IDENFICATION OF ISOTROPIC HARENING PARAMETERS FOR STAINLESS STEEL SHEET BY CYCLIC LOADING TOOL

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ABSTRACT

This project presents the new developed experiment tools for bending and unbending test to identify the parameters hardening of isotropic equation. Stainless steel is used as specimen due to it very widely used in many industries. This experiment helps to improve the performance of simulation to solve forming problem such as springback. The new developed tools are fabricated by using CNC machine with Solidwork and Mastercam software. The new developed tool is installed on the tensile test machine for bending and unbending experiment. The experimental load-extension data are converted to stress-strain data. The hardening parameters are identified using optimization software from Matlab. The fitting curve shows adjusted R-square values recorded are more than 0.9, which mean the parameters values identified are very good for fitting the experimental curves. Improvements in the newly developed tools are suggested to reduce the friction and specimen holding method by installing roller in the holder.

ABSTRAK

Projek ini membentangkan satu alat eksperimen membengkok yang baru untuk mengenal pasti parameter pengerasan persamaan isotropi kerana ini digunakan secara meluas dalam banyak industri. Alat yang baru direka dibuat dengan menggunakan mesin CNC dengan Solidwork dan perisian Mastercam. Eksperimen data ditukar kepada stress-strain data. Parameter pengerasan dikenal pasti dengan menggunakan perisian pengoptimuman dari Matlab Software. Nilai adjusted R-square menunjukkan nilai 0.9 and ke atas, ini bererti nilai parameter yang dikanl pasti adalah sangat baik untuk pemasangan keluk eksperimen. Parameter ini adalah penting untuk aplikasi dalam simulasi membidas lembaran logam membentuk kecacatan seperti membidas.

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LIST OF SYMBOLS

P	Force (load)
r_1	Length of Hand part
r_2	Length of Holder part
x_B	Length of Header part with Specimen
F_x	Force at x-axis
F_y	Force at y-axis
F_R	Resultant force
M	Moment
σ	Stress
I	Moment of Inertia
b	Width of Specimen
h	Thickness of Specimen
r_c	Radius of Curvature
s	Length of Unclamped Specimen
ε	Strain
y	Half of Specimen Thickness

LIST OF ABBREVIATIONS

SSE	Sum Square Error
RMSE	Root Mean Square Error

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

In a typical sheet metal forming practice, the material points may experience cyclic loads, For example, the process of bending-unbending on the die shoulder and reverse bending-unbending at the punch. So, the transient of the cyclic behavior of the material must be modeled properly for a realistic simulation of the sheet metal forming process and subsequent prediction.Recently in uniaxial applications showed the importance of a proper choice of isotropic hardening law in order to predict the correct stress distribution after forming (Carbonnie`re et al., 2009). During bending-unbending of the material, removal of the forming tools, the amount of springback depends to a great extent on the elastic stiffness of the material on Young’s modulus (Mullan, 2004). In classic plasticity theory, the bending-unbending of a material after plastic deformation is assumed to be linearly elastic with the stiffness equal to Young’s modulus. Various types of models can be used to describe this initial and induced anisotropy, according to their required ability to explain and predict the details of the plastic behavior during a given deformation process (Qian et al., 2007). Thus, rather simple models of isotropic hardening can already give a sufficiently good estimate of the drawing or ironing forces occurring during the process.

1.2 PROBLEM STATEMENT

Precise prediction of the springback is a key to designing bending dies, to controlling the process and the press, and to assessing the accuracy of part geometry (Eggertsen and Mattiasson, 2007). A complete theory and reliable simulation has been developed to improve springback prediction. One of the areas to be improved is to provide reliable material parameter inputs into the simulation software. Thus works to improve the method of determining material parameters are important and have been done by several researchers.

1.3 OBJECTIVES

To identify reliable hardening parameters of stainless steel in sheet metal forming by using newly developed tool.

1.4 SCOPE OF PROJECT

i. To conduct literature review and identify any weakness and strength in the existing experimental tool for potential improvement.
ii. To design a new experimental tool. Work includes drawing and the force analysis of the tool reliability.
iii. To fabricate the tools. The job includes developing M-Code and G-Code for machining the tools' components using CNC machine.
iv. To conduct the experimental works with developed tools.
v. To analyze the experimental data acquire which stated at number iv.
vi. To identify the hardening parameters. To fulfill the job, the optimization tool in Matlab Software is used.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter discusses about the hardening theory. There are three hardening laws which are isotropic, kinematics and mixed hardening. This project will only focus on the isotropic hardening. There are several type of bending test methods are used such like tensile test, three point bending test and bending-unbending test. To identify the parameter hardening, the optimization tools in Matlab is Levenberg-Maquardt Method was used. There also shown an overview of the springback.

2.2 HARDENING THEORY

Hardening rule is a specification of the dependence of the yield criterion on the internal variables, along with the rate equations for these variables. Firstly, we will look for three rules for material hardening. Afterwards, we will look more details on some isotropic hardening types.

2.2.1 Hardening Laws

In uniaxial experiment, it is observed that the yield stress associated to a material can vary upon plastic loading. Furthermore, for some class of materials the yield stress in the reverse load direction which can define as compression is different than for tension. These phenomena can be modeled using various hardening laws.

2.2.2 Three Rules For Material Hardening

The three rules are kinematic, isotropic and combined hardening and these three rules have been applied to consider the effect of complex deformation history that has undergone stretching, bending, and unbending deformation on the sheet springback. The Figure 2.1 shows the stress strain relationship of the three material hardening rules.

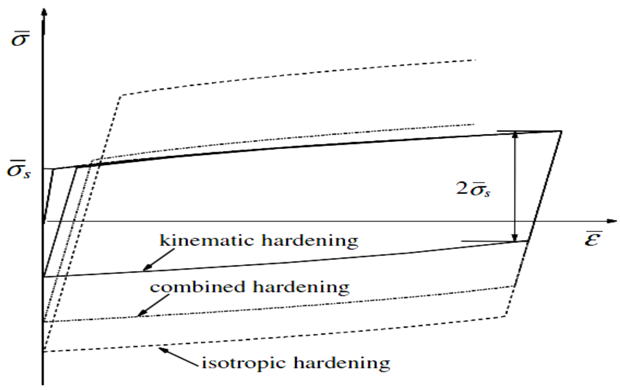


Figure 2.1 : The stress-strain relationship of three material hardening rules

Source : Carbonnie` re et al. (2009)

As shown in Figure 2.1, for forward loading, the stress strain relationship of three material hardening rules is the same, that is

$$\bar{\sigma} = \begin{cases} E\bar{\varepsilon} & \bar{\varepsilon} \leq \bar{\varepsilon}_{e\ lim} \\ k(\varepsilon_o + \bar{\varepsilon})^n & \bar{\varepsilon} \geq \bar{\varepsilon}_{e\ lim} \end{cases} \tag{2.1}$$

where $\bar{\sigma}$ and $\bar{\varepsilon}$ are effective stress and effective strain, respectively: k, n are hardening coefficient and hardening exponent, respectively; E is Young's modulus; $\bar{\varepsilon}_{e\ lim}$ is elastic limit strain($\bar{\sigma}_s$/E); is initial yielding stress; ε_o is the strain corresponding to $\bar{\sigma}_s$.

2.2.3 Isotropic Hardening

The hardening behavior of isotropic is the shape of the yield surface remains fixed, whereas the size of the yield surface changes under plastic deformation. In other words, the yield surface expands without translation under plastic loading. There are two most common isotropic hardening which is Swift’s law and Voce’s law. Figure 2.2 shows the patterns of the isotropic hardening.

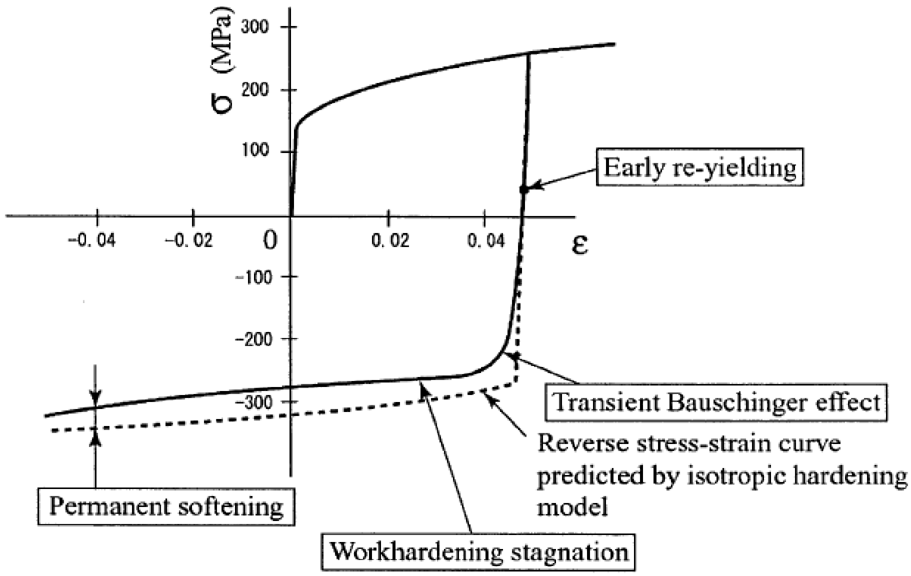


Figure 2.2 : Example of stress–strain response in a forward-reverse deformation

Source : Geng et al. (2002)

2.2.4 Swift Hardening Law

The Swift hardening law is one of the most used isotropic hardening law. The author Safaei et al. (2012) was cited the Swift hardening law is described as Equation (2.2)

$$\sigma^{iso} = C_R \, (\varepsilon_o + \varepsilon^P)^n \qquad (2.2)$$

and Figure 2.3 shows the Swift hardening curve.

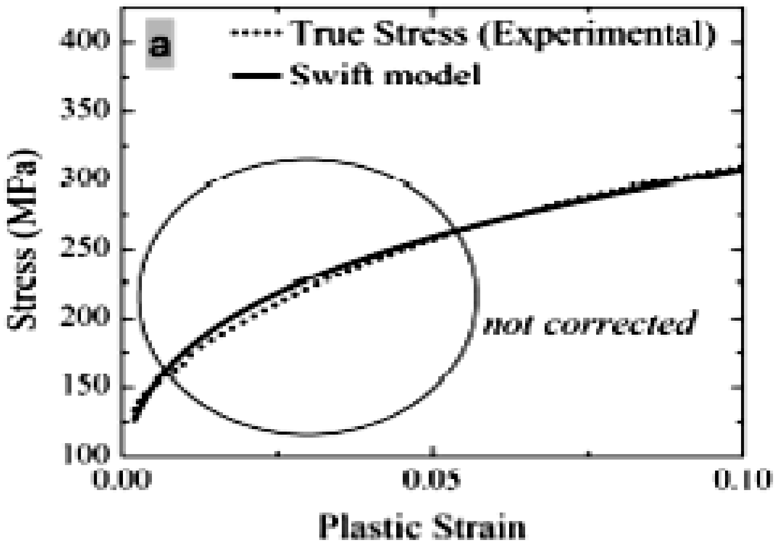


Figure 2.3 : Swift hardening curve at rolling direction for Swift model

Source : Safaei et al. (2012)

2.2.5 Voce Hardening Law

The second type is the Voce hardening law for the isotropic hardening law. This law was used in Qian et al. journal. The final general equation is describe as

$$\sigma = \sigma_o + R(1 - \ell^{-b\varepsilon_p}) \qquad (2.3)$$

For a Voce-type hardening material, the stress–strain curve may be given by the following equation as stated in the Figure 2.4.

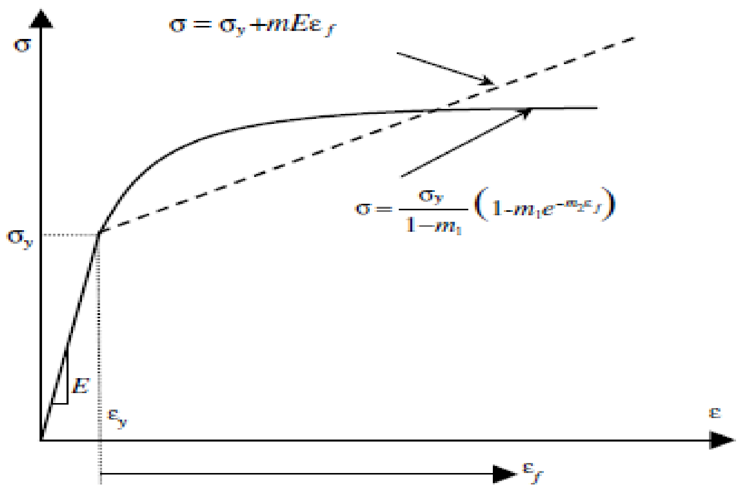


Figure 2.4 : Schematic of the stress–strain curves of linearly hardening and Voce type hardening materials

Source : Qian et al. (2007)

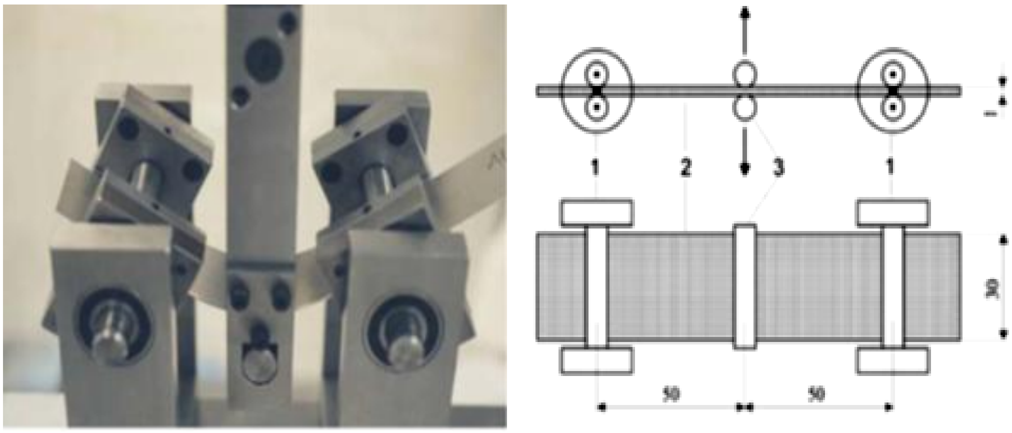
2.3 TEST IN DETERMINING PARAMETERS

2.3.1 Bending Test

Bending test also known as a bend test, is used to determine the strength of a material by applying force to the item in question and seeing how it reacts under pressure. Typically the bend test measures ductility, the ability of a material to change form under pressure and keep that form permanently.

2.3.2 Three-point Bending Test

The three-point bending test is the most practical method for determining the fracture strength of columnar minerals due mainly to the simplicity of sample preparation compared with that for other mechanical tests such as the simple tensile test. The equipment used in the experiments has previously been described in Omerspahic et al. (2005) and Eggertsen and Mattiasson(2007). The test set-up is illustrated in Figure 2.5. Especially, the design of the end supports should be noticed. These provide a moment-free support, while the sheet strip is allowed to slip freely between two rollers in the axial direction. The punch in the middle is moved with a prescribed sinusoidal displacement.



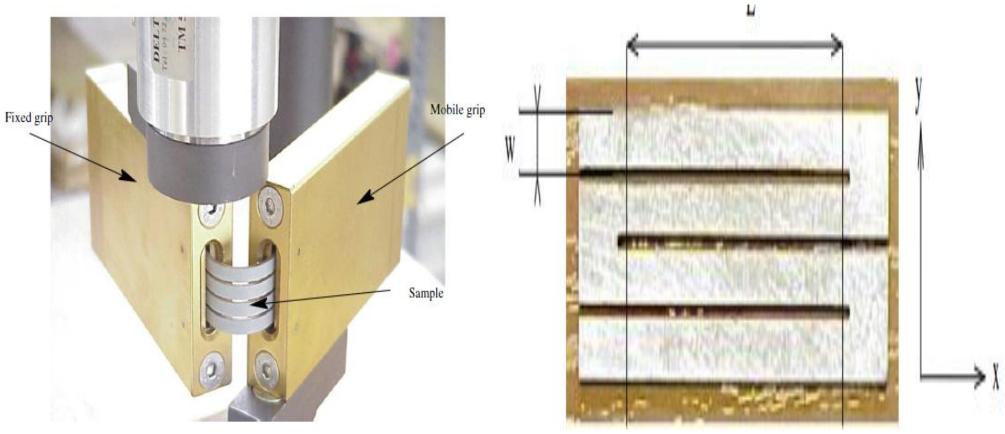
(a) (b)

Figure 2.5 : Experimental set-up used in the three-point cyclic bending tests. (a) picture of experimental equipment and (b) sketch of the test arrangement.

Source : Omerspahic et al. (2005)

2.3.3 Bending–unbending Test

This bending-unbending test method has been used in the Carbonnie` re et al. (2009). The test specimens have a rectangular shape with three rectangular slots machined in order to obtain four narrow strips of width w = 5 mm and the gauge length is 31.5 mm. The role of these slots is to avoid an anticlastic curvature of the sheet in the y direction, as was noticed in making it then reasonable to assume a plane stress state with $\sigma_{yy} = 0$. A cyclic experiment is necessary to identify the hardening behavior. Therefore, the specimen is bent, unbent and finally re-bent in the opposite direction as show in Figure 2.6.



(a) (b)

Figure 2.6 : Types and geometry specimen. (a) photograph of the bending test and (b) geometry of the samples

Source : Carbonnie`re et al. (2009)

2.4 OPTIMIZATION

Nowadays, the optimization method was used to find the parameters for the stress-strain curve is very famous. Singiresu (2009) was cited that the methods of optimizations are useful in finding the optimum solution of continuous and differentiable functions. These methods are analytical and make use of the techniques of differential calculus in locating the graph’s point.

2.4.1 Levenberg-Marquardt Method

Levenberg-Marquardt Optimization is a virtual standard in nonlinear optimization which significantly outperforms gradient descent and conjugate gradient methods for medium sized problems. It is a pseudo-second order method which means that it works with only function evaluations and gradient information but it estimates the Hessian matrix using the sum of outer products of the gradients (Bahram et al. 2005).

2.5 SPRINGBACK IN BENDING-UNBENDING

2.5.1 Bending Theory Related Springback

The theory bending of sheet steel using linear-elastic laws has been the subject of many theoretical investigations (Mullan, 2004). However, Figure 2.6 show the application of plasticity theory to sheet bending is often simplified, to facilitate the development of simplified solutions. These have been used effectively for prediction of bends for small diameter to gauge ratios, their applicability to alternative scenarios such as larger diameter to gauge ratios, where the elastic recovery of the springback is greater, have been quantified and are found to want (Mullan, 2003). Bending operations for the latter are well suited to material models reflecting an elastic perfectly plastic behaviour. Springback is often denoted as a unit less quantity '*K*', the value of which directly reflects the ratio of elastic to plastic deformation. The measurement is defined as the springback ratio, which is a ratio of the press angle, to that of the final formed angle:

$$K = \frac{\theta}{\theta + \Delta\theta} = \frac{\rho}{\rho + \Delta\rho} \tag{2.4}$$

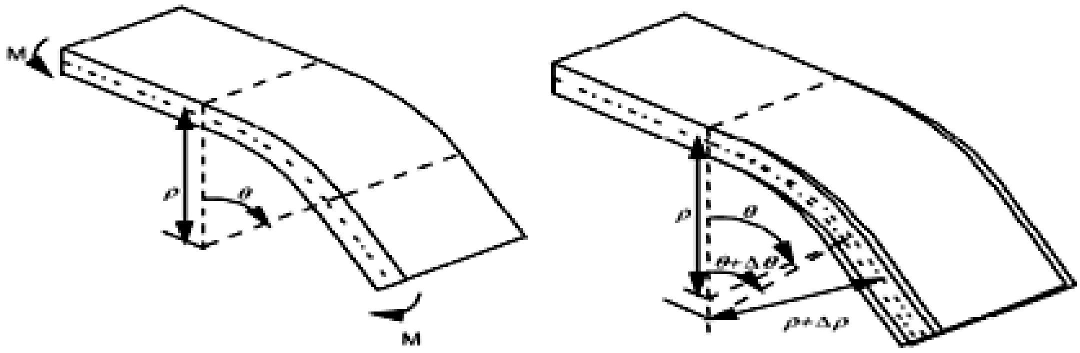
As *K* tends towards 1, springback is low, where *K* tends towards 0, springback is high. Figure 2.7 shows the schematic of sheet bending and resultant springback for the equation. Figure 2.8 shows the cyclic material models and the shrinkage in length and the latter is usually neglected. The formula used for predicting springback in plane strain bending is

$$\Delta K = \frac{M(1-\nu^2)}{IE} \tag{2.5}$$

The elastic springback stress is given by Equation (2.6)

$$\Delta\sigma = \frac{(1-\nu^2)\Delta\varepsilon}{E} \tag{2.6}$$

Instead of considering the springback as elastic reverse loading, a more natural method is simulating the unloading process until both the stretching force and the bending moment become zero. This is implemented in a bending studying system.



(a) (b)

Figure 2.7 : Schematic of sheet bending and resultant springback. (a) bending on the sheet and (b) continuous bending with larger angle

Source : Mullan (2004)

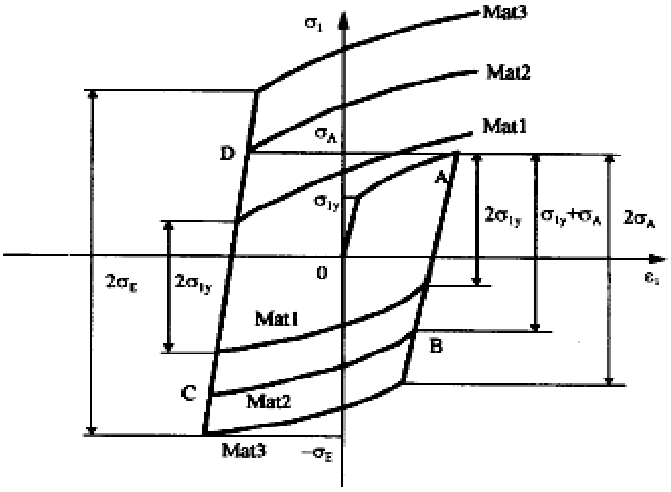


Figure 2.8 : Cyclic material models

Source : Mullan (2003)

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter discusses about the method use in project. Figure 3.1 shows the flow chart to explain the sequence of this project. This chapter explains steps in designing a new experimental tool, fabricating the tool, specimen preparation, force and displacement analysis, conducting the experiment, analyzing the data and optimization method to identify the hardening parameters.

3.2 DESIGN NEW EXPERIMENTAL TOOL

Fabricate new cyclic experimental tools by first creating the drawing by using Solidwork software . The designed tool being fabricated according the dimension. Figure 3.2 is the isotropic view of the assembly parts.

3.3 SPECIMEN

The specimen used for this project is stainless stain. It can be formed into a variety of different shapes. Stainless steel is innumerable application across all industries such as marine, construction, furniture and cutlery equipments.

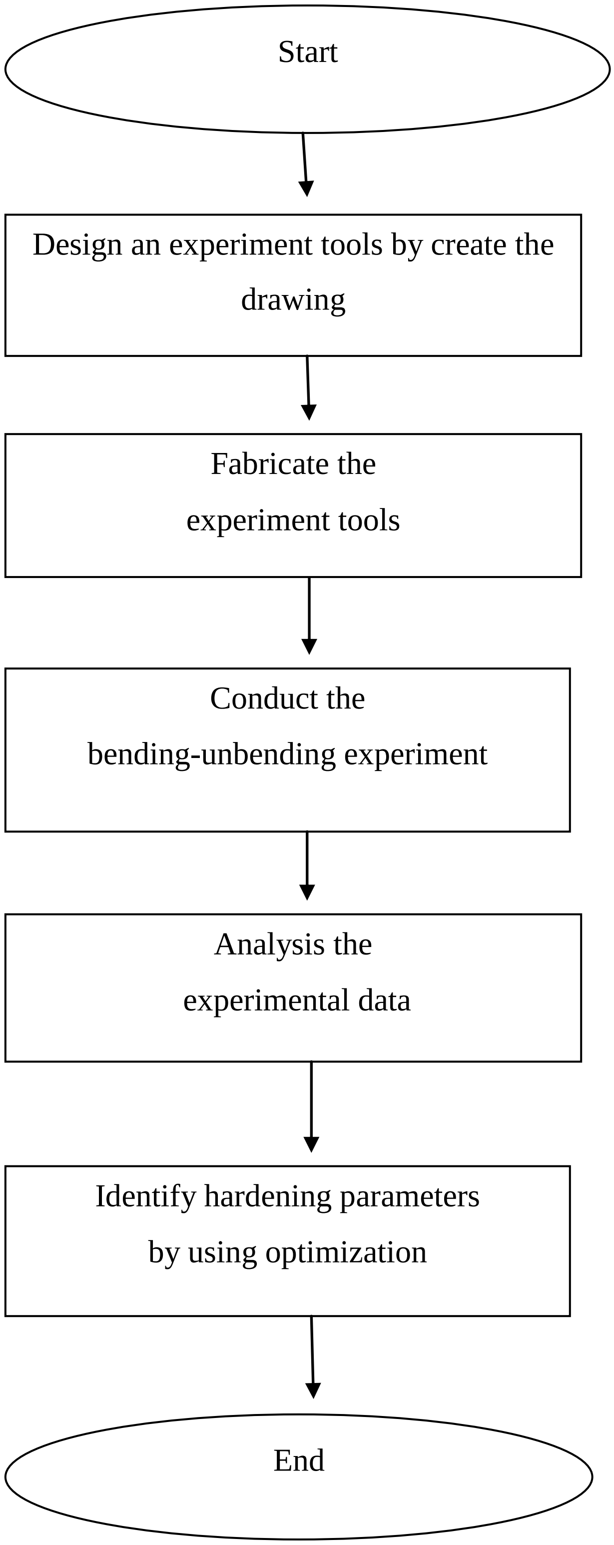


Figure 3.1: Flow chart of the project

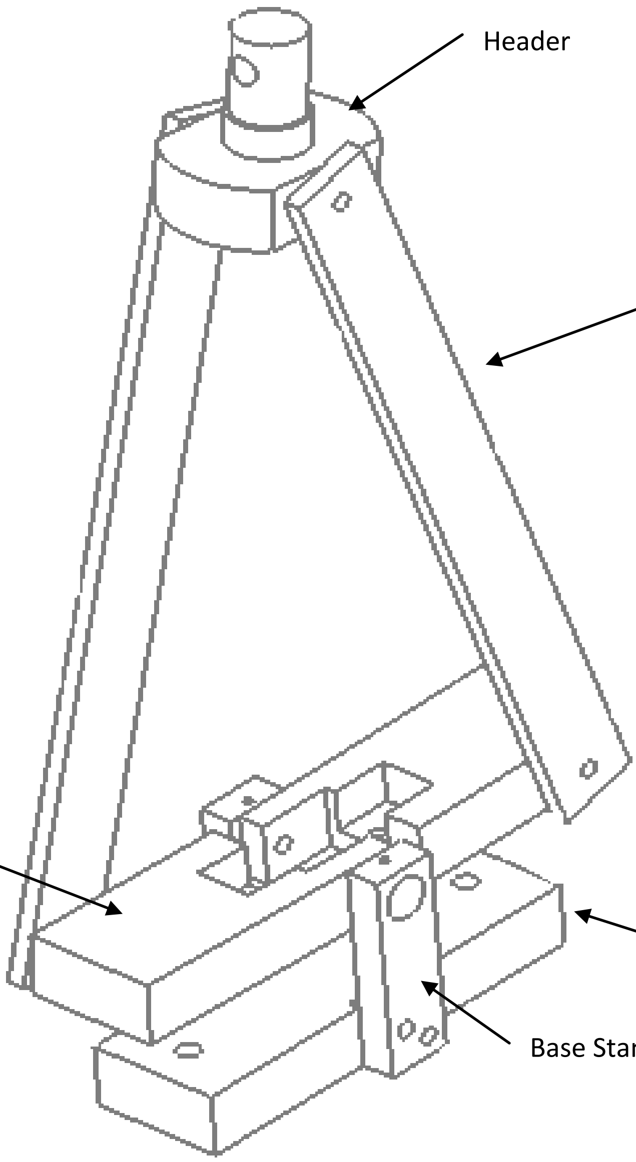


Figure 3.2 : Isometric view of the assembly parts

3.3.1 Specimen Preparation

Stainless steel sheet metal is cut by using LVD shearing cutting machine. The size of the specimen is 100mm X 25mm. EDM wiring cut machine is used to cut the finishing shape and dimension of the specimen. This shape and dimension is show in Figure 3.3.

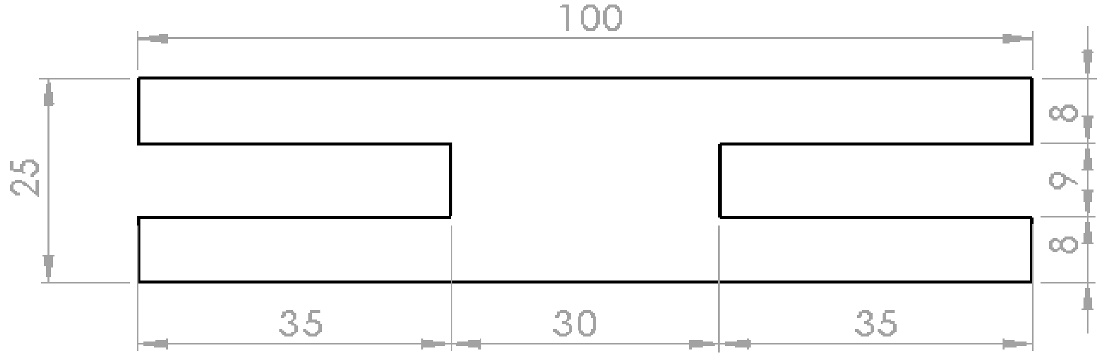
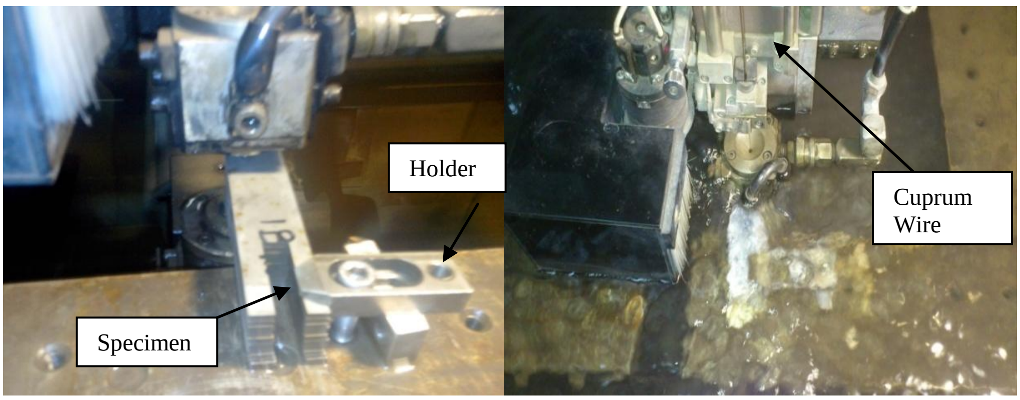


Figure 3.3 : Dimension of specimen in millimeter

The basic processes of the EDM wire cut machine for the specimen are listed below :

1. Clamp the specimen as shown in Figure 3.4(a)
2. Draw the specimen dimensions in the EDM screen
3. Setting the initial position for wire cut
4. Run the cutting process as shown in Figure 3.4(b)



(a) (b)

Figure 3.4 : Preparation of Specimen by using EDM machine. (a) specimen being clamped and (b) cutting process