Experimental and Numerical Analysis on Springback of JIS 3302 Grade Steel Sheet Material Under Various Heat treated Conditions

A thesis submitted by

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Under the Supervision & Guidance of

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SCHOOL OF MECHANICAL, CHEMICAL AND MATERIAL ENGINEERING

DEPARTMENT OF MECHANICAL DESIGN AND MANUFACTURING ENGINEERING

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BY

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Approved by Board of Examiners

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Internal Examiner	Signature	Date
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Declaration

I hereby declare that the work which is being presented in thesis entitled "**Experimental and Numerical Analysis on Springback of JIS 3302 Grade Steel Sheet Material Under Various Heat treated Conditions**." In partial fulfillment of the requirement for the award of the degree of Masters of Science in Manufacturing Engineering is my own work carried out September to June 2018 under the supervision of **DrPerumalla Janaki Ramulu and Dr. NRR.Anbusagar,** program of Mechanical Design and Manufacturing Engineering, Adama Science and Technology University, Adama, Ethiopia.

The matter embodied in this thesis has not been submitted by me for the award of any other degree or diploma. All relevant resources of information used in this thesis has been duly acknowledge.

Kemal Ramato Kayo ________________ ________________

Candidate Signature Date

This is to certify that the above declaration made by the candidate is corrected to the best of my knowledge and belief. This thesis has been submitted for examination with our approval.

Dr. Perumalla Janaki Ramulu ________________ ________________

Advisor Signature Date.

Dr. NSR.Ambusager ________________ ________________

Co-Advisor Signature Date

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ABSTRACT

JIS 3302 grade steel sheet metal is wide area of usage in various industry and bending processes. One of the most significant design criteria of bending methods for steel sheet metal is springback, which can be basically defined as elastic recovery of the material during unloading. So, the springback effect on the sheet metal must be taken into consideration in the bending process. Also, the amount of springback should be identified in order to produce bent sheet metal material within tolerable acceptance limits. However, the importance of springback effect analysis on JIS 3302 grade steel sheet material to overcome this problem, heat treatment is applied to the specimen material to improve tensile properties. Basically, heat treatments have significant effect on the mechanical properties of steel. In this study, the effect of various heat treatments on springback characteristics of JIS 3302 grade steel sheet metal studied by using experimental and finite element analysis. Also, the influence of directional rolling angle on the springback should be known to produce the acceptable product during the bending process. For this purpose, three different rolling directions are selected. In this research, an experimental and FE simulation study has carried out on V-bending die (90^0), with the dimensions of specimen 150x40x2mm and ASTM standard for tensile testing respectively. Microstructure, microhardness values and comparison of the Finite element (FE) simulation and experimental results are given. The output showed that, before heat treatment workpiece has the highest value of load and maximum value of springback. Whereas the annealed work piece has the lowest load and lowest springback value. Also, the experimental method agreed with the FE simulation results by maximum 1% differences. The influence of heat treatments on springback was discussed in detail

Keywords: Springback; Finite element; Sheet metal forming; Heat treatment; V-die bending ;JIS 3302 grade steel ; Annealing; Normalizing

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CHAPTER ONE

INTRODUCTION

1.1 PROJECT BACKGROUND

Plastic deformation is concerning about sheet metal forming method which has huge applications in various industries. Their main attribute is high efficiency, repeatability and economy; simultaneously keeping the proper surface condition in mass production (Swiatoniowski and Bałon, 2012). The most frequently used techniques for sheet metal forming are bending, stretching and stamping (Abdulaziz, 2013). Bending is one of the most commonly used methods beyond the sheet metal forming process. The common product obtained with the aid of bending were; automobile panels, supermarket shelves, automotive component, aerospace vehicles, pressure vessels, medical equipment, electrical component, drums and housing utensils (Zulkafli, 2012).

Bending operation is commonly used for sheet metal forming because the method is simple and last sheet product with desired shape and appearance can be rapidly and easily produced. In bending operation, plastic deformation is followed by some elastic recovery, by removing the load to the finite modulus of elasticity on a given materials. When the forming forces are removed, the metal tries to coming back to its original shape and results in a phenomenon named “springback” (Chou and Hung, 1999). This is due to the elastic deflection that occurs in the material after the bending process takes place (Wan-Nawang et al., 2015). The Springback phenomenon introduces the important changes in the final shape of a part and thus increase manufacturing costs (Mrad,et.al., 2013). Main factors that changes the springback effect are sheet thickness, material properties and tool geometry (Manjunathan, et al., 2017). (Sanjay Kumer Patel, 2013) studied springback analysis in sheet metal forming. The main aim of the study was to investigate the effect of the thickness in springback ratio. Then finally concluded that, the Springback ratio increases with increasing thickness. Springback is enormous problem among the sheet metal forming process. It is the elastically driven change of shape concerning a metal sheet during unloading and following forming (Soualem, 2014) and (Wagoner, et al., 2013).

This project has dealt with experimental and FE evaluation on springback of JIS 3302 grade steel sheet metal of 2mm thickness. This sheet metal has a wide applications and economic considerations in the many the sectors. To analyze Springback effect V-bending test was done on press brake machine at different parameters. The parameters that considered for this project were heating conditions and different sheet rolling directions.

1.2 STATEMENT OF THE PROBLEM

Metal bending is the most common process to change the shape of material by deforming. Although this method is simple but it has a main problem which is springback. It can be described as the extra deformation of sheet metal material after the loading is removed, which can lead to production of unacceptable products with wrinkle, tear, poor dimension precision, and so on. Due to this; many researchers were investigated on the parameters that influence springback of sheet metal forming process. From these parameters, material properties are very important to predict the springback performance in sheet metal bending process. Due to material properties, springback of the sheet metal forming at room temperature is increase and the formability of the sheet metal is decrease. However, the significance of heat treating to change material properties for minimizing springback effect on JIS 3302 grade steel sheet material during bending process expected to be imminent for improving the above mentioned limitation.

1.3 OBJECTIVE

1.3.1 General Objective

The goal of this work is to investigate experimentally and numerically springback effect of JIS 3302 grade steel sheet material under various heating condition.

1.3.2 Specific Objectives

- ✓ To analyze the springback effect experimentally.
- ✓ To evaluate the mechanical properties of JIS 3302 grade steel sheet material under two different heating conditions in 3 different directional rolling angle.
- ✓ To simulate the springback analysis by using finite element software (ABAQUS).
- ✓ To validate experimental results with simulation results.

1.4 SCOPE OF THE STUDY

In order to accomplish this research, flow of project has focused concerning some of scope of works to achieve objective regarding the research. Basically, the thesis scope is limited to:

- ✓ To Conduct the literature review for overview concerning previous works
- ✓ To Conduct the tensile test experiment that determines the mechanical properties of JIS 3302 grade steel
- ✓ To Conduct V-Bending experiment and FE simulation in order to determine the springback effect.
- ✓ To Compare FE results with experiment results for reliability evaluation of FE

1.5 SIGNIFICANCE OF THE RESEARCH

The analysis concerning selected materials is used to predict the parameters that influence bending properties, which formed due to elastic recovery during unloading. This study was focused on springback analysis of JIS 3302 grade steel at two different heat treating conditions. It's significant is for the industry that using JIS 3302 grade steel sheet to minimize the trial and error and also to minimize time and cost required for the bending process. In other hand, it is used with minimum modification in other types of research.

1.6 LIMITATION OF THE STUDY

The constraint those faces the researcher during conducting this work are: lack of machine and uncomfortable working workshop.

1.7 THESIS ORGANIZATION

This thesis is organized in 5 chapters:

Chapter 1 has provided clearly about summary of the entire project consist of introduction, problem statement, objectives, scope of the works and organization of the thesis.

Chapter 2 has presented the literature review based on journals that have related to this project. The background of the system including the specimen preparation, material properties, parameter, tensile test, bending test, finite element method and measuring of springback from the previous journals was presented.

Chapter 3 has discussed of methodology and materials that use in this project based on chapter 2. It contains a flow chart of this thesis, such as tensile test experiment to define the material properties, FE method to predicting the angle of springback and v- die bending method as comparison for validity of FE in predicting springback angle.

Chapter 4 has discussed the results of tensile test, finite element method and v-bending experiment. The result from FE method was compared with v-bending result in term of springback angle.

Chapter 5 has concluded this study and has answered the objective have been listed first. Also those, the output from this investigation are listed.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

A great deal concerning research has been performed in order to decrease springback, which would optimize the sheet forming process with the aid of decreasing geometrical or material variables in the formed part. Finite element technique has performed on sheet metal bending springback analysis to obtain accurate results. This chapter provided a literature review concerning previous research on springback and it to be a guideline to run this project. This chapter had discussed about concept of springback: types of bending, V-bending, FE method, and tensile test, heating conditions, and material properties that affects springback.

2.2 SHEET METAL FORMING

As a fundamental and traditional metal working process in manufacturing, the sheet metal forming has broadly existence employed in almost all industries. Some common sheet metal forming techniques used to manufacture required sheet metal product such as cutting off, blanking and punching, bending, deep drawing, hydro-forming, spinning, flow turning, piercing, stretching, stamping or draw die forming, coining and ironing and etc. (Gupta and Payal, 2002). Bending method is one of the most vital manufacturing processes in sheet metal prototyping, along with bending sequences and selection of bending perimeters as fundamental steps along with the process (Garcia-Romeua *et al*., 2007).This process in which force is applied to a piece of sheet metal to modify its geometry instead of removing any material. The sheet can be bent into a variety of complex shapes. The preference of forming operation depending on the desired size, configuration, and production quantities of a part.

In sheet metal forming industry sheet bending process, springback has a big role. In this process, the dimensional precision is a primary concern, due to the considerable elastic recovery during unloading which leads to springback. Also, at different conditions, that is possible for the ultimate bent angle according to stay smaller than the original angle. Such bend angle referred to a spring-go or spring-forward (Zulkafli, 2012). The amount of springback or spring-go was affected by many process parameters, like tool shape, dimension, contact friction condition, material properties, sheet anisotropy, and sheet thickness (Ramlan, 2012). Typical examples of sheet-metal bends are illustrated in Figure 2.1

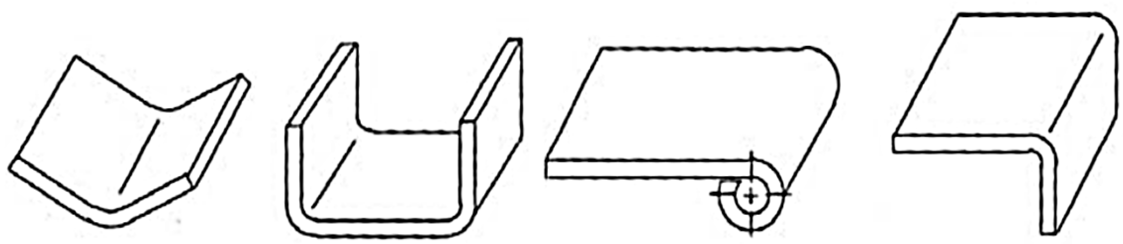

Figure2. 1Typical example of sheet metal bend parts (Sarikay, 2008)

2.2.1 Material properties that affect sheet metals formability

Annamalai, (2013) presented, about the different mechanical properties that influence on overall operation of forming procedures such as ductility, yield strength, elastic modulus, discontinuously yielding, work hardening rate and anisotropy or directionality.

a) Ductility: Metal used in the sheet metal forming must be ductile. If we use a brittle metal, it can simply undergo failure during forming. That is why metal's ductility is very essential 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 fewer stretchable and drawable than minor strength metals. Stretch distribution characteristic is determining the steel's capability to distribute stretch over a large surface area.

c) Elastic modulus: Stretch distribution effects is 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 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: Work hardening rate is a very essential in 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 additional factor that affects formability. Once consequence of directionality is a change in mechanical properties with direction. When forming sheet metal, practical consequences of directionality contain such phenomena as extra wrinkling, puckering, wear formation, local thinning, or real rupture.

2.3 CONCEPT OF SHEET METAL BENDING

Sheet metal bending plays a very significant in the manufacturing industry (Akinlabi et al., 2013). The bending and forming concern to sheet metal was an essential process in manufacturing industry to produce parts related to automobiles, aircraft, casings for electronic parts, housings, cabinets etc. Bending is the manufacturing process where sheet metal is plastically deformed to change its shape without removing any chips around a definite axis through or without heat. It 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 (Balaji et al., 2014). Bending is occurring from stressing a workpiece within a localized area, and such results within non-uniform deformation (contradiction and elongation) within the cross-sectional area of bending. Because about this in homogeneities, analyses regarding stress strain distributions are of utmost significance when evaluating bending conditions. To produce a bend in the completed part, applied bending force must exceed the yield strength of the material to ensure the material retains a permanent set or bend when the load is removed (Buang et al., 2015). Manjunathan et al., (2017) presented about sheet metal bending elastic recovery during angle and bend curvature and affect the geometric changes of the final product.

The main factors that influence the springback effect were sheet thickness, material properties, tool geometry, and ratio of die radius to sheet thickness, blank holder force and coefficient of friction. Additionally, (Esther et al. 2013) done on the bending operation and described a springback causes geometrical inaccuracies of bent parts. To control springback, numerous factors such as bending parameters and material properties need to be considered. The geometrical accuracy of a bent part was important in determining the quality of the component. Analysis of the process about sheet metal bending displays known as springback.

According to Simões, (2012), the springback was measured as the difference between the final shape of the part and the shape of the forming dies which defines the part's shape at the end of the forming stage. Figure 2.2 shows an example of the different final shapes obtained after a deep drawing process, done with the same tools and process conditions, using two blanks with different material properties, to better understand the importance of this phenomenon. This phenomenon plays an important role in process design, because wrong part dimensions is a problem to the assembly process, increasing the amount of scrape and, consequently, the part's cost.

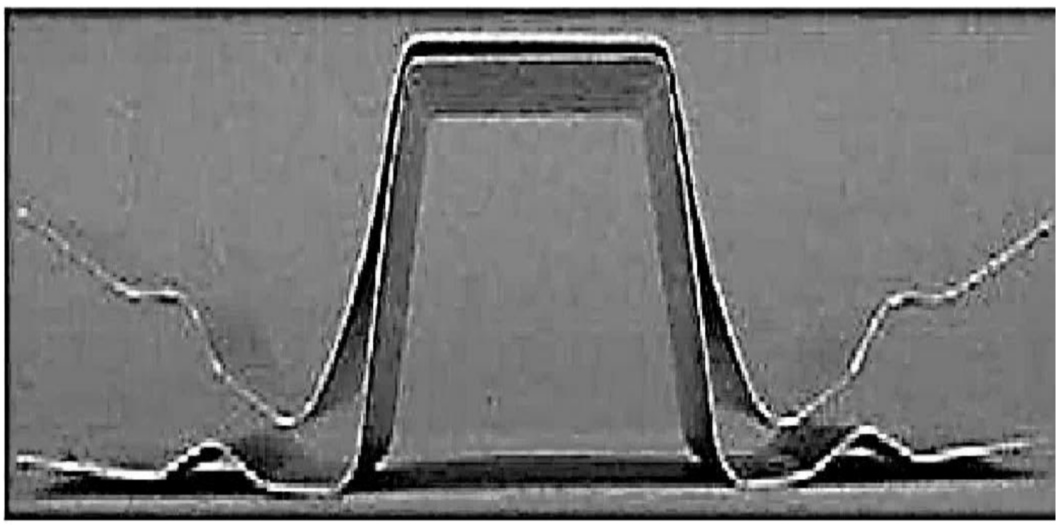

Figure2. 2: Example of springback (Simões, 2012)

Krinninger (2016) investigated the influence of punch velocity on the springback behavior and the flat length in free bending to improve the predictability of the springback. In a free bending method, a tool with an integrated optical measuring system used to determine the influences of bending angles, radii, component widths and orientations of the bending axis to the rolling direction on the sheet. The quasi-static parameter variation was extended with different punch velocities to investigate its influence on the bending process, the springback and the flat length. Figure2.3 shows the stage of sheet metal bending.

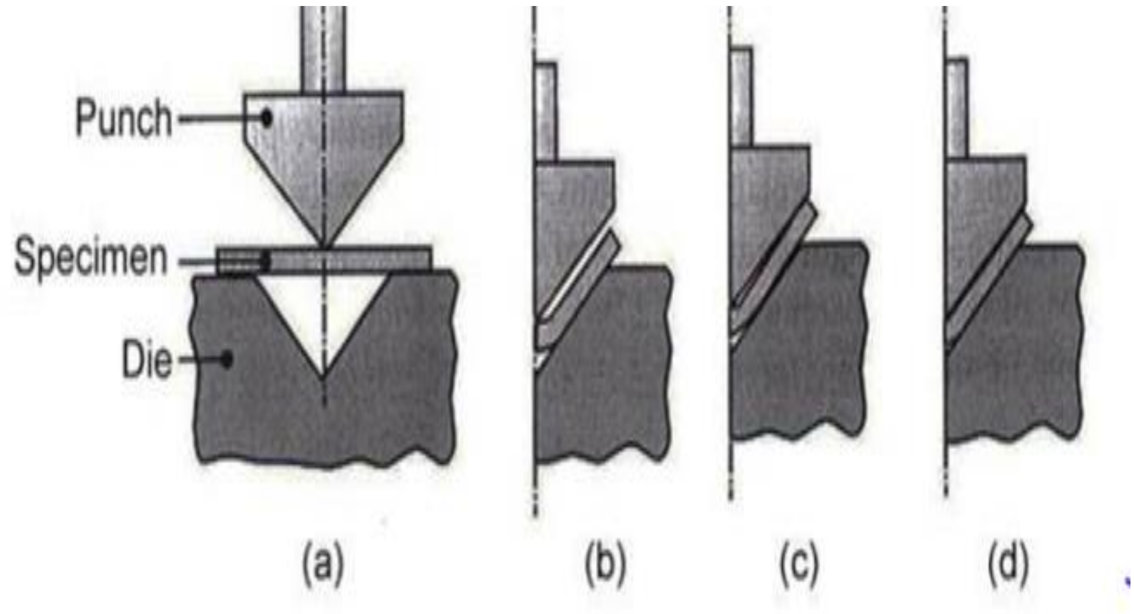

Figure2. 3: Illustration of stages in bending by V-dies (Aljoša, 2013)

2.4 TYPES OF BENDING

There are several types of bending that commonly used in the industries such namely Air bending, V- bending, and U-bending.

2.4.1 Air Bending

Air bending is a flexible bending method in which different materials of different thicknesses can be bent in varying bend angles using the same tool set (Šarić et al., 2016). As the definition of springback, when the punch is released, the specimen springback is a little and ends up with less bend than that on the punch (greater included angle). Figure 2.4 showed the air bending method during loading and after unloading. Air bending is used mainly to straighten workpieces (Sarikay, 2008)

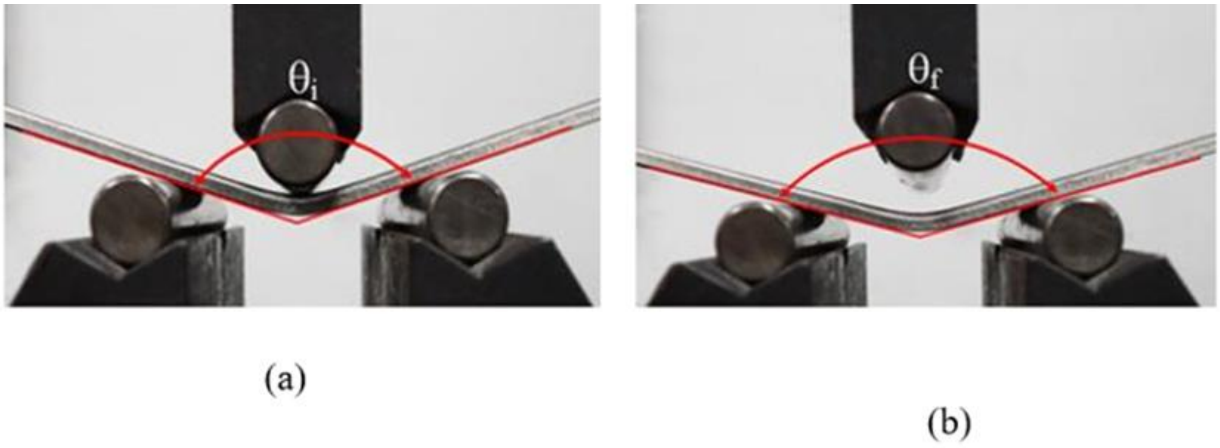

Figure2. 4: Air bending process during loading (a) and after unloading (b) (Buang, 2015)

2.4.2 V-bending

The V-die bending method is the bending of a V-shaped part in a single die. The specimen is bent between a V-shaped punch and die. The force acting over the punch causes punch displacement and then the specimen is bent. The specimen 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 below the punch. V-die bending and is illustrated in Figure 2.5.

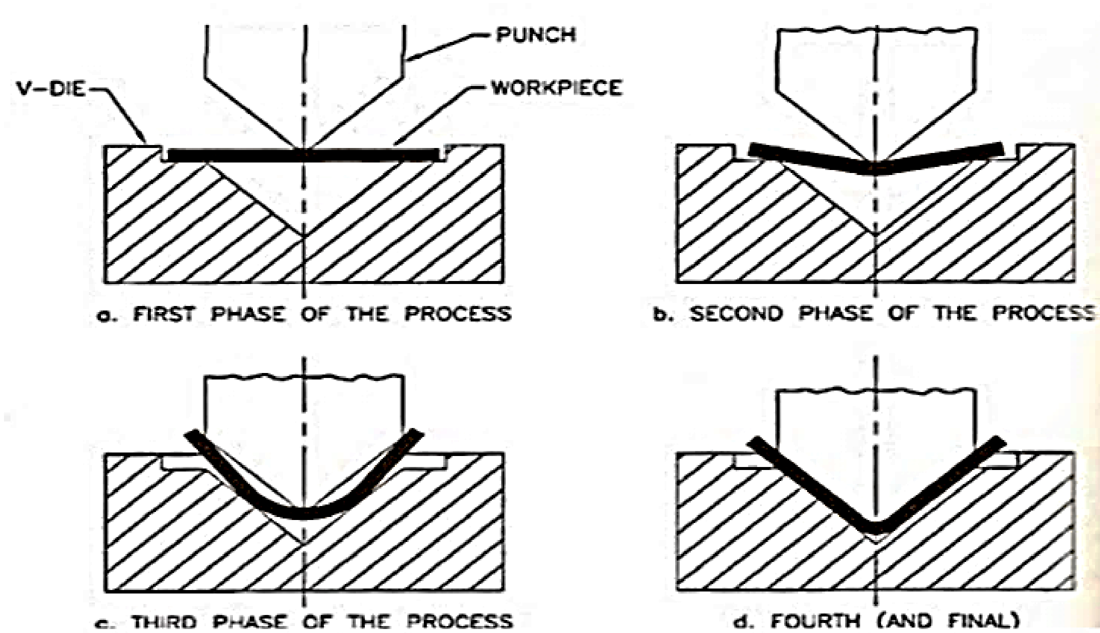

Figure2. 5: V-die bending (Sarikay, 2008)

2.4.3 U- bending

U – Bending is achieved when two parallel bending axes are bent in the equal operation as shown on Figure 2.6. Generally U – bending process had divided into two steps, loading and unloading. In the loading step, the punch will completely move beneath and the metal is being bent among the die. During this step, the specimen undergoes elastoplastic deformation and temperature rise under frictional resistance. For the second step which is unloading step, the deformed sheet metal is ejected beside the tool set and metal was experiencing the residual stress release and the temperature drop to reach a thermo-mechanical equilibrium state (Ramlan 2012). Adibi et al., (2010) studied springback analysis of sheet metal laminates after u-bending. Based on both theoretical and experimental investigations, the springback behavior of sheet metal laminates is strongly affected by the strength difference between the component layers of the laminates, the relative position of the layers, and the layer-thickness ratio, as well as by the stretching force acting on the laminates.

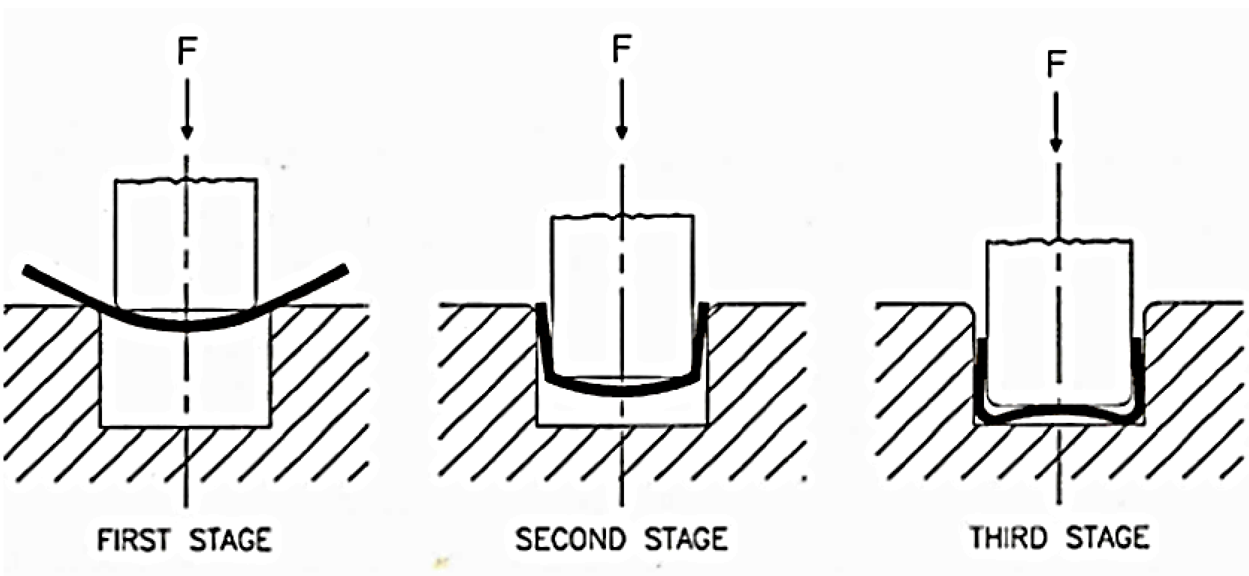

Figure2. 6: U-die bending process (Sarikay, 2008)

2.5 SPRINGBACK IN V – BENDING

There were many researchers investigated and attempted to acquire a basic understanding of springback behavior. Among them, a few authors presented the work which was concerned along the springback analysis through using different methods, certain as much experimental method, numerical method, analytical method and finite element method (FEM), applied to know the sheet metal springback during V bending.

The major problem in sheet metal bending process is springback. It is the amount of elastic tolerance, which presents in all materials (Bhav et al., 2016). Kadkhodayan & Zafarparandeh, (2009) explained springback of sheet metal parts after removing the load as shown on Figure 2.7. Prediction of springback angle helped in determining the amount of over-bend (i.e. springback compensation) required so that exact V bend angle can be obtained in the component. During V-die bending, the punch slides down, contact with the unsupported sheet metal. By progressing farther, it forces the material to follow along, until finally bottoming on the V shape of the die (Bhav et al., 2016).

Dametew, (2016) presented sheet metal components produced in different size and accuracy using various sheet metal forming processes. In his research, the authors concluded that, in sheet metal forming process, a major factor preventing accurate final product dimensions was springback. Mustafa, (2017) also studied the bending process on the AISI304 sheet metals at different thicknesses and different punch type radii by using air V-bending technique. The common aim was to find out the parameters that affect springback and spring-go values in the bending. In his study, after the bending, the amount of springback in the sheet metals were examined. Finally, the Authors concluded that, as thickness of the sheet metal increased, the value of springback decreased; whereas, the values of springback increased in the increasing punch tip radii. In sheet metal forming process, springback was increased with increase of yield stress, also the increase in elastic modulus and in strain hardening exponent leads to a decrease in springback (Ouakdi et al., 2012).

Ramulu et al.,(2016) studied springback analysis on AA 6061 Aluminum alloy sheets with seven different rolling directions of sheet with the combination of U and V die shape. In order to make bending at a desired angle the process parameters considered were different load, displacement, and die angle. Finally, concluded that, the effect of roll direction on springback effects are very sharp and prominent as shown on Figure 2.8.

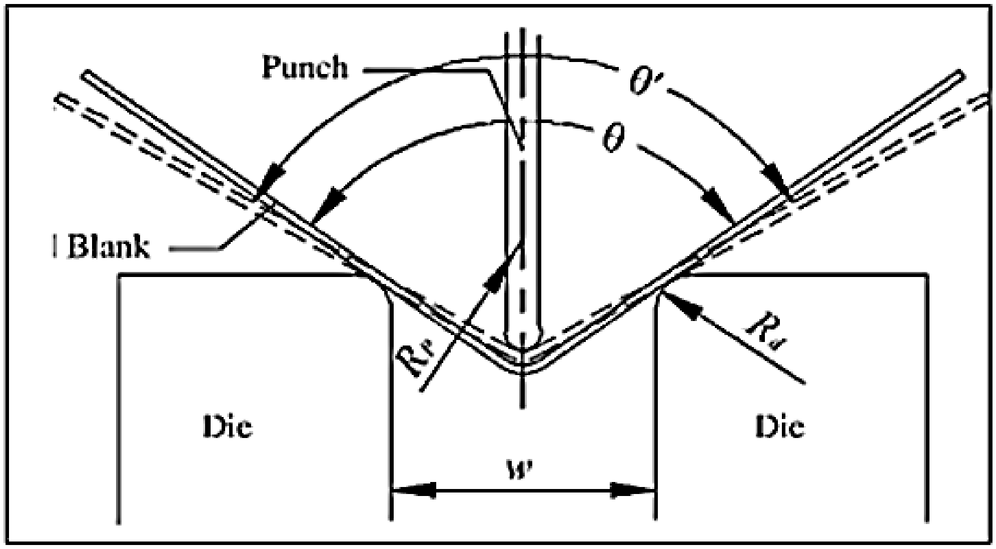

Figure2. 7: Illustration of V-die bending springback (Mustafa, 2017)

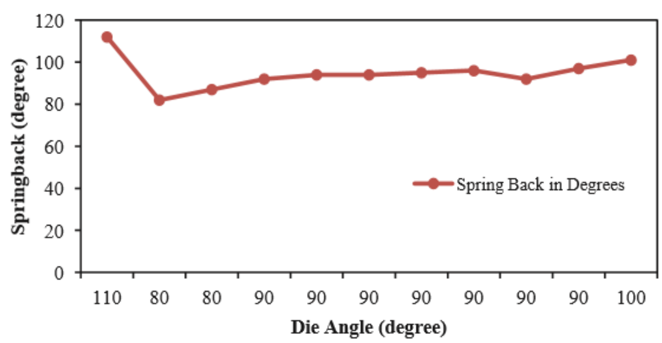

Figure2. 8: Springback variation with respect to die Angle (Ramulu et al.,2016)

2.6 SPECIMEN PREPARATION FOR BENDING

For experimental V-bending process most of the researchers described the dimensions of the specimens for example: Osman et el., (2010) used V-die bending experiments which conducted on 38 mm x100 mm annealed steel specimens cut from 1000 mm x 2000 mm commercially available cold rolled low carbon steel sheets having thicknesses of 0.7, 1.5, and 2.5 mm. Additionally, Balaji et al., (2014) presented on FE410 sheet with 8 mm thickness taken for research study with V bending. A sample specimen of 100x30x8 mm used to perform for the experiment. Stainless steel 304 sheet metal (120mm×30mm) cut along the rolling direction was used in experiment and thickness was 3 mm (Buang et al., 2015). According to, (Wan-Nawang et al., 2015) springback was due to the elastic deflection that occurs in the material after the bending process takes place. In this paper an investigation was concerning on the influence of the material rolling direction on springback in the case of w-shaped bending parts were the tensile and bending behaviors of the parts are observed through the experiment. Stainless steel sheets (SS 316L) with three different thicknesses of 100m, 75m and 50m were tested. Bending specimen was prepared from strips cut at 0◦, 45◦ and 90◦ to the rolling direction of the strips respectively. The results revealed that various parameters influence the springback, such as thickness of the sheet, force applied, material rolling-direction and holding time during the sheet-deformation. Talele et al., (2014) presented on a metal was deformed into the plastic region; the total strain was made up of two parts, the elastic part and the plastic part. When the load was removed, a stress reduction occurred and accordingly the total strain decreased by the amount of the elastic part, which results in springback. The amount of springback increased with greater yield strength or with the material's strain-hardening tendency (Bhav et al., 2016).

2.8 MEASURING SPRINGBACK ANGLE

Springback is a very complicated behavior and not easy to predict through the mathematical models. Therefore, some experiments for understanding springback behavior were conducted and some mathematical models were developed by different researchers. Various experimental methods and procedures have been developed to investigate and characterize springback on sheet metals. The most popular and frequently used methods are cylindrical bending, U-bending, V-bending and flanging. These techniques are attractive because the level of springback is large and it can easily be measured. Many researchers have tried to compensate the springback by various means. Springback describes the change in shape of a formed sheet upon removal from the tooling. (Ameen, 2012) presented the effect of the springback on the bending operation of different materials. The procedure of measuring the springback factor discussed as follows: first, Drawing the radius of the die (25mm) on the paper and measure the angle of the radius as shown in Fig. (9). Then drawing the radius of 1st specimen tangent to the die radius. Finally, measuring the angle of the specimen and calculated the springback factor according to the equation:

$$\mathbf{K_s} = \frac{ai}{af} = \frac{=(2Ri/t)+1}{\left(\frac{2Rf}{t}\right)+1} \ldots\ldots\ldots\ldots\ldots (1)$$

K_s=springback factor

α_i=internal angle curvature

α_f=external angle curvature

t = Thickness of the plate (mm)

R_i = Internal radius curvature (before spring back) (mm)

R_f = Real internal radius curvature (after spring back) (mm)

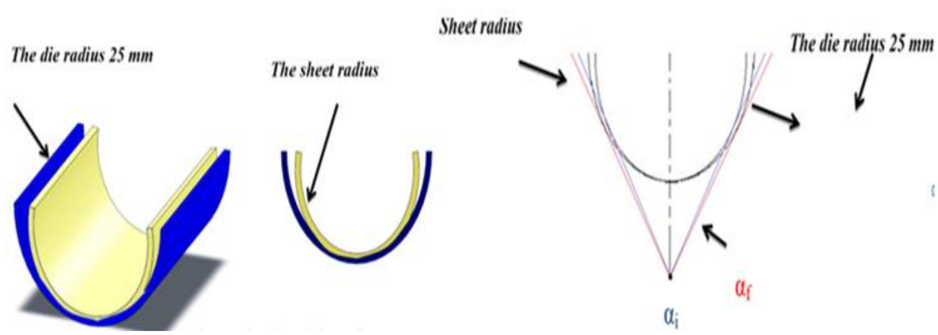

Figure2. 9: procedure of measuring springback factor (Ameen, 2012)

Ramlan, (2012) presented the angle after springback and difference between depth of specimen before springback and depth of specimen after springback was measured. Due to difficulty of using conventional methods, measured in MATLAB concluded that springback angle can be calculated and evaluated accurately using MATLAB measuring method. Photos of real experiment were loaded in the MATLAB and then five points on each arm of specimen was selected. After points were selected, linear regression was used to reach equation of straight line for each arm of specimen. Then based on equations of straight lines, angle in the middle of two straight lines was computed.

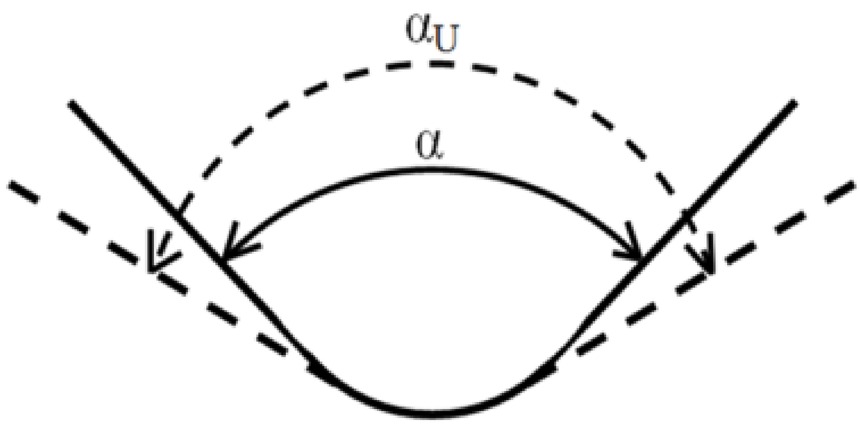

Figure2. 10: Illustration of experiment: αu-angle after unloading and α before unloading. springback equal to the difference these variables (Ramlan, 2012)

2.9 FINITE ELEMENT SIMULATION (FE)

FE simulation of sheet metal forming was a well-established tool which is used in industrial works to evaluate geometrical defects affected by elastics springback (Burchitz, 2008). It is a simulation technique which analysis the behavior of components, equipment's and structures for different loading conditions including applied forces, pressures and temperatures. Engineering simulation tools based on the finite elements method were employed regularly in the design of stamping dies for sheet metal parts. However, a bad material model choice or the uses of non-accurate enough parameters lead to imprecise simulation results (Quesada et al., 2014). Talele et al., (2014) given the simulation and parametric FE analysis for sheet metal forming method with varying blank holding force, materials, blank thickness, and coefficient of friction and their effects on the springback. To improve the springback prediction by FE analysis, guidelines concerning the mesh discretization were provided and a new through-thickness integration scheme for shell elements were launched. Springback prediction and compensation were still major challenges in the simulation of sheet metal forming process (Mrad et al., 2013). Toros et al., (2011) developed the models for the materials in FE software had significant effects on the accurate prediction of the forming results.

Wagoner et al., 2013) studied the numerical investigation of springback on sheet metal bending process to produce bent sheet metal parts within acceptable quality. The numerical analysis was done using ANSYSTM LS-DYNATM. The influence of sheet metal thickness, sheet metal type, friction, tool radius and tool shape on springback for aluminum, copper, mild steel and high strength steels, sheet metal were considered for investigations. Buang et al., (2015) focused on the design of experiment approach by using the full factorial and analysis of variance methods to identify the die or punch radii significant input parameters in predicting springback. ANOVA and full factorial design (2^k), with five process parameters and two-level values (2^5), were used. The results from the experiments showed that springback was affected by the die and punch radius values in the air V-bending experiments.

2.10 MICROSTRUCTURE AND HEAT TREATMENT

Metallic materials take the form of a crystalline structure in the solid state. The crystalline structure and the alloying elements added to pure iron give carbon steel the ability to have a wide variety of properties, which make it one of the most useful materials in industry. The crystalline structure of carbon steel might include body-centered cubic (ferrite), face centered cubic (austenite), or body-centered tetragonal (martensitic) forms. At higher temperatures, the ferrite structure is unstable and transforms into a face centered cubic structure called gamma (γ) austenite (figure 2.11). At even higher temperatures, the austenitic structure might again transform into a higher temperature form of ferrite; this is called delta (δ) ferrite. The transformation temperatures indicate the points at which the structure becomes unstable form and begins to undergo a transformation to a different crystalline structure. It can be seen that carbon steels, with a typical high value of carbon content of less than 0.35% for pressure-containing applications, will have a transformation temperature range that will differ with the carbon content and the rate of heating or cooling (figure 2.11).

In air bending a sheet was bent on après brake with help of a die and punch. During bending operation, previous heating of the sheet metal provided some advantage, such as reducing the maximum force, springback and increased the bend ability. As (Wan-Nawang, 2015) presented on springback of high-strength steel next to hot and warm sheet forming, the springback of high-strength steel next to hot and warm sheet forgings was studied. In this investigation, a series of hot and warm sheet forming experiments on high-strength steel sheets were performed using a hot compression testing machine, and the effect of forming temperature on the amount of springback was evaluated. As the result of this studies showed, the springback was markedly reduced when the forming temperature is higher than 750K, which was approximately the critical temperature for the recrystallization of ferrite grains.

Larsson (2005) discussed forming at elevated temperature to distinguish warm forming from hot forming. In warm forming, the microstructure was stable, but in hot forming microstructural changes occurred, including recrystallization and grain growth. Usually, the temperature interval for warm forming starts at 0.3 times the melting temperature and ends at 0.5 times the melting temperature. At higher temperatures, the term hot forming was used.

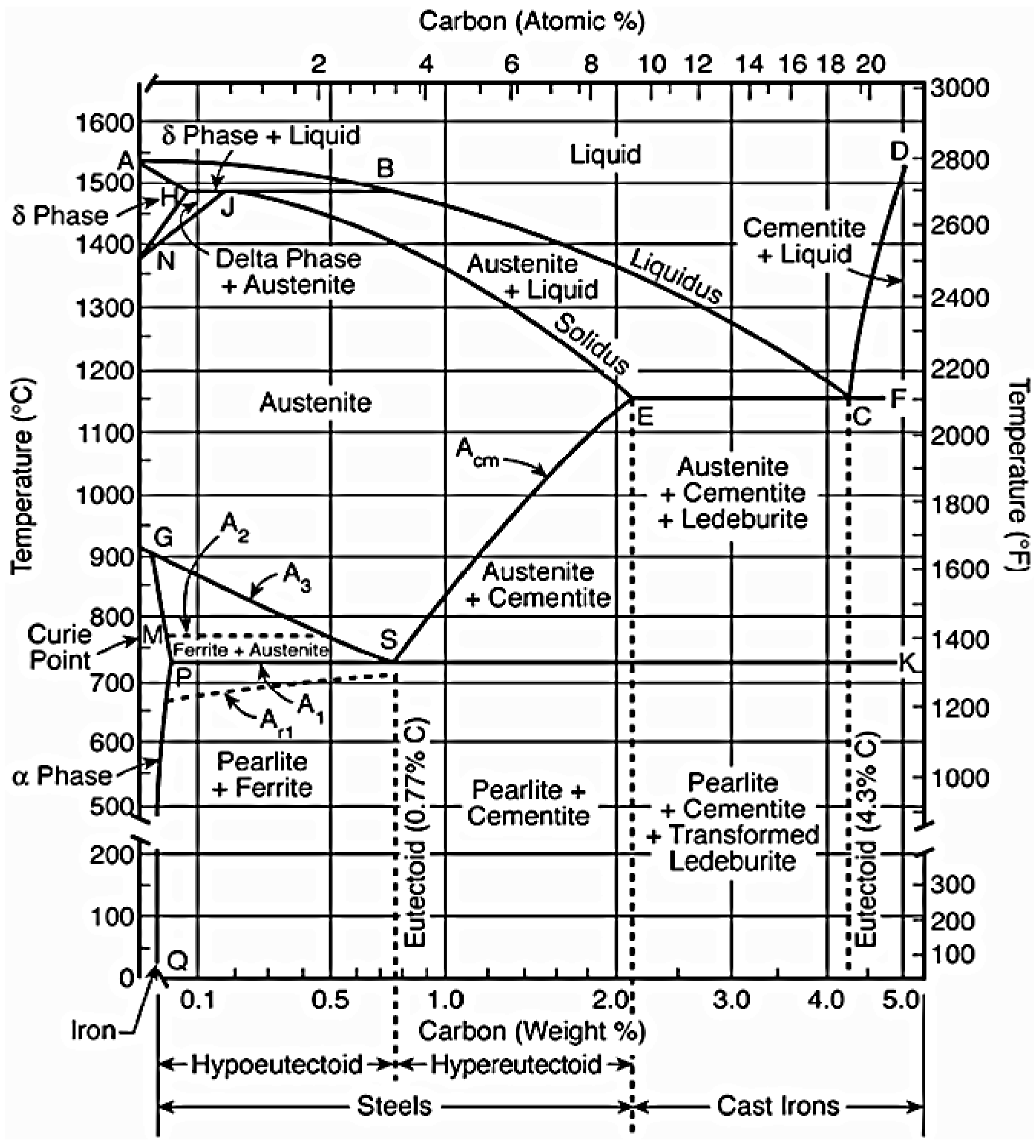

Figure2. 11: Iron-Iron Carbide Phase Diagram (Gandy, 2007)

As per above literatures, most of the researchers were investigated on springback analysis of various materials by considering different parameters. Sheet metal forming process was carried out at room temperature and resulted in decrease of the formability of sheet and increased springback. But for springback analysis at various heat treatments was not investigated on JIS 3302 grade steel sheet material. This was the gap for this work, JIS 3302 grade steel sheet material was selected to analyze springback by different heat treatments conditions.

CHAPTER 3

METHODOLOGY AND MATERIALS

3.1 INTRODUCTION

This study was performed to investigate springback formation in sheet metal bending and predict the parameters affecting this phenomenon, by using of experimental and simulation Analysis. The aim of this section is to present the details of the experimental and FE simulation procedures that used in this study. A simple 2D and 3D bending process were investigated through FE simulations for JIS 3302 grade steel material. The effects of factors investigated in this study include; rolling directions and heat treatment. For the FEM evaluation ABAQUS software was used for all simulations. The detailed methodology was mentioned in the Fig. 3.1 in the form of flow chart.

3.2 PROJECT FLOW CHART

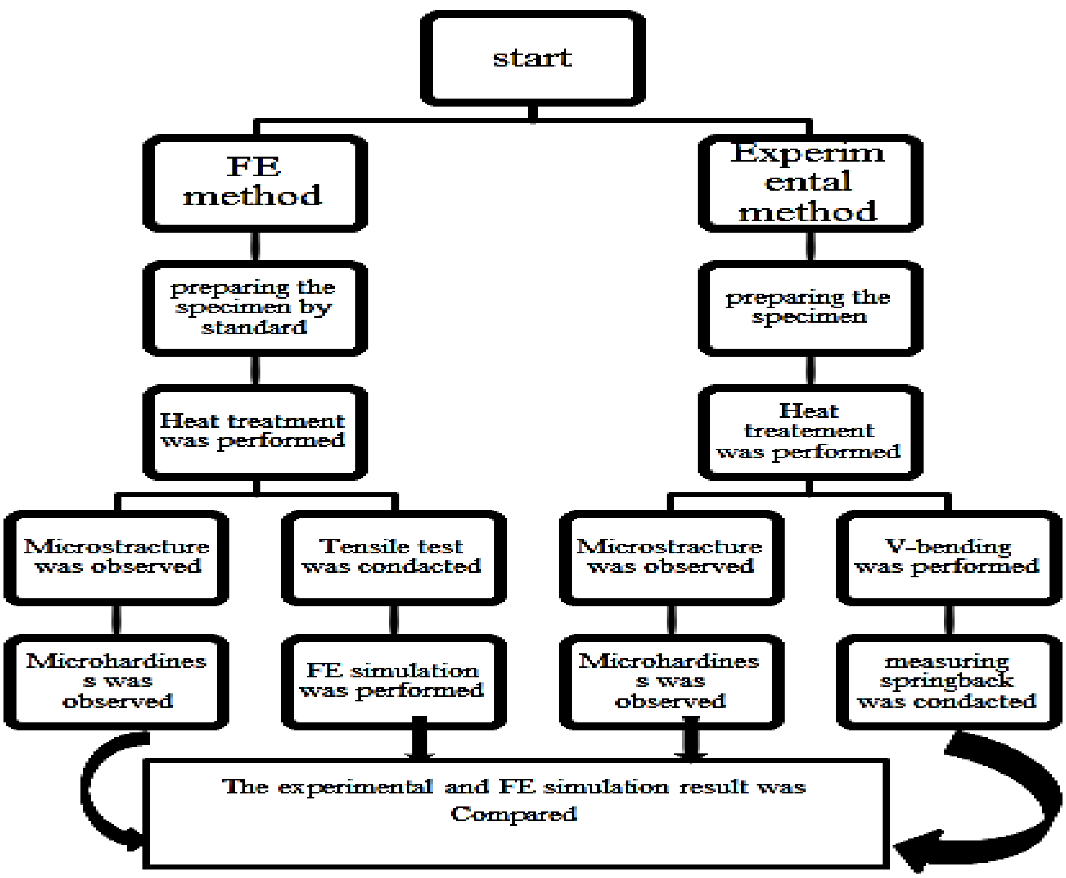

Figure 3. 1: Project flow chart

3.3 MATERIALS

JIS 3302 grade steel sheet of 2mm thickness was used as base materials for the present work which was used in a wide-ranging of applications and economic considerations in the industries. This grade was also represented as ASTM A653 standard. Initially, the chemical composition testing was performed to know the exact elements existed in the sheets metal. Table 3.1 shows the chemical composition of selected material before heat treating.

3.3.1 Chemical composition

table 3. 1: JIS 3302 grade steel chemical composition

C max%	Si max%	Mn max %	P max%	S max%	Cr max%	Mo max%	Ni max%	Cu max%	W max%	Fe max%
0.05	0.0065	0.19	0.078	0.035	0.041	0.003	0.014	0.02	0.04	99.5

3.4 EXPERIMENT BENDING PROCESS

The aim of this experiment was to determine the influence of technological parameters on the amount of springback. Initially experimental specimens were prepared in the form strips based on the different rolling directions. This experimental specimen was prepared by hydraulic sheering machine. The strips of bending specimen were prepared from 1000x2500x2mm sheet metal cut in 0^0 ,45^0 and 90^0 rolling directions with specimen dimensions of 150x40x2mm as shown in Fig. 3.2. Total 9 experiments were planned, for which 27 samples were prepared with three reputations for each perimeter. After that, the full annealing and normalizing heat treatment methods were performed at 900ºC.

Figure 3. 2: Prepared specimen for bending

The V-bending process was used for the bending process. The experiment set-up was composed of a punch, a die and guide pins which are given in Figure 3.3. The blank is a piece of sheet metal, typically a rectangle shape, which was pre-cut from stock material and heat treated by different condition. This experiment was performed on hydraulic press brakes machine for V-bending test. In V-bending process, a tool called a punch moves downward into the blank and draws, or stretches, the material into the die cavity. The movement of the punch was hydraulically powered, to apply 20KN force to the blank.

Figure 3. 3: Experimental setup

Experimental setup was not disturbed for all experiments and the tests were conducted under same operating conditions. Three experiments were conducted for each parameter; rolling direction and heat treat condition. The resultant springback effect for each sheet heat treat and rolling direction was obtained by averaging the values of the springback effect for the three experiments.

3.4.1 Springback measurement

To determine the springback in V-bending and to get a blank of 90° bend angle by studying the effect of heat treatment and rolling direction angle on the sheet metal was performed. The punch stroke distance was fixed; it should not move up to the bottom of the die. A gap of 2mm, which was equal to sheet thickness, was maintained between the final position of punch and the die. This was to avoid crushing of the sheet material at the bending profile. The angle of the die and the punch was 90^0. The steps that were followed during the springback testing are as follows.

1-Fixed the die and punch in the compression device. The punch was moved down. 2- The punch in contact with the sheet and the sheet was drawn through the opening in the die.

3-The punch proceeds downwards, the outer radius of the workpiece is reduced

After unloading the specimens, angles were measured within two munities by using bevel protractor (Figure 3.4) (Kumar, 2010). Then, the angle of the die was reduced from the measured angle. The unloaded bend angles were measured three times on each of the upper and lower sheet surfaces for each experiment. Also, the bended specimen angle was measured within time interval.

Figure 3. 4: Measuring the angle of bended sample

3.5 Heat treatments of specimens

Full Annealing: -Metals are annealed to relieve internal stresses, soften them, make them more ductile, and refine their grain structures. In this process, specimens were heated up to

900^{o}C in Muffle furnace (Fig.3.5) for one hour, and then cooled it to room temperature in furnace.

Normalizing: Ferrous metals are normalized to relieve the internal stresses produced by machining, forging, or welding. Normalizing prior to hardening is beneficial in obtaining the desired hardness, provided the hardening operation performed correctly. Because of this, normalizing was achieved by heating the metal to 900^{o}C in furnace for one hour and soaking the metal until it was uniformly heated, and then it was cooled in still air. All the heat treatment processes were done according to SAE AMS 2770G standards (Sarikay (2008)).

Figure 3. 5: Muffle furnace

3.6 MICROSTRUCTURE OF THE SPECIMEN

The micro structure of the specimen was observed by using Metallurgical Microscope of model: Huvitz HR-300 series, magnification: 50X, 100X, 200X, 500X, 1000X, scanning area: 104x102mm, illumination system: 12v, 1000W halogen lamp (Fig. 3.8). Firstly, samples were cut from the heat treated and before heat treated. Then, these specimens were mounted in phenolic resins by hot mounting press machine at Material Engineering lab, ASTU, Ethiopia (Fig. 3.6). This machine consists upper ram, lower ram, cylinder, heating part, cooling part and mold. This system automatic mounting press that automatically operate pressure, heat, cooling by water. After that the specimen was rough cleaned by grinder, rough polished (Fig. 3.7), then final polished using standard manual techniques was performed. Finally, etching was performed to see the microstructure of the material. All, samples are seen at 1000x magnification for this thesis study. For that testing, three specimens were prepared (Fig. 3.10). Those were: annealing, normalizing and before treating specimen. For each one specimen testing five trails were performed.

Figure 3. 6: Mounting press machine

Figure 3. 7: Grinding machine

Figure 3. 8: Metallurgical Microscope

3.7 HARDNESS OF THE SPECIMEN

Hardness is the resistance of a material to deformation, indentation or scratching. The basic goal of hardness testing is to quantify the resistance of a material to plastic deformation. The indentation value has high importance for technical applications which reflects the resistance to deformation which is a complex property and related to modulus, strength, elasticity, plasticity and others. The Vickers hardness test uses square-based pyramid diamond indenter with an angle of 136^0 between the opposite faces at the vertex, which is pressed into the surface of the test piece using a prescribed force, F.

HV= Constant x Test Force/Surface Area of Indentation

$$= \frac{0.102 * 2F(\frac{sin136^0}{2})}{d^2}$$

The HVS-50 machine used for this project has measuring range: 5-2900 HV, test force: 9.807, 49.03, 98.07, 196.1, 294.2, 490.3N, maximum height of test piece: 180mm, depth of throat: 125mm, magnifications of the measuring system: 125X, 250X and minimum scale value of the optical micrometer: 0.5µm. Load used during hardiness test was 49.03 N (10kg.f) on five trail per each sample. Average result was taken for comparison of HV value of all samples. Hardness testing was performed on the same specimen that prepared for microstructure.

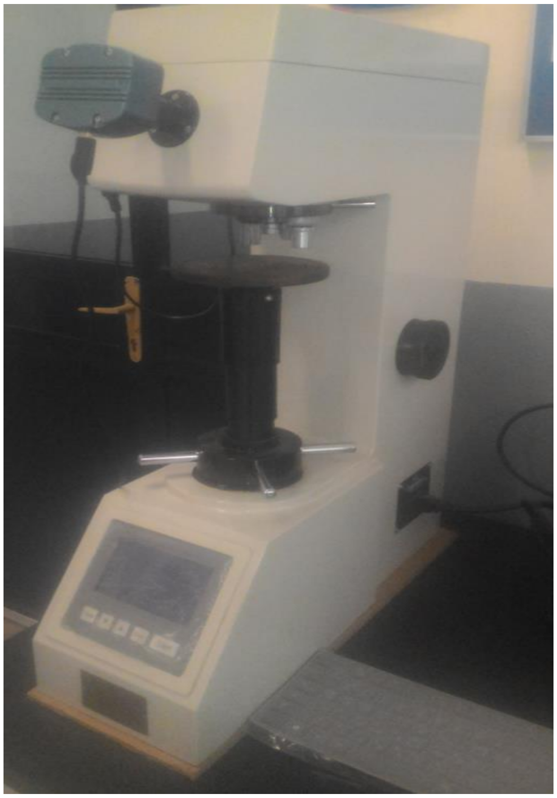

Figure 3. 9: Vickers hardness tester

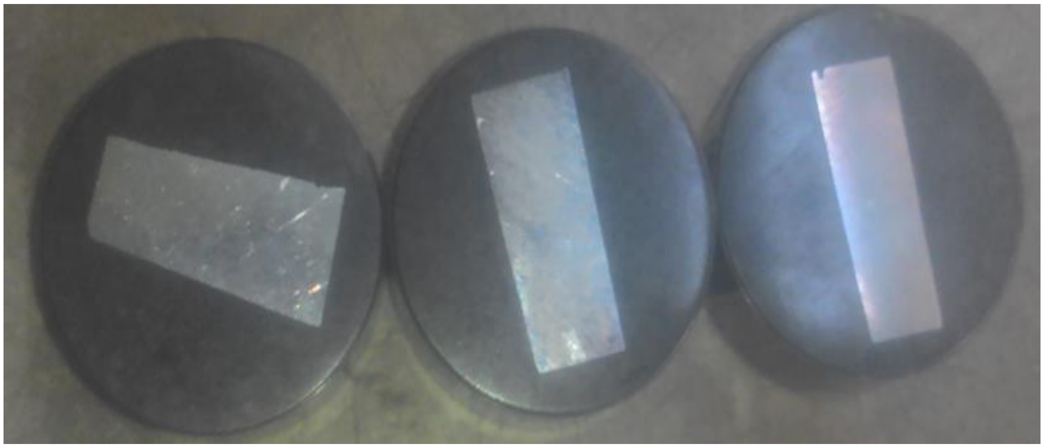

Figure 3. 10: Specimen prepared for microstructure and micro hardiness

3.8 TENSILE TEST PROCEDURE

The tensile test was widely used for the measurement of basic mechanical properties of metals, plastics, and composite materials. Mechanical properties are an important measure in order to know the material properties, and the tensile test is just one way to certify the material. In tensile test, the materials properties 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.

3.8.1 Tensile specimen preparation

Based on the ASTM standard, there were three types of the specimens for the tensile test process where it was plate, sheet and round type specimen. In this project, sheet metal was performed to get the material properties. For this purpose, the specimens were prepared from sheet metal cut at 0^0 ,45^0 and 90^0 to the rolling direction of the specimens by using sheering press machine with the dimension of 200x25x2mm. To evaluate the mechanical properties of the specimen, tensile tests were performed according to the ASTM standard E-8M (J.R., (2004)). This specimen was prepared from strips by using milling machine. The detail dimension and specification of the tensile test specimen prepared was shown in the Figure 3.11 and Table 3.2. The prepared specimens were as shown in Fig. 3.12 as per the standards.

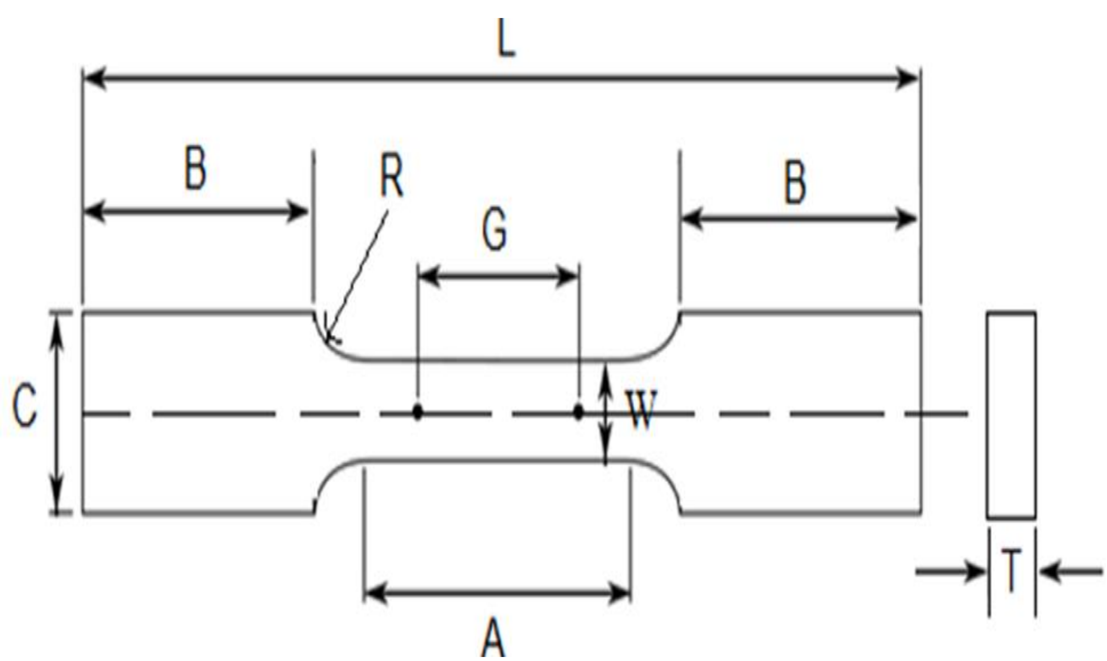

Figure 3. 11: tensile test specimen specification (J.R., (2004))

table 3. 2: Tensile test specimen specification and dimension as per the ASTM standards

Symbol	**Name**	**Dimension**
G	Gage length	50mm
W	Width	12.5mm
T	Thickness	2mm
R	Fillet radius	20mm
L	Overall length	200mm
A	Length of reduced section	60mm
B	Length of grip section	50mm
C	Width of grip section	25mm

Figure 3. 12: Specimen prepared for tensile test

3.8.2 Tensile test experiment

The experimental procedure had two stages. In the first one, the experimental study concerned material property characterization by tensile test. The mechanical and forming properties of the base material were obtained from standard tensile tests as per ASTM standards E-8M. 27 numbers of specimens were tested by nine different parameters with three numbers of repetitions. The material properties were taken from the average of three specimens that tested with the same perimeters. The specimens are designed as shown in Table 3.4. All the samples were tested by universal testing machine (UTM 2000kN) in Ethiopian conformity assessment enterprise.

table 3. 3: Numbers of specimen tested and its parameters

Rolling direction	After heat treated and before heat treated	Number of specimens
0^0	Annealing	3
45^0	Annealing	3
90^0	Annealing	3
0^0	Normalizing	3
45^0	Normalizing	3
90^0	Normalizing	3
0^0	Without heat treatment	3
45^0	Without heat treatment	3
90^0	Without heat treatment	3

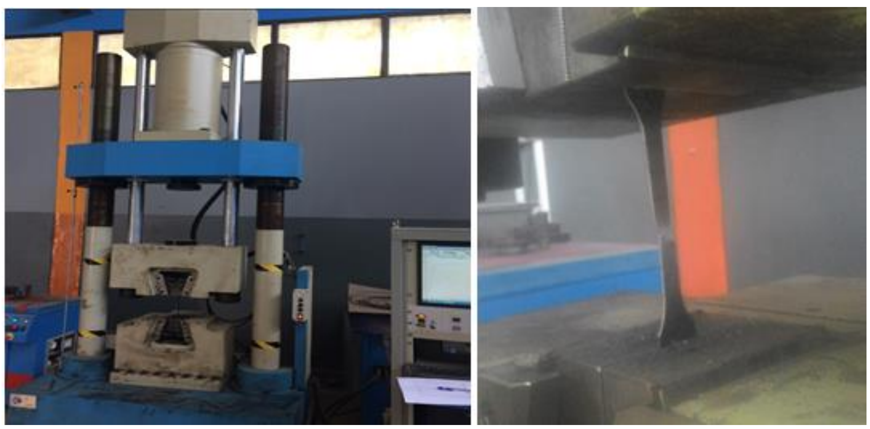

Figure 3. 13: Tensile testing by using UTM-2000kN

After the tensile test was performed the value of yield stress, ultimate stress, engineering stress and strain, true stress and strain, *K* value and *n* value was determined on the output data from UTM. From the output data, force and elongation was used to provide the described parameters. Initially, the engineering stress and strain was determined respectively. Then true stress and strain was determined from engineering stress and strain by using equation respectively. The yield stress was determined from the graph of true stress-strain and the offset of true strain (true strain + 2%) with true stress. Then the contact point of both graphs is yield stress as shown on the Figure 3.13 as example. From the data of true stress and strain, the data for 'n' graph was determined. This data was selected from yield stress up to ultimate stress. The value of 'n' was determined from the graph as shown on the Figure 3.14. Finally, the value of K was determined from the graph of first 'n' was determined from by using equation. All the mechanical properties of 27 specimens were determined by the same procedures.

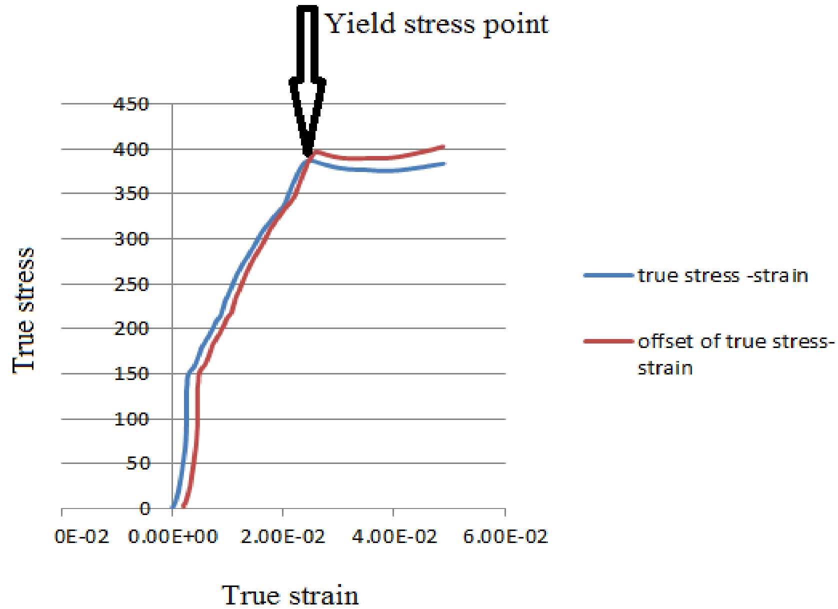

Figure 3. 14: Shows How to find yield stress from true stress and 2% offset of true strain

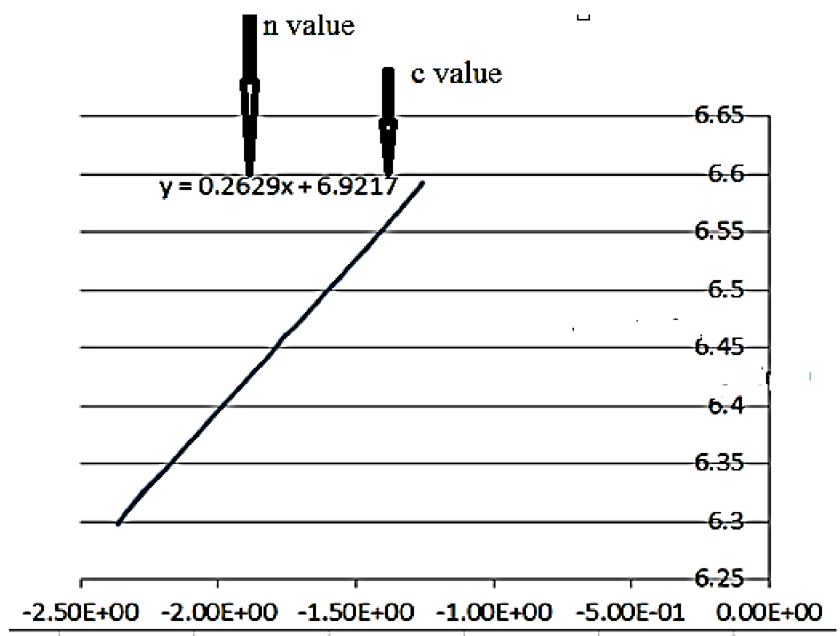

Figure 3. 15: Shows how to find ‘n’ value and ‘K’ exponent

3.9 FINITE ELEMENT SIMULATION PROCESS

Extensive knowledge of influence of all the variables on the sheet metal bending process is required to design the tools adequately to manufacture a product with the desired shape and performance. After the first design of the tools, a large number of time-consuming trial and error experiments required to determine the proper tool design and all other variables, leading to the desired product. This trial and error process sometimes may even require redesigning the expensive tools. To reduce the time and cost, process modeling by computer simulation was used to replace the experimental trial and error process by a virtual trial and error process.

FE simulation was applied to investigate the springback and spring-go phenomena in a V-die bending process and to investigate the effects of process parameters. In the V-bending process a “blank” of sheet metal was placed on die surface. A punch was moved against the blank which was drawn into the die. The blank was drawn from between these two tools. To obtain a successful bending process, it was controlled the slip between the blank and die. The rigid punch and the die, the coefficient of friction between the interface and the punch is taken to be 0.1. In the first step the punch was moved toward the blank through a total distance of 10mm. In the simulations performed, special attention is given in order to remain as close as possible to the physical process. Using a dynamic explicit and static implicit time integration scheme.

The bend angle of the blank during loading and unloading is found out by performing the Springback simulation on the deformed blank. Two nodes one on each side of the bending region are selected and the angle between them is being found out. The same procedure was repeated at every regular position of the blank and the average of all the angles is being taken. The same procedure is adopted for the blanks before and after considering the springback and the difference between them is the value of springback. The material properties that were used in the simulation were given in Table 4.1.

3.9.1 Parameters for FE simulation input

In engineering application, material selection was important term to make sure that material is suitable for the produce products. JIS 3302 grade steel sheets were selected as the materials of the blank in this study. The dimensions of the specimen are: blank size, 150×40 mm; material thickness, 2 mm; punch width, 40 mm; die entrance radius, 2.5mm; load of pressure pad, 20kN; and intended bending angle, 90°. For reasons of symmetry in V-channel processing, it was reduced the 3D problem to a 2D problem by assuming a plane-strain condition. The material properties were input for ABAQUS simulations were: -modules of elasticity, poison ratio, yield stress and plastic strain. The value of poison ratio that used was 0.3. The others detail of this material properties was presented in Table 4.1 and 4.2.

3.9.2 Material modeling

The geometric models of the die, punch and blank were modeled in the pre-processor. Figure 3.16 shows the assembly of tools in the code. The blank used is JIS 3302 grade steel of size 2mm. The number and type of elements used in a typical simulation for different objects were shown in Table 3.4.

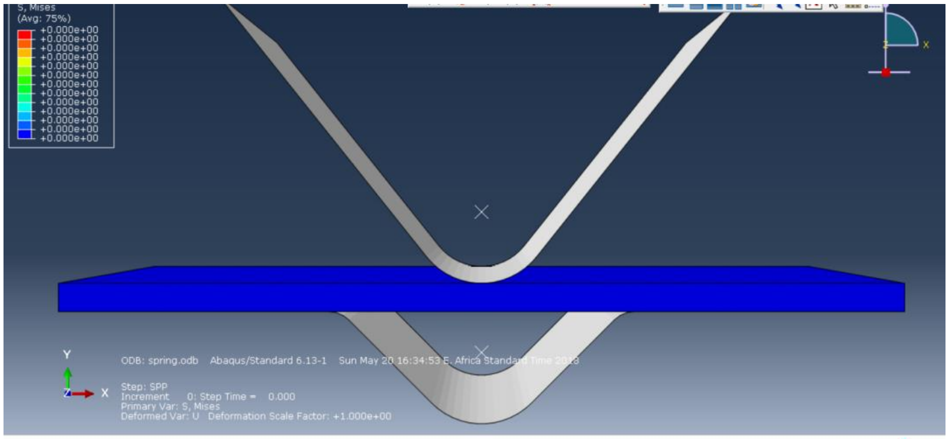

Figure 3. 16: Showing solid model of the arrangement

3.9.3 Mesh Details

The model was meshed with quad, by default the solver selects meshing with respect to physics nature. The Finer meshing was performed to obtain accurate results of V-bending. In this case explicit was selected for the meshing and solving. Figure 3.17 and 3.18 shows the mesh structure of the arrangement and simulated model.

Table 3. 4: Parameters used in a typical FE

Object type	Type of body	Node/elements
Punch	Rigid	4616/22309
Die	Rigid	14020/11951
Blank	Deformable	4080/3000

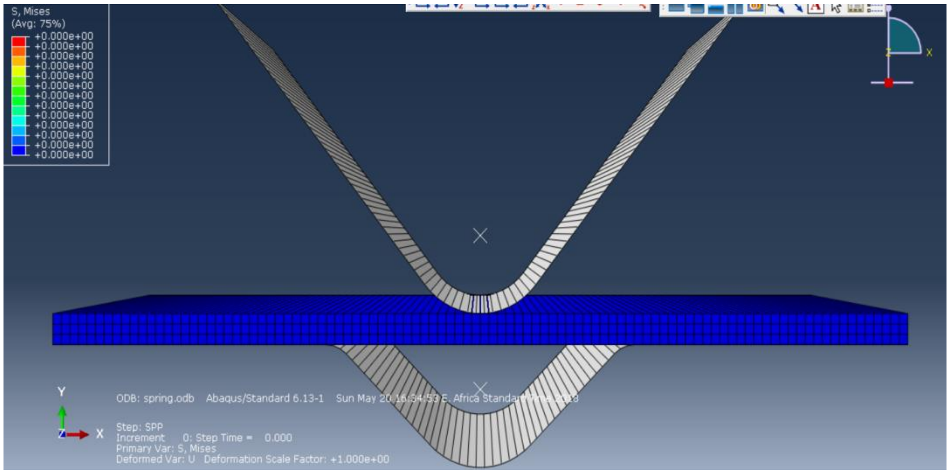

Figure 3. 17: Mesh structure of the arrangement assembly of V-bending process

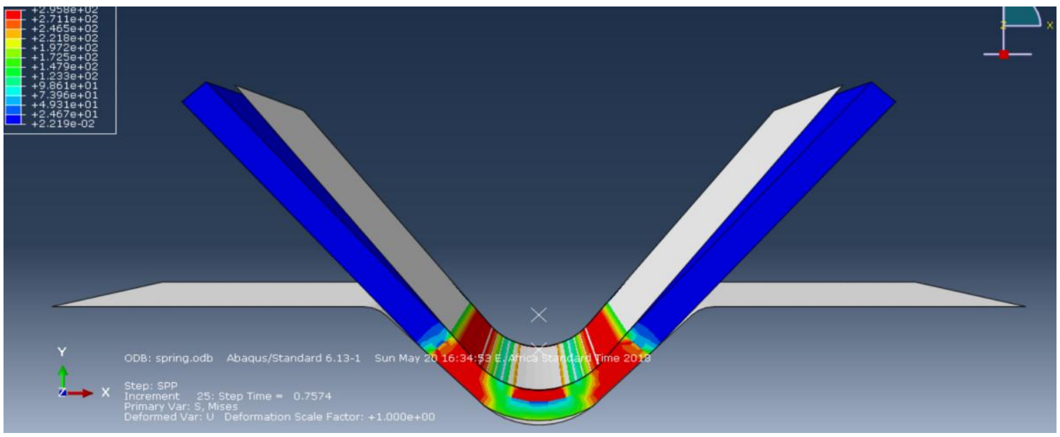

Figure 3. 18: Final simulated model after V die bending

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

Experiments and FE simulation were conducted to evaluate the effectiveness of the heat treatments and cutting angle on the springback effect of the selected material. The influence of the heat treatments and rolling angles on the springback in the V-bending tests for these two factors have a significant influence.

4.2 TENSILE TEST RESULT

The results of tensile tests are shown in the Table 4.1 such as ultimate stress (Tensile stress), yield stress, total elongation, strain hardening coefficient (n) and Material Strength (K). The ultimate stress and yielding stress for annealed specimens is the lowest when it is compared with the result from normalized and before heat treating specimen as presented in Table 4.1, Fig. 4.1 and 4.2. By which, the stress of specimens before heat treating has the largest leads to the force required for specimen testing after heat treatments is minimum.

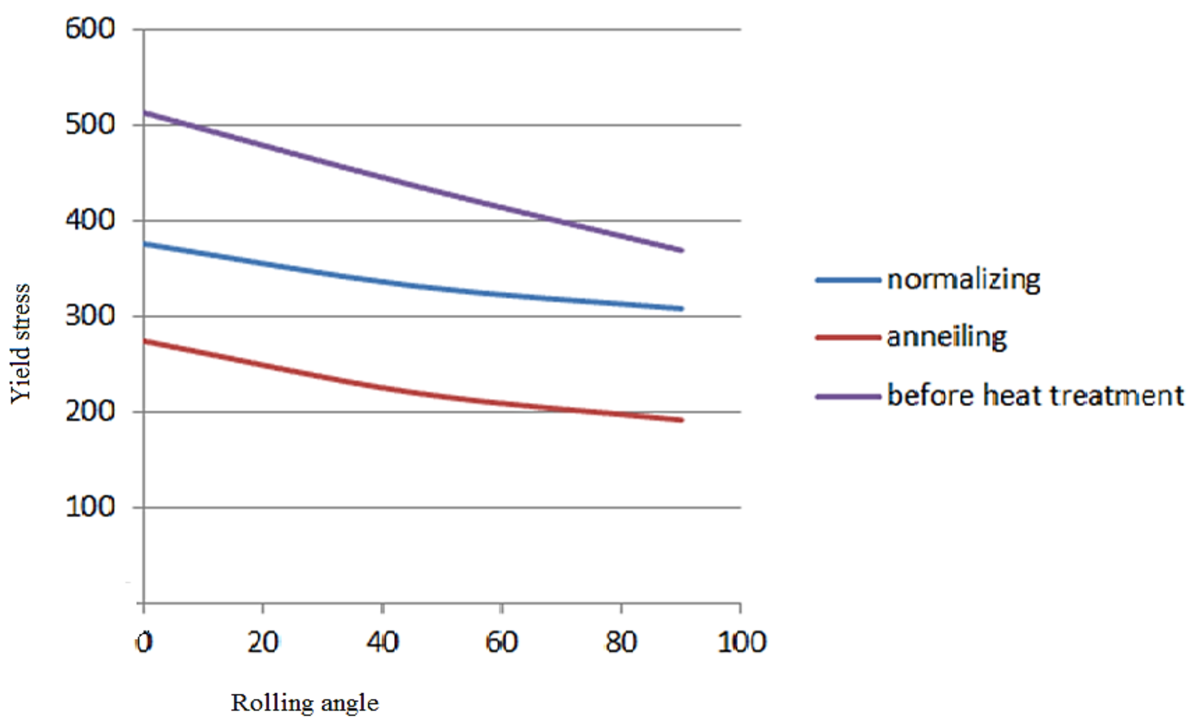

Figure 4. 1: Graph of rolling angle with yield stress

Table 4. 1 Mechanical properties of JIS 3302 grade steel sheet material

Condition of specimen	Rolling direction	Trials	Mechanical properties of the specimens				
			Tensile stress (MPa)	Yield stress (MPa)	%elongation	*n*	*K*(MPa)
Annealing	0^0	1	350.3	278.4	52	0.35	723.283
		2	361	214.3	60	0.855	869.3
		3	408.4	330.2	60	0.53	970.97
		average	373.23	274.3	57.33	0.578	854.518
	45^0	1	300	212	58.375	0.32	720.46
		2	299.6	174.1	56	0.4	680.35
		3	320.3	275	54	0.52	856.13
		average	386.53	220.37	56.125	0.413	763.86
	90^0	1	395.5	132.4	55.6	0.49	824.35
		2	397.1	152.4	48.1	0.376	801.67
		3	405.4	289.8	60.7	0.4354	885.28
		average	399.33	191.53	54.8	0.4338	837.1
Normalizing	0^0	1	382.8	376	84.6	0.49	877.4325
		2	424.9	352.7	61.5	0.491	977.4039
		3	451.9	395.1	61.5	0.3758	883.596
		average	419.87	308.23	69.2	0.452	912.81
	45^0	1	485.43	267.82	73.1	0.5	945.13
		2	402.87	348.12	60	0.51	956.23
		3	444.65	380.18	55.2	0.47	934.56
		average	431.32	332.04	62.77	0.493	945.91
	90^0	1	492.2	421.8	53.8	0.51	1154.474
		2	395.5	334	61.5	0.5325	941.995
		3	440.1	372.3	53.8	0.5412	1051.423
		average	442.6	176.9	56.37	0.5279	1049.297
Without heat treatment	0^0	1	572.5	508.5	44	0.258	1049
		2	562.6	501.8	60	0.0038	363.5
		3	572	529.5	48	0.246	1030.81
		average	569.03	513.27	50.67	0.169	814.437
	45^0	1	474.7	387.3	46.7	0.2864	903.6119
		2	534.67	447.8	48.2	0.34	765
		3	584.7	476.65	48	0.53	876
		average	531.36	437.25	46.3	0.385	848.2
	90^0	1	562.8	501.2	46.2	0.153	912.14
		2	549.6	482.3	38.5	0.262	1014.042
		3	521.5	124.3	38.5	0.3	1024.439
		average	544.63	369.27	41.07	0.238	983.54

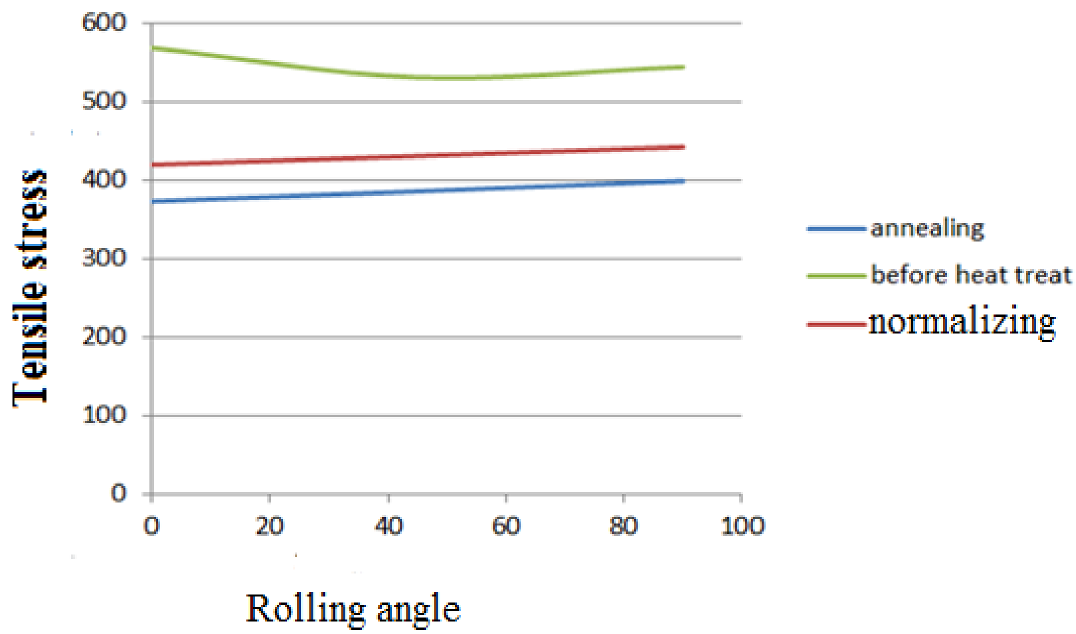

figure 4. 2: Graph of rolling angle with tensile stress

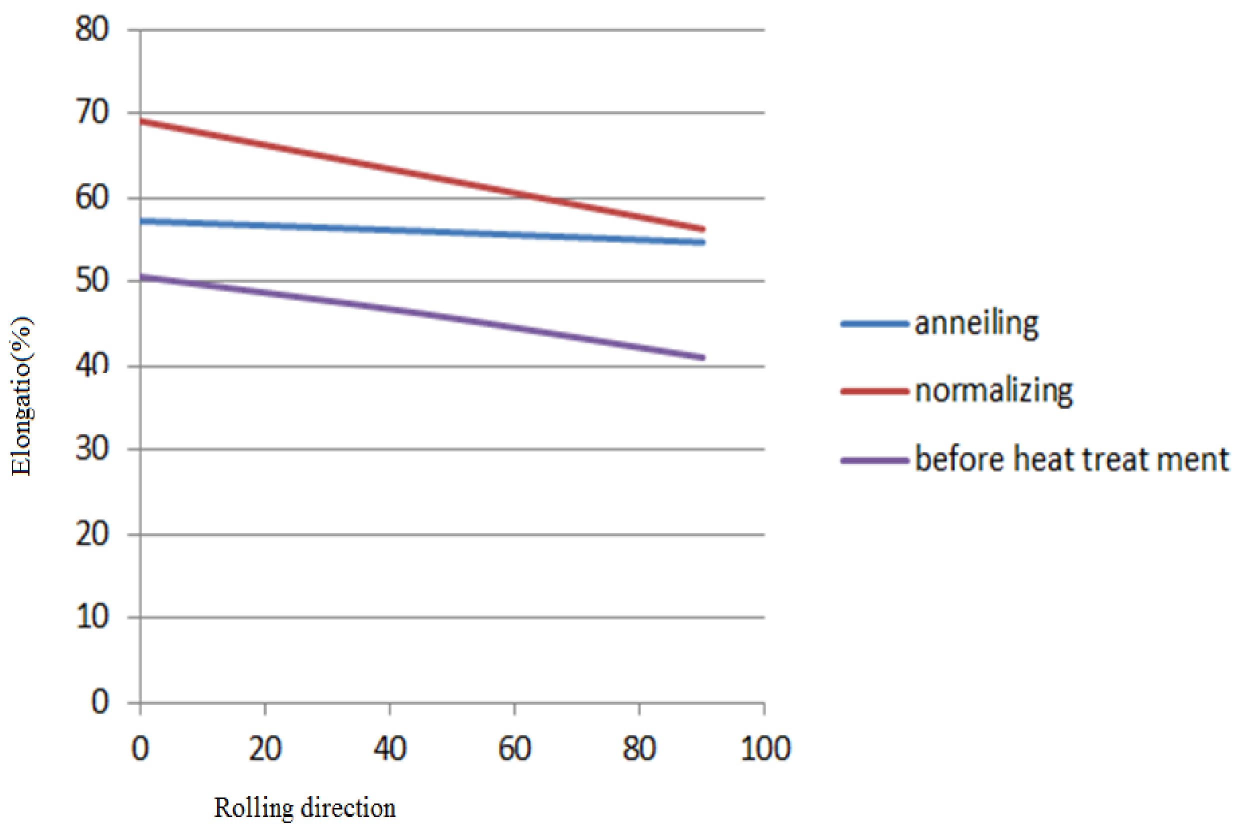

figure 4. 3: Graph of elongation with rolling angle

Table 4. 2: modules of elasticity

Annealing	Rolling angle	Modules of elasticity(GPa)
	0^0	150
	45^0	165
	90^0	160
Normalizing	0^0	130
	45^0	142
	90^0	153
Without heat treat	0^0	205
	45^0	230
	90^0	199

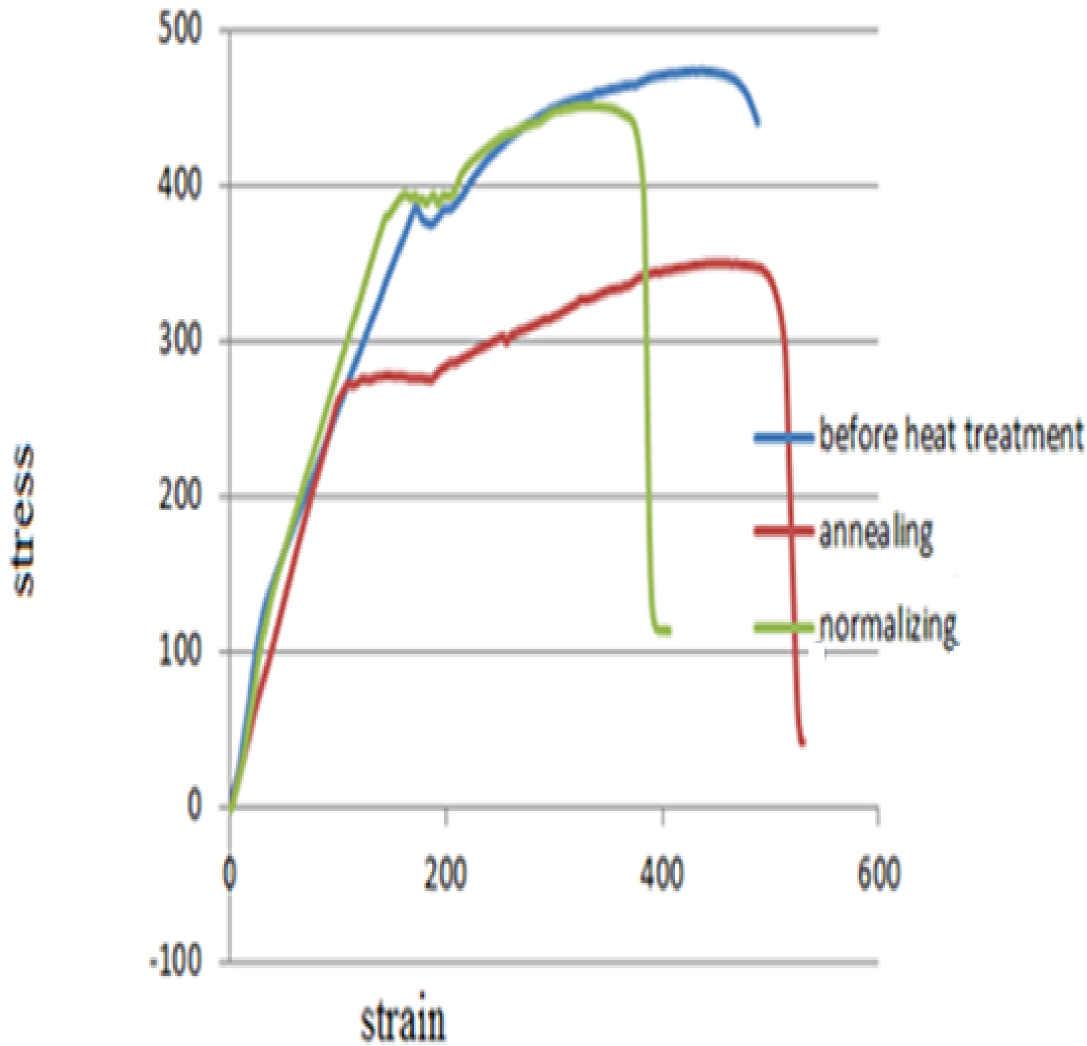

figure 4. 4: comparison of stress-strain diagram

The smallest elongation specimen from Table 4.1 was 41.07% of before heat treatments. But the ultimate stress of the before heat treatments was the largest (Figure 4.4) and the ultimate stress of the annealing was the lowest (Figure 4.2 and 4.4). Additionally, the hardening coefficient is the smallest on annealing specimen (Table 4.1). Inversely, it was the largest on before heat treating specimen (Table 4.2).

4.3 HARDNESS PROPERTIES OF THE SPECIMAN

The average micro hardness value of before heat treating is found to be 282.72 HV while the annealing and normalizing specimen are 174.88 and 183.9 respectively as shown in Table 4.3. This indicates that the micro hardness before heat treating is more compared to the annealing and normalizing specimen. But, the micro hardness of annealing is the lowest when it is compared with the normalizing and before heat treatment specimen. This shows that the annealed specimen has got ductile behavior and formable. Due to this, the springback to be found from annealing is the smallest (Table 4.4 and 4.5).

Table 4. 3: The value of Micro hardiness the materials

Type	Hardness value					Average
	1	2	3	4	5	
Before heat treat specimen	284.7	287.2	274.7	282.1	284.9	282.72
Annealed specimen	178.3	168.6	177.7	177.7	172.1	174.88
Normalized specimen	188.9	179.6	191.7	180.2	179.1	183.9

4.4 MICROSTRACTURE RESULT

A typical microstructure of the specimens are presented in Figures 4.5, 4.6, and 4.7. It is observed that the microstructure of the specimen with different heat treated conditions are different. The investigated cold rolled steel has shown a ferrite matrix microstructure (Fig.

4.5) whereas the annealed and normalized steel are showing austenitic microstructure (Fig. 4.6 & Fig. 4.7) (Gandy, 2007).

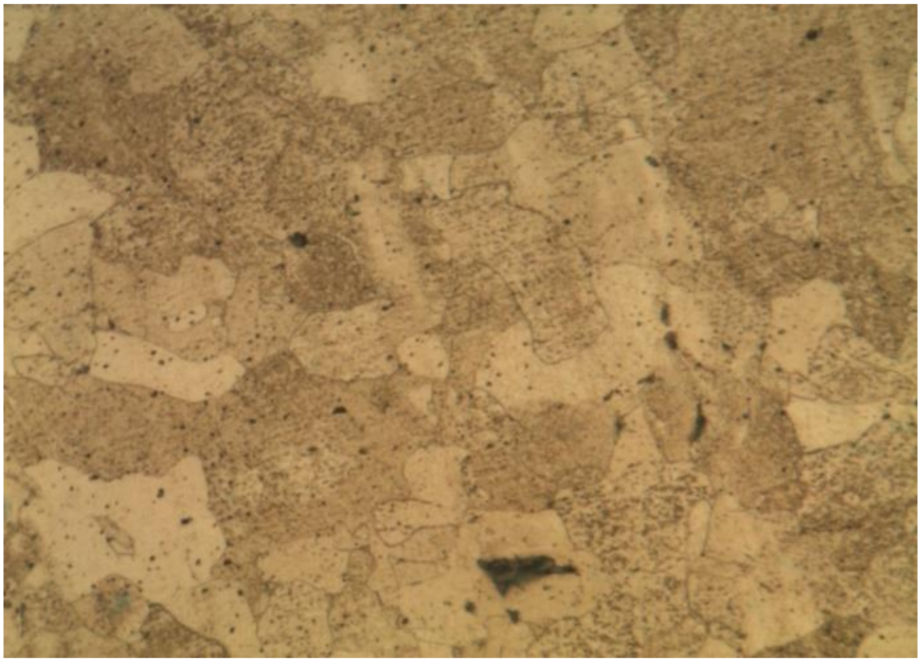

figure 4. 5: Before heat treatment at 1000x magnification

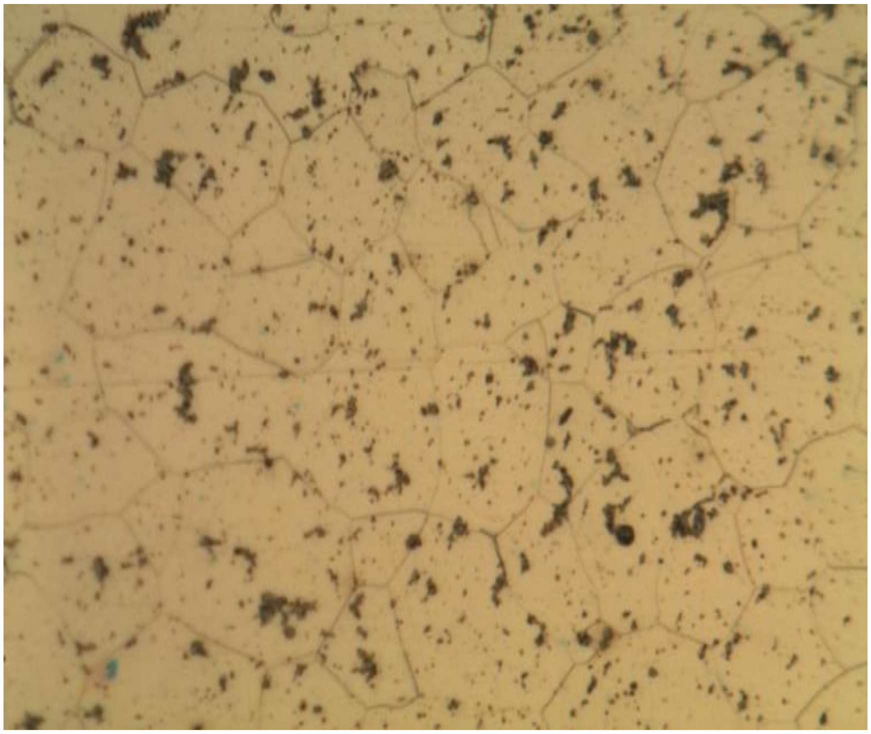

figure 4. 6: Annealed specimen at 1000x magnification

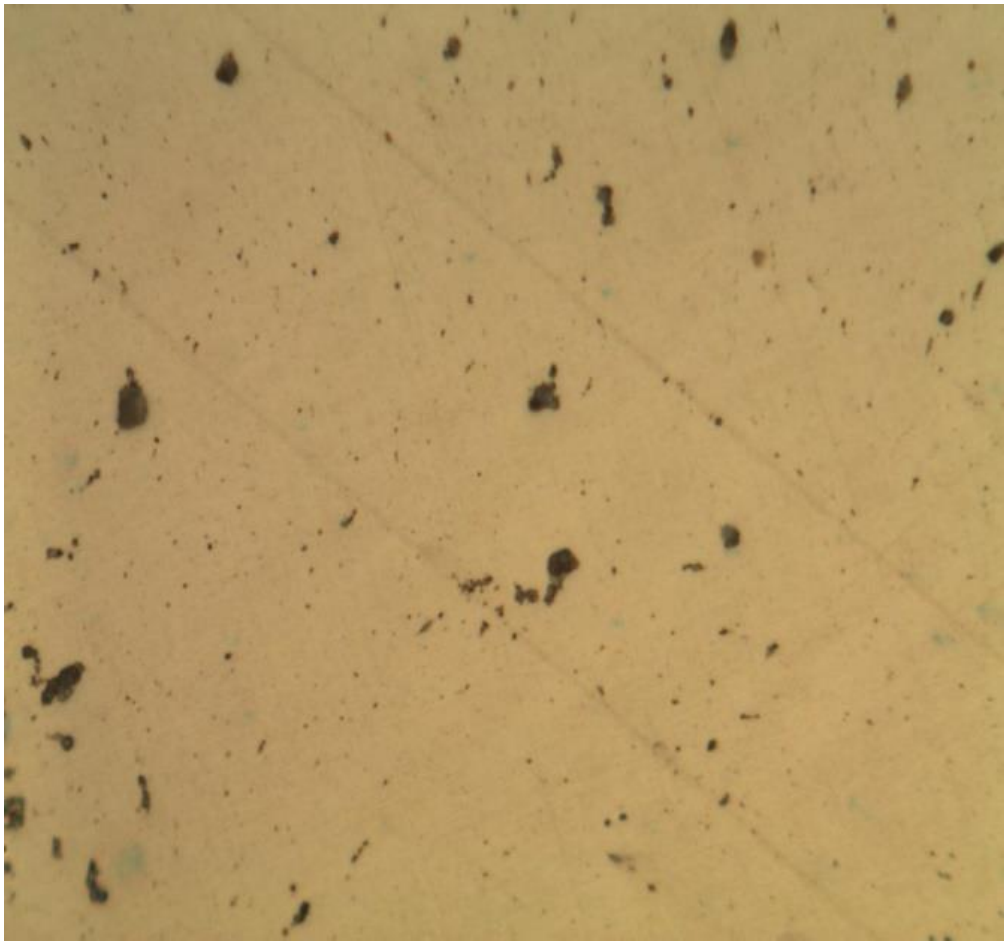

figure 4. 7: Normalized specimen at 1000x magnification

4.5 SPRINGBACK RESULT FROM EXPERIMENTAL

The experiments are conducted on JIS 3302 grade steel sheet of 2mm thickness with different rolling directions. For illustration few of the deformed sheets are shown in Figure 4.8. All the springback tests are conducted at ambient conditions only. For each test, three reputations are followed. In each reputation springback angles are measured with equal time interval. All the experimental data is tabulated in the Table 4.4. Among all the specimens, the major springback has seen without heat treated specimen as 3.5° in 90° rolling direction and minimum is in annealed sample as 0.5° in 0° rolling direction. Hardness without heat treated has more value than heat-treated values. This is also another reason to relate the springback analysis along with microstructures.

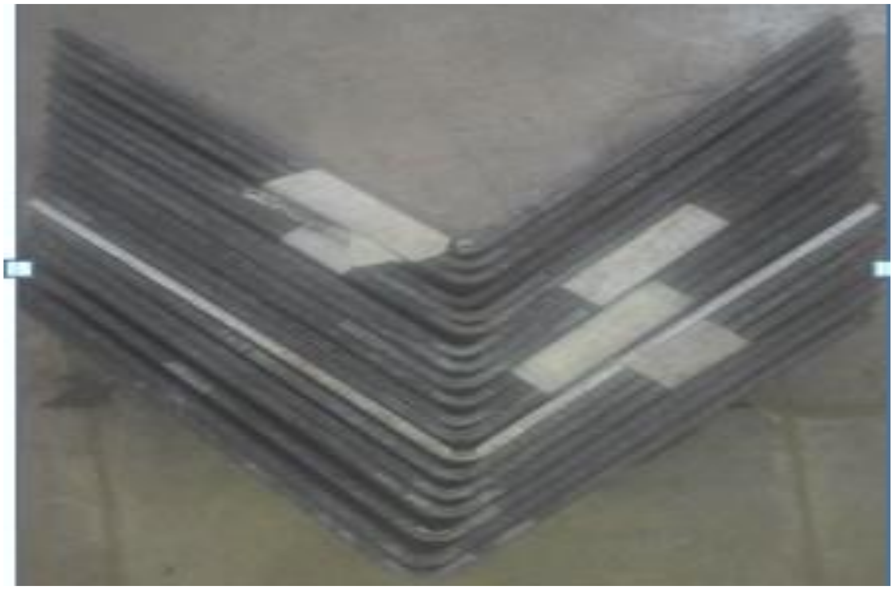

figure 4. 8: After V-bending at different heating conditions

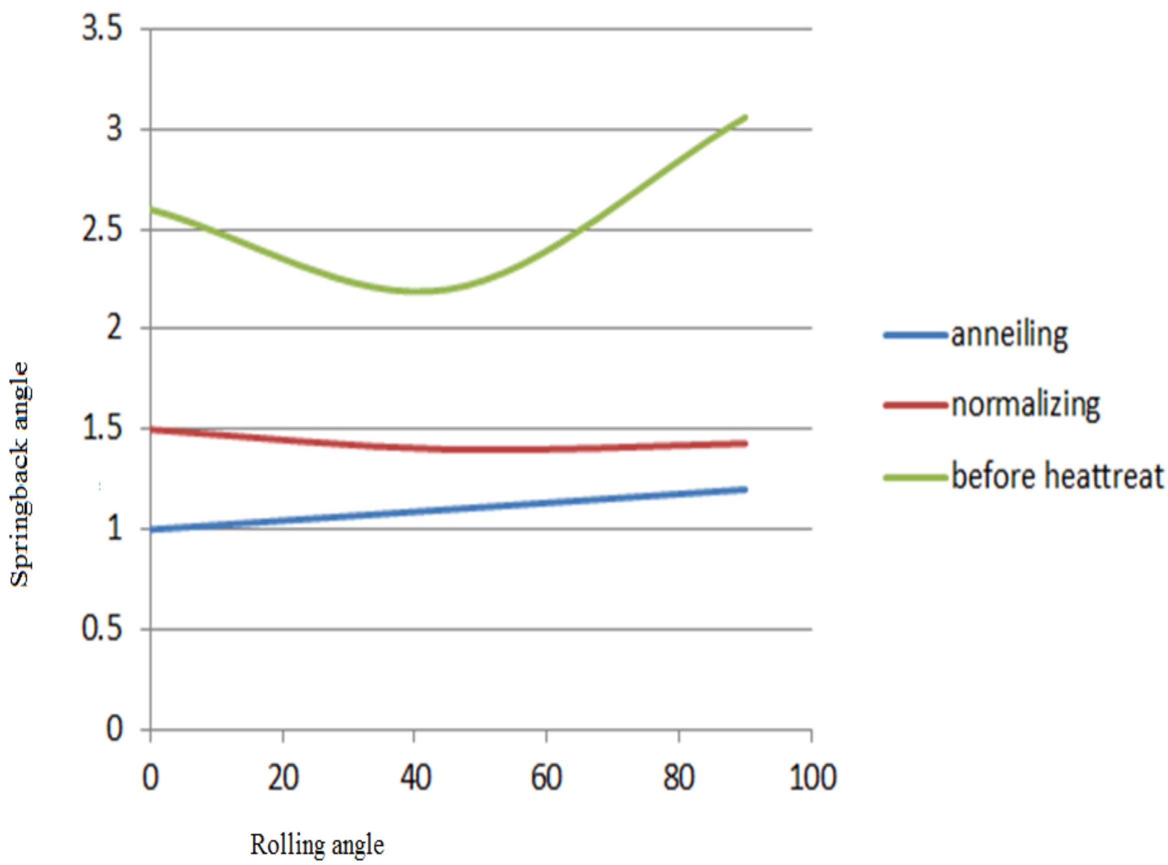

figure 4. 9: Showing experimental springback with rolling direction

Table 4. 4: Experimental result

Heat treatment and without of heat treat specimen	Sheet rolling direction	Trials	Measured value for (90^0) die angle	Springback
Annealed specimen	45^0	1	91^0	1
		2	91^0	1
		3	91.5^0	1.2
		average	91.1^0	1.1
	90^0	1	91.5^0	1.5
		2	91^0	1
		3	91^0	1
		average	91.2^0	1.2
	0^0	1	91.5^0	1.5
		2	91^0	1
		3	90.5^0	0.5
		average	91^0	1
Normalized specimen	0^0	1	91.5^0	1.5
		2	91.5^0	1.5
		3	91.5^0	1.5
		average	91.5^0	1.5
	90^0	1	91^0	1
		2	91.5^0	1.5
		3	91.8^0	1.8
		average	91.27^0	1.43
	45^0	1	91.2^0	1.2
		2	91.5^0	1.5
		3	91.5^0	1.5
		average	91.23^0	1.4
Without heat treatment specimen	0^0	1	92.5^0	2.5
		2	92.8^0	2.8
		3	92.5^0	2.5
		average	92.6^0	2.6
	90^0	1	93^0	3
		2	92.7^0	2.7
		3	93.5^0	3.5
		average	93.06^0	3.06
	45^0	1	92^0	2
		2	92.2^0	2.2
		3	92^0	2
		average	92.067^0	2.067

4.6 SPRINGBACK RESULT FROM ABAQUS

The evaluated mechanical properties form the tensile tests are given as input the ABAQUS finite element solution. The complete setup for V-bending was modeled and run the simulation by giving proper input conditions. The springback is noted for all the heat-treated conditions as shown in Table 9. From the simulation results, maximum springback is noted as 2.3 in 90^0 rolling direction in without heat treated specimen and minimum is in annealed specimen as 1.3 in 0^0 rolling direction. For illustration an example of the FE simulation output was shown in Figure 4.10.

Table 4. 5: Springback result from ABAQUS

Heat treatment	Sheet angle	Springback
Annealed specimen	45^0	1.5
	90^0	1.6
	0^0	1.3
Normalized specimen	0^0	1.6
	90^0	1.8
	45^0	1.7
Without heat treatment specimen	0^0	2.15
	90^0	2.3
	45^0	2.1

4.7 COMPARISON OF EXPERIMENTAL AND FE SIMULATION

Due to the changes is mechanical properties after heat treatment, there have been variations in springback angle after the bending operations in both experimental and FE simulation. For the same material, because of the decreasing in yield strength from before heat treatment to annealing condition, it has been observed that higher springback is obtained in before heat treatment condition in both experimental and FE simulation. Before heat treatment specimen has higher yield strength than annealing and normalizing type heat treated material whereas the yield strength of material in annealing condition is the lowest.

In the normalizing case, the value of micro hardiness is slightly increased as presented in Table 4.3 and the springback also increased as described in Table 4.4 and 4.5 related to full annealing. This is due to some fine pearlite structure which produced from normalizing process where the faster cooling in still air gives fine pearlite (Figure 4.7).

In the case of full annealed specimen, the value of microhardness is the lowest (Table 4.3) and the value of springback is also lowest as presented in Table 4.4 and 4.5. Where the steel is initially heated to produce homogeneous austenite (FCC γ phase), then allows the steel to cool slowly in a furnace, producing coarse pearlite (Figure 4.6) provides relatively low strength, low hardness and good ductility.

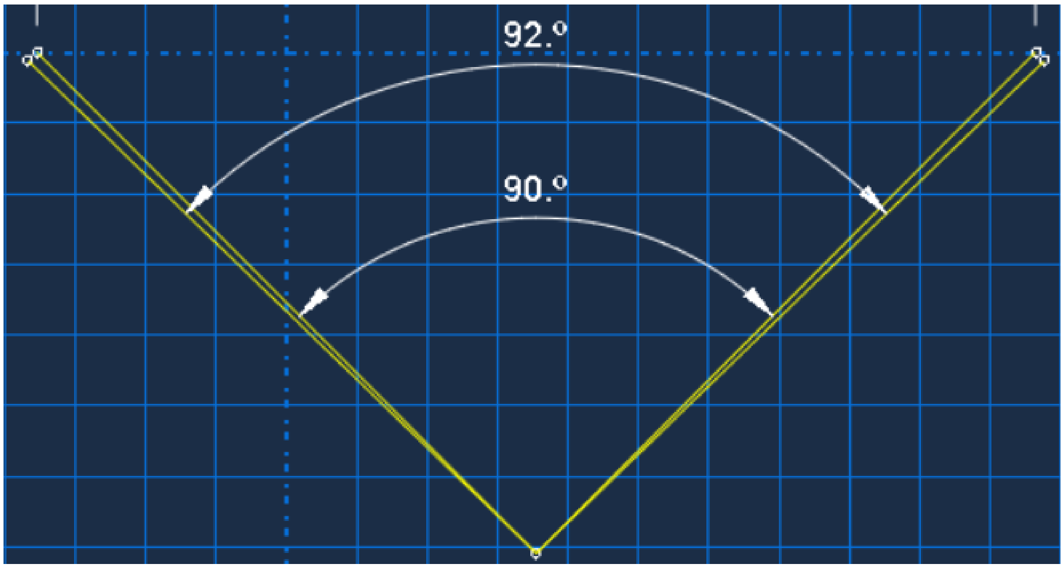

figure 4. 10: Example of the springback of FE simulation result

Table 4. 6: Comparison of FE simulation and experimental

Heat treat and with heat treat specimen	Cutting angle of specimen	FE simulation result	Experimental result
Annealing	0^0	1.3	1
	45^0	1.5	1.43
	90^0	1.6	1.4
Normalizing	0^0	1.6	1.5
	45^0	1.7	1.4
	90^0	1.8	1.43
Without heat treat	0^0	2.3	2.6
	45^0	2.1	3.06
	90^0	2.15	2.067

Before heat treated specimen shows the greatest value of microhardness (Table 7) and as well as the value of springback is largest (table 10).

The effect of springback and resulting properties of mechanically formed steel plates have been presented and discussed. It was found that the 2mm v-bended sheet metal exhibited the largest value of springback 3.06^0 for experimental and 2.3^0 for FE simulation. In other words, the springback caused a v-bending errors 3.06^0 for experiment and 2.15^0 for FE simulation. Due to the springback errors, the desired angle of 90^0 was not achieved. From this stand of point it can be concluded that springback causes geometric inaccuracies in sheet metal bending. It also found that the ferrite changed to austenite. The microhardness of the annealed specimens is improved compared to before heat treating and normalizing to reduce the error due to springback. In this case, annealing can be considered as a method of compensating for the springback.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATION

5.1 CONCLUSIONS

In this thesis, several bending operations were analyzed in order to determine the effect of heat treatment to the springback. For this purpose, two different types of heat treatment were applied to the JIS 3302 grade steel and the amount of springback was determined under three circumstances. Moreover, the effect of rolling angle to the springback is also studied individually in the scope of this work. Hence, the general conclusions attained in this study can be stated as follows:

i. The specimen used have the highest yield strength, microhardness in without heat treatment condition compared to annealing and normalizing and it is observed that higher springback values are obtained in the specimen compared to others.

ii. It is observed that as microhardness increase the springback also increase along with ferrite micro structure changed to austenite the springback decrease.

iii. It observed that when rolling direction increase the elongation of specimen is decreases.

iv. It is observed that experimental and FE simulation results are in good agreement

v. FE results also showed that, in before heat treatment condition, required punch force to bend the sheet metal was higher than the material in normalizing condition where the lowest in annealing condition

5.2 RECOMMENDATIONS

One of the future studies related to this study may be the simulation and analysis of different bending operations such as U-die bending and bending with flexible tooling. In such a case, the tooling configurations may be varied and the changes in the processes may be investigated.

Another further study may be to analyze more complex bending operations by utilizing under heating forming processes. Effect of material model to the springback simulation and bending method may also be studied.

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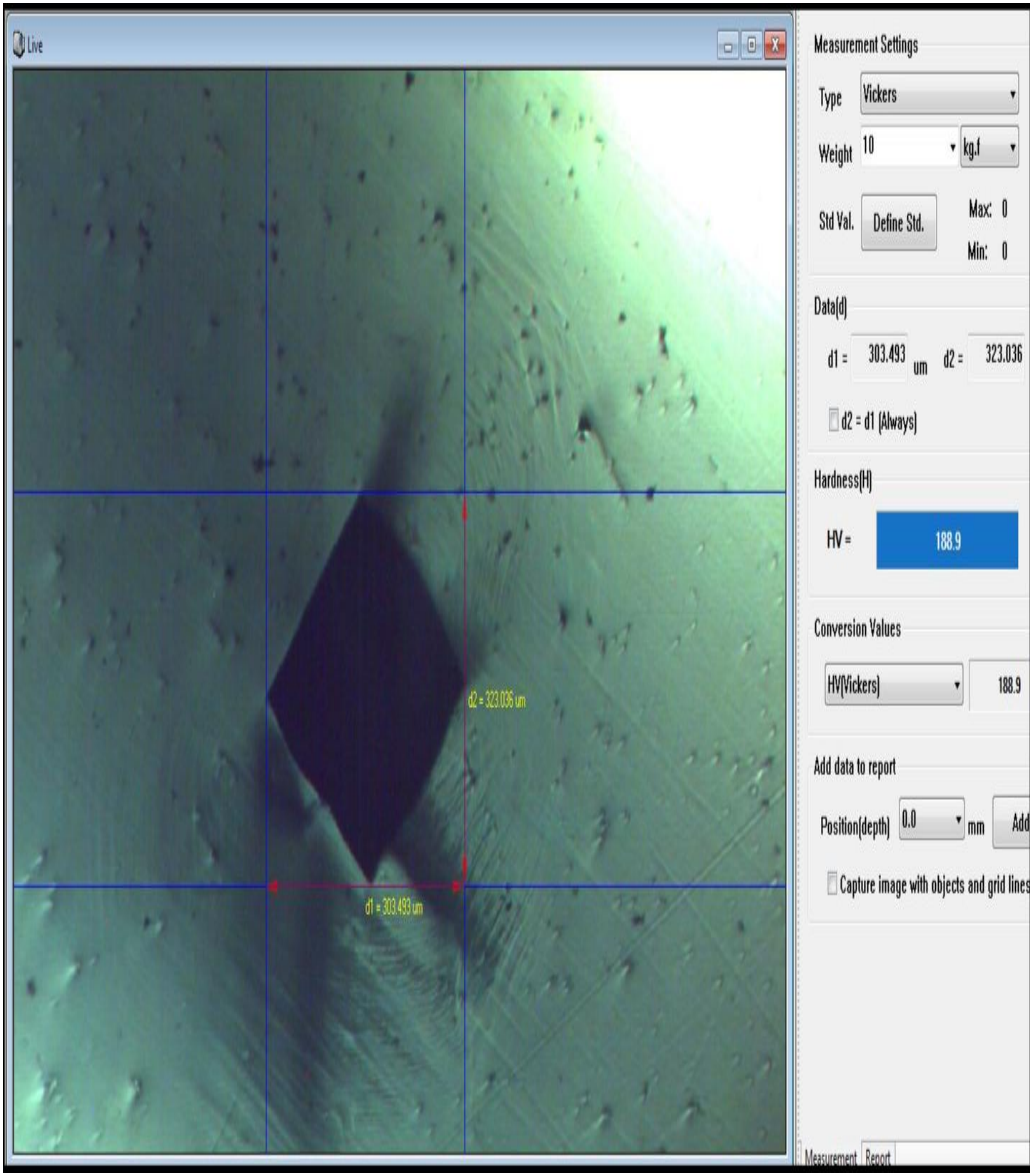
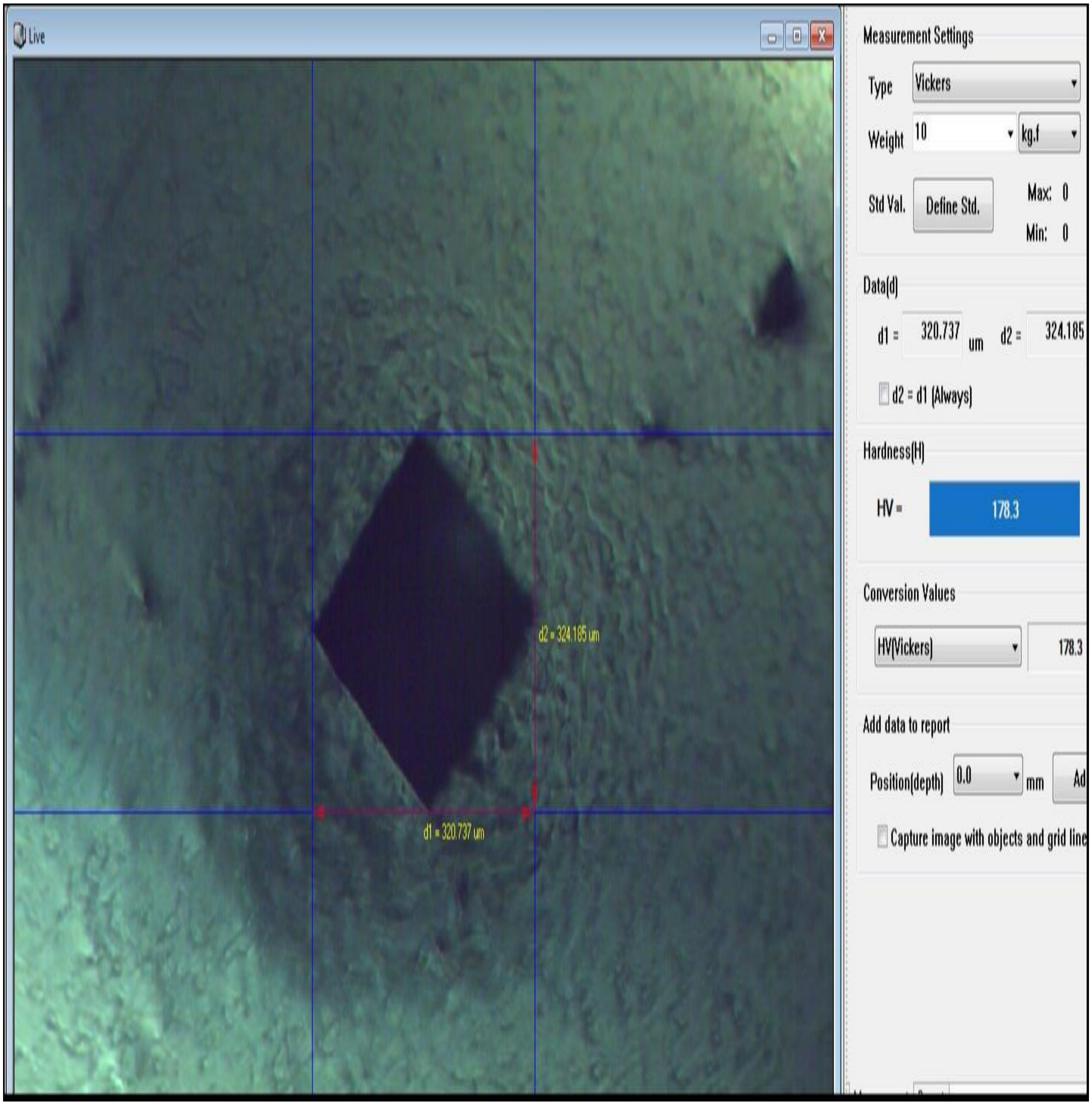
APENDECS

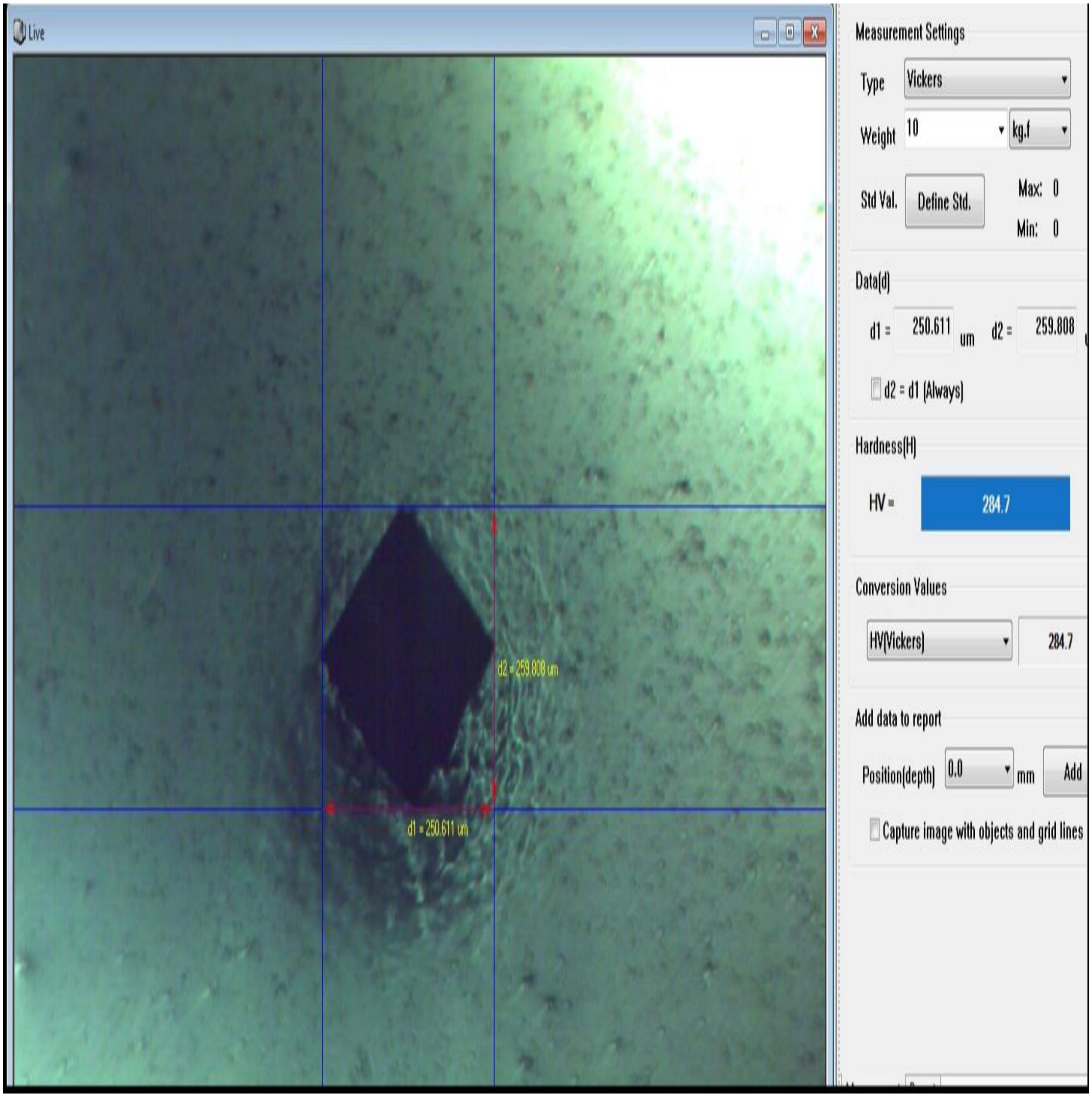
Micro hardiness of normalizing specimen result



Micro hardiness of annealing specimen result

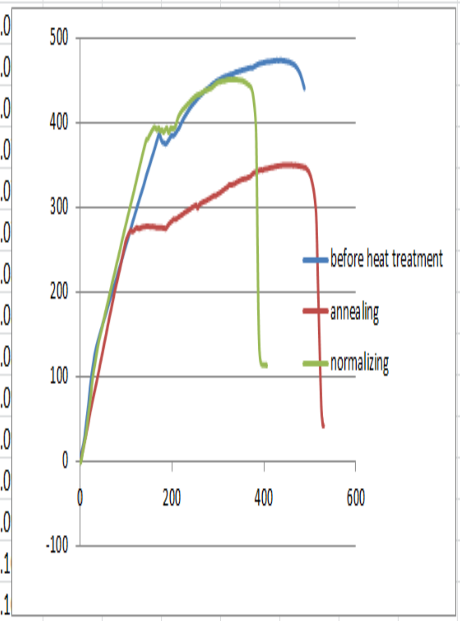


Micro hardiness of Before heat treatment specimen result



Example of stress- strain finding

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	L(m	F(N)	eng strain	eng stress	true strain	true stres	OFFSET	true stress												
2	0.02212	166.438	4.42E-04	6.42123	0.00044221	6.42E+00	0.02044	6.42407		5.76E-02	410.258	-2.8539	6.01679							
3	3.00E-02	228.164	6.00E-04	8.80262	0.00059936	8.81E+00	0.0026	8.80789		5.86E-02	411.426	-2.837	6.01963							
4	3.45E-02	288.401	6.90E-04	11.1266	0.00068994	1.11E+01	0.00269	11.1343		5.96E-02	412.749	-2.8204	6.02284			2.32396		9.06E-05		
5	4.04E-02	346.441	8.08E-04	13.3658	0.00080796	1.34E+01	0.00281	13.3766		6.06E-02	414.046	-2.804	6.02598							
6	4.59E-02	409.575	9.19E-04	15.8015	0.00091821	1.58E+01	0.00292	15.816		0.06151	415.596	-2.7885	6.02971			2.56E+04				
7	5.16E-02	473.809	1.03E-03	18.2797	0.00103224	1.83E+01	0.00303	18.2986		0.06245	416.949	-2.7734	6.03296							
8	5.73E-02	547.304	1.15E-03	21.1151	0.00114544	2.11E+01	0.00315	21.1393		0.06338	418.259	-2.7586	6.0361							
9	6.13E-02	624.537	1.23E-03	24.0948	0.00122433	2.41E+01	0.00322	24.1243		0.06434	419.351	-2.7435	6.03871							
10	6.66E-02	710.205	1.33E-03	27.3999	0.00133084	2.74E+01	0.00333	27.4364		0.06531	420.404	-2.7287	6.04122		3.30508					
11	7.18E-02	820.597	1.44E-03	31.6588	0.00143585	3.17E+01	0.00344	31.7043		0.06618	421.696	-2.7154	6.04428		1.07E-04					
12	7.91E-02	944.914	1.58E-03	36.455	0.00158018	3.65E+01	0.00358	36.5127		0.067	423.212	-2.7031	6.04787				3.10E+04			
13	8.49E-02	1076.65	1.70E-03	41.5373	0.00169719	4.16E+01	0.0037	41.6079		0.06776	425.059	-2.6918	6.05223							
14	9.09E-02	1195.78	1.82E-03	46.1333	0.0018166	4.62E+01	0.00382	46.2172		0.06859	426.685	-2.6796	6.05605							
15	9.49E-02	1312.61	1.90E-03	50.641	0.00189678	5.07E+01	0.0039	50.7371		0.0694	428.342	-2.6679	6.0							
16	0.10032	1430.02	2.01E-03	55.1703	0.0020043	5.53E+01	0.004	55.281		0.07024	429.769	-2.6558	6.0							
17	0.10558	1545.2	2.11E-03	59.614	0.00210935	5.97E+01	0.00411	59.7399		0.07106	431.498	-2.6443	6.0							
18	0.11109	1662.75	2.22E-03	64.1495	0.0022194	6.43E+01	0.00422	64.292		0.07194	432.92	-2.6319	6.0							
19	0.11489	1782.64	2.30E-03	68.7745	0.00229523	6.89E+01	0.0043	68.9325		0.07279	434.549	-2.6201	6.0							
20	0.1184	1928.14	2.37E-03	74.3882	0.00236516	7.46E+01	0.00437	74.5644		0.07369	436.031	-2.6079	6.0							
21	0.12147	2077.37	2.43E-03	80.1454	0.00242642	8.03E+01	0.00443	80.3401		0.07459	437.521	-2.5958	6.0							
22	0.1244	2228.61	2.49E-03	85.9802	0.00248481	8.62E+01	0.00448	86.1941		0.07552	438.847	-2.5833	6.0							
23	0.12547	2354.85	2.51E-03	90.8505	0.00250635	9.11E+01	0.00451	91.0785		0.07644	440.259	-2.5713	6.0							
24	0.12619	2473.05	2.52E-03	95.4109	0.00252061	9.57E+01	0.00452	95.6517		0.07735	441.695	-2.5594	6.0							
25	0.12647	2584.75	2.53E-03	99.7204	0.00252615	1.00E+02	0.00453	99.9726		0.07827	443.042	-2.5476	6.0							
26	0.12658	2693.44	2.53E-03	103.914	0.00252848	1.04E+02	0.00453	104.177		0.07911	444.348	-2.5369	6.0							
27	0.12658	2795.54	2.53E-03	107.853	0.00252843	1.08E+02	0.00453	108.126		0.07994	445.689	-2.5264	6.0							
28	0.12653	2886.87	2.53E-03	111.376	0.00252738	1.12E+02	0.00453	111.658		0.08076	447.105	-2.5163	6.1							
29	0.12645	2972.53	2.53E-03	114.681	0.00252588	1.15E+02	0.00453	114.971		0.08167	448.369	-2.5051	6.1							
30	0.12637	3068.35	2.53E-03	118.378	0.00252416	1.19E+02	0.00452	118.677		0.08252	449.772	-2.4947	6.10874		903.612					
31	0.12626	3164.54	2.53E-03	122.089	0.00252195	1.22E+02	0.00452	122.397		0.08338	451.14	-2.4843	6.11178							
32	0.12614	3256.06	2.52E-03	125.62	0.0025196	1.26E+02	0.00452	125.937		0.08424	452.607	-2.4741	6.11502							



Example of universal testing machine out put

F(N)	R(MPa)	L(mm)	A(%)	t(s)	Lb(mm)	F/t(N/s)	R/t(MPa/s)	L/t(mm/min)	En(J)
-5.210876	-0.2582198	-1.238983E-04	-9.450015E-02	1.490625E-02	0	8.529199	0.422656	1.524802E-03	0
50.52185	2.503561	8.642875E-03	-8.645118E-02	0.2019062	0	-41.61192	-2.062037	5.960725E-03	1.986155E-04
100.7279	4.99147	3.113574E-02	-6.579999E-02	0.1961063	0	0.1429562	7.084054E-03	5.960725E-03	1.899635E-03
155.3537	7.698401	4.429777E-02	-5.371564E-02	0.2415463	0	0.1429562	7.084054E-03	5.960725E-03	3.584912E-03
213.9239	10.60079	5.659605E-02	-4.242432E-02	0.2556742	0	0.1429562	7.084054E-03	5.960725E-03	5.855652E-03
269.6884	13.36414	6.511872E-02	-3.459947E-02	0.2737879	0	0.1429562	7.084054E-03	5.960725E-03	7.916485E-03
331.4088	16.42264	7.444209E-02	-2.603947E-02	0.2866362	0	0.1429562	7.084054E-03	3.468117	1.071861E-02
391.5727	19.404	8.144069E-02	-1.961391E-02	0.2960286	0	0.1429562	7.084054E-03	3.468117	1.324854E-02
454.179	22.50639	8.986792E-02	-1.187668E-02	0.3066767	0	0.1429562	7.084054E-03	3.468117	1.681221E-02
510.6087	25.30271	9.464849E-02	-7.487534E-03	0.3136848	0	0.1429562	7.084054E-03	3.468117	1.911833E-02
581.7075	28.82594	0.1007223	-1.911056E-03	0.3234161	0	0.1429562	7.084054E-03	3.468117	2.243558E-02
656.0673	32.51077	0.1045685	1.620251E-03	0.3299639	0	0.1429562	7.084054E-03	3.468117	2.481596E-02
733.2838	36.33715	0.1099627	6.572749E-03	0.3394197	0	0.1429562	7.084054E-03	3.468117	2.856315E-02
801.2029	39.70282	0.113485	9.806696E-03	0.3456205	0	381.1354	18.88679	3.468117	3.126565E-02
867.3135	42.97887	0.1186931	1.458836E-02	0.3517518	0	381.1354	18.88679	3.468117	3.561055E-02
933.3911	46.25328	0.1221278	1.774184E-02	0.3574182	0	381.1354	18.88679	3.468117	3.870299E-02
998.58	49.48365	0.127279	2.247125E-02	0.3629777	0	381.1354	18.88679	3.468117	4.367896E-02
1066.083	52.82867	0.1306826	2.559621E-02	0.3716229	0	381.1354	18.88679	3.468117	4.719264E-02
1140.849	56.53366	0.1358136	0.0303071	0.3776639	0	381.1354	18.88679	3.468117	5.285453E-02
1224.095	60.6588	0.1409315	3.500595E-02	0.3868011	0	381.1354	18.88679	3.468117	5.890629E-02
1311.636	64.99682	0.1463838	4.001176E-02	0.3928367	0	381.1354	18.88679	6.850099	6.581899E-02
1400.481	69.39944	0.1501619	4.348056E-02	0.4020713	0	381.1354	18.88679	6.850099	7.094237E-02
1478.675	73.27428	0.1519369	4.511021E-02	0.4083253	0	381.1354	18.88679	6.850099	0.0734976
1553.541	76.98421	0.1529917	4.607866E-02	0.4146231	0	381.1354	18.88679	6.850099	7.509682E-02
1620.611	80.30779	0.1535038	0.0465488	0.4201334	0	381.1354	18.88679	6.850099	7.590951E-02
1684.727	83.48499	0.1537698	4.679301E-02	0.4254951	0	381.1354	18.88679	6.850099	7.634909E-02
1746.172	86.52985	0.1538789	4.689324E-02	0.4338695	0	381.1354	18.88679	6.850099	7.653636E-02
1824.202	90.39655	0.1538983	4.691102E-02	0.4430166	0	381.1354	18.88679	6.850099	7.657094E-02
1903.66	94.334	0.1538552	4.687145E-02	0.452921	0	381.1354	18.88679	6.850099	7.649062E-02
1988.49	98.53767	0.1537765	4.679922E-02	0.4629313	0	1026.557	50.87	6.850099	7.633751E-02
2054.161	101.7919	0.1536927	4.672228E-02	0.4699142	0	1026.557	50.87	6.850099	7.616811E-02
2119.574	105.0334	0.1536122	4.664832E-02	0.4795128	0	1026.557	50.87	6.850099	7.600001E-02
2177.146	107.8863	0.1552672	4.816787E-02	0.4922292	0	1026.557	50.87	6.850099	7.955569E-02
2236.743	110.8396	0.1572705	0.0500071	0.5060922	0	1026.557	50.87	7.650467	8.397676E-02
2293.614	113.6578	0.1614256	5.382199E-02	0.523808	0	1026.557	50.87	7.650467	0.0933888
2349.303	116.4174	0.1660883	0.0581029	0.5425238	0	1026.557	50.87	7.650467	0.104213
2401.608	119.0093	0.171288	6.287687E-02	0.5654101	0	1330.868	65.94987	7.650467	0.1165647
2451.541	121.4837	0.1749618	0.0662499	0.5863305	0	1330.868	65.94987	7.650467	0.1254795
2500.114	123.8907	0.1784367	6.944024E-02	0.6076919	0	1330.868	65.94987	7.650467	0.1340827
2548.044	126.2658	0.1832989	7.390437E-02	0.6285483	0	1330.868	65.94987	8.937809	0.1463554

Example of *n* and *k* finding

1	L(mm	F(N)	engstress	engstrain	truestress	tr strain		
2	-1.18E-03	26.56555	1.239065	-4.55E-05	1.24E+00	-4.54959E-05	#NUM!	2.14E-01
3	2.60E-02	69.79371	3.255304	1.00E-03	3.26E+00	0.000999541	-6.90821	1.18E+00
4	3.79E-02	110.4172	5.150056	1.46E-03	5.16E+00	0.001455206	-6.53261	1.64E+00
5	5.26E-02	158.4375	7.389809	2.02E-03	7.40E+00	0.002020379	-6.20447	2.00E+00
6	6.65E-02	221.8954	10.3496	2.56E-03	1.04E+01	0.002555932	-5.96934	2.34E+00
7	0.079159	299.7117	13.97909	3.04E-03	1.40E+01	0.003039967	-5.79591	2.64E+00
8	8.96E-02	380.675	17.75536	3.45E-03	1.78E+01	0.00344104	-5.67198	2.88E+00
9	9.76E-02	452.0153	21.0828	3.76E-03	2.12E+01	0.003748718	-5.58634	3.05E+00
10	0.10478	513.2057	23.93683	4.03E-03	2.40E+01	0.004021901	-5.516	3.18E+00
11	0.111246	573.2538	26.73758	4.28E-03	2.69E+01	0.004269546	-5.45625	3.29E+00
12	0.117395	632.5006	29.50096	4.52E-03	2.96E+01	0.004505018	-5.40256	3.39E+00
13	0.121609	693.8597	32.36286	4.68E-03	3.25E+01	0.004666365	-5.36737	3.48E+00
14	0.127107	755.2734	35.2273	4.89E-03	3.54E+01	0.004876804	-5.32327	3.57E+00
15	0.132474	832.6402	38.83583	5.10E-03	3.90E+01	0.005082225	-5.28201	3.66E+00
16	0.138052	913.2086	42.59368	5.31E-03	4.28E+01	0.005295657	-5.24087	3.76E+00
17	0.143646	1000.316	46.65653	5.52E-03	4.69E+01	0.005509655	-5.20125	3.85E+00
18	0.149282	1074.79	50.13013	5.74E-03	5.04E+01	0.005725207	-5.16288	3.92E+00
19	0.154949	1151.376	53.70224	5.96E-03	5.40E+01	0.005941881	-5.12573	3.99E+00
20	0.160625	1220.651	56.93335	6.18E-03	5.73E+01	0.006158895	-5.08986	4.05E+00
21	0.16458	1294.615	60.38316	6.33E-03	6.08E+01	0.00631005	-5.06561	4.11E+00
22	0.168185	1364.827	63.65798	6.47E-03	6.41E+01	0.006447818	-5.04401	4.16E+00
23	0.169643	1435.224	66.94142	6.52E-03	6.74E+01	0.006503529	-5.03541	4.21E+00
24	0.170601	1512.616	70.55112	6.56E-03	7.10E+01	0.006540155	-5.02979	4.26E+00
25	0.171021	1595.403	74.41245	6.58E-03	7.49E+01	0.006556173	-5.02735	4.32E+00
26	0.171219	1689.002	78.77808	6.59E-03	7.93E+01	0.006563773	-5.02619	4.37E+00
27	0.171263	1768.343	82.47868	6.59E-03	8.30E+01	0.006565439	-5.02594	4.42E+00
28	0.171254	1840.638	85.85065	6.59E-03	8.64E+01	0.006565102	-5.02599	4.46E+00
29	0.17122	1898.257	88.53811	6.59E-03	8.91E+01	0.00656378	-5.02619	4.49E+00