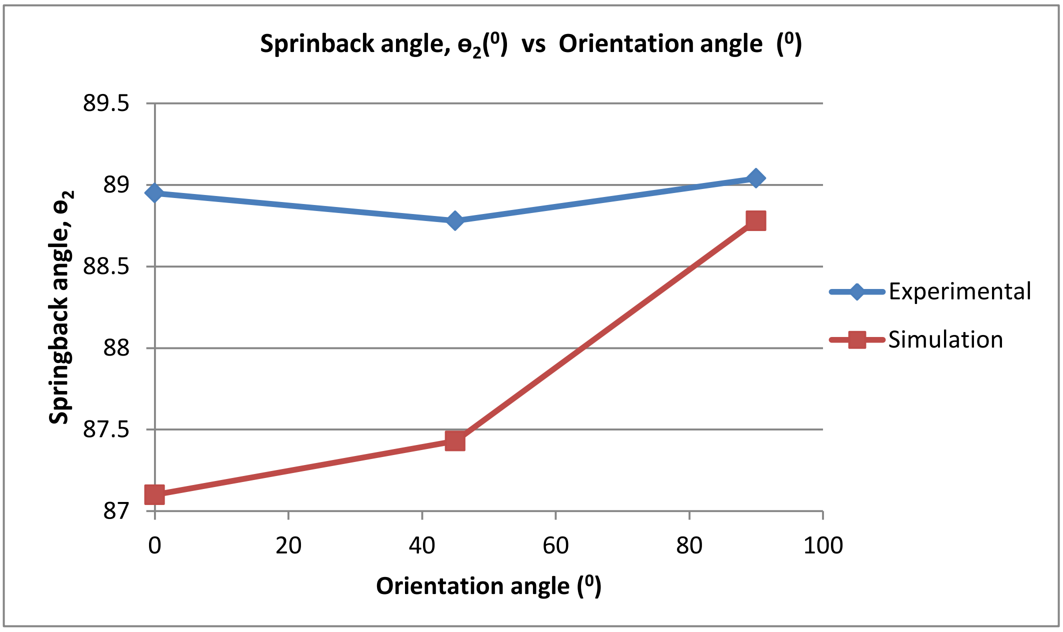

Figure 4.18 : Comparison between simulation and experimental for θ_2

Figure 4.17 and Figure 4.18 show the experimental and simulation effect of orientation angle on the springback of the Mild Steel material for 1.5 mm thickness. Comparing the result of the springback angle through the orientation angle, it is noted that orientation angle are strongly affected the springback angle. For springback angle from the simulation , by increasing the orientation angle, will increasing the springback value. But for experimental value, the graphs show that 45 degree has the lowest springback. This difference occurred due to the experimental that have been mentioned earlier and sheet metal bending belonging to out of plane forming process is characterized by small strain but large deformation, as well the frictional contact boundary changes during the process. This implies that the finite element analysis of sheet metal bending process is quite difficult and a lot of parameters need to be considered.

CHAPTER 5

CONCLUSION

5.1 INTRODUCTION

Generally this chapter concludes the study. Besides that, the objective is also be reviewed in this chapter to determine if it is achieved or not. The contribution of this study, the limitation are also been discussed in this chapter.

5.2 CONCLUSION

Based on the study, the following remarks are drawn :

1. The amount of springback angle are in the range of :
   i. Springback angle , Θ_1 : 92.13^0 to 99.22^0. This is proven on Figure 4.17.
   ii. Springback angle, Θ_2 : 87.20^0 to 89.04^0 . This is proven on Figure 4.18.
2. Orientation angle are strongly affected the amount of springback which are by increasing the orientation angle will increasing the springback.
3. Finite Element Analysis can be used to predict springback since the pattern of the graphs compared are nearly the same and the percentage of errors, (POE) are less than 10 %.

5.3 RECOMMENDATIONS

For the improvement of the study, there are several matters can be done:

(i) Using a variety of materials in the experiment and simulation such as are Aluminium, Stainless Steel and so on to investigate which material that have a less springback.

(ii) Using different thickness for every material used to investigated the effect of thickness on springback.

(iii) Study the meshing effect to predict the springback by using a different mesh in the simulation and choose the result that has a nearest value with the experiment.

(iv) Consider the blank holder force since this parameters are strongly affected the amount of springback.

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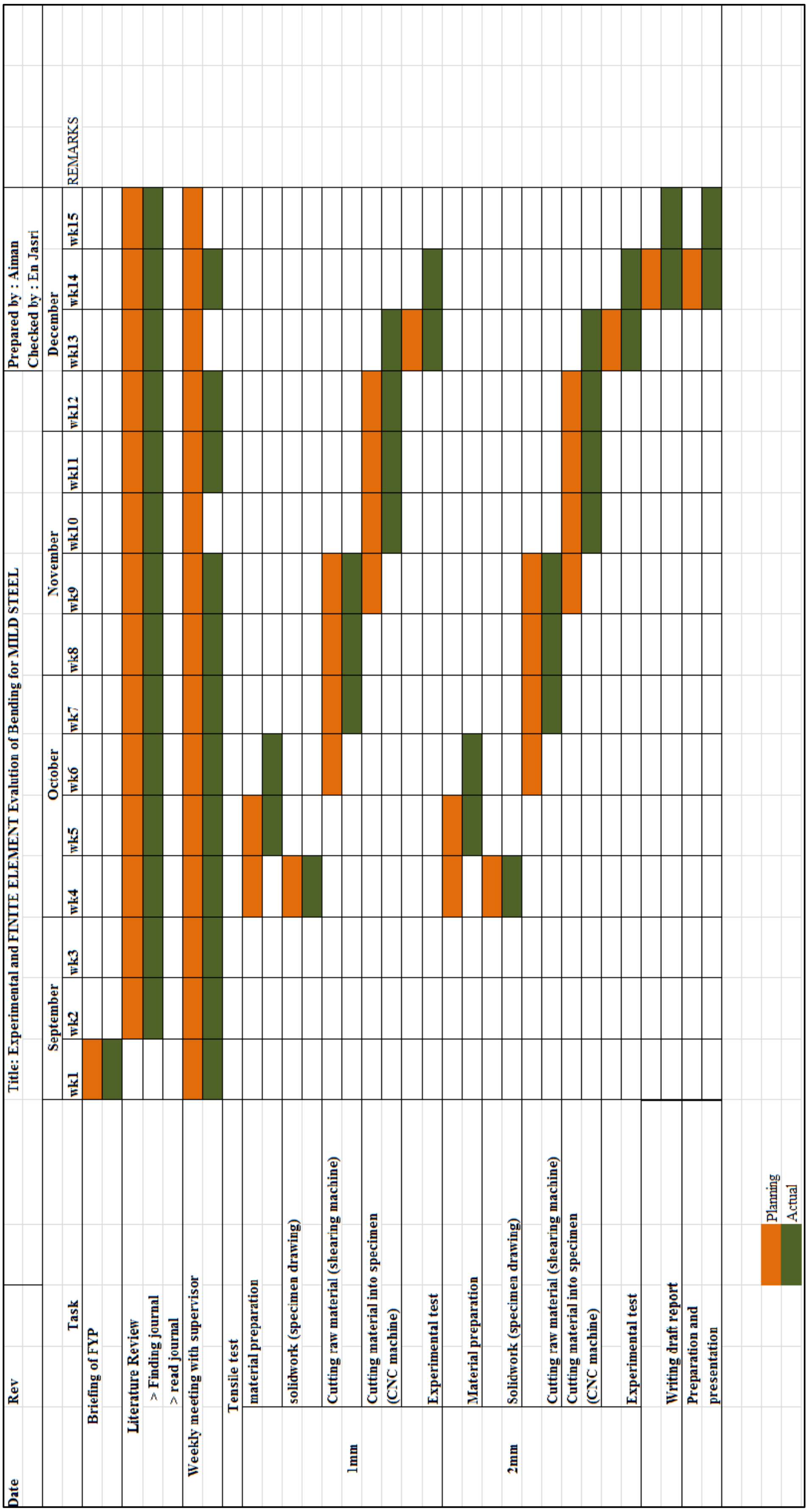
APPENDICES

APPENDIX A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Prepared by : Aiman
Checked by : En Jasri
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REMARKS
Briefing of FYP
Literature Review
> Finding journal
> read journal
Weekly meeting with supervisor
Tensile test
1mm
material preparation
solidwork (specimen drawing)
Cutting raw material (shearing machine)
Cutting material into specimen
(CNC machine)
Experimental test
2mm
Material preparation
Solidwork (specimen drawing)
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(CNC machine)
Experimental test
Writing draft report
Preparation and
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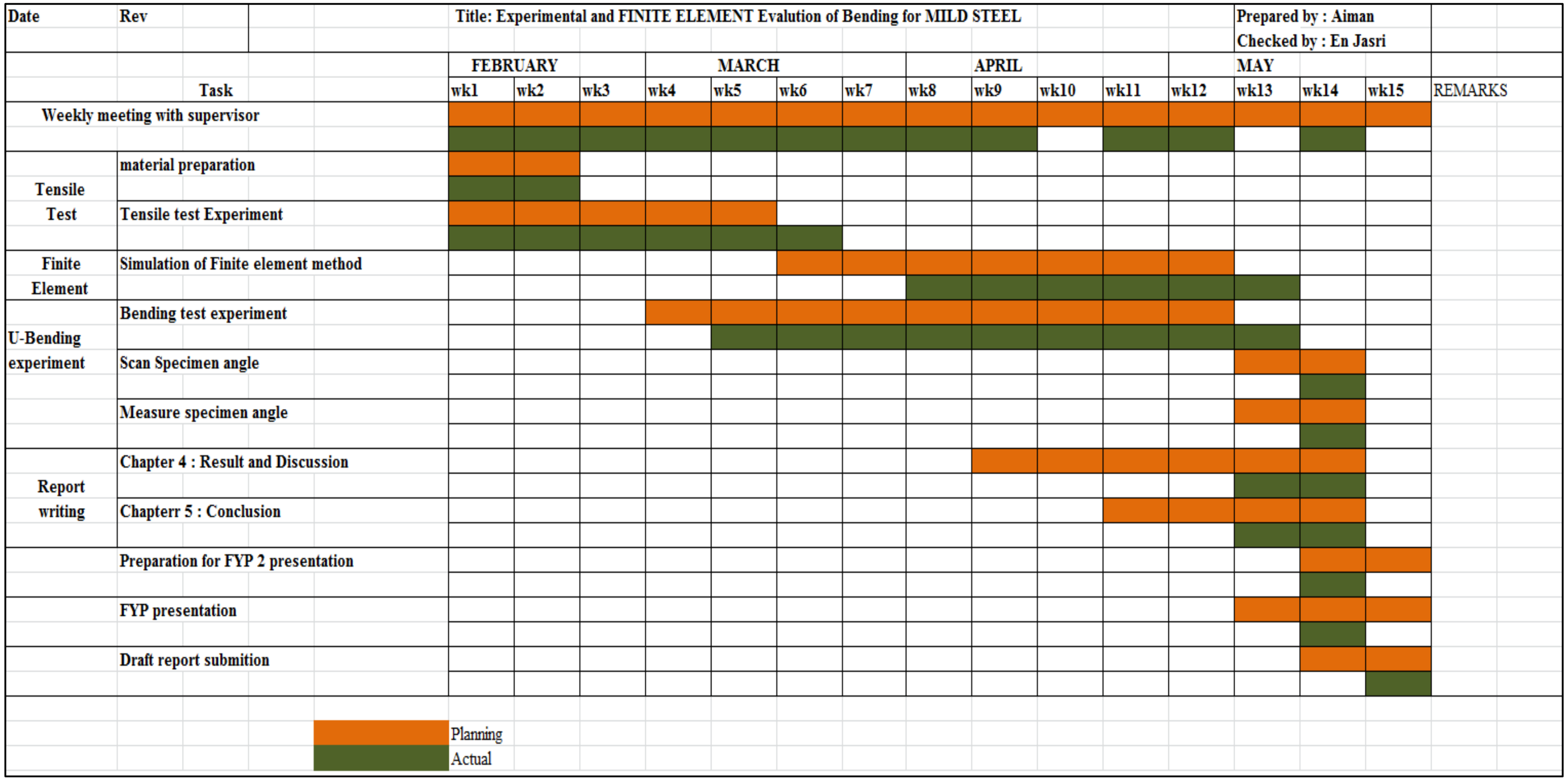
Actual

APPENDIX B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Checked by : En Jasri
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REMARKS
Weekly meeting with supervisor
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Tensile test Experiment
Finite Element
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U-Bending experiment
Bending test experiment
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Chapterr 5 : Conclusion
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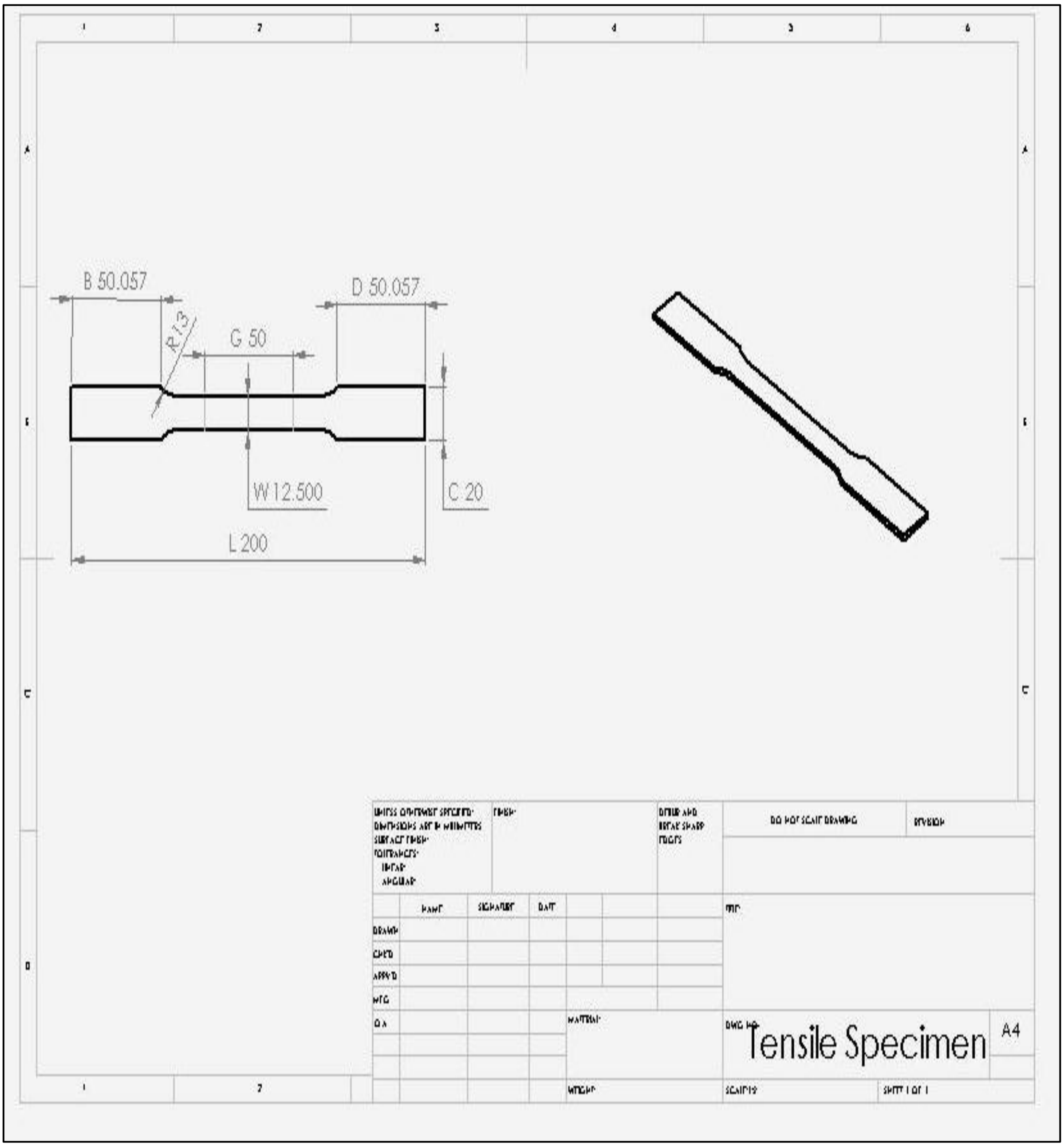
Actual

APPENDIX C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D 50.057
R 13
G 50
W 12.500
C 20
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Tensile Specimen
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APPENDIX D

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N104 T1 M6
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N108 G43 H1 Z25. M8
N110 Z5.
N112 G1 Z-2.5 F10.
N114 X-42.85 F40.
N116 X-40.513 Y15.692
N118 G3 X-37. Y14.25 R5.
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N126 X100.
N128 G0 Z25.
N130 X-100. Y-18.
N132 Z5.
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APPENDIX E