PRE-STRAINING EFFECT ON YIELDING BEHAVIOUR OF LOW-CARBON STEELS

AHMAD SHUKRON BIN ZULKIFLI

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DECLARATION

I declare that this thesis entitled "*Pre-straining effect on yielding behaviour of low-carbon steels*" is the result of my own research except as cited in references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree

Signature : ______________________________

Name of candidate : **AHMAD SHUKRON BIN ZULKIFLI**

Date : ______________________________

DEDICATION

To my beloved mother and father
my lecturer, family and friends.

ACKNOWLEDGEMENT

First of all I am grateful to ALLAH S.W.T for blessing me in finishing my final year project (PSM) with success in achieving my objectives to complete this project.

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ABSTRACT

Roll forming is yet used widely in the industry yet known to the world. It has complexity to design the product but it can be study and determined by evaluating and studying the mechanical properties on the stress-strain curve of the material. The study show how on the specimen that is setting up for a variable different pre-staining stages indicates that stress-strain curve help the designer to identify the yielding region effect on the bending deformation of the product while some defects such as springback will occur. The findings of this method can be relates to roll forming process in terms of stages and bending phenomenon that are something that is occur when doing roll forming process could lower the percent of defect for the products made by roll forming machine.

ABSTRAK

Pembentukan pengulungan telah digunakan meluas di dalam industri tetapi kurang dikenal di khalayak ramai. Ianya mempunyai ciri-ciri yang kompleks semasa membentuk sesuatu produk tetapi ianya boleh di kaji dengan mempelajari ciri-ciri mekanikal pada lengkungan stress-tegangan untuk beberapa pra-tegangan. Ini dilakukan dengan mengaitkannya dengan beberapa pembentukan yang berulang didalam proses pembentukan pengulungan. Dengan mengkaji kesan-kesan yang berlaku pada setiap pra-tegangan, pereka produk dapat mengelakkan daripada terhasilnya produk yang gagal dah ini akan menjimatkan penggunaan kos untuk menghasilkannya.

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P	-	Load
A_o	-	Cross-sectional Area
e	-	Engineering strain
l	-	Instantaneous length of the specimen
l_o	-	Original length of the specimen
σ y	-	Yield strength
ef	-	Elongation
σ	-	Stress

CHAPTER 1

INTRODUCTION

1.1 Introduction

Roll forming is a process that use to produce a product that are not well known to common people but widely use by them. The products that usually produce by roll forming are panels, door and picture frames, channels, gutters, siding, and pipes and tubing with lock seams. People may not realize it but roll forming is important.

The example of the material that usually use in roll forming application are Carbon Steel, HSLA (High-Strength Low Alloy) and UHSS (Ultra High-Strength Steels), Stainless Steel, Aluminium, Wrought Aluminium Alloy. Typical roll formed metals are copper, brass, tin, zinc, titanium, zirconium, and nickel alloys (such as Monel, Hastelloy, Inconel, Invar, etc.) and many other metals and alloys. Many of these alloys work harden quickly. This increases the springback and can limit the formability. Occasionally stress relieving or annealing is required after or in between roll forming. Non-metallic materials can be roll formed too. Thick rubber or plastic coating extruded on thin metal carrier is occasionally “roll formed” after the extrusion process. Certain plastics (e.g., thermoplastics) can also be roll formed. The sheet metal that will be used and analyzed in this research are low-carbon steel (mild steel) and aluminium alloy. Nowadays mild steel and aluminium alloy is used widely in roll forming product. This is because it easily to shape and low on material and production cost, but the profile of roll forming can have a defect such as bow, twist, flare, springback and oil canning[3].

To decrease or avoid the possible defect, safely withstanding the expected maximum load without permanent deformation (or to stay within the specified deflection) is a basic requirement for any product. The "resistance" against the load is a function of the cross-section and the mechanical properties (or in loose terms the "strength") of the material. The most important mechanical properties are the yield strength, tensile strength, and elongation. By using most effective method or test in knowing these mechanical properties, we can actually avoid any unnecessarily loss in term of cost and time. This method is known as tensile test.

1.2 Problem Statement

Complexities of material properties are often overlooked by engineers while developing a manufacturing process. In the case of multiple stages cold roll forming process, the material might experience strain path changes such as bend, release (i.e.…elastic recovery) followed by further bending(further straining). Therefore the strain path changed throughout the roll forming stages. The effect of strain path changes can be explained using a simple an unaxial tensile case. If a specimen stressed beyond its yield strength level, followed by a removal of stress, it will undergo elastic recovery with a certain amount of permanent deformation. If the specimen is applied with tensile stress again, it will have a higher or lower yield strength and tensile strength. However, the specimen now has lower ductility, by repeating the procedure the strength will continue to increase and the ductility continues to decrease until the alloy becomes very brittle. This work hardening phenomenon must be properly characterized. In certain type of material the strain hardening is affected by strain path changes. It affect primarily in the transient, region of subsequent yielding or as softening in the large strain area. The effect can be substantial in a dual phase microstructure such as a ferrite-pearlite structure in steel

1.3 Objectives

1.3.1 To carry out unaxial tensile test with different pre-straining stages.

1.3.2 To measure and characterize yielding region of pre-straining material

1.4 Scope

1.4.1 The material is limited to Low-carbon steel

1.4.2 Limited to only use tensile properties.

1.5 Justification

The reason on doing this research because the application of roll forming begin taking place on industries by replacing the usage of wood and other orthodox material that takes time and cost to produce it, in other words the demand for the product that make by cold roll formed is high. This project is done by counting the root of the production by knowing the mechanical properties of the material that will be produce. It will avoid any defect to the product. Thus, it will save cost and time.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

The steel industry has had a long history of development, yet, despite all the time that has passed, it still demonstrates all the sign of longevity. New ideas continue to revolutionize the steel-producing process today as much as they did hundred years ago. Only a few examples that illustrate the great potential for further innovation and discoveries. It is no wonder specialists, engineers and scientists from around the world still find the steel industry an exciting field for implementation of their creativity.

In this section, we will review everything that involved in this research about roll forming, mechanical properties, and microstructure characterisation of the material and etc. Still, the resource for this research is quite limited due to lack of research that had been done about roll forming. That is just the past, but now we all can see the products that use the roll forming application is everywhere. It is starting to become useful to everyone. This phenomenon will make people became more interested to do a research and exploring everything that base on roll forming application. This literature review research will improve or maybe help for the future use to everyone who involve.

2.2 Roll Forming

Roll forming is a process which is also called contour-roll forming or cold roll forming, is used for forming continuous length of sheet or strip metal and for large production runs. The sheet or strip metal is gradually formed in some set of rollers until the cross-sectional area that are needed is obtained or in other word, the shape that we desired. A variety of cross-section profiles can be produced, but each profile requires a carefully crafted set of roll-tools. A schematic illustration of the roll forming process is shown in the Figure 1.0.

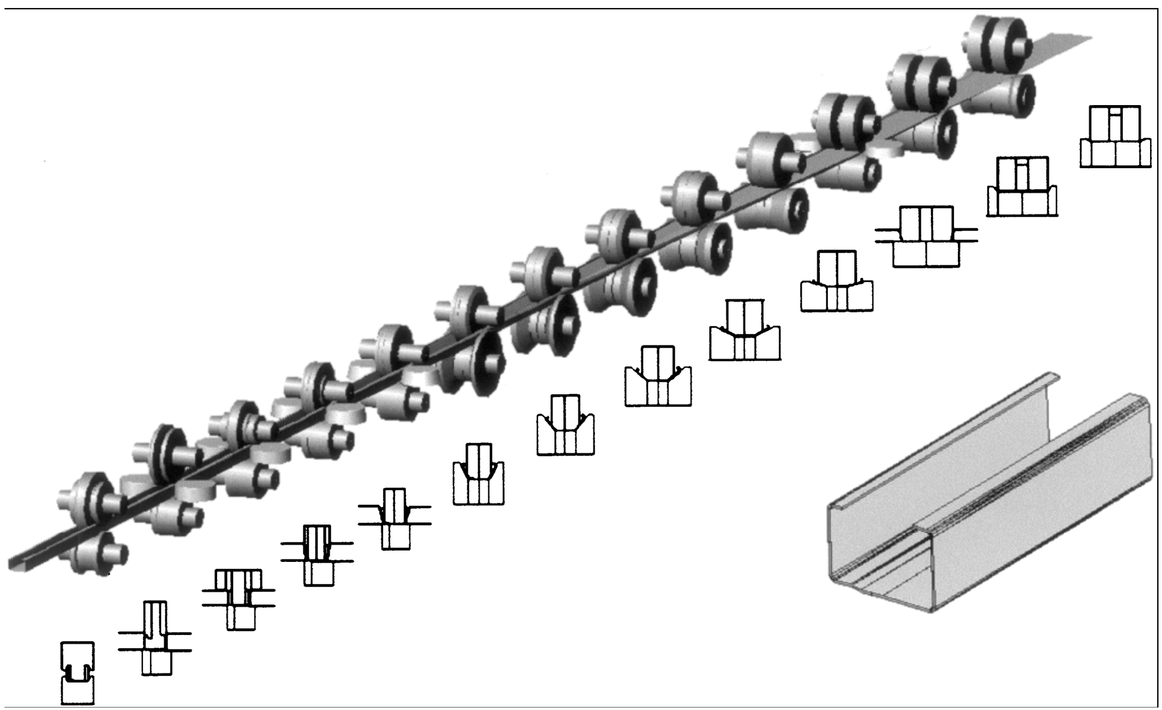

Figure 2.0: Gradual forming of a strip into finished section. (Courtesy of data M Software GmbH.)

The roll forming process is somewhat flexible. Certain design changes may strengthen and improve the functionality of roll formed part. Roll forming allows numerous other processes to be performed while the material is being formed. We can eliminate multi-secondary work such as stamping and extrusion with our in-line capabilities [7].

Typical roll-formed products are panel, door and picture frame and pipes. The length is of the part is limited only by the amount of material supplied to the rolls from the coiled stocked.

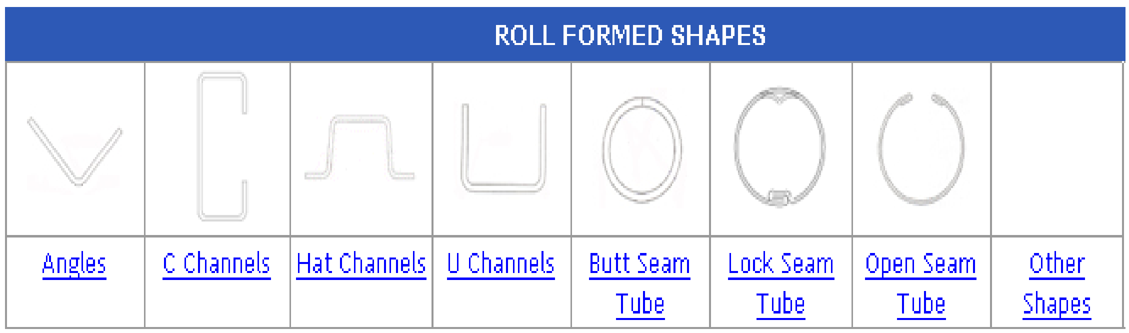

Figure 2.1: Roll-formed shapes (http://www.samsonrollform.com/)

The design and sequencing of the rolls (which usually are mechanically driven) require considerable experience. Dimensional tolerances and springback, as well as tearing and buckling of the strip, have to be considered. The rolls generally are made of carbon steel or of gray iron, and they may be chromium plated for a better surface finish of the formed product and for better wear resistance of the rolls. Lubricants may be used to reduce roll wear, to improve surface finish, and to cool the rolls and the sheet being formed.

Design of the rolls starts with a **flower pattern**, which is the sequence of profile cross-sections, one for each stand of rolls. The roll contours are then derived from the profile contours. Because of the high cost of the roll sets, simulation and knowing mechanical properties is often used to validate the designed rolls and optimize the forming process to minimize the number of stands and material stresses in the final product

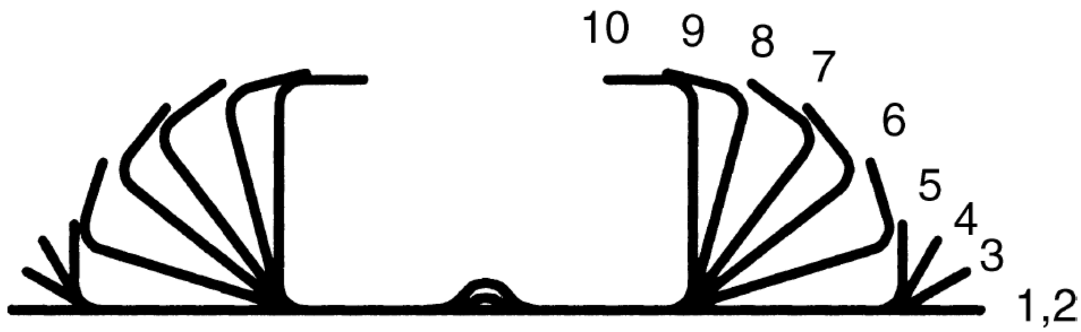

Figure 2.2: Flower Pattern [3]

Roll-forming lines can be set up with multiple configurations to punch and cut off parts in a continuous operation. For cutting a part to length, the lines can be set up to use a pre-cut die where a single blank runs through the roll mill, or a post-cut die where the profile is cut off after the roll forming process. You can add features in a part (holes, notches, embosses, shear forms, etc) by punching in a roll-forming line. These part features can be done in a pre-punch application (before roll-forming starts), in a mid-line punching application (in the middle of a roll-forming line/process) and/or a post punching application (after roll-forming is done). Some roll-forming lines incorporate only one of the above punch or cut off applications others incorporate some or all of the applications in one line.

2.3 Material

. Practically all metals that can be formed by other processes can be roll formed, but for the scope of this research is that the material is limited to Low-carbon steel. _Materials are selected to suit the specified product requirements at the possible lower price. However, the mechanical properties, surface, deviation from thickness, width, straightness, and flatness of the material will influence roll design.

2.3.1 Low Carbon Steel

Low carbon steel, also called mild steel, has less than 0.30% carbon are unresponsive to heat treatments and is therefore neither extremely brittle nor ductile.. Mild steel is the most common form of steel as its price is relatively low while it provides material properties that are acceptable for many applications. It becomes malleable when heated, and so can be forged. It is also often used where large amounts of steel need to be formed, for example as structural steel. Density of this metal is 7,861.093 kg/m^3 (0.284 lb/in^3), the tensile strength is a maximum of 500 MPa (72,500 psi) and it has a Young's modulus of 210 GPa. Strengthening is accomplished by cold work. These alloys are relatively soft and weak but outstanding ductility and toughness; in addition, they are machinable, weldable, and, of all steel are the least expensive to produce. It often is used for common industrial product (such as bolts, nuts, sheet, plate, and tubes) and for machine components that that do not require high strength. Other typical applications automotive body component, structural shapes (I-beams, channel and angel iron), and sheets that are use in pipelines, buildings, bridges, and tin cans.[5]

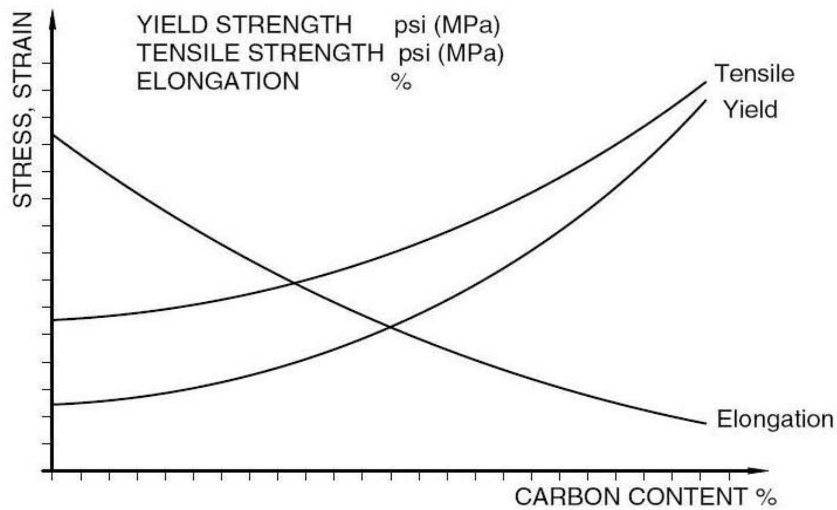

Figure 2.3: Influence of the carbon content on the mechanical properties of steel.[8]

2.4 Mechanical Properties

During roll forming, the strain (elongation) of the outside fibre of the strip must remain below the uniform engineering strain. Therefore, the roll designer must know the yield strength, maximum tensile strength, and elongation of the material. These data are usually available from the supplier. In low carbon steel, the correlation between hardness and tensile strength is reasonably good. Therefore, hardness is sometimes used to “check” the incoming material and “screen out” the too “hard” or the too “soft” steel. However, “good hardness” does not guaranty good formability. Cold work (plastic deformation under the annealing temperature) such as bending, tensioning, compressing, and other operations will increase the yield and tensile strengths and reduce elongation. Cold working of some materials, for example, certain stainless steels, zirconium, and other special alloys significantly increases the yield and tensile strength. Based on past experience, the roll designer can usually judge the anticipated formability of the material, including the minimum radius and springback. A straight piece of steel wire or strip, rigidly held at one end, bent by a small load to a few degrees, will"spring back" to its original shape when the load is released. [3]

By placing a double load at the end of the steel specimen, the rate of deflection will be twice as high but the specimen will still return to its original shape when the load is taken off. In other words, the specimen is loaded within its "elastic" range. After increasing the load and the deflection to a certain limit, the specimen will not return to its original shape upon the removal of the load. At that load, the wire will remain "permanently" deformed because the stresses in the material exceeded the yield strength limit. Similar occurrences can be observed with springs **(Figure 2.4).** The linear relation between load and deflection is utilized in the fish scale but the load is always kept safely within the elastic range of the spring. If a spring is stretched over its elastic range (over yield limit), then it will not spring back to its original shape.[3]

However, the highly work-hardening materials may have similar mechanical properties to mild steel before roll forming, but by the time bending is completed, the properties are closer to high strength steels. The result can be a 15° to 25° springback at a 90° bend instead of 1 to 2° normally associated with material having similar starting mechanical properties. Materials having high yield strength, small difference between tensile and yield stresses, and small Elongation require more forming passes.[3]

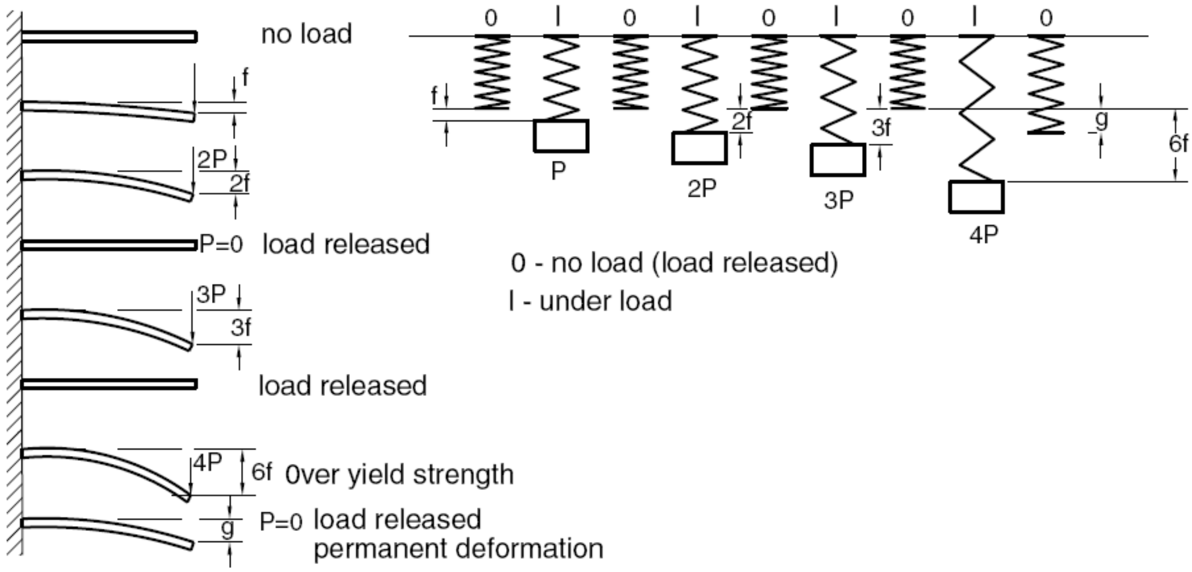

FIGURE 2.4: Spring that has similar occurrences with springback. [3]

2.4.1 Springback

In addition to the mechanical properties of the material, springback is influenced by the r: t ratio, the method of forming, and by the elastic modulus (E) of the material.[3]

Process condition

- Forming process
- Process velocities
- Tribology
- temperature

Geometry

-sheet thickness
-sheet dimensions
- tool geometry

Influence on springback

Material

- Young’s Modulus
- Yield strength
- Hardening type
- Pre-treatment
- Plastic strain
- anisotropy

Numerical

-material model
-hardening rule
-spacediscretisation and size element
-time discretisation implicit or explicit
-friction model

2.5 Tensile test

The tensile test is the common for determining such mechanical properties of material as strength, ductility, toughness, elastic modulus, and strain hardening. The test first requires the preparation of a test specimen.[9]

Figure 2.5: Multi purpose testing machine.(tensile and compression)

2.6 Stress-strain curve

Stress-strain curves are an extremely important graphical measure of a material's mechanical properties. A typical sequence of deformation of the tensile test. When the load is first applied, the specimen elongates in proportion to the load. This effect is called linear elastic behavior. If the load is removed, the specimen returns to its original length and shape, in an elastic process similar to stretching a rubber band and releasing it.[9]

The engineering tension test is widely used to provide basic design information on images/the strength of materials and as an acceptance test for the specification of materials. In the tension test a specimen is subjected to a continually increasing uniaxial tensile force while simultaneous observations are made of the elongation of the specimen. An engineering stress-strain curve is constructed from the load elongation measurements.[9]

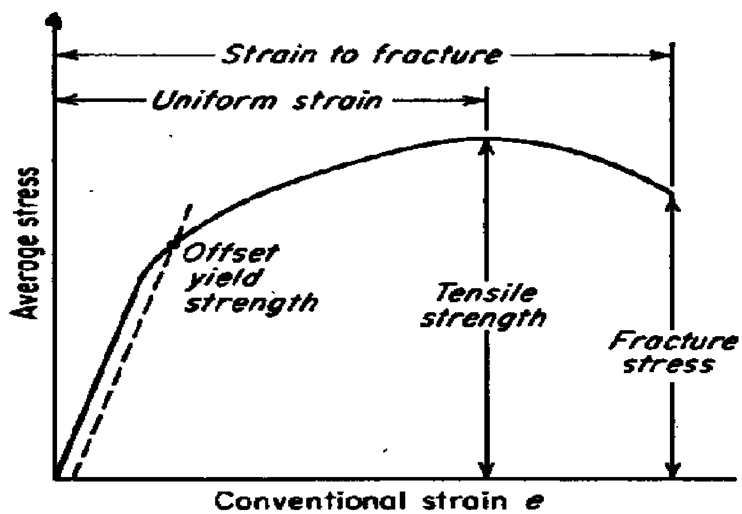

Figure 2.6: Stress-strain curve

(Resource: http://www.key-to-steel.com/articles/art43.htm)

From the Serope Kalpakjian, Steven Schmid. Manufacturing, Engineering and Technology book, the engineering stress, or nominal stress, is define as the ratio of the applied load P to the original cross-sectional area A_o of the specimen;

Engineering stress, $\sigma = P/ A_o$

The engineering strain is defined as

Engineering strain, $e = (l-l_o)/ l$

*where l is the instantaneous length of the specimen

The shape and magnitude of the stress-strain curve of a metal will depend on its composition, heat treatment, prior history of plastic deformation, and the strain rate, temperature, and state of stress imposed during the testing. The parameters, which are used to describe the stress-strain curve of a metal, are the **tensile strength, yield strength or yield point, percent elongation, and reduction of area**. The first two are strength parameters; the last two indicate ductility.[9]

As the load is increased, the specimen begins, at the some level of stress, to undergo permanent (plastic) deformation. Beyond that level, the stress and strain are no longer proportional, as they were in the elastic region. The stress at which this phenomenon occurs is known as the yield stress, Y, of the material. The term proportional limit is also used to specify the point where the stress and strain cease being proportional. The yield stresses and other property for various metallic and non-metallic is different.

For most metallic materials, to cause the specimen to continue to elongate requires a continually increasing load. This is because the material becomes stronger as it is plastically deformed, and the material is said to work or strain harden.

However, beyond a certain load and elongation, it is observed that subsequent plastic deformation occurs in a very localized region, which exhibits a decrease in cross-sectional area, which is called necking.

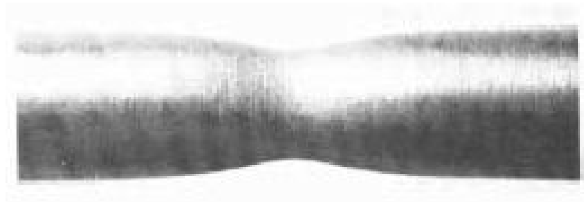

Figure 2.6.1: Necking in a tensile specimen [10]

Since the supporting cross-sectional area is now reduced, fewer loads are required to continue to elongate the specimen. Therefore the load-elongation curve passes through a maximum, and the load decreases until fracture occurs.

Because the stress at which plastic deformation first occurs is difficult to locate, an approximation to this value is used. It is called the yield strength and is based on the stress that corresponds to a small but specified plastic strain. Usually the value of strain of 0.002 is used. (0.2%)

In some materials (for example, normalized low and medium steels), yielding is very prominent in the stress-strain curve

A prominent feature of the engineering-stress – engineering-strain curve is the maximum, and the stress at the maximum is called ultimate tensile strength or more commonly tensile strength. The tensile strength may or may not equate to the strength at break. This all depends on what type of material that are been test. brittle, ductile, or a substance that even exhibits both properties. And sometimes a material may be ductile when tested in a lab, but, when placed in service and exposed to extreme cold temperatures; it may transition to brittle behaviour.

2.6.1 Yielding and yield strength

The yield point marks the transition from essentially elastic behavior (strain is recoverable upon unloading) to plastic behavior (some permanent deformation upon unloading). Some metals (including mild steel) exhibit the stress-strain relationship shown in Figure 3, part (a) where the yield point is clearly defined. In this figure, the yield point and the proportional limit coincide. The elastic to plastic transition is well defined by an upper yield point. However, for such materials the yield strength is taken as the average strength associated with the lower yield point. For metals exhibiting a stress-strain relationship similar to that shown in part (b), with no well defined yield point, the 0.2% offset strain is used to determine the yield strength.
The yield strength is typically denoted as σ y.[11]

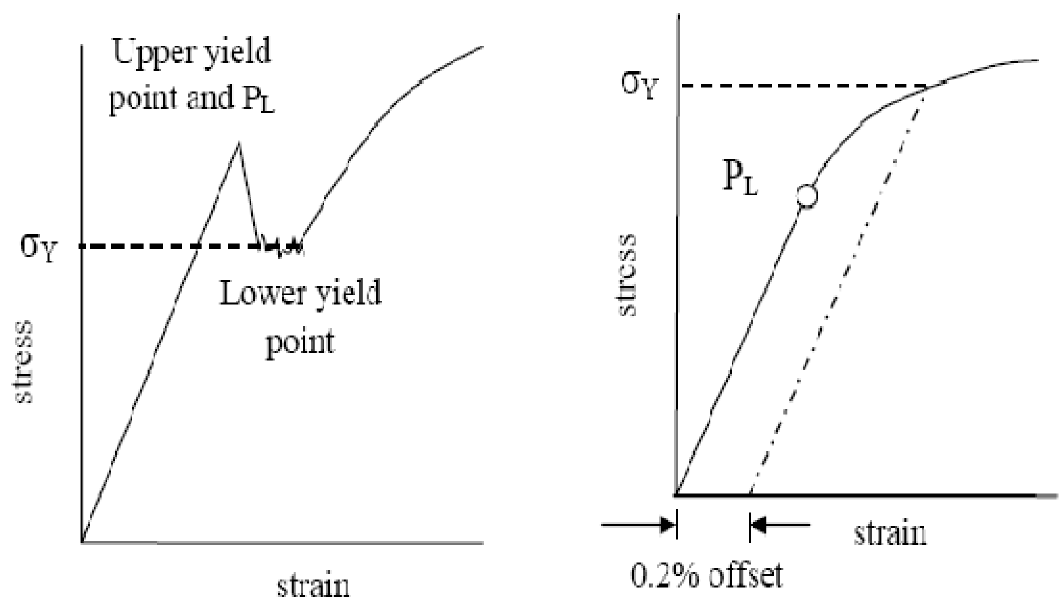

Figure 2.6.2: Yield Point [11]

2.6.2 Plastic Behaviour

As a metal deforms past its yield point, plastic deformations will result. Plastic deformation is associated with slip in crystalline materials such as metals. The process is not reversible.

2.7 Annealing process

Heat treatment of a metal or alloy is a technological procedure, including controlled heating and cooling operations, conducted for the purpose of changing the alloy microstructure and resulting in achieving required properties. There are two general objectives of heat treatment: hardening and annealing. [13]

Annealing is a heat treatment procedure involving heating the alloy and holding it at a certain **temperature (**annealing temperature**),** followed by controlled cooling. Annealing results in relief of internal stresses, softening, chemical homogenizing and transformation of the grain structure into more stable state. [13].

In the annealing process the structure and properties of the material will changes after heated and held at suitable temperature and then cooled at a fairly slow rate. There are three stage of annealing process which is recovery, recrystalization and grain growth. This process will occur due to the increasing of temperature.[13]

Stress relief (recovery) is a relatively low temperature process of reducing internal mechanical stresses, caused by cold-work, casting or welding. During this process atoms move to more stable positions in the crystal lattice. Vacancies and interstitial defects are eliminated and some dislocations are annihilated. Recovery heat treatment is used mainly for preventing stress-corrosion cracking and decreasing distortions, caused by internal stresses. [13]

Recrystallization means alteration of the grain structure of the metal. If the alloy reaches a particular temperature (recrystallization or annealing temperature) new grains start to grow from the nuclei formed in the cold worked metal. The new grains absorb imperfections and distortions caused by cold deformation. The grains are equi-axed and independent to the old grain structure. As a result of recrystallization mechanical properties (strength, ductility) of the alloy return to the pre-cold-work level. The annealing temperature and the new grains size are dependent on the degree of cold-work which has been conducted. The more the cold-work degree, the lower the annealing temperature and the fine recrystallization grain structure. Low degrees of cold-work (less than 5%) may cause formation of large grains. Usually the annealing temperature of metals is between one-third to one-half of the freezing point measured in Kelvin (absolute) temperature scale.[13]

Grain growth (over-annealing, secondary recrystallization) is a growth of the new grains at the expense of their neighbours, occurring at temperature, above the recrystallization temperature. This process results in coarsening grain structure and is undesirable.

The purpose of the annealing process is to reduce hardness, refine the grain structure, restore ductility, and remove internal stresses of the material. This process also will improving machinability, facilitating cold working, producing a desired microstructure and obtaining desired physical, mechanical, or other properties.

2.8 FRIEDEL'S MODEL

Friedel's model is an empherical method to determine relationship between the amount of recovery, time and temperature. By using true stress – true strain curve of static recovery process the degree of recovery (X_{rec}) can be determined [8].

Using tensile test machine the graph of stress versus strain can be plot. Figure 2.2 shown the point of yield stress of deformed material (σ_m), yield stress of undeformed material (σ_o) and yield stress of recover material (σ_r).

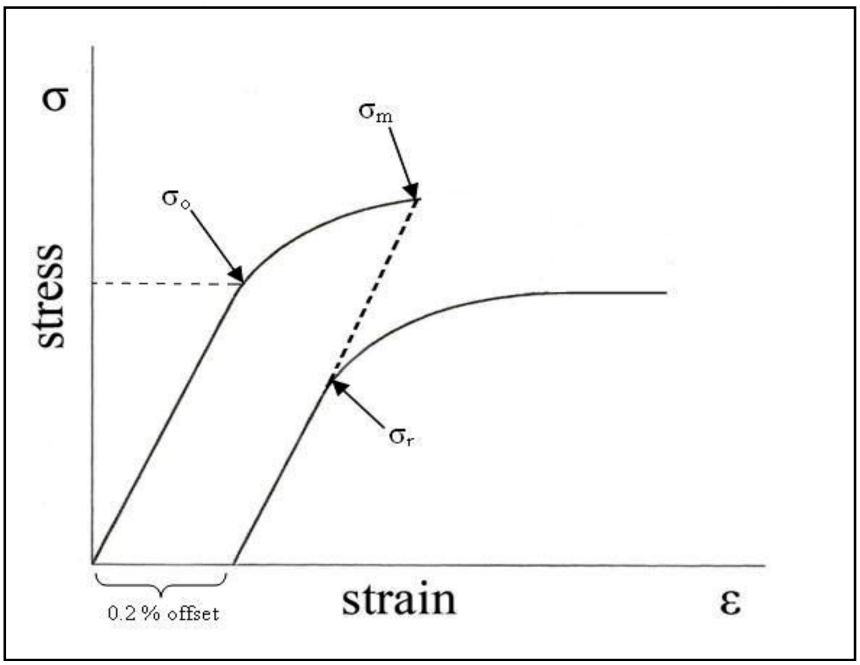

Figure 2.7: Stress versus strain of recovery process

$$X_{rec} = \frac{\sigma_m - \sigma_r}{\sigma_m - \sigma_o} \tag{2.1}$$

X_{rec} = degree of recovery

σ_m = yield stress of deformed material

σ_r = yield stress of recover material

σ_o = yield stress of undeformed material

* In this project X_{rec} is known as R

CHAPTER III

METHODOLOGY

3.1 Introduction

Through this research, it will basically based more on mechanical properties and microstructure characterization of steel grade used in roll forming application. The method that is used to complete this research will be more on using the tensile test machine. The implementation of this machine will be conducted in a few months and there are many benefit using this kind of method like reducing the time and cost. This is the method that is most flexible and suitable to complete this kind of research. To be able to use the test, first, we must have the specimen, by that we have to learn how to make the specimen test. By determining the material, the shaped and the method to make it then we can precede it to the testing section.

FLOW CHART

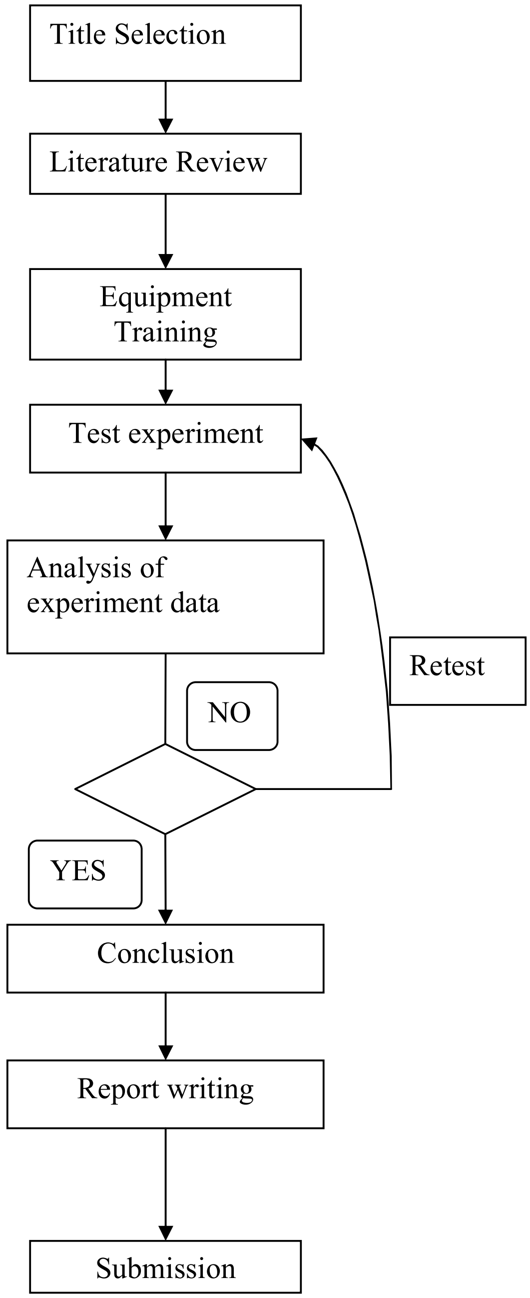

Figure 3.0: Flowchart

3.2 Problem Identification and Solving

This project is done by observing the strain path changed on material in the application from the roll forming. In the case of multiple stages cold roll forming process, the material might experience strain path changes such as bend, released followed by further bending(further straining). Therefore the strain path changed throughout the roll forming stages. The simulation on how the stress-stress curve looks like by considering the changes happened in the material. Friedel's Model is used for the calculation. Annealing process is done as part of heat treatment after the first bending. The effect for pre-strain on several temperature of annealing could be studied.

3.3 Application of AutoCAD

As the first stage, determining the shape and the dimension are needed. Then by using AutoCAD, draw the shape of the specimen. The specimen can come with different shape but in this research the specimen is in standard (preparation of a test specimen ASTM E8M-94a and in sheet shape. This is because that the mechanical properties material produced by roll-formed application which is in sheet or strip shape.

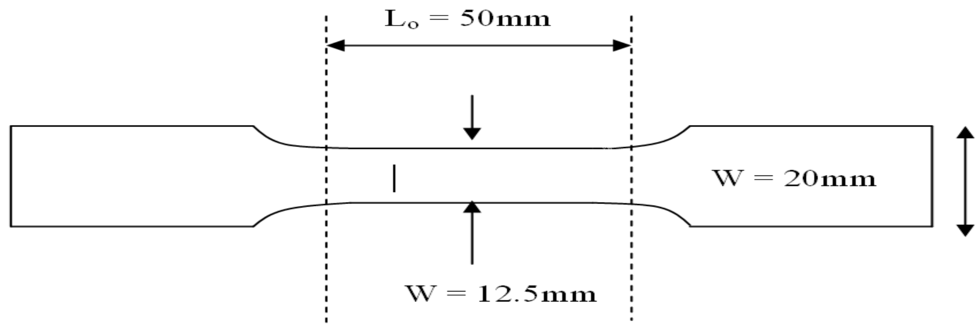

Figure 3.2: Dimension of the specimen

3.4 Specimen Producing

There is several ways on how to produce the specimen. For this project, raw sheet metal of low-carbon steel sized 1220 x 2440 x 15 mm, shearing machine, punching machine and puncher (for numbering) are used. First and foremost, the raw materials are cutted into desired size which is 1220 x 30 x 15 mm by using shearing machine. The test specimens are produced by punching the cutted sheet metal using puncher. Lastly, the test specimens are numbered until desired amount of specimen.

Figure 3.3: Sheet metal (1220x30x15mm) before punching

Figure 3.4: Sheet metal (1220x30x15mm) after punching

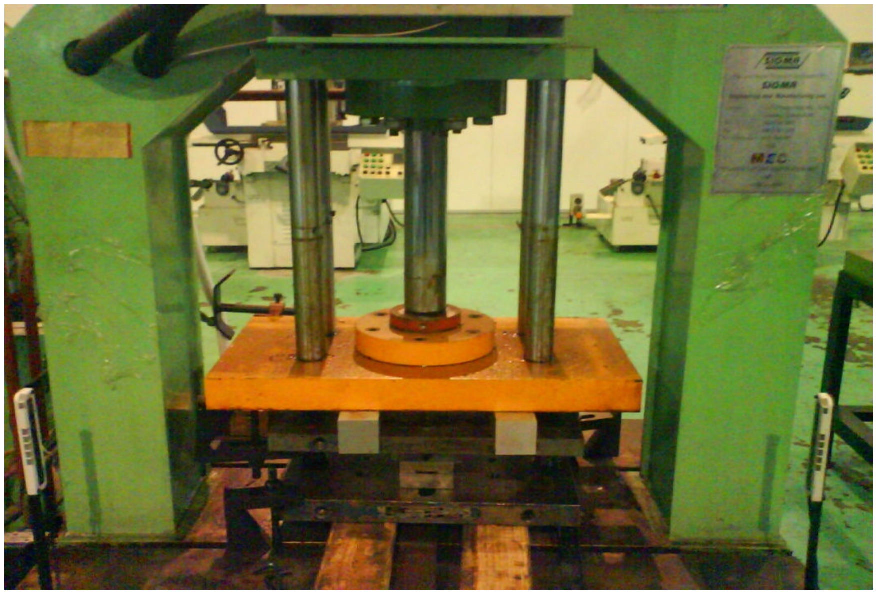

Figure 3.5: Punching machine used in this project

Figure 3.6: Finished product of testing specimen

3.5 Tensile Testing

This process was done after the specimens are prepared. The root of this project is about knowing the stress-strain curve obtained from tensile testing machine. Based on Friedel's Model, the value of σ_o, σ_m and σ_r is determined. The formula from the Friedel's Model is applied. The value of R is calculated. From the basic idea how the stress-strain curve looks like, there are two curves involved in this process. The first curves are done by using pre-strain variable which is 5%, 7.5% and 10%. The value of σ_o and σ_m are obtained from the first curve. In the second curve, the value of σ_r is obtained after the specimen experienced heat treatment which is annealing.

Figure 3.7: Tensile machine

3.6 Annealing

Annealing process is part of heat treatment. This process is done by assuming that between passes in roll forming application there are heat treatment involved. The value temperature that involved is 200^{o}C.250^{o}C and 300^{o}C. The duration for the annealing is 1 hour which means the initial temperature is from 200^{o}C, 250^{o}C or 300^{o}C. After 1 hour, the specimens are cooled slowly in the furnace for along duration (more than 4 hour).

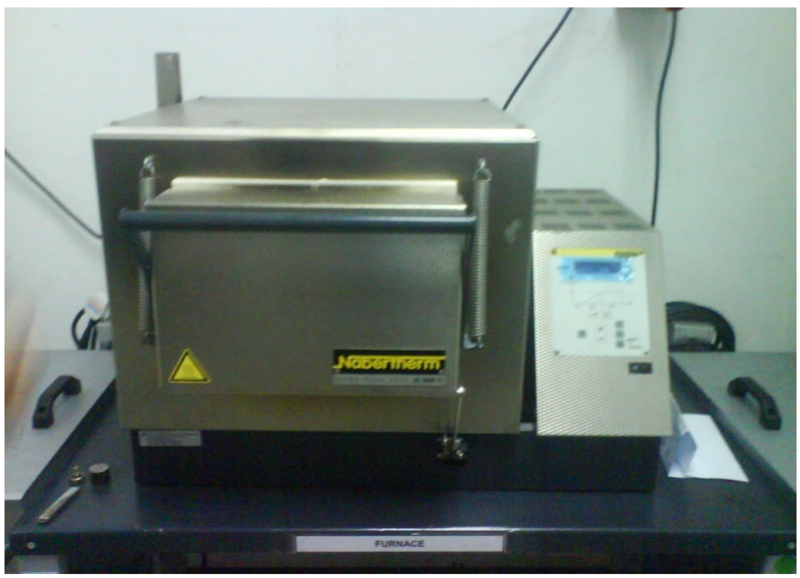

Figure 3.8: Furnace machine

3.7 Result and Analysis

From the collected data of σ_o, σ_m and $\sigma_{r.}$, the data is calculated into value of R and converted into plotted graphs. The plotted graphs are studied and discussed on how the pre-straining and heat treatment effected low-carbon steel.

CHAPTER IV

RESULT AND DISCUSSION

4.1 Introduction

This project was done by understanding the concept of deformation process in the roll forming process. It is based on the bending phenomenon which is like the essence in roll forming process. Depends on the shape and the profile of the material itself, the bending will take place into several bending process. During a typical roll forming process, the major type of deformation that involved are transverse bending and lateral deformation. In the case of multiple stages cold roll forming process, the material might experience strain path changes such as bend, release (i.e.…elastic recovery) followed by further bending(further straining). Therefore the strain path changed throughout the roll forming stages. The effect of strain path changes can be explained using a simple an unaxial tensile case.

In order to understand the pre-straining effects on yielding behaviour, tensile test experiment is changed into experiment that is compatible with bending, unbending and re-bending phenomenon of the process. By modifying the method of the tensile method, expected result is required.

4.2 Tensile Test Analysis

For this project, the value of σ_o, σ_m and σ_r taken from stress-strain curves are important measure to finish this project. The formula from Friedel's Model is taken to calculate the value of R. Then the plotted graphs are studied and discussed.

SET	Temperature(^oC)	5%(pre-strain)	7.5%(pre-strain)	10%(pre-strain)
1	200	-1.08	-2.5	-1.89
	250	-1.10	-1.49	-1.26
	300	-0.87	-1.2	-1.00
2	200	-1.43	-0.87	-1.2
	250	-2.04	-1.81	-1.18
	300	-2.09	-1.39	-1.16
3	200	-2.13	-1.07	-1.04
	250	-1.81	-1.29	-1.23
	300	-2.27	-1.49	-1.33
4	200	-1.63	-0.95	-1.26
	250	-1.90	-1.14	-1.00
	300	-2.77	-1.09	-0.94

Table 4.1: Calculated data of value of R

4.3 Discussion.

From the data collection and calculation, the graph will be plotted R versus temperature (T). This will include the average value of R from all 4 sets of data.

4.3.1: Pre-straining: 5%

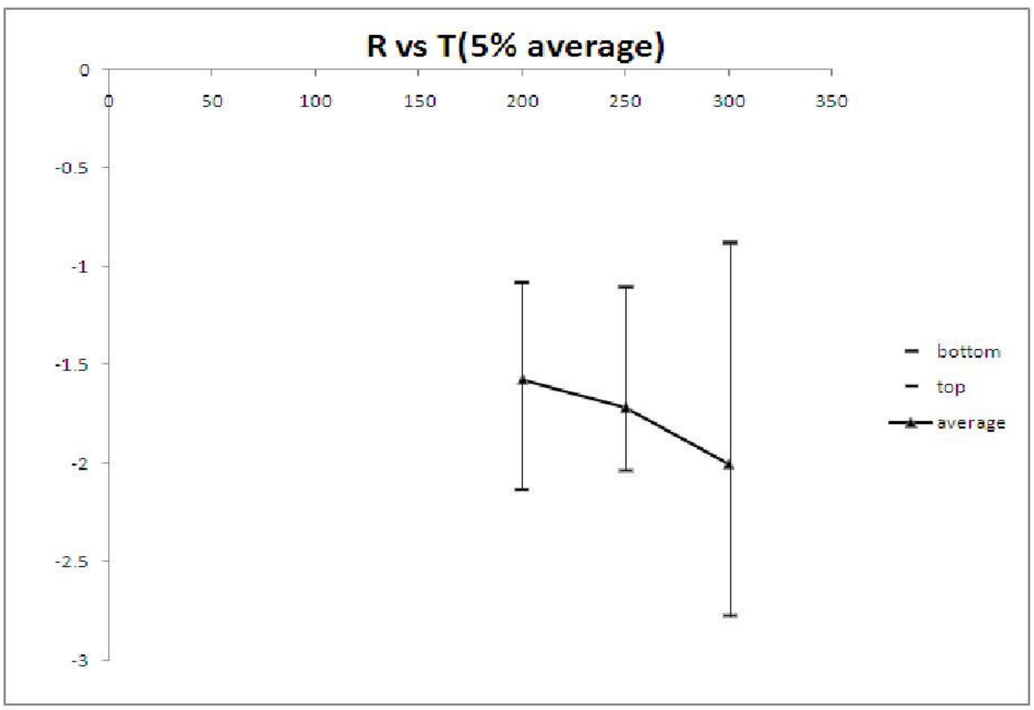

Figure 4.1: Graph R versus T for 5% of pre-straining

From the 5% of pre-straining of all 4 sets of data, the graph show that the value of R is decreasing with the addition of temperature. For 200^{o}C, maximum value of R is -2.1388 and the minimum value is -1.0838. The average value of R for 200°C is -1.5743. For 250°C, maximum value of R is -2.0407 and the minimum value is -1.1036. The average value of R for 250°C is -1.7167. For 300°C of temperature, maximum value of R is -2.7766 and the minimum value is -0.8773. The average value of R for 300°C is -1.7167. For 300°C, the range value of R is wider than 200°C and 250°C.

4.3.2: Pre-straining: 7.5%

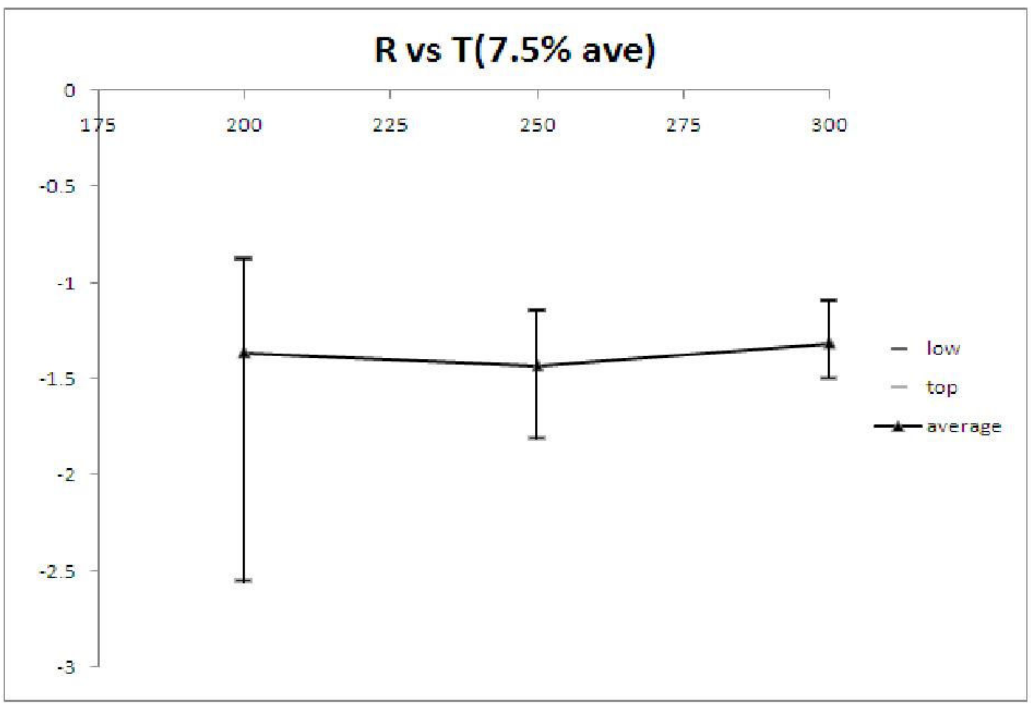

Figure 4.2: Graph R versus T for 7.5% of pre-straining

From the 7.5% of pre-straining of all 4 sets of data, the graph show that the value of R is less difference between the temperatures. For 200°C, maximum value of R is -2.552 and the minimum value is -0.8722. The average value of R for 200°C is -1.3632. For 250°C, maximum value of R is -1.81 and the minimum value is-1.1427. The average value of R for 250°C is -1.4339. For 300°C of temperature, maximum value of R is -1.4935 and the minimum value is -1.0941. The average value of R for 300°C is -1.314.

4.3.3: Pre-straining: 10 %

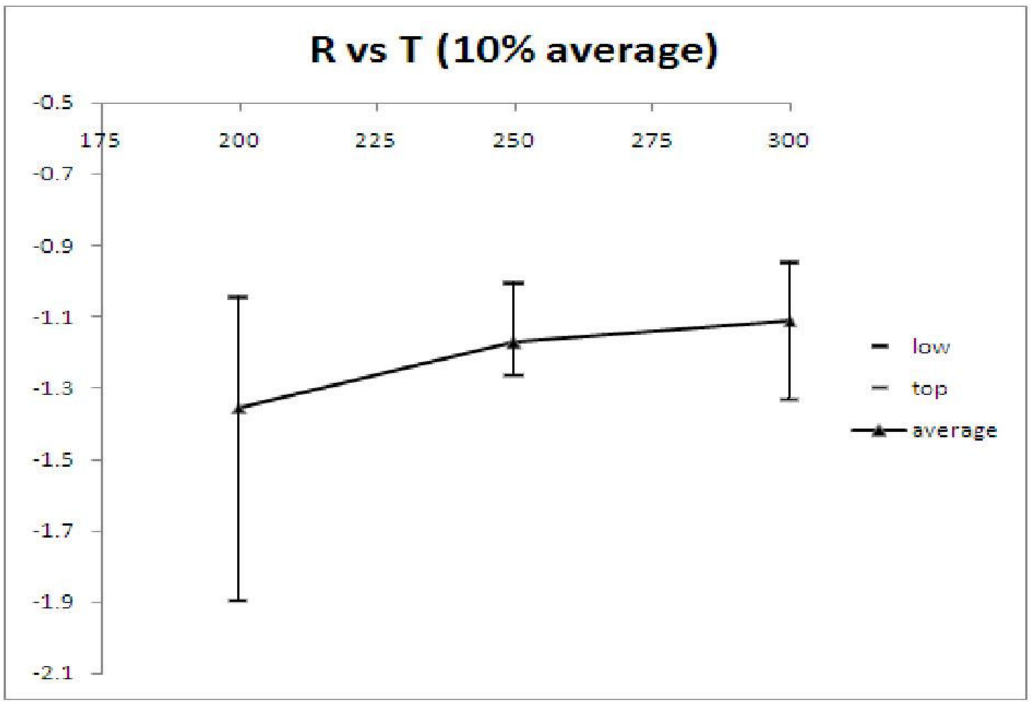

Figure 4.3: Graph R versus T for 10% of pre-straining

From the 10% of pre-straining of all 4 sets of data, the graph show that the value of range for R for every designation annealing temperature and it average value. In the temperature of 200°C, maximum value of R is -1.8972 and the minimum value is -1.0476. The average value of R for 200°C is -1.3559. For the annealing temperature of 250°C, maximum value of R is -1.2648 and the minimum value is -1.0057. The average value of R for 250°C is -1.1721. For 300°C of annealing temperature, maximum value of R is -1.3354 and the minimum value is -0.9497. The average value of R for 300°C is -1.1126.

4.4 Summary

In this project, by simplify all the data into average value and combined it into one graph, we can see the pattern or how the data affected by the pre-straining and temperature involved.

(°C)	Pre-straining (5%)	Pre-straining (7.5%)	Pre-straining (10%)
200	-1.57	-1.36	-1.35
250	-1.71	-1.43	-1.17
300	-2.01	-1.31	-1.11

Table 4.2: Average value of R of all 4 sets of data

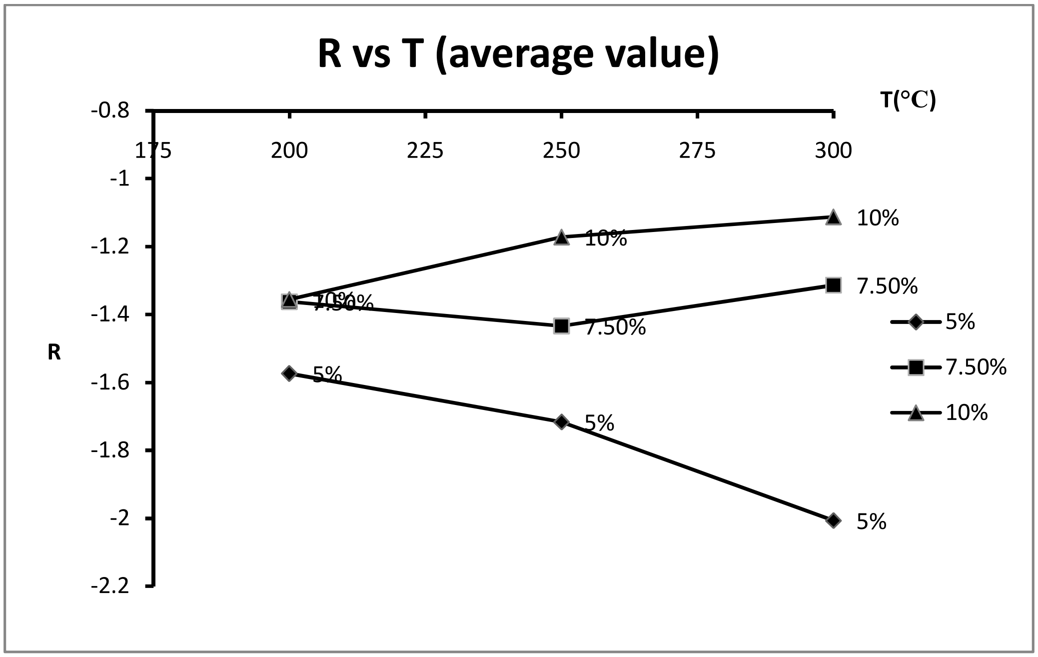

Figure 4.4: Graph R versus T for average value of pre-straining

From the Figure 4.4 and Table 4.13, if the R values are in negative value, it shows that the material after the second curve will have higher stress than the first curve. The material is hardened.

The explanation for this lies in dislocation theory.The overall lattice strain energy is decreased when the carbon atom is placed into the already distorted lattice in the vicinity of both edge and screw dislocations. In other words, from a thermodynamic standpoint the carbon atoms and the dislocations prefer to be next to each other. The effect of the interstitial atom, then, is to "pin" the dislocations, making it difficult for them to move. Therefore, large stresses are required to move the dislocations [14].

The graph shows that 10% of pre-strain have the highest data and the 5 % of pre-strain is the lowest. The effect of pre-strain is greater in 5% pre-strain than in 10%, but after heat treatment, the more the temperature involve the more it reduce its plastic deformation resistance.

The second curve with annealing process (200°C -300°C) is considered to take place near the phase boundaries. Since in this range carbon atoms are considerably easy to move, the internal stress in the ferrite and vacancy aggregates near the phase boundaries are released by the diffusion, leading to the disappearance of anisotropic deformation structure thus to a hardening. The recovery of the cold-worked microstructure produced by plastic deformation in metal has been reported [12] to occur by annihilation of point defects, annihilation, migration, and rearrangement of dislocations and the formation and growth of sub grains. It maybe has greater strength and it is also has greater ductility.

CHAPTER V

CONCLUSION

5.1 Conclusion

Springback, bending, forces, strain path are only some of the many concerns that must be addressed when forming materials especially forming sheet metal. From this project can be summarized as below:

1. The higher pre-strain involve the lower recovery involve**.**
2. The higher temperature involve the higher ductility occur.
3. There are two types of hardening involve in this project, thermal diffusion (first curve) and forced deformation (second curve after annealing).
4. Uniaxial tensile test method is the best method to determine the mechanical properties.
5. Tensile test method also can be changed to make it suitable for roll forming application when studying the multiple bending phenomenons.
6. Studying the stress-strain curve on the material is the best method to avoid any unnecessary defect to the product

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APPENDIX A

DATA COLLECTION

TENSILE TEST ANALYSIS: 200^{o}C

Set 1

(MPa)	5%	7.5%	10%
σ_o	85.9	289	294.9
σ_R	370.5	380.8	395.9
σ_m	323.2	332.6	348.7
R	-1.08	-1.10	-0.87

Table 5: First set of data for 200^{o}C temperature

Set 2

(MPa)	5%	7.5%	10%
σ_o	283.1	286.2	286.1
σ_R	374.1	383.1	407
σ_m	320.4	337.4	340.7
R	-1.43	-0.87	-1.21

Table 6: Second set of data for 200^{o}C temperature

Set 3

(MPa)	5%	7.5%	10%
σ_o	287.2	294.6	281.1
σ_R	366.3	384.6	401.9
σ_m	312.4	338	340.1
R	-2.13	-1.07	-1.04

Table 7: Third set of data for 200^{o}C temperature

Set 4

(MPa)	5%	7.5%	10%
σ_o	290.8	287.7	285.1
σ_R	370	384.2	404
σ_m	320.8	337.2	339.1
R	-1.63	-0.95	-1.26

Table 8: Fourth set of data for 200^{o}C temperature

TENSILE TEST ANALYSIS: 250^{o}C

These are the data collected including calculated value of R in temperature of 250^{o}C.

Set 1

Table 9: First set of data for 250^{o}C temperature

(MPa)	5%	7.5%	10%
σ_o	280.5	281.5	284.2
σ_R	383.4	399.7	404.8
σ_m	309.5	329.0	339.6
R	-2.55	-1.49	-1.26

Set 2

(MPa)	5%	7.5%	10%
σ_o	285.5	291.5	376
σ_R	377.4	407.1	516.4
σ_m	315.7	332.5	440.2
R	-2.04	-1.82	-1.18

Table 10: Second set of data for 250^{o}C temperature

Set 3

(MPa)	5%	7.5%	10%
σ_o	276.2	284	289.8
σ_R	366.7	392.5	411.2
σ_m	308.3	331.4	344.2
R	-1.81	-1.29	-1.23

Table 11: Third set of data for 250^{o}C temperature

Set 4

(MPa)	5%	7.5%	10%
σ_o	286.2	288.3	289.1
σ_R	383.2	392.8	408.9
σ_m	319.6	337.1	348.7
R	-1.90	-1.14	-1.01

Table 12: Fourth set of data for 250^{o}C temperature

TENSILE TEST ANALYSIS: 300°C

Set 1

(MPa)	5%	7.5%	10%
σ_o	282.6	293.1	286.5
σ_R	373.9	389.5	414.6
σ_m	314.1	335.7	350.5
R	-1.89	-1.26	-1.00

Table 13: First set of data for 300°C temperature

Set 2

(MPa)	5%	7.5%	10%
σ_o	284.6	285.01	291.8
σ_R	373.7	394.5	409.7
σ_m	316.5	330.6	346.3
R	-2.09	-1.39	-1.16

Table 14: Second set of data for 300°C temperature

Set 3

(MPa)	5%	7.5%	10%
σ_o	274.7	279.6	288.5
σ_R	370.5	400.3	410.6
σ_m	304.0	328.1	340.8
R	-2.27	-1.49	-1.49

Table 15: Third set of data for 300°C temperature

Set 4

(MPa)	5%	7.5%	10%
σ_o	289.9	278.7	277.0
σ_R	376.6	390.6	400.4
σ_m	312.8	.332.1	340.3
R	-2.77	-1.09	-0.949

Table 16: Fourth set of data for 300°C temperature

APPENDIX B

RESULT

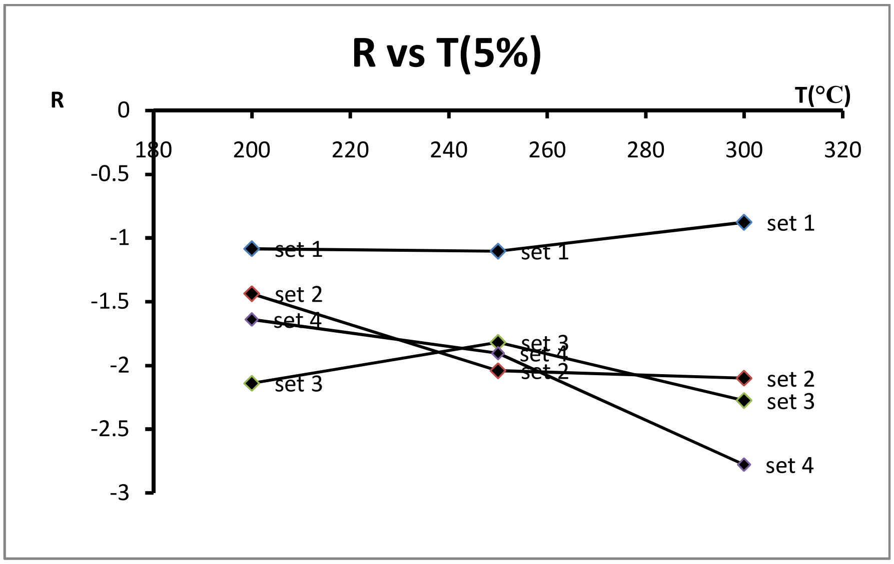

Figure 5: Graph of pre-strain for 5% (All 4 sets of data)

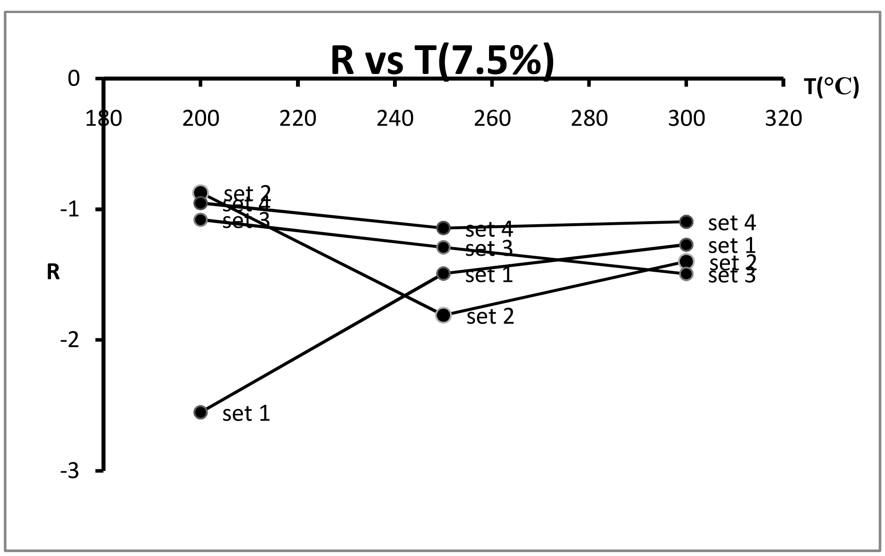

Figure 6: Graph of pre-strain for 7.5% (All 4 sets of data)

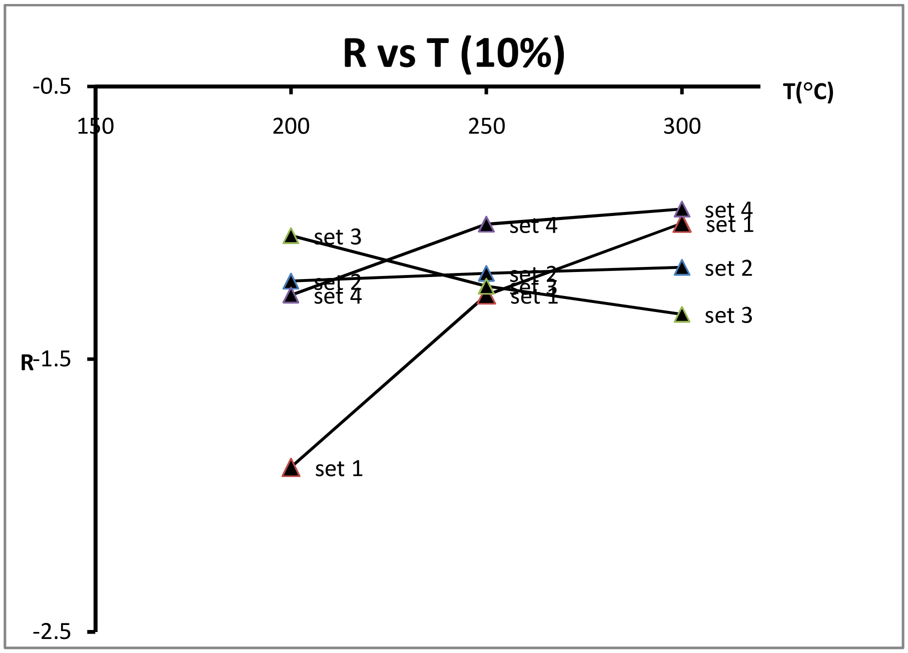

Figure 7: Graph of pre-strain for 10% (All 4 sets of data)