INFLUENCE OF THE WORK HARDENING ON SPRINGBACK OF THE U-BEND 316L STAINLESS STEEL

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This report is submitted
in fulfillment of the requirement for the degree of
Bachelor of Mechanical Engineering (Structure & Materials)

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

MAY 2017

DECLARATION

I declare that this project report entitled "Influence of the work hardening on springback of the U-bend 316L Stainless Steel" is the result of my own work except as cited in the references

Signature : ....

Name : ....

Date : ....

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Structure & Materials).

Signature   :.   ....
Name of Supervisor :   ....
Date   :   ....

DEDICATION

For my beloved family and friends

ABSTRACT

This research purpose is to study the influence of the work hardening on springback of u-bend stainless steel by using Hv Profile and surface morphology analysis. Springback is known as elastic recovery of formed part after unloading of the stainless steel material. Besides that, springback is a phenomena that occur after the material is rolled and bend until certain point. It is a geometrical changes in the final bending angle in the materials. Springback is influences by sheet thickness, yield strength, elastic modulus and bend radius. The material used in this project is known as 316L Stainless Steel which falls in ferrous alloys material. 316L stainless steel has been applied in many applications especially in surgical implant devices. Most of engineering part especially in medical implants, it consist of variety of shape, thickness and geometry. The metal forming processes were used to fabricate the plate either in straight or curve shape. For curve plate, there is thickness variation from 2.0 mm to 1.0 mm. for curve plate, it will introduce springback phenomenon and it can be analyse using experimental approach. For the experimental approach, there is an opportunity to investigate the relation between springback and other properties such as microhardness profile and the surface morphology of the metal.

ABSTRAK

Kajian ini dijalankan adalah bertujuan untuk mengkaji kesan "work hardening" terhadap "springback" keluli tahan karat berbentuk U melalui Mikro-Hardness profile dan analisis permukaan morfologibahan tahan karat. "Springback" dikenali sebagai pemulihan elastik dalam pembentukan bahagian bahan keluli tahan karat selepas beban dilepaskan terhadapnya. Selain itu, "springback" adalah phenomena yang berlaku selepas bahan dikenakan proses penggolekkan dan pembengkukkan pada sesuatu tahap. Ia adalah perubahan geometri pada sudut akhir pembengkukkan pada bahan keluli tahan karat. "Springback" dipengaruhi oleh tebal kepingan bahan, kekuatan hasil (yield strength), modulus elastik, dan sudut pembengkukkan. Dalam projek ini, bahan yang digunakan adalah dikenali sebagai bahan keluli tahan karat jenis 316L dan di kelaskan dalam kelas bahan logam ferus. Bahan keluli tahan karat jenis 316L telah diaplikasikan dalam pelbagai bidang terutamanya dalam bidang pembedahan alatan ortopedik. Kebanyakan barangan mekanikal terutama dalam bidang perubatan, ia terdapat dalam pelbagai bentuk, ketebalan dan geometrinya. Proses pembentukan besi digunakan untuk menghasilkan kepingan plat sama ada dalam bentuk lurus atau dalam bentuk lengkung. Kepingan plat berbentuk lengkungan, ia mempunyai ketebalan yang variasi dari 2.0 mm kepada 1.0 mm. Kepingan plat berbentuk lengkung akan memperkenalkan phenomena "springback" dan ia boleh diuji melalui pendekatan experimen. Melalui pendekatan eksperimen, ia akan mewujudkan peluang untuk menyiasat hubungan antara "springback" dan unsur yang lain seperti Mikro-Hardness profile dan permukaan morfologi bahan keluli tersebut.

ACKNOWLEDGEMENT

I would like to convey my thanks to the all person who had contributed in ensuring a successful occurrence throughout the duration of my final year project. I also gratefully acknowledge to my PSM supervisor, Dr. Wan Mohd Farid Bin Wan Mohamad, for his encouragement, fully support, by providing me enormous guidance and idea for my research project. Without them all, this project may not valuable. Their knowledge and experience has fully inspired, motivated and drive me to complete my final year project successfully.

Also, my special thanks to all my peers, especially Syaza Najwa, Norizzati, Amira Shamsulnizam, and Nursolehah Rosli, and to those who are undergoing final year in Degree programs, thanks for your all kindness of delivering ideas and motivation that necessary for me to complete this study. Besides those mentioned, I also would like to express my gratitude with highly appreciation and dedication to my family because without them, I won’t be here to complete my study in Universiti Teknikal Malaysia Melaka.

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CHAPTER 1

INTRODUCTION

1.1 Background of study

Springback is known as “elastic recovery” of formed part in unloading of the stainless steel material. Springback occurs in various form such as bending, torsion, twist and etc. It causes the shape error in final product of sheet metal forming processes. There are various factors that affecting the springback such as blank holding force, punch velocity, orientation and temperature. In addition, during product designing phase, springback is influences by several factors such as sheet thickness, elastic modulus, yield stress and work hardening exponent. The springback effect caused the changes in the final bend angle after the 316L stainless steel material undergoes bending process by the release of elastic component of the bending moment.

Springback is a phenomenon that occur when the material tries to return back to its original shape after being bent. This bending angle is angularly exceed beyond the material’s maximum yield stress and required bent angle which resulting in springback phenomenon. Figure 1.1 shows how the springback effect is presented in the sheet metal forming. The bending angle at the beginning is the over-bending action and the metal spring back to the desired bent angle.

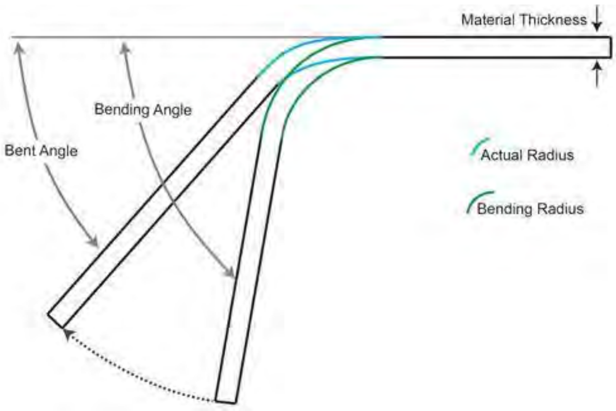


Figure 1.1: The sheet metal forming condition after over-bending action applied and how the metal spring back to its desired bent angle.
(Source: Steve Benson, The Fabricator, July 9, 2014)

Springback happened as it was influenced by the tensile strength and the thickness of the material. As the material bent, the inner region having a compression while the outer region of the material is being stretched by tension. Therefore, the molecular density of the material on the inner region is higher than on the outer region. The material try to return to its original position is caused by the compressive force that is less than the tensile force on the outer region of the bend material. Type of tooling and type of bending are also influence the springback. Prediction and the best solution accounting for springback are critical, especially when working with intense radius of bending as well as thickness reduction and high strength of material.

Thickness reduction of 316L stainless steel material was done by using metal-working method which is rolling. Rolling is the process when one or more pairs of rolls used to reduce the thickness and to make a uniform thickness of a metal. In this project, cold rolling is introduced. Cold rolling is the process where the temperature of the metal is below its recrystallization temperature which usually a temperature at room temperature. Cold rolling causes increase in strength and strain hardening up to 20%. It is also improve the surface finish of the material and holds tighter tolerances.

The plastic – elastic characteristics of a metal is typically known that any deformation of metal sheet at room temperature, it will have both elastic and plastic deformation. An elastic deformation will be release after the metal work is removed from the bending tools and only plastic deformation will remained. Springback has to be compensated in order to achieve an accurate result. Springback is usually happened due to over-bending of the material correspondent to the magnitude of the springback and delivers a plastic deformation at desired bending angle.

In the case of complex tools of the springback, the microhardness profile work correlation have been studied. The surface morphology analysis is used to inspect crack lines at the springback region and the crack line is produced are perpendicular to the direction of rolling process. The analysis is conducted by using microscope image analyzer and scanning electron microscope (SEM). Besides that, practical experiment will be done using trial – and – error method to get the desired results. In this study, work hardening study on springback of the u – bend 316L stainless steel have been performed in order to go deep in the understanding of the behavior between the microhardness profile of the material used and the surface analysis at the springback region. The following are general mechanical properties of material type ferrous metals and alloys for Stainless Steel group:

- General applications: transport, chemical and food processing plant, nuclear plant, domestic ware (cutlery, washing machines, stoves), surgical implemnets, pipes, pressure vessels, liquid gas containers
- Melting temperature or glass temperature, $T_m or\ T_g^1 = 1375 - 1450$ ℃
- Density, $\rho = 7.6 - 8.1\ Mg/m^3$
- Young’s Modulus, $E = 189 - 210\ GPa$
- Yield Strength, $\sigma_y = 170 - 1000\ MPa$
- Tensile Strength, $\sigma_{ts} = 480 - 2240\ MPa$
- Fracture Toughness, $K_{IC} = 62 - 280\ MPa\sqrt{m}$

(Ashby, Shercliff and Cebon, 2014).

Based on the studies, the metallurgy and application of stainless steel and alloy for surgical implants has been continued since 1900s. Medical implant or orthopedic implants is a medical device that was designed to replace a missing joint and to support a missing biological structure or damaged bone. Orthopedic medical implants mainly manufactured from austenitic stainless steel, titanium, titanium alloy and cobalt-based alloy. In this project the material used is stainless steel.

For material type 316L stainless steel, it is commonly used in surgical procedures to replace biological tissues. The medical implants manufactured from this material helps to stabilize a biological structure such as bone tissue to aid the healing process. This material mostly important to corrosion resistant when in direct contact with biological fluid. By adding 16% of chromium element to stainless steel, this metal become corrosion resistant. This is important because for the purpose of surgical implants the 316L stainless steel contain approximately 17% to 19% of chromium and 14% of nickel element as surgical implant does not susceptible to corrosion when placed inside the human body. This will prevent any infection occurring in the human body and with the existence of molybdenum added to the stainless steel it forms a protective layer sheltering the metal from exposure to an acidic environment. Material type 316L stainless steel is very ideal as it is particularly effective orthopedic implants when in cold-worked condition. Besides that, material type 316L stainless steel is also ideal because lack of inclusion in the material. Material with inclusion contain sulfur that encourage corrosion.

In application of springback in medical implants, the material type 316L stainless steel is a material used for internal fracture fixation. An internal fixation is an operation in orthopedics that involve implementation of implants for the purpose of repairing bones. Example of type of medical implant used to anchor fractured bones while they heal is semi tubular plate. Figure 1.2 shows the common semi tubular plate used in medical implants.

Figure 1.2: Semi Tubular Plate

(Source: Anonymous, 2016)

Semi tubular plate was designed in the shape of half tube plate. The physical characteristics of semi tubular plate are; it has 1-12 holes with holes spacing between 16 mm and 26 mm, and the thickness of semi tubular plate is around 1mm with width 11mm. This semi tubular plate is commonly used in the area where they are subjected to tensile forces. The oval plate holes allow axial compression if 4.5mm cortex screws are inserted eccentrically on each side of the fracture. Next, the arc underside design is designed for better load support. There are several advantages of using semi tubular plate which are the deep penetration of unthreaded neck of screw into the cortex, which entails in some risk of cortical splitting. The enlarging cortex to 4.5mm as mentioned could prevent such splitting. Nowadays, the semi tubular plate is occasionally used as extension bond plate in open pelvic injuries or as second plate in the metaphysis of long bone.

1.2 Problem statement

In the area of using bending technology, the most common problem occur is achieving accurate and repeatable bending angle. In this project, in processes of sheet metal 316L stainless steel the elastic springback occur after the sheet was rolled and bend at different thickness reduction. As mentioned before, the springback effect occur due to elastic recovery after the unloading of the stainless steel material. Theoretically, when the cold rolled increase from 0% to 50% of thickness reduction, the springback of the u – bend 316L stainless steel will increase.

Besides that, bending process can affect the mechanical properties and the morphology of the material. Therefore, rolling and bending process may be the factors that can manipulate the relationship between mechanical properties of a material and its surface morphology analysis of the internal crack around the springback region and the crack line is produced following the direction of the rolling process.

1.3 Objectives

The objectives of this project are as follow:

1. To observe the surface morphology of u-bend after bending.
2. To determine the microhardness profile of the U – bend 316L Stainless Steel structure at the maximum U - bending region.

During the experiment, there are four different thickness reduction of 316L stainless steel and both sides of the specimen of the similar thickness specimen will be used. The experiment will be conducted two to three times to collect average result for each specimen. Since the material have different thickness reduction, the different springback angle after unloading will be observed.

1.4 Scope of project

The scope of this project are as follow:

1. This thesis project will covers a literature researches of work hardening on springback.
   The concepts and theories are reviewed from different sources such as text books, journals, standard references and web search.

2. The project will covers the develop preparation and experiment on the test specimen due to an influence of work hardening on springback of the U-bend 316L Stainless Steel.

3. The Microhardness Testing and Morphology Analysis are only taken at different thickness reduction from 2.0 mm, 1.4 mm, 1.2 mm and 1.0 mm.

4. Next, data from both tests will be collected and analysed accordingly.
   This project only focused on the result on the Microhardness Profile Testing at the maximum bending region. Therefore, method of Measure Strain Distribution using Digital Image Correlation (DIC) does not covered in this project.

1.5 General methodology

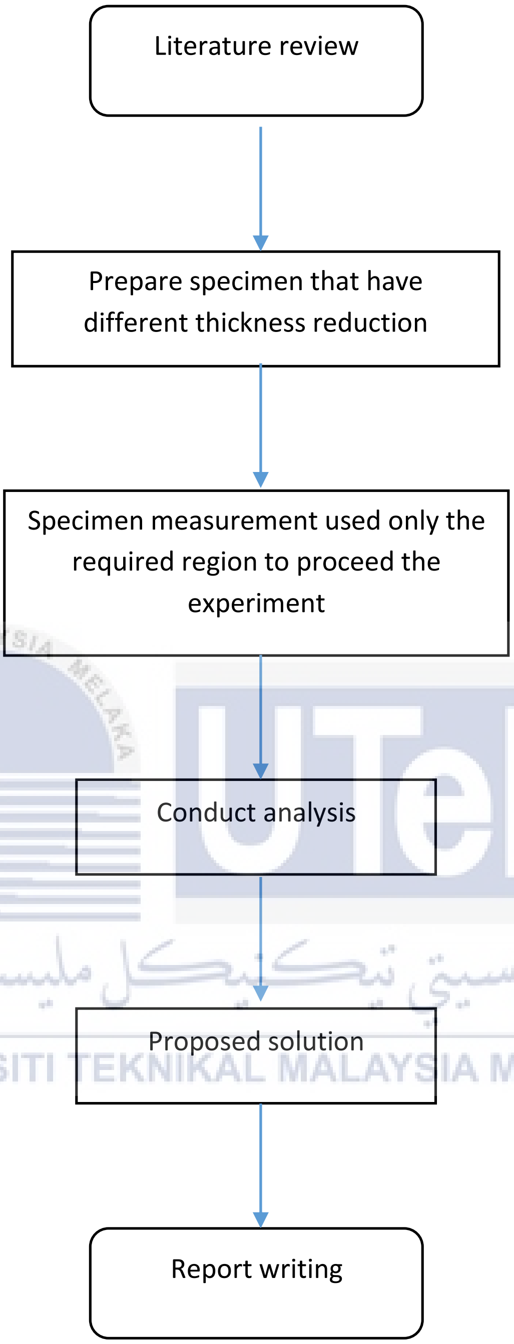
The general actions that need to be carried out to achieve the objectives of this project are as follows:

1) Literature review
   a) Different researches, journals and articles regarding the project will be reviewed. All information collected will be cited accordingly.
2) Specimen preparation
   a) The U – bend of 316L stainless steel at different thickness reduction was prepared after undergoes cold rolling process and bending process.

   b) Both sides of each specimen of different thickness reduction will be used as to do repeated experiment to find the average results.

3) Specimen measurement
   a) The specimens will undergo hand grinding and polishing procedure to remove corrosion and scratches.
   b) Before taken for Microhardness Profile Testing, the specimens will be taken for microscopy inspection to ensure all scratches have been removed and the texture is smooth and clean enough to be taken for Microhardness Profile Testing.
4) Analysis and proposed solution
   a) Analysis will be represented on how the crack lines are presented after undergo bending and the exact location of the springback of the 316L stainless steel material happen after bending. The result of microhardness profile will determine the constant value in the 316L stainless steel material. The constant value is assume to be the starting point of the springback occur in the material. Therefore, suitable solution will be proposed based on the result obtain from the analysis.
5) Report writing
   a) A proper report on this project will be written at the end of this project.

The general methodology is summarized accordingly in the flow chart below.



CHAPTER 2

LITERATURE REVIEW

2.1 Forming process

Forming process involves shaping of materials into desired shape. While the specimen is subjected to shape changes, in sheet metal forming operations, the cross-section of the specimen remains unchanged because sheet metal forming is a process of converting a flat sheet metal into any desired shape without fracture or excessive localized thinning. The tooling that is usually used is punch or die where the forming process requires a sheet metal with less than 6 mm thickness. Sheet metal forming involve bending, punching, drawing, and stretching. Common failures encountered during sheet metal forming are wrinkling, puckering, and shape distortion factors. Besides that, this forming process are very diverse in type, extent and rate. No single test can provides an accurate indication of the formability of the material in all situation. Factors influence on overall operation of forming processes are stretching, elongation, anisotropy, and grain size. In addition, there are typical mechanical property of sheet metal such as thickness, process condition, surface finish, material properties. (Abhinav, Annamalai, January 2013)

2.2 Work Hardening and Springback

"*Strain hardening is a phenomena whereby a ductile metal becomes harder and stronger as it is plastically deformed*". A work hardening or cold working are another termed for strain hardening phenomena. Work hardening happened when the deformation takes place at cold temperature that relative to absolute melting temperature of the metal, which also known as cold working. (Callister, *Materials science and engineering* (8th Ed.), 2010). Work hardening is a process that makes the metals become harder and stronger through plastic deformation. This happened as the metals plastically deformed, dislocations within a material is generated. The more interaction of the dislocations become pinned or tangled. As a result, the mobility of the dislocations become decrease. Thus, increase or strengthening the material itself.

All metals that undergo work harden gives respective pros and cons. In this analysis, all specimens are rolled into thin sheet with different thickness and applied bending to all specimens. The advantage of work hardening; it is an effective strengthening method especially for alloys material. Alloys cannot be heat-treated to give precipitation hardening. In contrast, the disadvantage of work hardening is it caused the material's yield strength to increase too high and it needed to be annealed or heat it up to remove the accumulated dislocations. (Ashby, Shercliff and Cebon, 2014)

According to Callister, (2010), metals and alloys are mostly contain dislocations. Basically, the plastic deformation and dislocations are both related to the motion of large number of dislocations. There are several characteristics of dislocations. These characteristics are important with regard to the mechanical properties of the metals such as strain fields that exist around the dislocations. As the cold working happened at low temperature, the atoms cannot rearrange themselves and the increasing in strength caused a reduction in ductility. The graph in figure 2.1 shows the yield strength and the percentage of elongation as a function of percent cold-work in different materials. From the graph, notice that the amount of cold working results in a significant reduction in the material ductility.

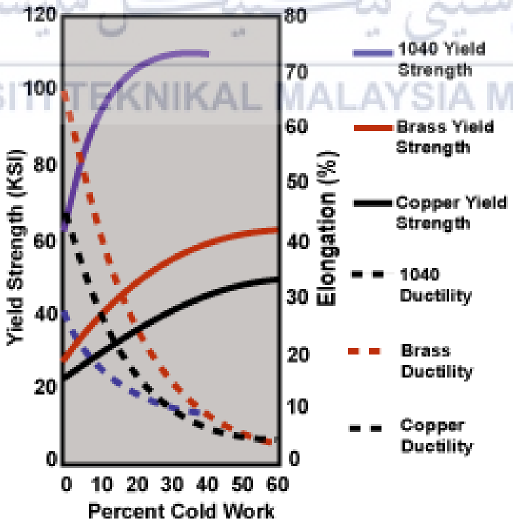


Figure 2.1: Graph of yield strength against percentage of elongation of percent cold-work in different material

(Source: Callister, *Materials science and engineering* (8th Ed.), 2010)

Springback is an elastic recovery which is resulting after plastic deformation in metals. The metal having the tendency to return back to its original position or shape after unloading of load. All metals have an elastic limits that act like an elastic bands. It can be bend and roll until certain point. Beyond than that, it will return back to their original shape or position. When the metal is rolled, the inside radius of the metal is squeezed together or forced into compression while the outer radius is stretched into tension.

Springback is a geometric changes due to forming process when the material has been released from the forces of the forming tool. In sheet metal forming process, the deep-drawn part and stretch-drawn part of springback affect the dimensional accuracy of a finished test specimen. During the development tool stage in prediction of springback, a software used as a simulator can not only detect springback, it also not enough to predict a deformation in classic sheet metal models. In intense tryout loops, a simulation software tools are improved and manufacturing costs are significantly been reduced. (GmbH, 2016)

2.3 Summary of Journal

According to Oliveira, *et al.*, (2007), in his thesis stated that springback is an important source of effect in geometrical and dimensional inaccuracy in sheet metal formed components. This thesis focused on the simulation by using Finite Element (FE) method and the models used in the simulation are based on phenomenological laws which consider the material parameters that fit of the model to mechanical experimental data.

Oliveira, *et al.*, stated that several numerical studies regarding springback prediction point out that kinematic hardening such as bending or unbending is important when the blank sheet is submitted to strong strain-path changes in the U-shape channel. By comparing the influence of the work – hardening models on springback, the expected results depend on the selected sheet metal formed along with the process conditions.

2.4 Factors affecting Springback

Factors that could affect springback must always be taken into consideration. There are several factors that could affect the springback. First, the mechanical properties of the test material or test metals can affect the springback phenomena. The rolled metal such as alloyed steels will have more springback effect than mild steels. (Anonymous, n. d.)

Second, metal thickness can affect the springback in a material. The springback is much less occur in a metal that have a thicker thickness. The grain direction always happened in opposite direction against the rolling direction. Next, if the test material is rolled into cylindrical shape; the longer the length of the cylinder, the more springback occurrence will occur in the test material. (Anonymous, n. d.)

Springback is mostly affected by various processes applied to the metal sheet. The complex combination of bending, unloading and stretching that are forced onto the metal sheet during deep drawing process is one of the factor that affect the springback phenomena. (Reddy, Rao, Reddy, & Reddy, 2014)

In simple V bending, the metal sheet is flexed along the straight line until a bend shape is obtained. There are three types of bending; V bending, U bending and lastly, edge bending. In figure 2.2 provided shows how the metal sheet formed a bending radius along a bending process along the straight line of the material. While figure 2.3 shows the springback effect after unloading of the bending process. (Chikalthankar, Belurkar, Nandedkar, 2014)

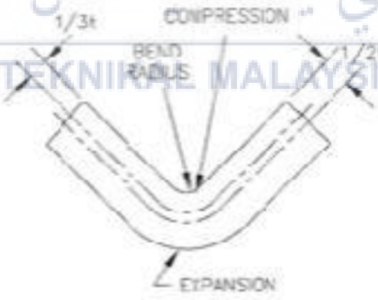


Figure 2.2 A metal sheet after undergoes simple V bending
(Source: Chikalthankar, Belurkar, Nandedkar, 2014)

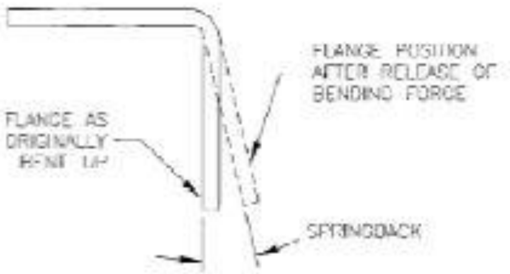


Figure 2.3 Springback effect after unloading of the bending process
(Source: Chikalthankar, Belurkar, Nandedkar, 2014)

2.5 Springback parameter

Springback depends on the bending moment where the stress distribution at each point in the plane of the sheet metal during drawing operation is influence by the thickness of the sheet metal. Theoretically, an accurate prediction of springback is difficult to develop as numbers of trial ar required but the springback prediction can be done depends on the development of internal stress distribution in the sheet metal during drawing operation. The development of internal stress distribution makes it sensitive to a range of variables. (Reddy, Rao, Reddy, & Reddy, 2014)

Springback phenomena is evaluated through dimension changes of the formed part after the pressure exerted by forming tool is released. It is the change in strain that was produced by elastic recovery. In metal forming process, the complex combination of stamping and deep drawing where bending or unbending is predominant. The material undergoes both elastic and plastic deformation during the process. Springback occurred when the punch reached the final draw depth and been removed. The springback occur in the non-uniform stress distribution region in the sheet metal. (Reddy, Rao, Reddy, & Reddy, 2014)

A sheet thickness is one of the parameter that can affect the springback in the material. The comparison between the experimental result and the Finite Element Method (FEM) result has been done to determine the relationship between the springback angles with sheet metal thickness. Figure 2.4 provided shows the comparison made between sheet metal thickness and effect of springback angle. (Chikalthankar, Belurkar, Nandedkar, 2014)

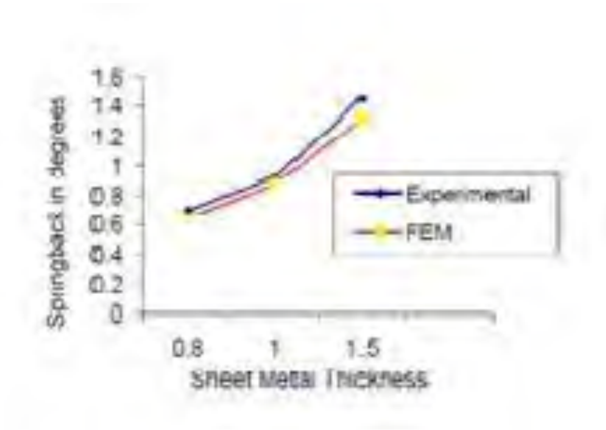


Figure 2.4 Graph of sheet metal thickness vs. Springback angle
(Source: Chikalthankar, Belurkar, Nandedkar, 2014)

2.6 Standard test for Springback

Figure 2.5 shows a draw/bend test that is a common standard test for springback that consist of two hydraulic actuators oriented at a 90° angle and a fixed or rolling cylinder to simulate a tooling radius to produce a sheet metal that made up of different thickness by using sheet metal type 316L stainless steel. The upper actuator is programmed to provide a constant restraining force, F_b. While the lower actuator is set to displace at constant speed, v. As a result, the material undergoes bending and unbending over the cylinder with constant tension and caused a reversible load in the material. Thus, springback occur by the removal of the material from the grips. Each specimen with different thickness drawn a different springback angle$\Delta\theta$. (Reddy, Rao, Reddy, & Reddy, 2014)

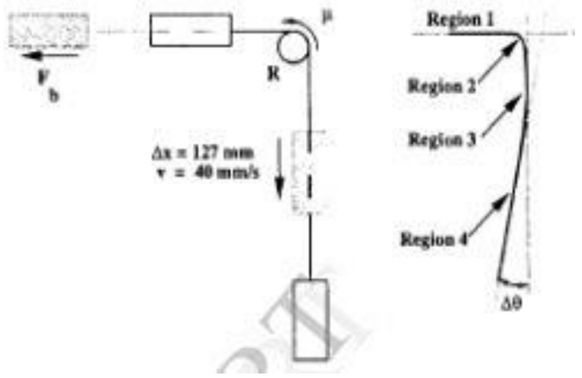


Figure 2.5 Draw/bend process of metal sheet
(Source: Reddy, Rao, Reddy, & Reddy, 2014)

2.7 Microhardness Profile

Hardness is one of the mechanical properties for metals. Hardness is important in measuring the material's resistance as it can localized the plastic deformation such as small dent or scratch. In the beginning, hardness tests were based on natural minerals with a scale constructed specially on the ability of one material to scratch the other softer material. Over the years of development, the hardness tests work with small indenter that forced into the surface of the tested material under controlled conditions of loads and rate of application. The depth or size of the resulting indentation is related to a hardness number; the softer the tested material, the larger and deeper the indentation. Therefore, the lower the hardness index number. (Callister, *Materials science and engineering* (8th Ed.), 2010).

2.8 Surface Morphology Analysis

Surface morphology of metal is important property at determine the crack line in the material. The cracks are occur after bending process and it is perpendicular to rolling process. ("Surface Morphology Of Metal Electrodeposits" 29-100)

Microscopy examination is a method to examine the structural elements, textures and defects that influenced the material properties. Under microscopic vision, the elements are large enough to be observed with unaided eyes. A microscopic is having a diameters that may on the orders of microns (μm). It also be called in terms of micrometer (10^{-6}m). In microscopy examination, optical, electrons and scanning probes microscopes are the most commonly used equipment or aid instrument to investigate the surface and microstructural features of all material types. In photomicrography, the technique employ a photographic equipment in combining with the microscope. (Callister, *Materials science and engineering* (8th Ed.), 2010).

Microscopy examination is a method and a useful tool in the study and characterizing the materials. Microscopy examination is a useful tool in real application because it delivers various advantages in the study of materials. The advantage of using microscopy examination is it will ensure that the relationship between the material properties and surface defects or textures can be easily understood. Besides that, microscopic examination can predict the properties of the material accurately once the relationship have been determined.

Next, the microscopic examination useful to determine whether the material has been correctly heat – treated and it also benefited to ascertain the mode of mechanical fracture of the materials. (Callister, *Materials science and engineering* (8th Ed.), 2010).

2.9 Material properties for 316L Stainless Steel

Materials will be subjected to loads or forces when it is in service. It is necessary to know the characteristics of the materials and the mechanical behaviors of the materials that reflect to relationship between its response or deformation to an applied force or load. The main key mechanical properties for metals are stiffness, strength, hardness, ductility and toughness. Metal alloys are differentiate into two group; Ferrous and non-ferrous. In this project, the material used is a ferrous alloy. (Callister, *Materials science and engineering* (8th Ed.), 2010).

The material type 316L is a stainless steel material. A stainless steel material is a high corrosive-resistant in different environments. It is highly resistant to corrosion or rusting especially in ambient condition as it made up of at least 11 wt% of chromium, Cr and the material is improved by additions of nickel and molybdenum elements in it. In addition, the chromium element is said to be the predominant alloying element in stainless steel. The material 316L stainless steel is fall into class of the predominant phase constituent of the microstructure that known as austenitic class. Callister, *Materials science and engineering* (8th Ed.), 2010).

The austenitic stainless steels are made up of austenite (γ) phase field and can only reach until room temperature. But it is being hardened and strengthened by cold working process as it is not heat-treatable. As mentioned, the austenitic stainless steel is predominantly by chromium element. Therefore, the austenitic stainless steels are most corrosive-resistant with the largest quantities of nickel additions element in it. (Callister, *Materials science and engineering* (8th Ed.), 2010).

2.9.1 Stainless Steel and its Technical Properties

Technical properties of materials include it Chemical Composition, Mechanical Properties and Physical Properties. In this project, all three technical properties are studied.

- Chemical Composition

Table 2.1: Summary of material type 316L Stainless Steel

Grade	Austenitic
Designation AISI/ ASTM	316L
Carbon, C	≤ 0.030
Silicone, Si	≤ 1.00
Manganese, Mn	≤ 2.00
P max	0.045
Sulphur, S	≤ 0.015[2]
Nitrogen, N	≤ 0.11
Chromium, Cr	≤ 0.11
Molybdenum, Mo	1650 to 1900
Nickel, Ni	1000 to 1500

Note: 2) for product to be machined, a controlled sulphur content is 0.015% to 0.030% is recommended and permitted. For weld-ability, a controlled sulphur content of 0.008% to 0.030% is recommended and permitted. For polish-ability, a controlled sulphur content of 0.015% max. is recommended.

(Source: "Stainless Steel: Tables of Technical Properties", 2017)

(Adapted: from "Raccolta di tabelle techniche" with kind permission of Centro Inox, Italy.)

- Mechanical Properties

Table 2.2: Summary of Mechanical properties of material type 316L Stainless Steel

No.	**Grade**	Austenitic		
1.	**Designation AISI/ ASTM**	316L (1.4404(1))		
	Product Form (1)	C	H	P (4)
	Thickness, max (mm)	8	13,5	75

	Heat Treatment (5) (13)	AT		
	Hardness, HB or HV max	-	-	146(21)
	Proof Strength, MPa min transverse **(14) (15)**	240	220	220
	Tensile Strength, Mpa	From 530 to 680		From 520 to 670
	Elongation after fracture, A_{80mm} min (%) **th<3mm** **(tr. and long) (2)**	40		45
2.	**Grade**	Austenitic		
	Designation AISI/ ASTM	316L (1.4435(I))		
	Product Form (1)	C	H	P (4)
	Thickness, max (mm)	8	13,5	75
	Heat Treatment (5) (13)	AT		
	Hardness, HB or HV max	-	-	146(21)
	Proof Strength, Mpa min transverse **(14) (15)**	240	220	220
	Tensile Strength, Mpa	From 550 to 700		From 520 to 670

	Elongation after fracture, A$_{80mm}$ min (%) **th<3mm** **(tr. and long) (2)**	40		45
3.	**Grade**	Austenitic		
	Designation AISI/ ASTM	316L(1.4432$^{(I)}$)		
	Product Form (1)	C	H	P $^{(4)}$
	Thickness, max (mm)	8	13,5	75
	Heat Treatment (5) (13)	AT		
	Hardness, HB or HV max	-	-	146$^{(21)}$
	Proof Strength, Mpa min transverse **(14) (15)**	240	220	220
	Tensile Strength, Mpa	From 550 to 700		From 520 to 670
	Elongation after fracture, A$_{80mm}$ min (%) **th<3mm** **(tr. and long) (2)**	40		45

Notes: I) Mechanical properties according to EN 10088-2, June 2005

1) C = Cold rolled strip; H = Hot rolled strip; P = Hot-rolled plate

2) The value apply for test pieces with a gauge length of 80 mm and a width of 20 mm; test piece with gauge length of 50 mm and a width of 12.5 mm may also be used; solely for the

austenitic types mentioned in EN 10088-2, June 2005, and EN 10028-7, January 2000, figures refer to the transverse direction only

4) For thickness exceeding 75 mm (martensitic and austenitic grades), mechanical properties may be agree upon

5) AT = solution annealed;

13) Solely for the austenitic types mentioned in EN 10088-2, June 2005, the solution treatment may be omitted if the condition for hot working and subsequent cooling are such that the requirements for the mechanical properties of the product and the resistance to intergranular corrosion as defined in EN ISO 3651-2 are obtained

14) If, in the case of strip in rolling widths <300 mm, longitudinal test pieces are taken, the minimum values are reduced as follows:

- Proof strength: minus 16 MPa

- Elongation for constant gauge length: minus 5%

- Elongation for proportional gauge length: minus 2%

15) For continuously hot-rolled products, 20 MPa higher minimum values of proof strength may be agreed at the time of enquiry and order

21) Hardness value (HB/HV) for plate format according to AISI manual, December 1974 edition; supplement, March 1979

(Source: "Stainless Steel: Tables of Technical Properties", 2017)

(Adapted: from “Raccolta di tabelle techniche” with kind permission of Centro Inox, Italy.

- Physical Properties

Table 2.3: Summary of Physical Properties of material 316L Stainless Steel

Grade	Austenitic
Designation AISI/ ASTM	316L
Density, at 20℃ (kg/dm^3)	8.0
Modulus of elasticity, at 20℃ (GPa)	200

(Source: "Stainless Steel: Tables of Technical Properties", 2017)

(Adapted: from “Raccolta di tabelle techniche” with kind permission of Centro Inox, Italy.)

For metals, the yield strength, σ_y (or elastic limit σ_{el}) with units MPa or MN/m^2 –requires the onset of plasticity that is identify σ_y with the 0.2% $proof\ stress$. Proof stress is the stress which the stress-strain curve for axial loading deviates by a strain with 0.2% from linear elastic line as shown in figure 2.6 stress – strain curve for metal provided as follows:

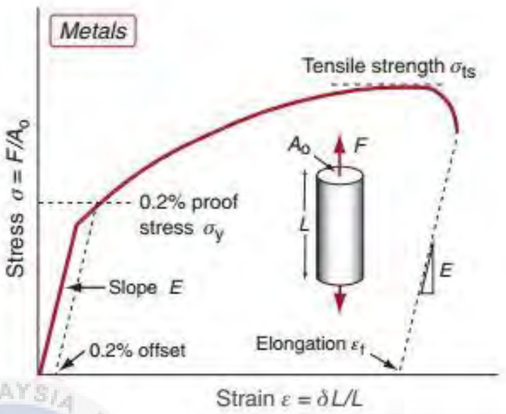


Figure 2.6: Stress – strain curve for metal

(Source: Ashby, Shercliff and Cebon, 2014)

For most metals that undergo work harden, the rising part of the curve occur when strained beyond the yield point. Thus, the maximum tensile strength is reached. (Ashby, Shercliff and Cebon, 2014)

As mentioned, springback is known as elastic recovery after plastic deformation of a formed part in unloading of the stainless steel material. This behavior is shown in the schematic diagram in figure 2.7 below. The point D is the point of unloading and the slope is fundamentally identical to the modulus of elasticity or parallel to initial elastic portion of the curve. For metals, the material will experience plastic deformation that was influenced by compression, shear and torsional loads. (Callister, *Materials science and engineering* (8th Ed.), 2010).

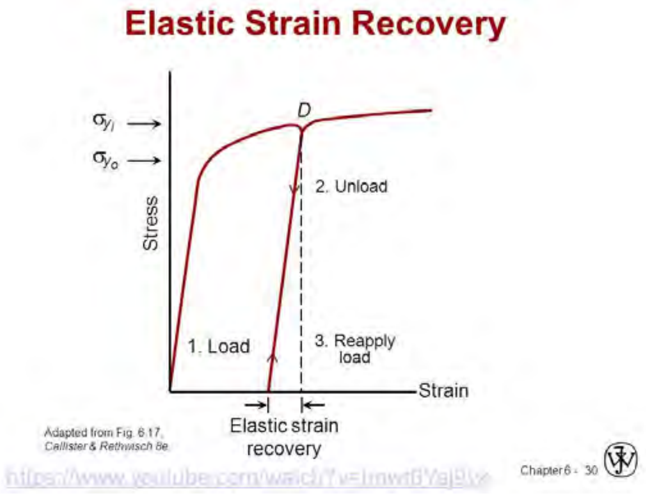


Figure 2.7: A schematic diagram of the phenomena of elastic strain recovery and strain hardening.

(Source: Callister, *Materials science and engineering* (8th Ed.), 2010)

Figure 2.8 shows the yield strength, σ_y or elastic limit, σ_{el}, is plotted against density, ρ. The range of strength for engineering materials is showed from 0.01 MPa for foams to 10 000 MPa for diamond. As for diamond, the tooling used for machining is such Vickers hardness test.

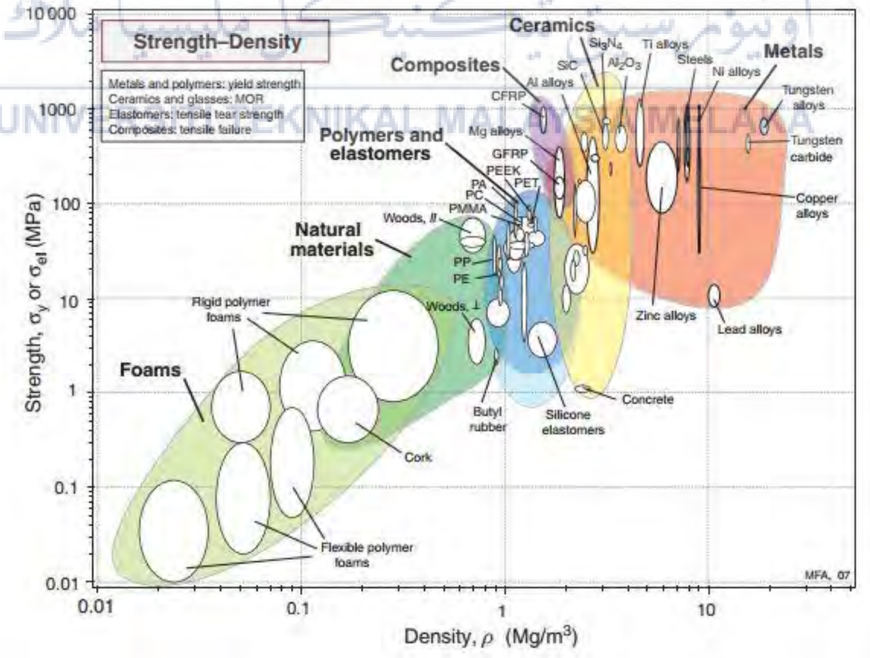


Figure 2.8: The Strength yield against density chart

(Source: Ashby, Shercliff and Cebon, 2014)

The material used in this analysis belong into stainless steels metal that have range of strength from 100 MPa to 1000 MPa while the spread in its stiffness is at most 10%. The strength bubbles for metals are long and thin because the density varies very little.

Figure 2.9 shows the Young's Modulus, E, is plotted against yield strength, σ_y or elastic limits, σ_{el}. This chart is useful for examine the material characteristics such as, the yield strain, σ_y/E, is used to examine the strain of the material which the material cease to be linearly elastic.

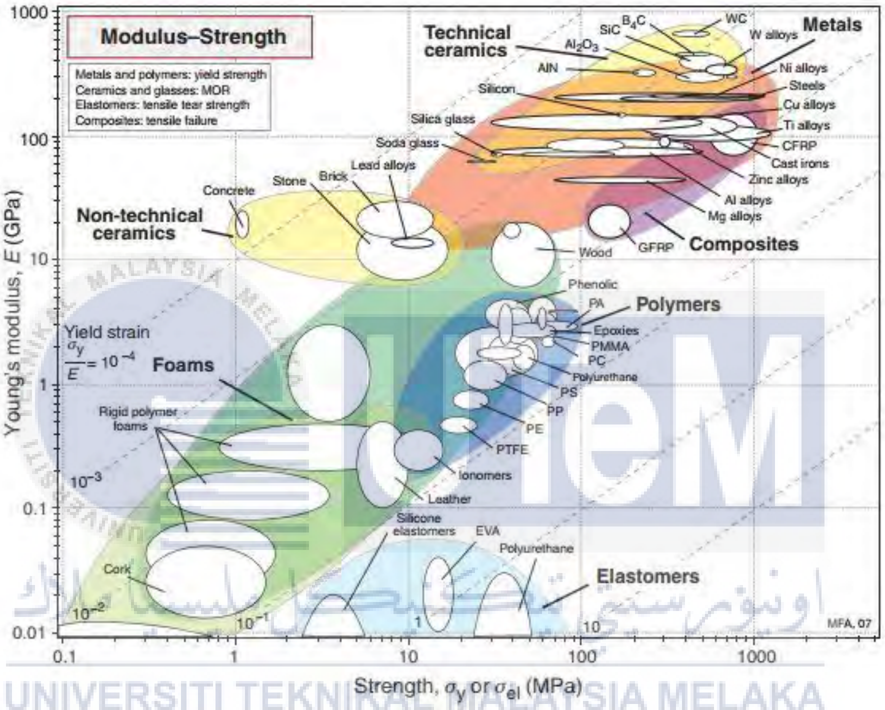


Figure 2.9: The Young's Modulus against Strength Yield chart

(Source: Ashby, Shercliff and Cebon, 2014)

2.10 Application of 316L Stainless Steel

The material type 316L Stainless Steel is commonly used in production of orthopedic implant devices. The orthopedic surgeons are specialized in the certain area of the body, for example foot and ankle, hand and wrist, fingers, neck and spine. (Orthopedics, 2013). The orthopedic device is an artificial mechanical device that is produce to support or replace the certain area of the skeletal structure in the human body. The device application in the human body works as internal fixation in the fractured skeletal parts by using bone plates, nails or intermedullary rods. The material 316L Stainless Steel is used in making medical implant because the material can exposed to the biochemical and dynamic environments of human body. Therefore, the design of the implant is dictated by anatomy and restricted by physiological condition of the patient.

The device failed when it must be prematurely removed from the body. The failure occur whether in mechanical ways or biological ways. This failure could bring danger to the patients. It is because the medical implant is considered as a foreign material that is implanted into the human body. The presence of these foreign implant device may restrain the defense mechanism of the body and cause the body to react unfavorable in several ways and that leading to infection in the body. The failures of the implant could cause the patient to experience the trauma and severe pain. Besides that, removal of failed implant will cause great deprivation and hardship to the patient. An improvement of the overall performance of the implant devices through revision engineering is highly desirable as a prevention step and to keep the number of failure to a minimum. The studies of the springback effect of the material 316L Stainless Steel can be used to develop or improve the durability of the implant devices. Therefore, the material used in making implant device should be inert and well tolerated by the body to prevent failures. (Sudhakar, 2005)

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, there will be further explanation from material preparation until every testing will be conducted on the material 316L stainless steel to study about the influence of the work hardening on the springback of the of the u-bend material. Every method used are well planned according to the Gantt chart or schedule provided to prevent from taking too much time on certain testing session. The strategies that have been made are start from the preliminary work such as rolling, bending and machining on the material 316L stainless steel to be in the form of u-bend material. After that, experimental work will be conducted toward the material type 316L stainless steel such as Microhardness Testing and Surface Morphology Analysis. There are two important experimental work in this project such as to observe the surface morphology and the internal crack of the material 316L stainless steel and to determine the microhardness profile on the springback of the material 316L stainless steel. Therefore, a proper understanding of the effects of process parameters and material properties on springback is very crucial in designing an effective test processes. (Reddy, Rao, Reddy, & Reddy, 2014)

3.1.1 Preliminary work

In metal fabrication techniques, there are three different types of technique such as forming operations, casting and miscellaneous. In forming operations, there are other four classification scheme in it. There are forging, rolling, extrusion and lastly drawing. As in this project, the metal fabrication technique that will be focused on is rolling, bending and machining operation. Before that, metal fabrication technique is a technique that involves refining, alloying and heat-treating processes. Through these processes, it allows the alloys produced with desired characteristics. The method of technique used is often depend on few important factors such as properties of the metal, the size and shape of the finished piece and of course the cost to purchase the material. (Callister, *Materials science and engineering* (8th Ed.), 2010)

Rolling is widely used in the industry. Rolling is a method that involves deformation process. Rolling's working principle is simple by passing a metal sheet between the two rolls. The rolls will exert compressive stresses. As a result, a reduction in material thickness will occur. Sheet, strip, and foil are usually produced by using cold rolling process with a very fined and high quality surface finished. (Callister, *Materials science and engineering* (8th Ed.), 2010)

U-bend channel test is a method used in this project to determine the springback phenomena. In this test, the material is drawn from a blank that known as rectangular blank. Figure 3.1 provided shows the schematic diagram of the u bend channel test. The rectangular blank was applied to the metal sheet with constant speed, v. The removal of the blank from the specimen after applied bending, unbending to the material, caused the material to have a springback effect. The springback angle $\Delta\theta$ occur in the metal sheet is different in different thickness of metal sheet.

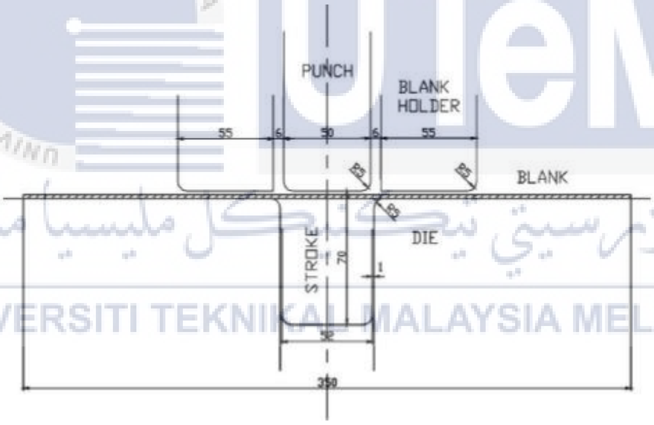


Figure 3.1: A schematic diagram of u-bend channel test
(Source: Reddy, Rao, Reddy, & Reddy, 2014)

The springback angle is defined on the corner bends and side wall curl of the specimen. The springback angle occur by elastic component released from bending movement and the changes in the final bend angle after the blank undergoes bending. A side wall curl was affected due to the release of residual bending movement. It also happened after the blank bent and unbent under tension while passing over a die radius. Figure 3.2 shows how to measure the springback effect in the material that was resulted from U bend test. (Reddy, Rao, Reddy, & Reddy, 2014)

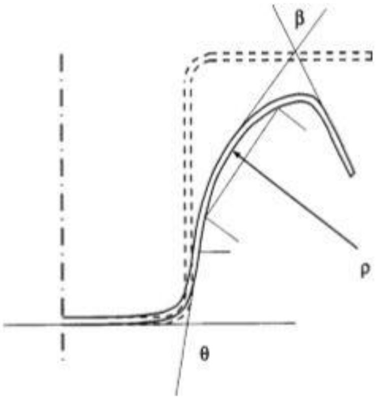


Figure 3.2: How to measure springback in material
(Source: Reddy, Rao, Reddy, & Reddy, 2014)

3.1.2 Experimental work

Experimental work is conducted to observe the surface morphology after the springback effect occur in the materials. As mentioned, the springback happened after a bending was applied to the material. Therefore, a proper morphology observation is required to find out the location of the crack lines produced after applied bending process and the direction of the crack line produced in the material. In surface morphology analysis, the crack lines are observe from top surface of materials. Next, experimental work is conducted to determine the microhardness profile of the u-bend of 316L stainless steel. This testing is required because to determine the maximum bending region of the u-bend material after springback effect occurred in the material.

3.1.3 Analysis & Finding

From the experimental work, the internal crack found from surface morphology analysis and springback effect can be determine based on the result obtained after conduct the experiment or test towards every specimen. Both microhardness test and surface morphology analysis can influence the relationship between surface textures of a material with its mechanical properties. The analysis and finding regarding the relationship between the surface morphology of a material against its mechanical properties is conducted according to the flow chart provided as a guidance to complete this project.

3.1.4 Flow chart

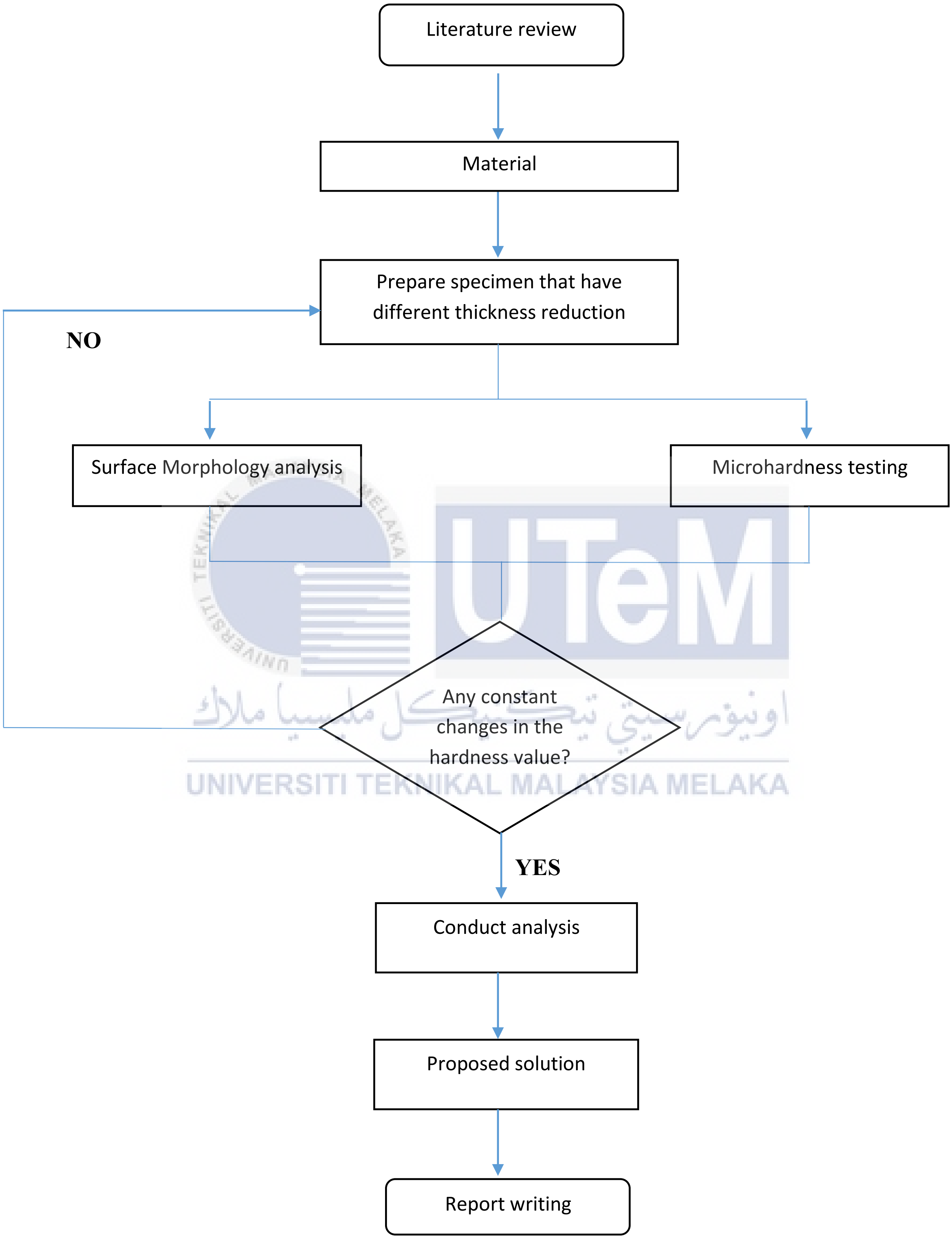


Figure 3.3: Flow chart for the project

3.2 Material dimension

As mentioned, the material used in this project is material type 316L Stainless Steel. The material is produced with different height and width dimensions as the springback of the u-bend is different according to their respective thickness. For specimen with thickness 1.0 mm, the bend radius of springback is approximately 290 mm. Next, for specimen with thickness 1.2 mm, the bend radius of the springback is at least 275 mm. The specimen with thickness 1.4 mm, the bend radius of springback is approximately 240 mm. Lastly, the specimen with thickness of 2.0 mm, the bend radius of springback is measured at least 180 mm. All four specimens are measured roughly by using a ruler to determine the bend radius of springback of each specimen. Figure 3.4 shows one of the bend radius of springback in specimen with thickness 2.0 mm.

Figure 3.4: Approximate value of bend radius of springback in specimen thickness 2.0 mm

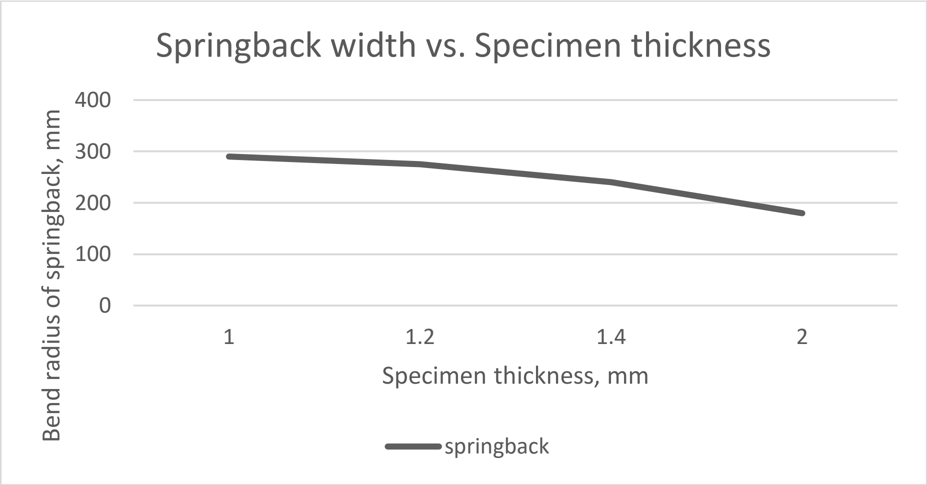


Figure 3.5: Bend radius of springback against specimen thickness

3.3 Mechanical Process

In mechanical processes, there are four specimen with different thickness produced after undergoes rolling, bending and machining processes. The four specimen are then been taken to undergoes sheer cut. This procedure is done to remove unnecessary region. After that, all specimen were taken to material science laboratory for surface finishing processes that was located at Fasa B, FKM.

Hand Grinding Machine is used to remove rust or corrosion on the surface of all specimens. The hand grinding machine is consist of three different roughness of abrasive papers. The water will flows on three abrasive papers and the surface of all specimens will be in contact with the sandpapers along with flowing water tap. The range of abrasive papers used are from P400, P600 and lastly P1000. P1000 is the finest abrasive papers. Time taken to clean both surface of each specimen is approximately five minutes.

Next, the specimens will be taken to the Grinding and Polishing Machine. At this stage, all specimens need to be polished to remove all scratches on the surface of the material. All specimen will be polished under speed, rpm approximately 100 rpm to 250 rpm to remove the scratches. The surface material type 316L stainless steel is very hard to remove the scratch. Therefore, the process requires plenty of time to have a satisfied surface finished.

Optical microscopy is one of the microscopic examination technique that is commonly used in the industry. This light microscope is used to study the microstructure of a material by using optical and illumination systems and reflecting mode as its basic elements. Material for all metals, many ceramics and polymers are opaque to visible light. Therefore, only the surface of the subject is able to be observed. Optical microscopy is often called or termed as “Metallographic” as it is the first technique used in investigate metals. (Callister, *Materials science and engineering* (8th Ed.), 2010).

In early stage, any test materials need to undergo material preparation stage. In preparing the materials, careful and detailed surface preparations are necessary to disclose the important details of the microstructures of the materials. The test material surface must first be ground and polished until the surface of the material is smooth and have a mirror-like finish onto it. These preparation steps can be successfully achieved by using a finer abrasive sand papers for grinding and suitable liquid reagents for polishing. Polishing stage is very important in removing scratches until it achieved the mirror-like finished and the scratches are acceptably not visible under microscope. (Callister, *Materials science and engineering* (8th Ed.), 2010).

3.4 Microhardness Profile

The hardness tests are frequently performed because of it is simple and inexpensive. Any types of specimen can be tested without any special specification and the apparatus is relatively inexpensive. Next, the test is considered as a non-destructive test. This is because the specimen is neither fractured nor excessively deformed. The small indentation cause only small deformation. (Callister, *Materials science and engineering* (8th Ed.), 2010).

Table 3.1 shows all mechanical properties often estimated from hardness data used to conduct the hardness test. In our project, the main focus on the hardness test is only in test by using Vickers Micro-indentation Hardness Tests. Knoop and Vickers hardness-testing techniques shared several similarity. Vickers hardness-testing technique is also termed as diamond pyramid. It use a very small diamond indenter having pyramidal geometry. The applied force of the diamond indenter is relatively much smaller than for Rockwell and Brinel hardness-testing techniques that ranging between 1 and 1000 g loads. (Callister, *Materials science and engineering* (8th Ed.), 2010). The equipment that is owned by the university have a maximum load that can be applied by the indenter is 2000 g.

Table 3.1 Hardness data in different hardness testing technique

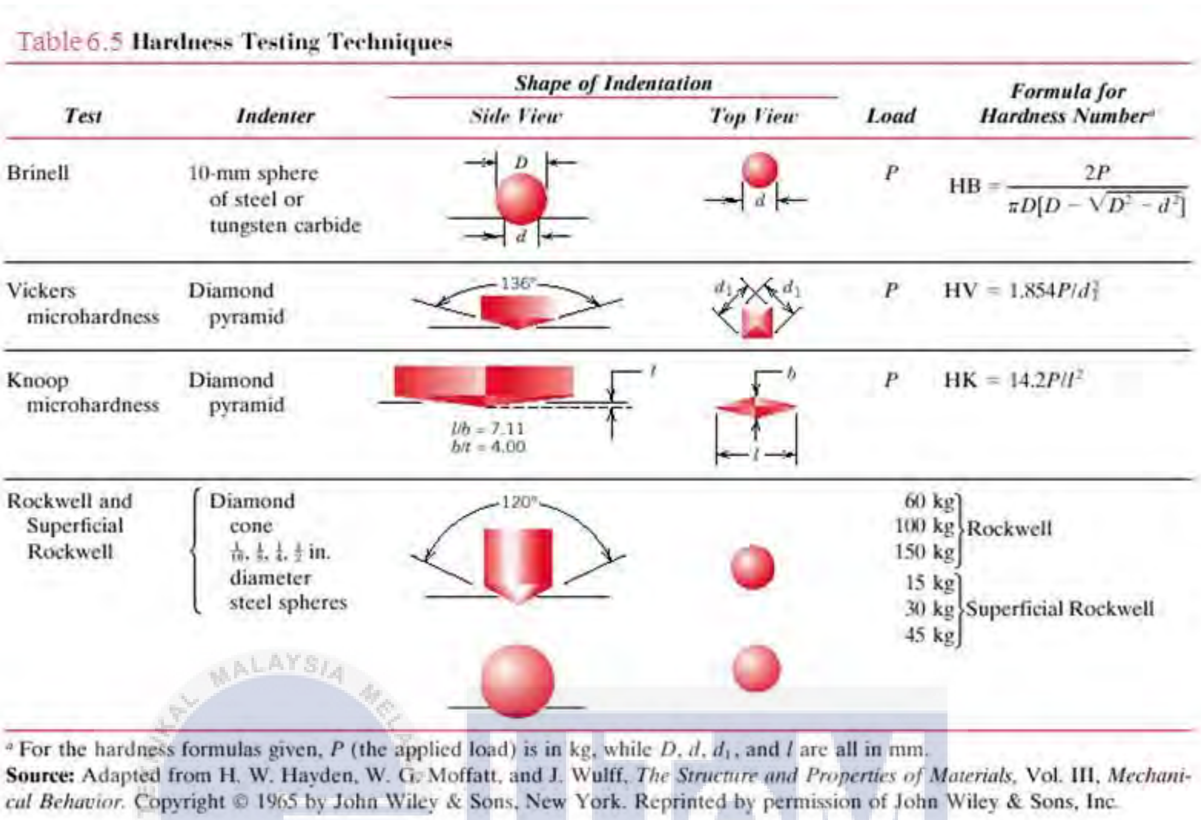


Table 6.5 **Hardness Testing Techniques**

Test	Indenter	Shape of Indentation: Side View	Shape of Indentation: Top View	Load	Formula for Hardness Number[a]
Brinell	10-mm sphere of steel or tungsten carbide			P	$HB = \frac{2P}{\pi D[D - \sqrt{D^2 - d^2}]}$
Vickers microhardness	Diamond pyramid			P	$HV = 1.854P/d_1^2$
Knoop microhardness	Diamond pyramid	$l/b = 7.11$ $b/t = 4.00$		P	$HK = 14.2P/l^2$
Rockwell and Superficial Rockwell	Diamond cone $\frac{1}{16}, \frac{1}{8}, \frac{1}{4}, \frac{1}{2}$ in. diameter steel spheres			60 kg, 100 kg, 150 kg Rockwell 15 kg, 30 kg, 45 kg Superficial Rockwell	

[a] For the hardness formulas given, P (the applied load) is in kg, while D, d, d_1, and l are all in mm.

Source: Adapted from H. W. Hayden, W. G. Moffatt, and J. Wulff, *The Structure and Properties of Materials*, Vol. III, *Mechanical Behavior*. Copyright © 1965 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.

(Source: http://images.slideplayer.com/15/4573662/slides/slide_13.jpg,(Callister, *Materials science and engineering* (8th Ed.), 2010).

Adapted from H. W. Hayden, W. G. Moffatt, and J. Wulff, *The Structure and Properties of Materials,* Vol. III, *Mechanical Behavior*. Copyright © 1965 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.)

As mentioned in the specimen preparation section, the surface of the test specimen need to be grinding and polishing before conducting the testing. It is necessary to ensure a well-defined indentation to get a rather accurate measurement of the test result. The result in Vickers hardness numbers is designated by HV. Vickers is referred as micro-indentation-testing or microhardness-testing because it suited for measuring the small, selected specimen regions. The modern microhardness-testing equipment has been an automated equipment. The indenter apparatus has been directly connected to an image analyzer that incorporates a computer and software package. The software is an important system that controlled indent location, indent spacing, computation of hardness values and plotting the data if the test. (Callister, *Materials science and engineering* (8th Ed.), 2010).

3.5 Surface Morphology Analysis

The surface morphology analysis of material 316L Stainless Steel were studied by using the Microscopic Image Analyzer and Scanning Electron Microscope (SEM). As mentioned, the surface of each specimens were polished with three types of abrasive papers range from P400, P600 and P1000 and the surface of the specimens are continued to be polished with diamond paste until a smooth surface finished is obtained. The surface of the specimen is scratches-free after being inspected under low power microscope. (Gubicza et al., 2016)

Microscopic Image Analyzer is another microscopic examination technique can be easily applied in the industry. This Microscopic Image Analyzer is known as more recent and extremely useful investigation tool used nowadays in the faculty. The Microscopic Image Analyzer works by scanning the surface of the test specimen similarly like a light microscope. The image shown on screen in a form of actual photographed visual that represents the surface features of the test specimen. This machine is able to provide the scales of imaging and the value of the surface features or textures found on the specimen. The Scanning Electron Microscope (SEM) is used to observe the crack line from the top surface of the specimens. The cracks happened after bending process applied to the specimens. Therefore, it is very useful tools in examine the surface features and crack width of the specimens accordingly.

CHAPTER 4

DATA & RESULTS

4.1 Preliminary work

Sample preparation works are crucial before the specimens are taken for microhardness testing and morphological observations. This procedure is to ensure the specimens are clean from scratches, contaminants or voids and have the mirror-like finished surfaces. All specimens are taken under automatic hand grinding machine to remove scratches and to ensure the surface is flat. The specimens are grinded from 240P grinding paper which will produce the roughest scratch. This grinding paper is used to produce a flat surface on the specimen. The specimen is taken under low power light microscope from time to time to check the condition or the surface finish of the specimens. After the surface is flat enough, the same procedures are carried out using 400P, 600P, 800P and lastly 1000P grinding paper. 1000P grinding paper will produce the finest scratch on the surface of the specimens. At this stage, the surface of the specimens are almost clean from any scratches or contaminants.

Next, all specimens are taken to polishing machine section. The polishing liquid used to polish the surface of the specimens named as Polycrystalline Diamond PC – 1001 – 500. This diamond liquid will make the surface of the specimens to reach the mirror-like finished surfaces. The small amount of the diamond liquid used is enough to polish all four specimens accordingly. After that, the specimens are eligible to be taken for microstructure analysis and microhardness testing. Figure 4.1 below shows the mirror-like surface finish on the test specimen. The surface of the specimen has been checked by using low power light microscope.

(a) (b) (c)

Figure 4.1: (a) polished specimen, (b) image of specimen surface, (c) surface finished under light microscope

4.2 Microhardness Profile Results

The Microhardness Testing is conducted by using Vickers hardness test method. Vickers hardness consist of indenting the surface of the material by using the diamond or pyramid with square base indenter. The indenter will produce 136º angle between opposite faces. The test load is range from 0.5 to 2 kgf. The hardness profile in the Vickers hardness test can be calculated by using the following equation:

$$HV = \frac{2F\sin\frac{136^{\circ}}{2}}{d^2}$$

$$HV = 1.854\frac{F}{d^2}$$

Where: F = Load in kgf
d = arithmetic mean of two diagonals, d_1 and d_2 (µm)

The Microhardness Testing has been conducted onto the specimen with thickness 1.4 mm, 1.2 mm, 1.0 mm and 2.0 mm. As mentioned, the springback effect happened after a bending was applied to the material. Therefore, the hardness profile or Hv profile is used to predict the critical point of springback from the curve region to the flat region. During conducting the test, the indentation force used is 0.5 kgf (4.905N). The test force loading speed is set to 15s. Other test load condition that was set during the testing are as follows:

Test force duration time: Loading = 5s
Duration = 10s
Unloading = 5s

Test force calculation: $0.5kgf \times 9.81 = 4.905\ N$

4.2.1 Results of Microhardness Testing for specimen thickness 1.0 mm

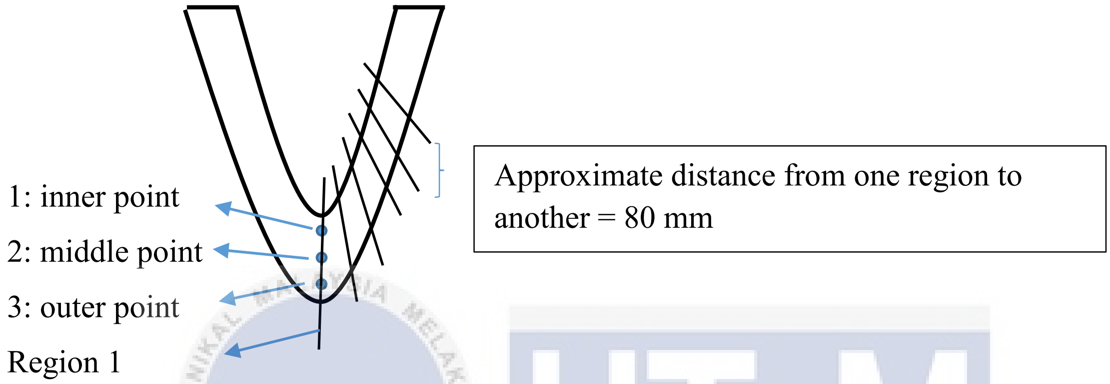


Figure 4.2 Rough sketch of the U-bend specimen

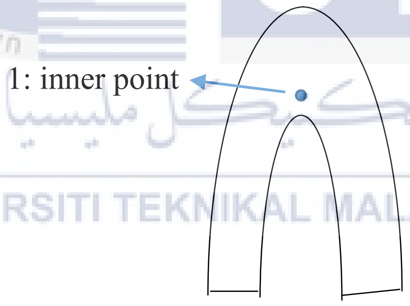


Figure 4.3: Location point in specimen thickness 1.0 mm

Based on table 4.1, the data tabulated are collected by conducting a hardness test on inner side of the specimen with thickness 1.0 mm. Next, all results collected are presented in a graph. The graph shown as in figure 4.4 illustrate the Hv profile against inner region 1 to inner region 8. Based on figure 4.4, region 4 recorded with the highest hardness value which is 383.8 kg/mm^2. Next, there is sharp fluctuation value occur at region 4 to region 5 and the hardness value remains constant until region 6. Based on assumption, the constant value of hardness test indicates the point where the springback effect occur. Therefore, region 4 to region 6 are selected to be the point where the springback effect start to occur in the specimen 1.0 mm.

Table 4.1: Inner point data for specimen 1.0 mm

Region	**X(mm)**	**Y(mm)**	**d_1(μm)**	**d_2(μm)**	**HV(kg/mm^2)**	**HV(kg/mm^2)**
1	0.000	0.000	55.7	50.1	331.3	331.3
2	0.000	0.000	51.7	50.2	357.2	357.2
3	0.000	0.000	50.2	49.4	373.9	373.9
4	0.000	0.000	46.2	52.1	383.8	383.8
5	0.000	0.000	52.1	52.7	337.7	337.7
6	0.000	0.000	51.9	53.0	337.0	337.0
7	0.000	0.000	49.9	52.4	354.4	354.4
8	0.000	0.000	50.3	52.1	353.7	353.7

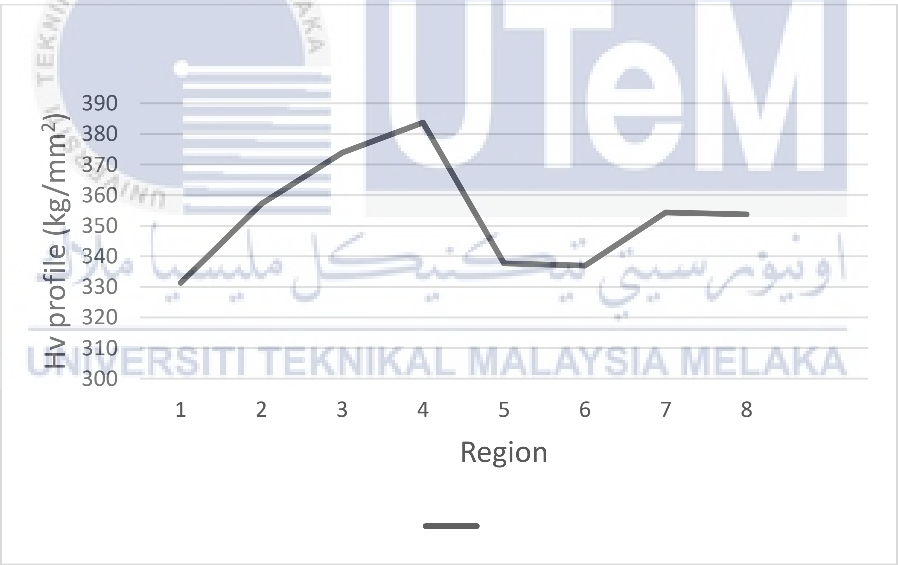


Figure 4.4: Graph for inner regions for thickness 1.0 mm

Based on table 4.2, the data tabulated are collected after conducting a hardness test on middle side of a specimen with thickness 1.0 mm for the middle points. Next, all results collected are presented in a graph. The graph shown as in figure 4.6 illustrate the Hv profile against the middle region 1 to middle region 8. Based on figure 4.6, region 4 recorded with the highest hardness value which is 366.5 kg/mm^2. The result shows for middle point regions does not varies sharply. The values start to constant at region 5 and region 6. Based on assumption, the constant value of hardness test indicates the point where the springback effect occur. Therefore, region 4 to region 6 are selected to be the point where the springback effect start to occur in the specimen 1.0 mm.

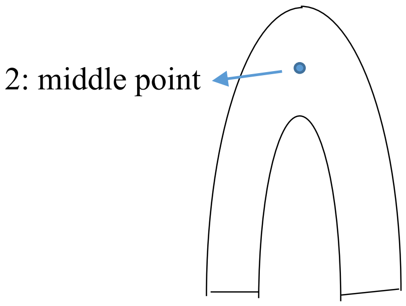


Figure 4.5: Location point in specimen thickness 1.0 mm

Table 4.2: Middle point data for specimen 1.0 mm

Region	**X(mm)**	**Y(mm)**	**d$_1$(µm)**	**d$_2$(µm)**	**HV(kg/mm^2)**	**HV(kg/mm^2)**
1	0.000	0.000	54.1	56.2	304.8	304.8
2	0.000	0.000	51.7	52.3	342.9	342.9
3	0.000	0.000	53.5	53.9	321.5	321.5
4	0.000	0.000	50.2	50.4	366.5	366.5
5	0.000	0.000	49.9	52.1	356.5	356.5
6	0.000	0.000	50.8	51.3	355.8	355.8
7	0.000	0.000	50.3	50.7	363.6	363.6
8	0.000	0.000	52.6	50.8	346.9	346.9

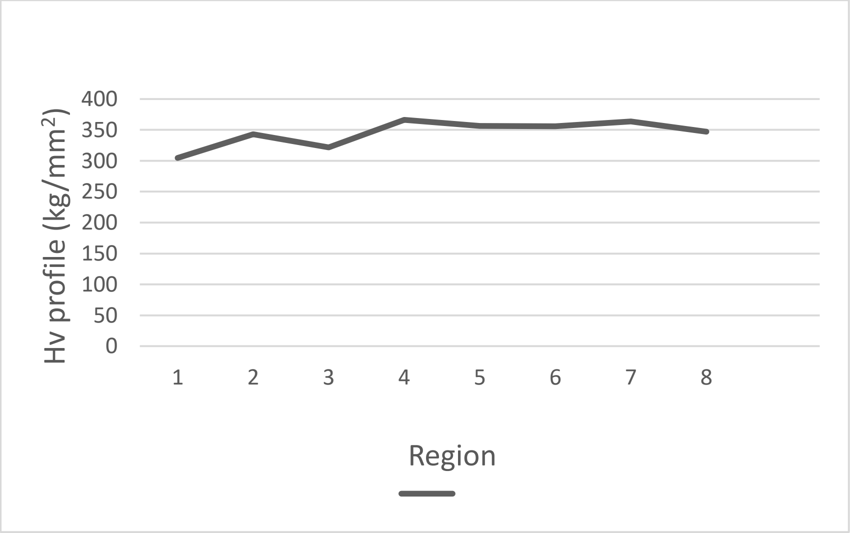


Figure 4.6: Graph for middle regions for specimen 1.0 mm

Based on table 4.3, the data tabulated are collected by conducting a hardness test on outer part of a specimen with thickness 1.0 mm for it outer regions. Next, all results collected are presented in a graph shown as in figure 4.8. The graph illustrates the Hv profile against outer region 1 to outer region 8. Based on figure 4.8, region 4 recorded with the highest hardness value which is 383.8 kg/mm^2. Next, there is sharp fluctuation value occur at region 4 to region 5 and the hardness value slightly remains constant until region 7. Based on assumption, the constant value of hardness test indicates the point where the springback effect occur. Therefore, region 4 to region 7 are selected to be the point where the springback effect start to occur in the specimen 1.0 mm.

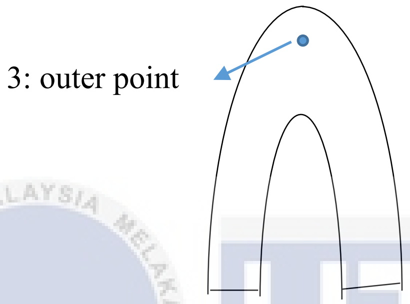


Figure 4.7: Location point in specimen thickness 1.0 mm

Table 4.3: Outer point data for specimen 1.0 mm

Region	**X(mm)**	**Y(mm)**	**d$_1$(µm)**	**d$_2$(µm)**	**HV(kg/mm^2)**	**HV(kg/mm^2)**
1	0.000	0.000	50.3	50.5	365.0	365.0
2	0.000	0.000	50.9	48.9	372.4	372.4
3	0.000	0.000	49.4	50.8	369.4	369.4
4	0.000	0.000	49.6	48.7	383.8	383.8
5	0.000	0.000	51.5	53.7	335.1	335.1
6	0.000	0.000	52.7	52.0	338.3	338.3
7	0.000	0.000	50.1	54.5	339.0	339.0
8	0.000	0.000	50.7	52.4	348.9	348.9

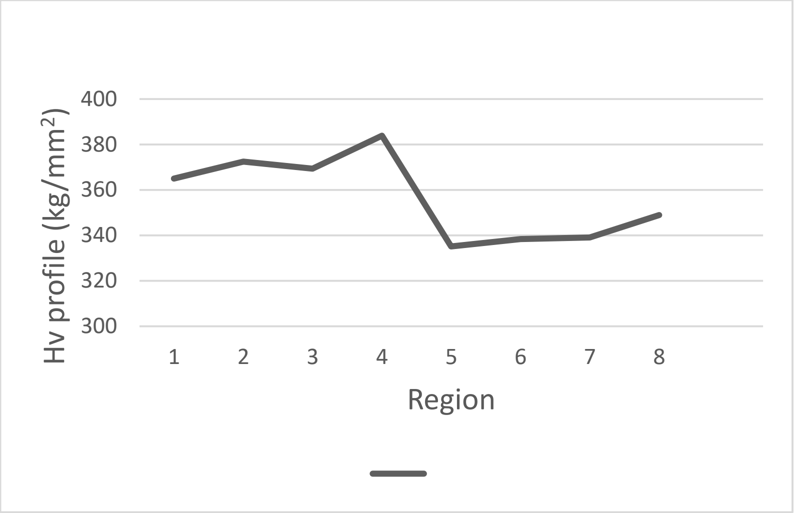


Figure 4.8: Graph for outer regions for specimen 1.0 mm

4.2.2 Results of Microhardness Testing for specimen thickness 1.2 mm

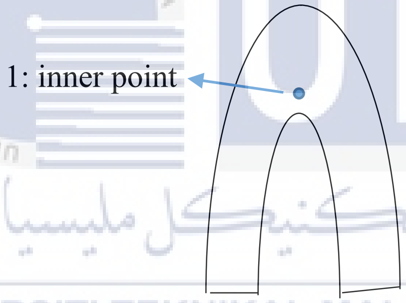


Figure 4.9: Location point in specimen thickness 1.2 mm

Based on table 4.4, the result are tabulated after conducting a hardness test on inner regions of specimen with thickness 1.2 mm. Next, all results collected are presented in a graph shown as in figure 4.10. The graph illustrates the Hv profile against outer region 1 to outer region 8. Based on figure 4.10, region 4 recorded with the highest hardness value which is 382.3 kg/mm^2. Next, there is sharp fluctuation value occur at region 4 and starting from region 5 until region 8, the hardness values are gradually increase. Based on assumption, the constant value of hardness test indicates the point where the springback effect occur. Therefore, region 5 to region 7 are selected to be the point where the springback effect start to occur in the specimen 1.2 mm.

Table 4.4: Inner point data for specimen 1.2 mm

Region	**X(mm)**	**Y(mm)**	**d_1(µm)**	**d_2(µm)**	**HV(kg/mm^2)**	**HV(kg/mm^2)**
1	0.000	0.000	54.5	49.1	345.5	345.5
2	0.000	0.000	51.6	51.9	346.2	346.2
3	0.000	0.000	51.9	52.6	339.6	339.6
4	0.000	0.000	49.1	49.4	382.3	382.3
5	0.000	0.000	53.2	53.8	323.9	323.9
6	0.000	0.000	51.6	55.2	325.2	325.2
7	0.000	0.000	51.5	54.6	329.5	329.5
8	0.000	0.000	52.3	52.5	337.7	337.7

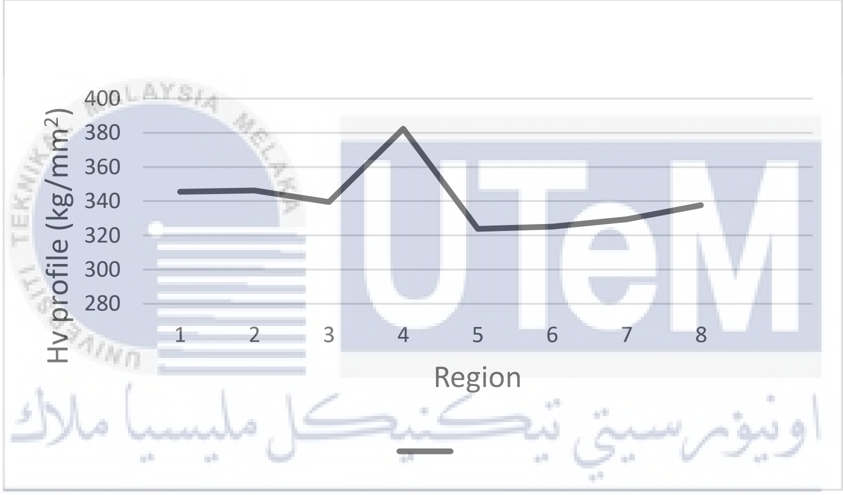


Figure 4.10: graph for inner regions for specimen 1.2 mm

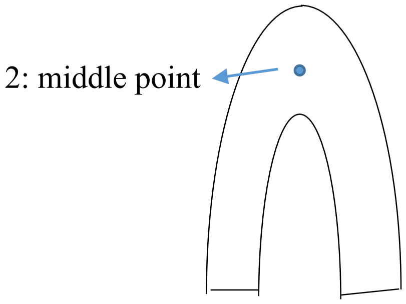


Figure 4.11: Location point in specimen thickness 1.2 mm

Based on table 4.5, the result are tabulated after conducting a hardness test on middle regions of specimen with thickness 1.2 mm. Next, all results collected are presented in a graph shown as in figure 4.12. The graph illustrates the Hv profile against outer region 1 to outer region 8. Based on figure 4.12, region 8 recorded with the highest hardness value which is 343.6 kg/mm^2. Based on assumption, the constant value of hardness test indicates the point where the springback effect occur but in this case, we assume at region 3 to region 5, the springback effect start to occur in the specimen 1.2 mm. This is because the hardness value at these regions does not varies rapidly which is 328.8 kg/mm^2, 332.6 kg/mm^2, 320.9 kgfmm^2 respectively.

Table 4.5: Middle point data for specimen 1.2 mm

Region	**X(mm)**	**Y(mm)**	**d_1(µm)**	**d_2(µm)**	**HV(kg/mm^2)**	**HV(kg/mm^2)**
1	0.000	0.000	56.6	55.5	295.1	295.1
2	0.000	0.000	54.8	52.6	321.5	321.5
3	0.000	0.000	52.5	53.7	328.8	328.8
4	0.000	0.000	52.2	53.4	332.6	332.6
5	0.000	0.000	52.3	55.2	320.9	320.9
6	0.000	0.000	55.8	53.3	311.6	311.6
7	0.000	0.000	51.7	58.0	308.2	308.2
8	0.000	0.000	52.2	51.7	343.6	343.6

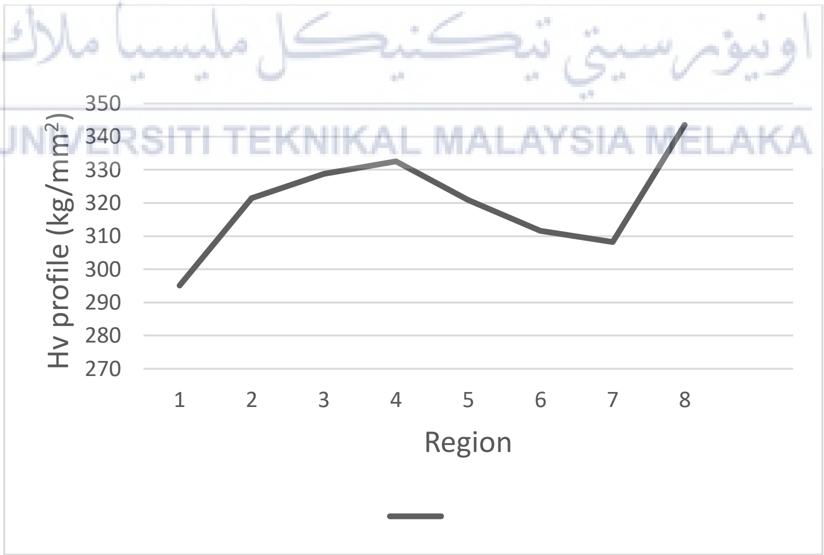


Figure 4.12: graph for middle regions for specimen 1.2 mm

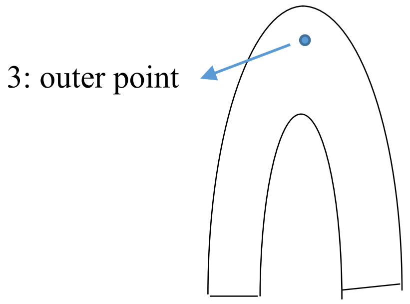


Figure 4.13: Location point in specimen thickness 1.2 mm

Based on table 4.6, the result are tabulated after conducting a hardness test on outer regions of specimen with thickness 1.2 mm. Next, all results collected are presented in a graph shown as in figure 4.14. The graph illustrates the Hv profile against outer region 1 to outer region 8. Based on figure 4.14, region 5 recorded with the lowest hardness value which is 322.7 kg/mm^2. Based on assumption, the constant value of hardness test indicates the point where the springback effect occur but in this case, we assume at region 5 to region 6, the springback effect start to occur in the specimen 1.2 mm. This is because the hardness value at these regions does not varies rapidly; 322.7 kg/mm^2 and 327.6 kg/mm^2 respectively.

Table 4.6: Outer point data for specimen 1.2 mm

Region	**X(mm)**	**Y(mm)**	**d$_1$(µm)**	**d$_2$(µm)**	**HV(kg/mm^2)**	**HV(kg/mm^2)**
1	0.000	0.000	50.1	51.3	360.7	360.7
2	0.000	0.000	50.9	52.3	348.2	348.2
3	0.000	0.000	49.5	50.9	367.9	367.9
4	0.000	0.000	51.0	53.4	340.3	340.3
5	0.000	0.000	53.3	53.9	322.7	322.7
6	0.000	0.000	53.5	52.9	327.6	327.6
7	0.000	0.000	52.1	52.0	342.2	342.2
8	0.000	0.000	52.4	52.3	338.3	338.3

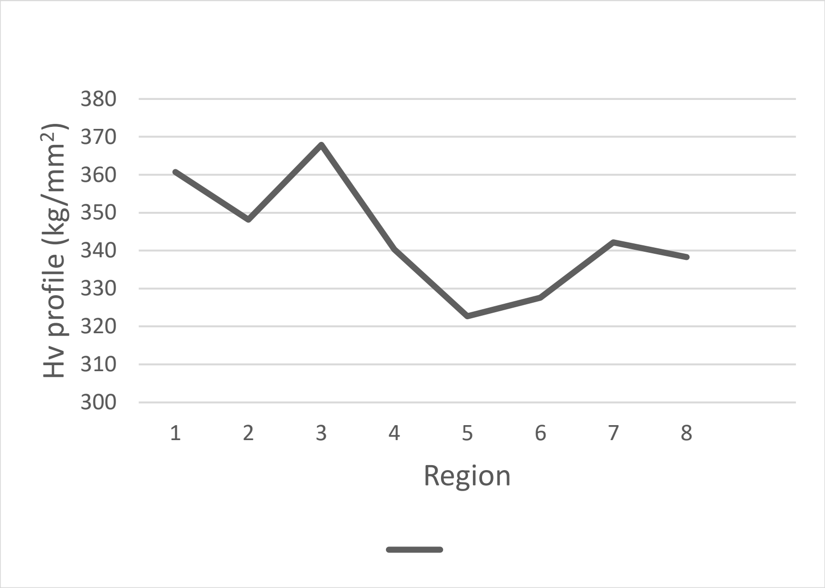


Figure 4.14: graph of outer regions for specimen 1.2 mm

4.2.3 Results of Microhardness Testing for specimen thickness 1.4 mm

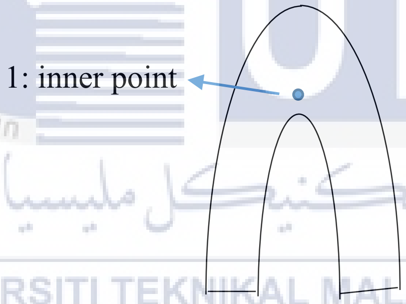


Figure 4.15: Location point in specimen thickness 1.4 mm

Based on table 4.7, the tabulated data was collected based on hardness test conducted at inner region for specimen 1.4 mm. After that, the data is presented in the graph as shown in figure 4.16. Based on graph, the region 4 and region 5 show a slight changes in values from 307.6 kg/mm^2 to 308.2 kg/mm^2 respectively. Therefore, we assumed that the springback effect occur in the stated region.

Table 4.7: Inner point data for specimen 1.4 mm

Region	**X(mm)**	**Y(mm)**	**d$_1$(µm)**	**d$_2$(µm)**	**HV(kg/mm^2)**	**HV(kg/mm^2)**
1	0.000	0.000	56.8	52.8	309.7	309.7
2	0.000	0.000	54.2	53.6	319.4	319.4
3	0.000	0.000	52.9	53.8	325.4	325.4
4	0.000	0.000	55.9	53.9	307.6	307.6
5	0.000	0.000	53.9	55.8	308.2	308.2
6	0.000	0.000	54.0	58.2	294.6	294.6
7	0.000	0.000	56.3	58.8	279.9	279.9
8	0.000	0.000	58.8	55.1	285.9	285.9
9	0.000	0.000	57.8	53.4	299.9	299.9

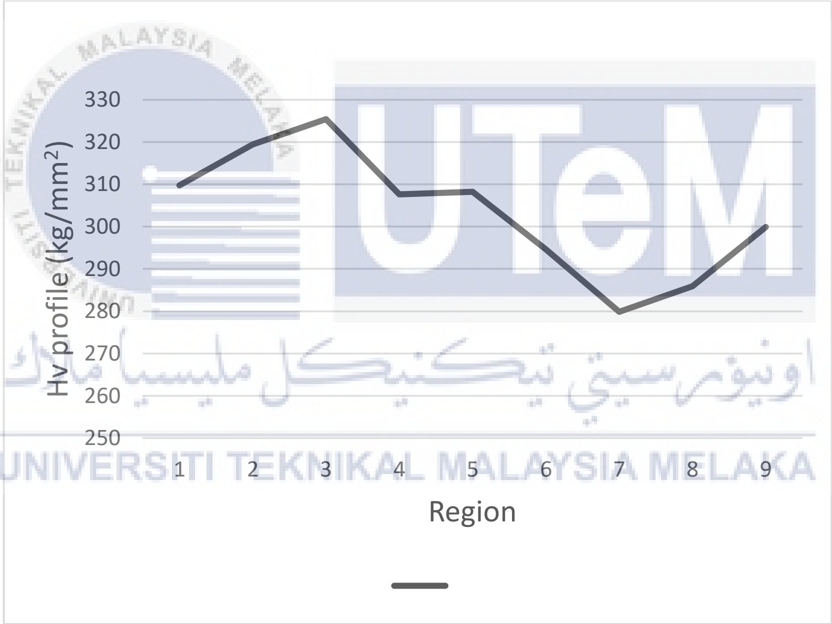


Figure 4.16: graph of inner regions for specimen 1.4 mm

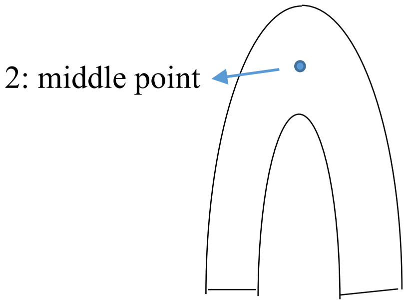


Figure 4.17: Location point in specimen thickness 1.4 mm

Based on table 4.8, the middle regions data are collected by conducting a hardness test. The data is presented in graph as shown figure 4.18. Based on figure 4.18, the graph shows an irregular pattern. As mentioned, a hardness test hardly give an accurate results and the middle regions are having combination distribution of compression and tension from inner regions and outer regions respectively. Therefore, the data collected are hardly accurate as required. The region 7 and region 8 show a slight changes in the hardness values which is 300.5 kg/mm^2, and 302.1 kg/mm^2 respectively after undergoes sharp fluctuation at region 6 with value 321.5 kg/mm^2. Therefore, an assumption has been made to the stated region as the starting point for springback effect to occur in the middle regions of specimen 1.4 mm.

Table 4.8: Middle point data for specimen 1.4 mm

Region	**X(mm)**	**Y(mm)**	**d_1(µm)**	**d_2(µm)**	**HV(kg/mm^2)**	**HV(kg/mm^2)**
1	0.000	0.000	56.7	58.5	279.5	279.5
2	0.000	0.000	56.0	56.1	295.4	295.4
3	0.000	0.000	54.7	54.7	303.2	303.2
4	0.000	0.000	58.5	57.9	273.7	273.7
5	0.000	0.000	58.3	54.2	293.0	293.0
6	0.000	0.000	53.5	53.9	321.5	321.5
7	0.000	0.000	53.8	57.3	300.5	300.5
8	0.000	0.000	55.2	55.6	302.1	302.1
9	0.000	0.000	55.5	56.1	297.8	297.8

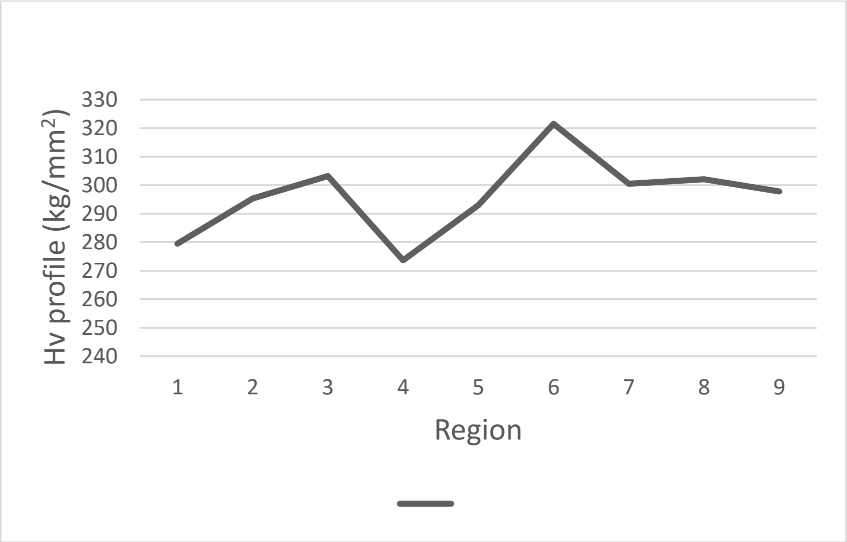


Figure 4.18: graph of middle regions for specimen 1.4 mm

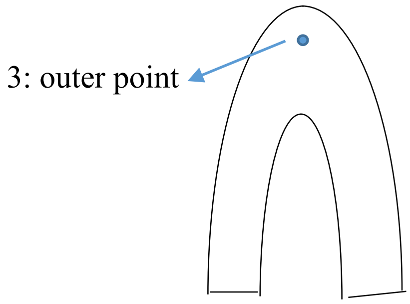


Figure 4.19: Location point in specimen thickness 1.4 mm

Based on table 4.9, the outer regions data are collected by conducting a hardness test. The data is presented in graph as shown figure 4.20. Based on figure 4.20, the graph shows an irregular pattern. As mentioned, a hardness test hardly give an accurate results. Therefore, the data collected are hardly accurate as required. The region 2 until region 4 show a slight changes in the hardness values which is 325.9 kg/mm^2, 325.0 kg/mm^2 and 323.9 kg/mm^2 respectively. Therefore, an assumption has been made to the stated region as the starting point for springback effect to occur in the outer regions of specimen 1.4 mm.

Table 4.9: Outer point data for specimen 1.4 mm

Region	**X(mm)**	**Y(mm)**	**d$_1$(µm)**	**d$_2$(µm)**	**HV(kg/mm^2)**	**HV(kg/mm^2)**
1	0.000	0.000	51.8	52.2	342.9	342.9
2	0.000	0.000	54.0	52.7	325.9	325.9
3	0.000	0.000	54.2	52.6	325.0	325.0
4	0.000	0.000	53.0	54.0	323.9	323.9
5	0.000	0.000	53.3	55.4	313.9	313.9
6	0.000	0.000	54.4	53.6	318.0	318.0
7	0.000	0.000	54.8	52.3	323.3	323.3
8	0.000	0.000	54.6	56.7	299.4	299.4
9	0.000	0.000	55.1	54.7	307.6	307.6

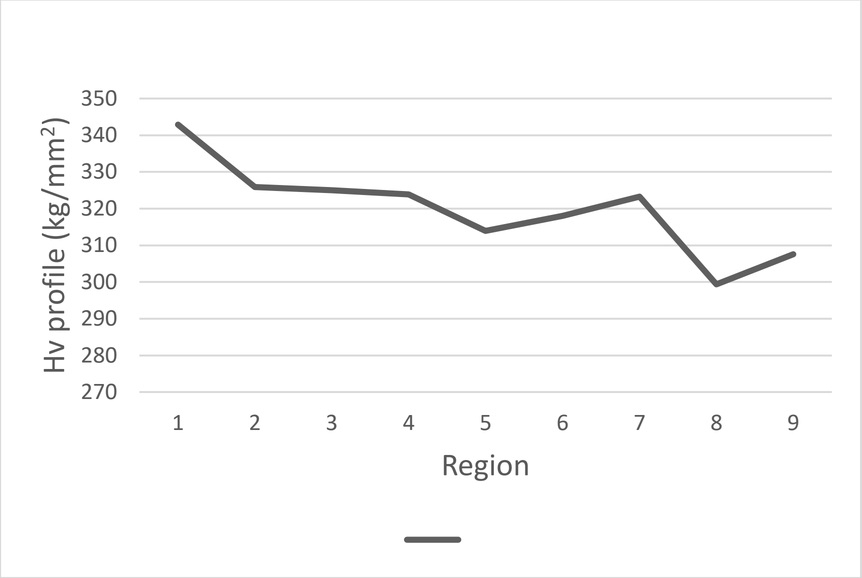


Figure 4.20: graph of outer regions for specimen 1.4 mm

4.2.4 Results of Microhardness Testing for specimen thickness 2.0 mm

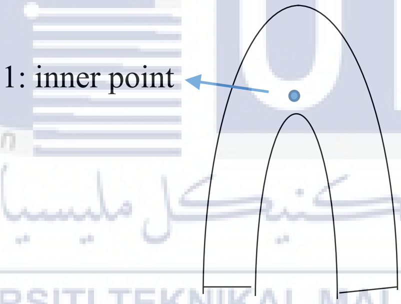


Figure 4.21: Location point in specimen thickness 2.0 mm

Based on table 4.10, the tabulated data was collected based on hardness test conducted at inner region for specimen 2.0 mm. After that, the data is presented in the graph form as shown in figure 4.22. Based on graph, the region 6 until region 8 show a constant reduction with values 156.0 kg/mm^2 , 154.0 kg/mm^2, 158.0 kg/mm^2 respectively. Therefore, we assumed that the springback effect occur in the stated region.

Table 4.10: Inner point data for specimen 2.0 mm

Region	**X(mm)**	**Y(mm)**	**d_1(µm)**	**d_2(µm)**	**HV(kg/mm^2)**	**HV(kg/mm^2)**
1	0.000	0.000	63.1	63.5	231.4	231.4
2	0.000	0.000	68.0	66.2	205.9	205.9
3	0.000	0.000	65.1	66.5	214.1	214.1
4	0.000	0.000	65.3	68.4	207.5	207.5
5	0.000	0.000	72.3	71.2	180.1	180.1
6	0.000	0.000	78.4	75.8	156.0	156.0
7	0.000	0.000	78.4	76.8	154.0	154.0
8	0.000	0.000	79.3	73.9	158.0	158.0

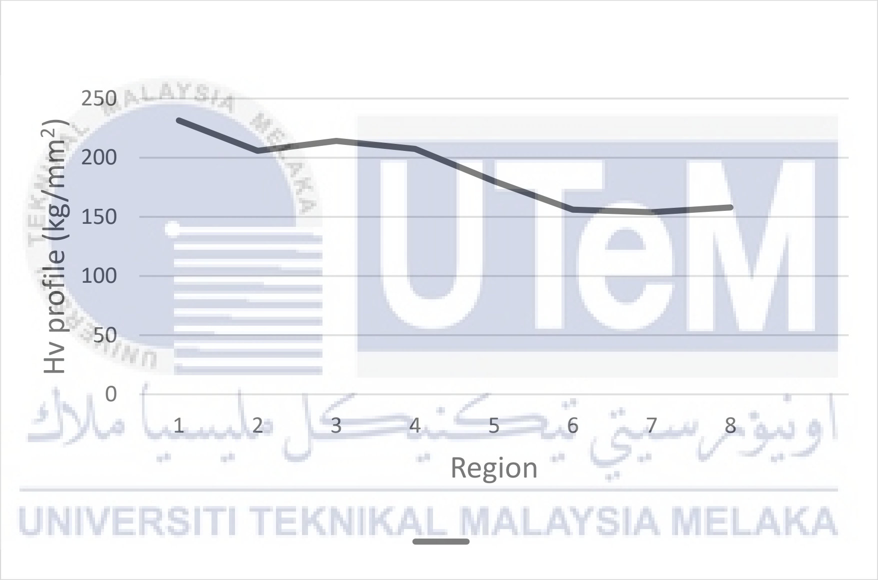


Figure 4.22: graph of inner regions for specimen 2.0 mm

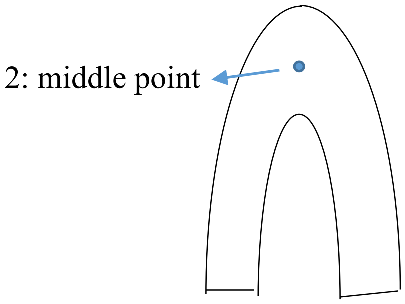


Figure 4.23: Location point in specimen thickness 2.0 mm

Based on table 4.11, the tabulated data is collected based on hardness test conducted at middle regions of the specimen 2.0 mm. next, the data is presented in figure 4.24. based on figure 4.24, the graph shows irregular pattern. This is because the middle regions are having combination of compression and tension behaviour between inner region and outer region respectively. The highest hardness value is located at region 4 which is 179.4 kg/mm^2. The region 5 and region 6 show a constant hardness value. Therefore, we assumed the stated regions as springback effect start to occur with 150.1 kg/mm^2 and 150.5 kg/mm^2 respectively.

Table 4.11: Middle point data for thickness 2.0 mm

Region	**X(mm)**	**Y(mm)**	**d_1(µm)**	**d_2(µm)**	**HV(kg/mm^2)**	**HV(kg/mm^2)**
1	0.000	0.000	72.4	78.3	163.3	163.3
2	0.000	0.000	75.5	75.7	162.2	162.2
3	0.000	0.000	72.8	77.5	164.2	164.2
4	0.000	0.000	71.2	72.6	179.4	179.4
5	0.000	0.000	77.9	79.3	150.1	150.1
6	0.000	0.000	80.1	76.9	150.5	150.5
7	0.000	0.000	76.0	77.3	157.8	157.8
8	0.000	0.000	79.3	77.2	151.4	151.4

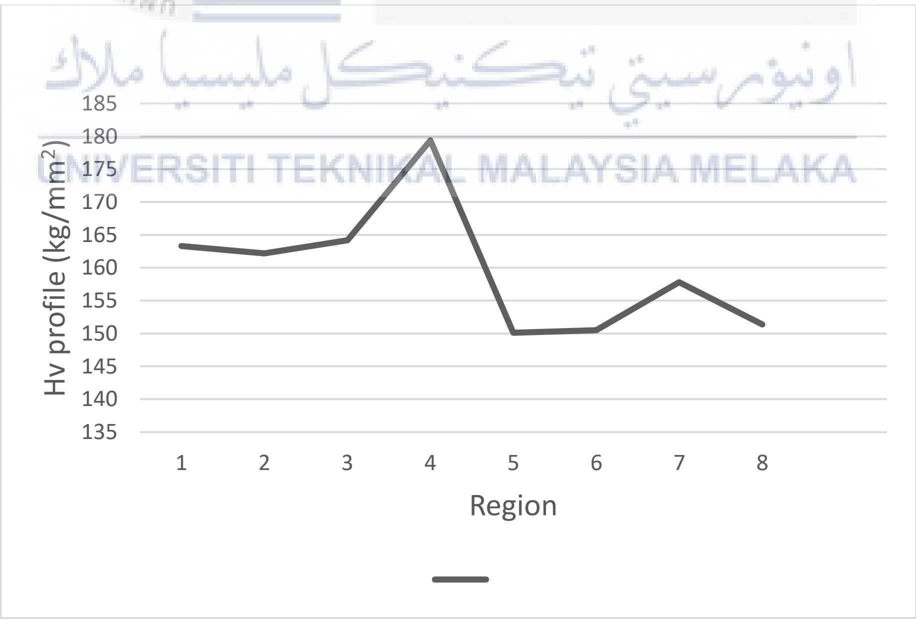


Figure 4.24: graph of middle regions for specimen 2.0 mm

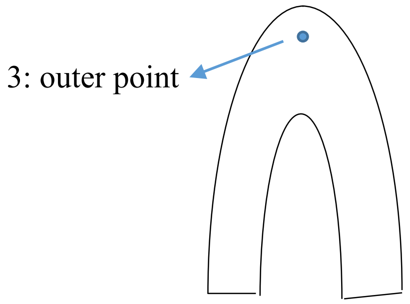


Figure 4.25: Location point in specimen thickness 2.0 mm

Based on table 4.12, the tabulated data was collected based on hardness test conducted at outer region for specimen 2.0 mm. After that, the data is presented in the graph form as shown in figure 4.26. Based on graph, the value shows a gradual reduction from region 1 to region 8. At region 3, the value start to fluctuate sharply until region 5. Region 5 until region 7 show a constant reduction with values 172.3 kg/mm^2 , 170.0 kg/mm^2, 164.8 kg/mm^2 respectively. Therefore, we assumed that the springback effect occur in the stated region.

Table 4.12: Outer point data for thickness 2.0 mm

Region	**X(mm)**	**Y(mm)**	**d$_1$(µm)**	**d$_2$(µm)**	**HV(kg/mm^2)**	**HV(kg/mm^2)**
1	0.000	0.000	59.8	63.2	245.1	245.1
2	0.000	0.000	60.8	63.1	241.6	241.6
3	0.000	0.000	62.8	62.1	237.7	237.7
4	0.000	0.000	66.9	66.3	209.0	209.0
5	0.000	0.000	73.1	73.6	172.3	172.3
6	0.000	0.000	71.8	75.9	170.0	170.0
7	0.000	0.000	75.8	74.2	164.8	164.8
8	0.000	0.000	80.4	79.2	145.6	145.6

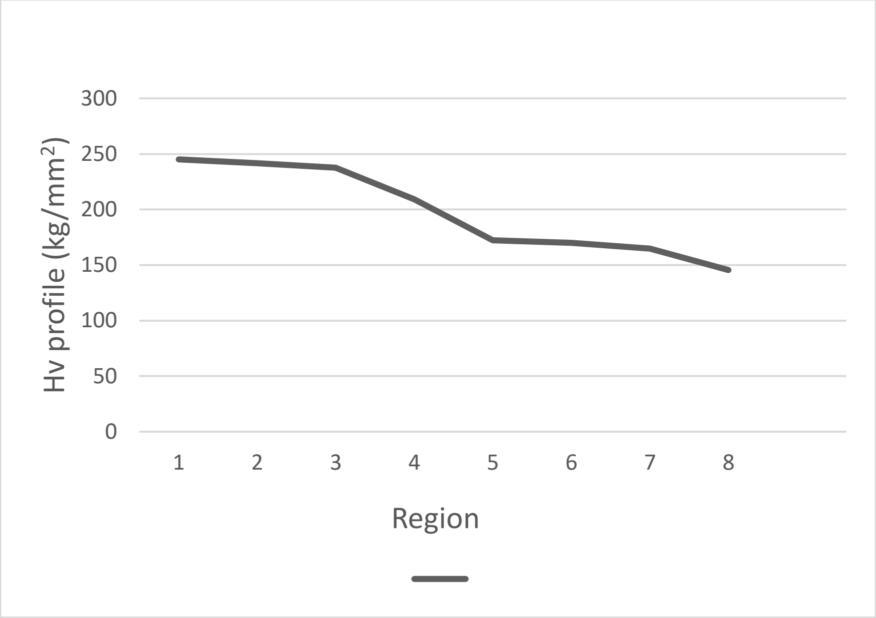


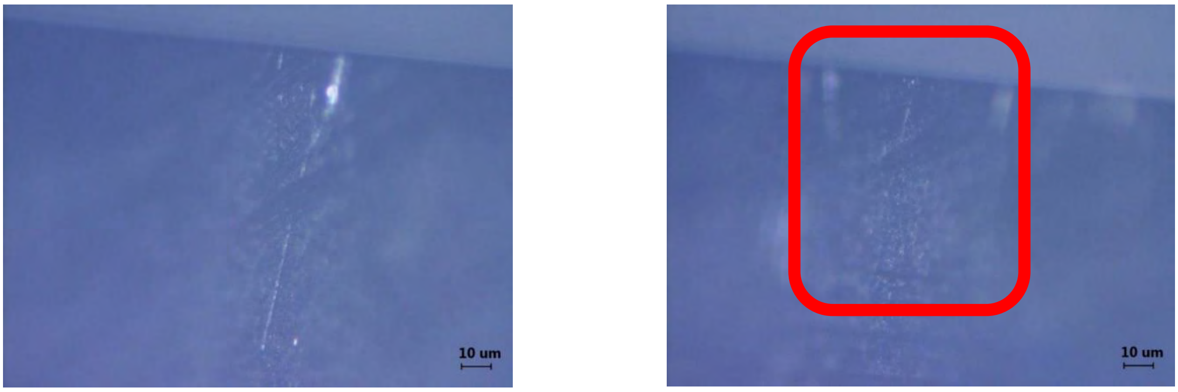
Figure 4.26: graph of outer regions for specimen 2.0 mm

4.3 Surface Morphology Analysis Results

4.3.1 Specimen thickness 1.0 mm

Figure 4.27: Indentation marks from region 1 to 8 in specimen 1.0mm

Figure 4.27 shows all the indentation marks of microhardness test onto the surface of the specimen. Next, figure 4.28 shows the internal cracks obtained in specimen 1.0 mm. The internal cracks obtained by using Microscopy Image Analyzer at 10um scale. From the observation, the crack lines in specimen 1.0 mm are thin and fine. The crack occur after the specimen undergoes bending process to form a U-bend material.



(a) (b)

(c)

Figure 4.28: (a), (b), (c) Crack lines in specimen 1.0 mm

4.3.2 Specimen thickness 1.2 mm

Figure 4.29: Indentation marks from region 1 to 8 in specimen 1.2 mm

Figure 4.29 shows all the indentation marks of microhardness test onto the surface of the specimen. Next, figure 4.30 shows the internal cracks obtained in specimen 1.2 mm. The internal cracks obtained by using Microscopy Image Analyzer at 10um scale. In specimen with thickness 1.2 mm, the crack lines obtained are much harder to locate. This is because the crack lines are too thin and small. Therefore, the visuals are blurry and much attentions are needed to see the crack lines.

(a) (b)

(c)

Figure 4.30: (a), (b), (c) Internal cracks for specimen 1.2 mm

4.3.3 Specimen thickness 1.4 mm

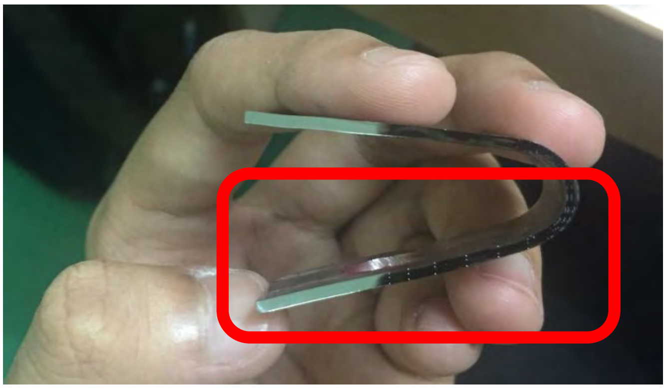
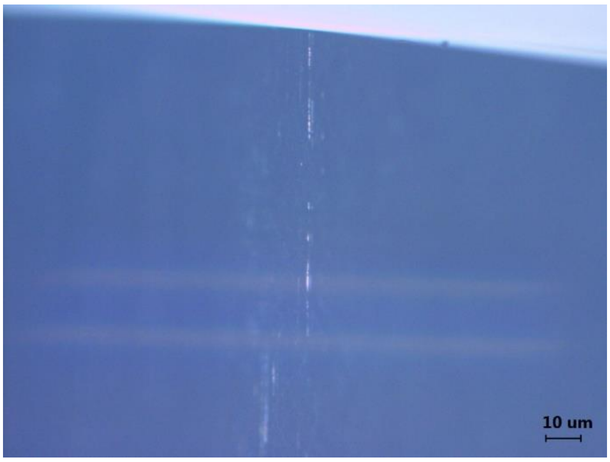


Figure 4.31: Indentation marks from region 1 to 9 in specimen 1.4 mm

Figure 4.31 shows all the indentation marks of microhardness test onto the surface of the specimen with thickness 1.4mm. Next, figure 4.32 shows the internal cracks obtained in specimen 1.4 mm. The internal cracks obtained by using Microscopy Image Analyzer at 10um scale are very fine line. The crack lines are also short. Therefore, it is hard to capture much clearer visual of the crack lines.

(a) (b)



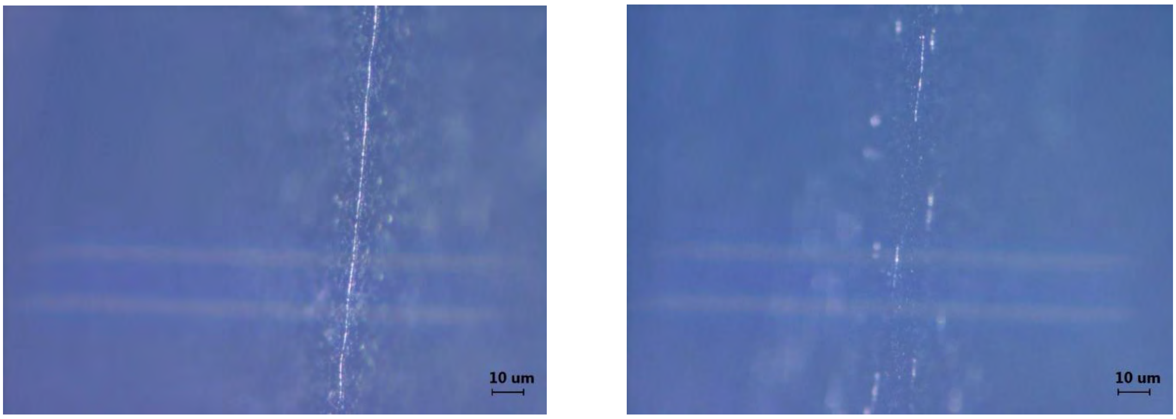
(c)

Figure 4.32: (a), (b), (c) Internal cracks in specimen 1.4 mm

4.3.4 Specimen thickness 2.0 mm

Figure 4.33: Indentation marks from region 1 to 8 in specimen 2.0 mm

Figure 4.33 shows all the indentation marks of microhardness test onto the surface of the specimen. Next, figure 4.34 shows the internal cracks obtained in specimen 2.0 mm. The internal cracks obtained by using Microscopy Image Analyzer at 10um scale are very fine line and requires extra attention in determined the location of the cracks. In this case, the crack line obtained is more visible and can be seen much clearer.



(a) (b)

Figure 4.34: (a), (b) Internal cracks in specimen 2.0 mm

CHAPTER 5

DISCUSSION

5.1 Discussion for Microhardness Profile

Based on the result collected from hardness test that was conducted to all specimen, the observation has been made on every specimen accordingly. All four specimens have been undergo hardness test at three points; inner points of U-shape area until flat area, middle points of U-shape area until it reach flat area and outer points of U-shape area until it reach flat area. All areas or regions are mark as region 1 until region 8 or region 9.

The hardness test's results for inner points shows a lower results than the outer point's results. The results obtained for outer points indicate the highest value among three indentation marks on every region made on the surface of all four specimens.

The results for inner regions are lower than the results outer regions because at the inner regions, the regions along the U-bend are having compression behaviour. The outer regions show the highest value among the other points because outer regions along the U-bend are having the tension load behaviour. While the middle regions show an inconsistent results because it having a combination behaviour between compression and tension behaviours.

Figure 5.1 below shows the comparison value of an average hardness profile between four specimens. Based on the graph, region (1) is known as maximum bending region for all specimens. This is because the value is taken at the U-shape location. The microhardness profile for sample 1.0 mm is highest compared to sample with thickness 2.0 mm. This shows that sample thickness 1.0 mm is having a 50 % thickness reduction than sample 2.0 mm and it has a strain hardened. In addition, the sample thickness 2.0 mm has the lowest hardness profile. It is because the specimen does not have strain hardened. Therefore, the strength of this sample is also lower compared to sample with 50% thickness reduction.

Microhardness profile at region (4) is predicted to be the maximum hardness profile. Thus, the springback is greater at this region. The transition changes from region (4) to region (5) show drastic reduction in the hardness profile. After region (5), the springback effect start to be constant. It is assume as the threshold/yield point as the springback effect start to decrease.

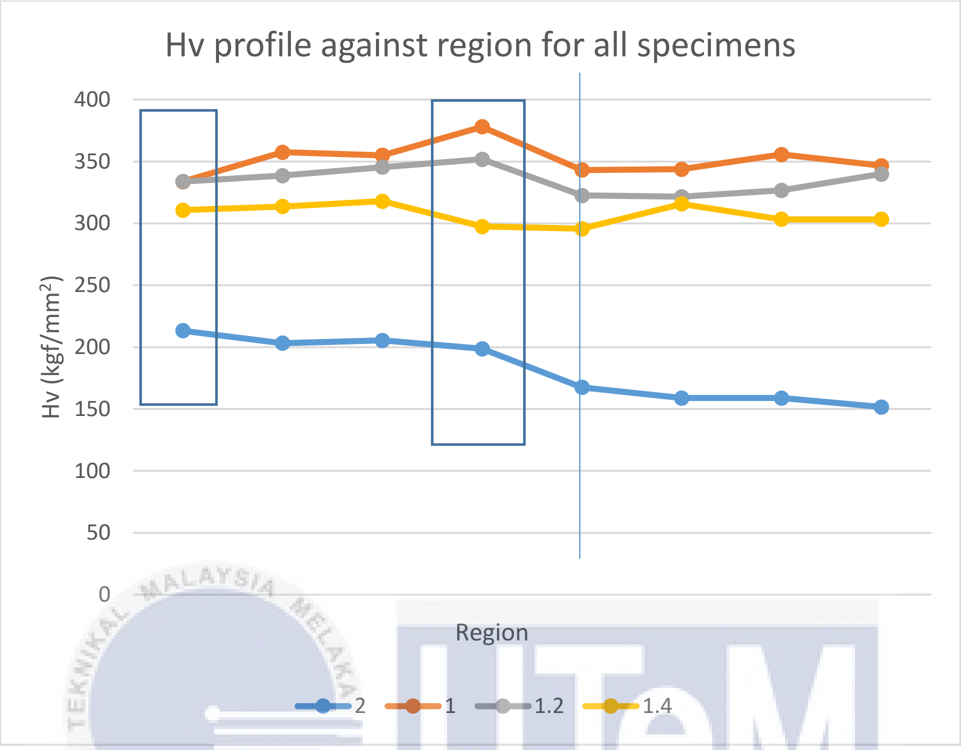


Figure 5.1: Comparison of an average Hv Profile between four specimens

Figure 5.2 shows the detailed comparison of hardness profile on region (4) between four specimens. Besides that, figure 5.3 also provided as detailed comparison of hardness profile on maximum bending region (1) between four specimens.

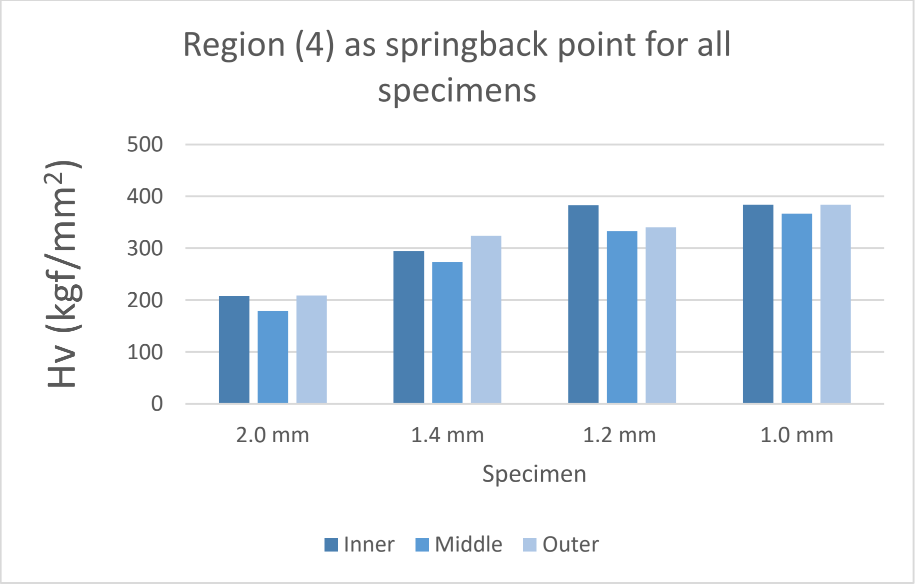


Figure 5.2: Comparison of hardness profile on region (4) between four specimens

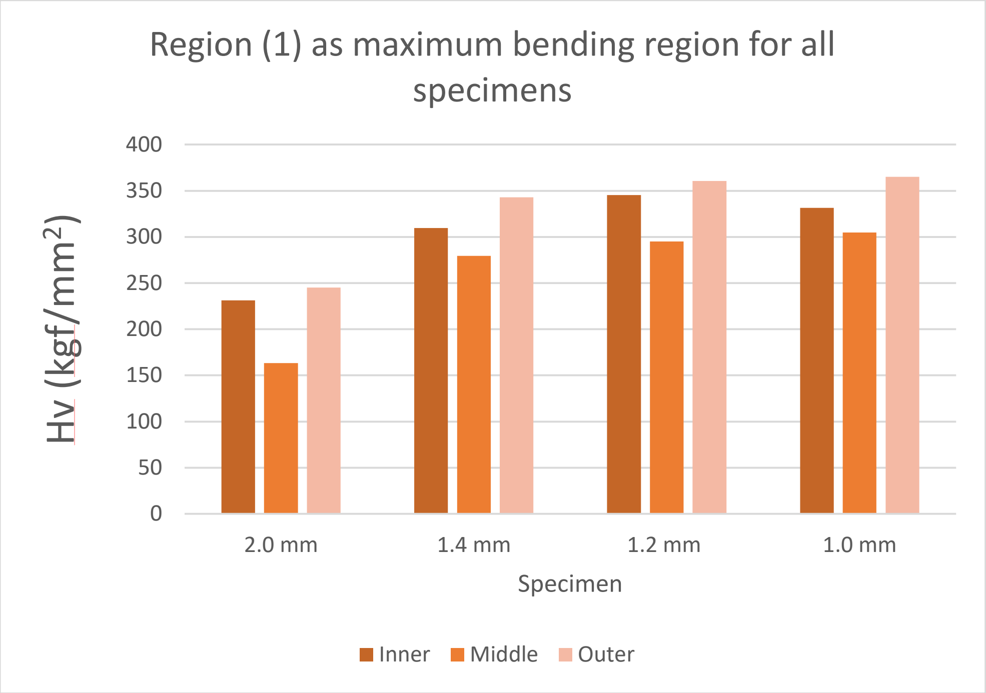


Figure 5.3: Comparison of hardness profile on region (1) between four specimens

A steel ruler can be bended elastically. Elastic means that a steel ruler will undergoes springback when released. The elastic stiffness of the steel ruler resist itself from bending. Though the thickness of the steel ruler is thin, it is still intrinsically stiff with it high value of elastic module, E. This idea has been applied to the test specimens in this project where the test specimen is in the form of sheet metal with variation thickness; 1.0 mm, 1.2 mm, 1.4 mm and 2.0 mm. A strong steel will hardly give a permanent bend. This is because permanent deformation related with the strength of the materials, not the stiffness. Therefore, from the observation, the test specimen in this project show the bending angle produced in different thickness of the material.(Ashby, Shercliff and Cebon, 2014)

The hardness test does not requires a large sample or specimen and the test will not destroy the sample entirely. Hardness test can be used to avoid large destruction onto the sample, although it has problems of its own.

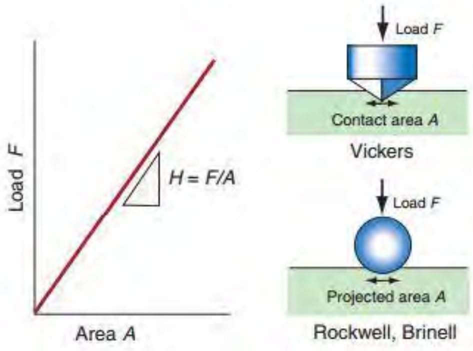


Figure 5.4: The Vickers Hardness Test using diamond indenter, Rockwell and Brinell test using steel ball indenter

(Source: Ashby, Shercliff and Cebon, 2014)

In hardness test, a pyramidal diamond is pressed into the surface of the sample as shown in figure 5.4. As the pyramidal diamond sinks into the surface of the sample, it leaves a tiny permanent indentation, which the size of the indentation is measured with a build-in microscope. The indent scars indicate that plasticity has occurred. A measurement of the strength is the resistance to it. The load F is divided by the area A of the indent projected onto a plane perpendicular to the load:

$$H = \frac{F}{A}$$

The indented region is surrounded by non-deformed material. Thus, this limits it so that H is larger than the yield strength, σ_y. In practice, H is a strength measured in MPa and the strength is about $3\sigma_y$. A commonly used scale in Vickers, symbol H_v, uses units of kg/mm^2, with the result that

$$H_v \approx \frac{\sigma_y}{3}$$

Figure 5.5 shows different types of hardness test's scale. Each scale is compared with the yield strength value accordingly. In addition, the advantage of using hardness test is that the test is non-destructive. Therefore, the strength can be measured without destroying the sample as it only caused a very thin layer of indent mark on material. Moreover, hardness test only requires only a small volume of sample or specimen. Figure 5.6 will illustrate the 2-dimensional visual on how the indentation process works.

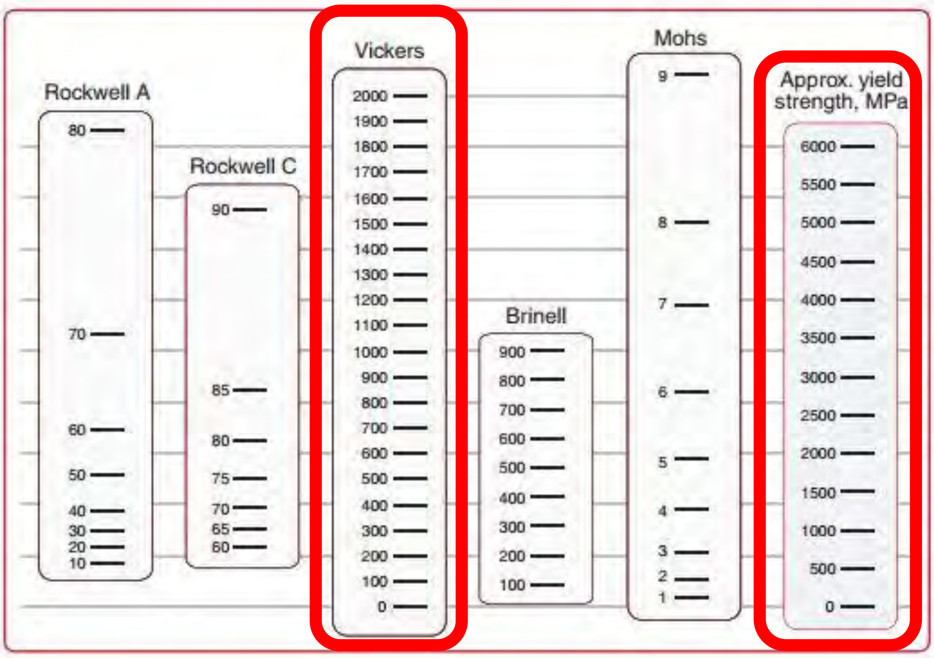


Figure 5.5: Hardness scales that are compared with yield strength

(Source: Ashby, Shercliff and Cebon, 2014)

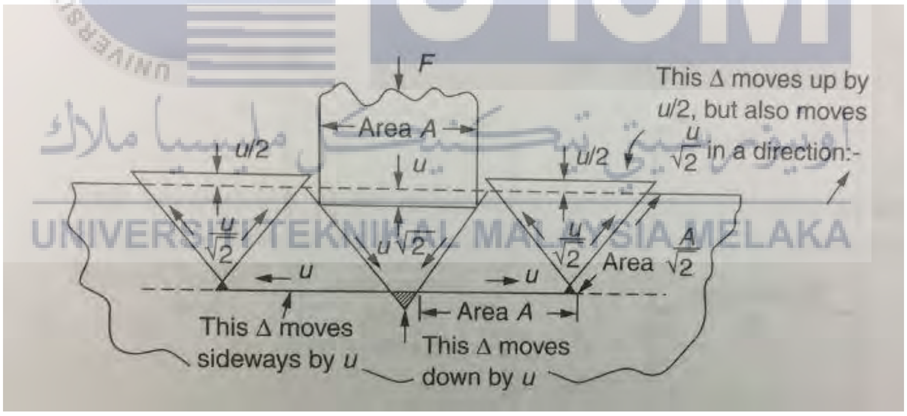


Figure 5.6: 2-dimensional visual indentation process

(Source: Ashby, & Jones, 2009)

Sample calculation to calculate HV profile for the first inner region for specimen thickness 1.0 mm is as follows:

$$H_v = \frac{F}{S} = \frac{2F\sin\frac{\theta}{2}}{d^2} = 1.854\frac{F}{d^2}$$

Where: *Hv = vickers microhardness (kg/mm^2)*

F= test load (kgf)

S=surface area of the indentation (*mm^2)*

d=average diagonal angle of indentation

$$\theta = angle\ of\ a\, pyramidal\ diamond\ indenter\ (degree)$$

$$Hv = 1.854\ \frac{0.5kgf}{[\frac{(0.0557+0.0501)mm}{2}]^2}$$

$$Hv = 331.3\ kg/mm^2$$

The disadvantage of using hardness test is that the information it provides is less accurate. It also provides less complete results than the tensile test. Therefore, hardness test is not suitable to provide a critical design data. (Ashby, Shercliff and Cebon, 2014).

Metals are relatively high in stiffness or well known as elastic modulus, E. Pure metals are soft and may deformed easily as it yield strength, σ_y is low. Metals become strong when it is being alloying by mechanical and heat treatment. When metals are alloyed, the yield strength increased, but it will remain ductile. Thus, the metals still able to undergo deformation processes. Besides that, deformation leads to irrecoverable strain and it relates to the test parameters in the hardness test.

First parameter that effect the hardness test result is thickness of the sample. The microhardness value will decrease when the thickness of the sample increase. This shows in the results based on specimen thickness 1.0 mm and 2.0 mm. The specimen with thickness 1.0 mm gives an average 300.0 kg/mm^2 hardness value regardless of inner point, middle point or outer point. The specimen with thickness 2.0 mm gives an average 150.0 kg/mm^2 hardness value regardless the inner point, middle point or outer point.

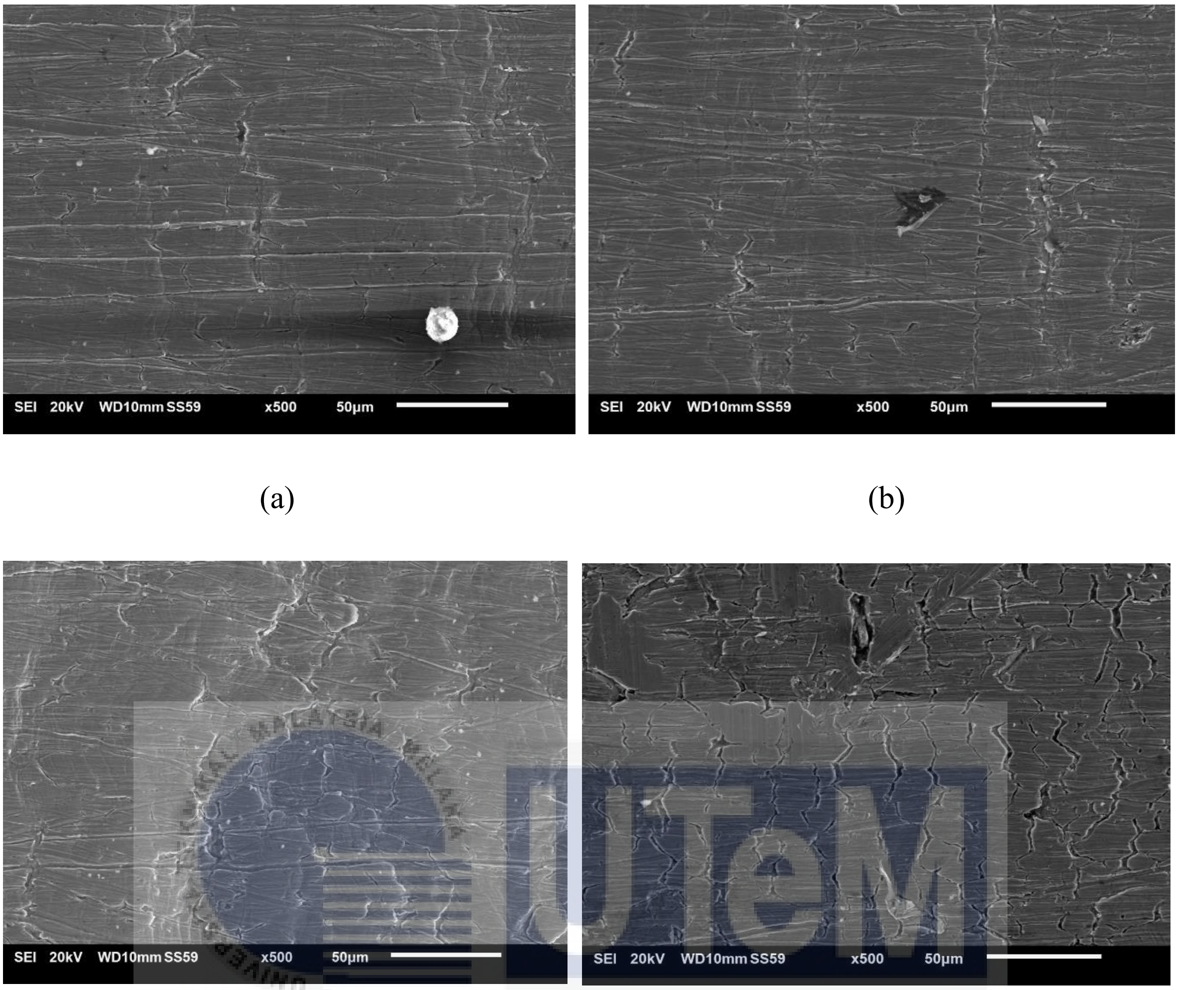
Next parameter is the shape and dimensions of the specimens. Microhardness test rely on the measurement of the volume of the specimens to ensure that the indenter is free of external stresses. Next, the surface of the specimens must be parallel to the base of the tester and must be well polished. In addition, all measurements of microhardness test must be sufficiently far apart on the material surface to ensure the plastically deformed zones around the indentation will not overlap with each other nor reaching the unsupported edge of the specimens.

5.2 Discussion of Surface Morphology Analysis

In this present project, we persue a different approach in observing the correlation between the deformation occur from microhardness test to the microscopic analysis by monitoring the evolution of the surface texture or morphology on to the surface profile of the materials. Initially, all specimens have undergo a few sample preparation processes which is grinding and polishing. Through these processes, the surface of the materials are sufficiently clean, smooth and free from any abrasive scratches.

By performing the surface morphology analysis on to the surface of the material, the evolution of a one-dimensional profile of the crack lines obtained through Microscopic Image Analyzer can be directly seen through the microscope lens at 10um scale. The crack lines produced in the material are caused by rolling and bending processes. Theoretically, the transverse crack line produced is perpendicular to the direction of the rolling process when observed from top surface of specimen. Nevertheless, the crack lines produced somewhat can be seen clearly or partially visible. This is because the crack lines produce are very thin and fine. Extra attention is needed to make sure the correct and clear visual can be easily obtain. Therefore, Scanning Electron Microscope (SEM) is conducted to archive much clearer image to observe the width crack lines produced in the specimen. Lastly, the evolution of the surface morphology or textures on the surface of the material can be related to the plastic distortion at the surface.

Based on figure 5.7, the analysis is conducted by using scanning electron microscope (SEM). From observation, the specimens are having a transverse crack which is perpendicular to rolling direction when observed from top surface. Specimen 2.0 mm contains bigger crack width compared to specimen 1.0 mm. The specimen 1.0 mm has almost fine crack width because the influence of strain hardened from rolling and cold working process. The grain structure in specimen 1.0 mm is embedded between one grain to another nearest grain caused a very thin width of cracks. This crack lines occur may be affected by the defects at the grain boundary.



(a) (b)

(c) (d)

Figure 5.7: Scanning Electron Microscopy (SEM) result (a) Specimen thickness 1.0 mm, (b) Specimen thickness 1.2 mm, (c) Specimen thickness 1.4 mm, (d) Specimen thickness 2.0 mm

CHAPTER 6

CONCLUSION & RECOMMENDATION

As a conclusion, the springback is difficult to be predicted. This is proved by many researchers in their journal articles and the results obtained from both test conducted to the specimens; Microhardness Test and Surface Morphology Analysis. The microhardness test results show the irregular values obtained after conducting a hardness test on all four specimen as shown in the tables and graphs provided for every specimens. As mentioned, the test hardly provide an accurate results and the springback effect is difficult to be predicted. Even though it hard to find an accurate location of springback, we are still able to predict the possible location of where the springback effect start to occur in all specimens.

The thinner the thickness of sheet metal, the higher the value of microhardness profile. This is influenced by strain hardening process applied to the materials. Next, region (4) is predicted to be the springback point as the Hv profile obtained show the highest value compared to other regions on all specimens. Significant changes between region (4) to (5) show the springback effect start to dissipate as the value remain constant.

In surface morphology analysis, the final finding obtained is the transverse crack lines occur in the specimens. The crack produced on the surface of specimens are parallel to bending direction.

In recommendation, I would recommend to the next researcher to further this thesis by focusses on the chosen region (4) to region (5) regarding the springback effect through microstructural evolution to study the behavior of the crystal structure of the material. Through the surface morphology analysis, the cracks in each specimen are obtained as shown in the images provided. The crack lines shown in each specimen mostly very fine but each specimen contain different crack width. Thus, it is recommended to further study the inner crack lines produced in the materials for the surface morphology analysis. The inner cracks should be observe from front view surface. Based on the results obtained from both tests, the objectives of this project are achieve accordingly.

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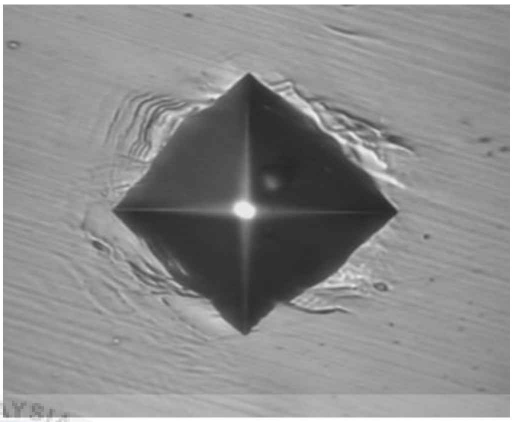
APPENDICES

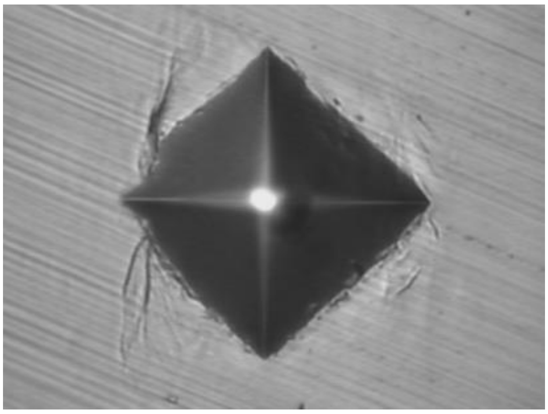
Microhardness indented marks on specimen with thickness 1.0 mm

- Inner indentation mark



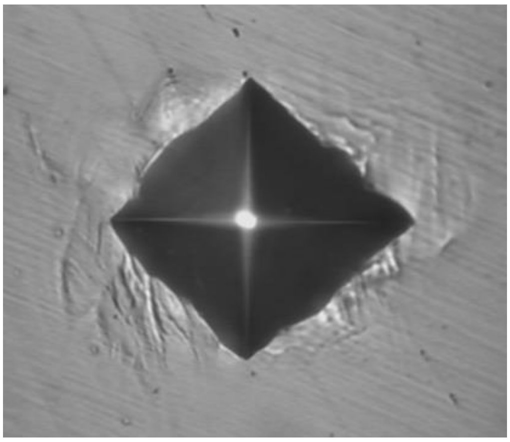
- Middle indentation mark

- Outer indentation mark

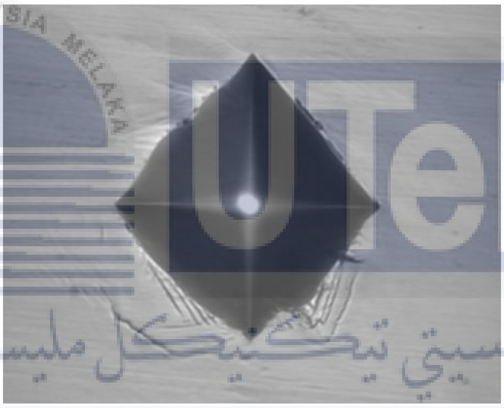


Microhardness indented marks on specimen with thickness 1.2 mm

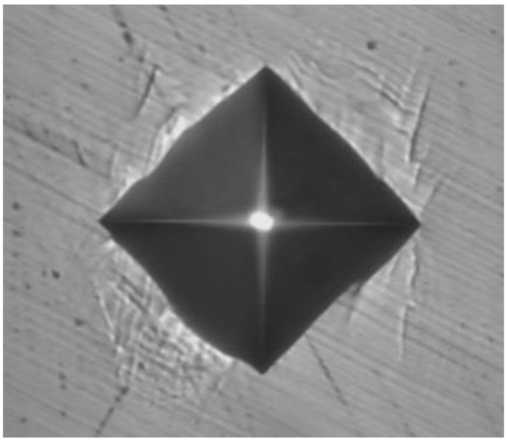
- Inner indentation mark



- Middle indentation mark

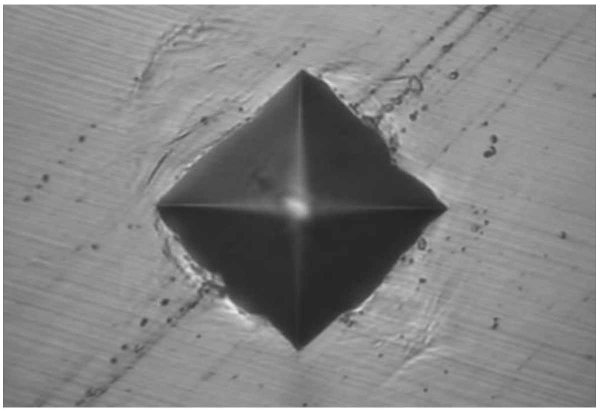


- Outer indentation mark



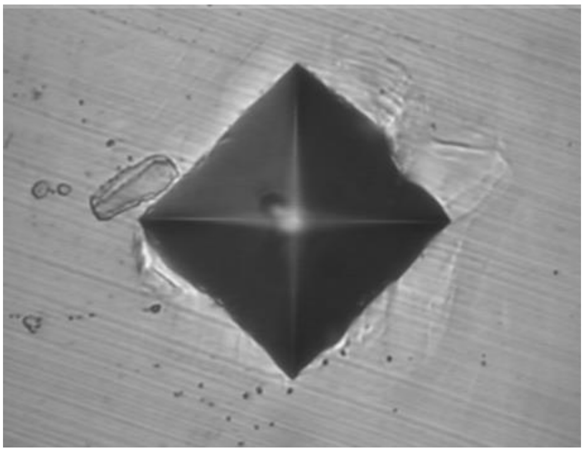
Microhardness indented marks on specimen with thickness 1.4 mm

- Inner indentation mark



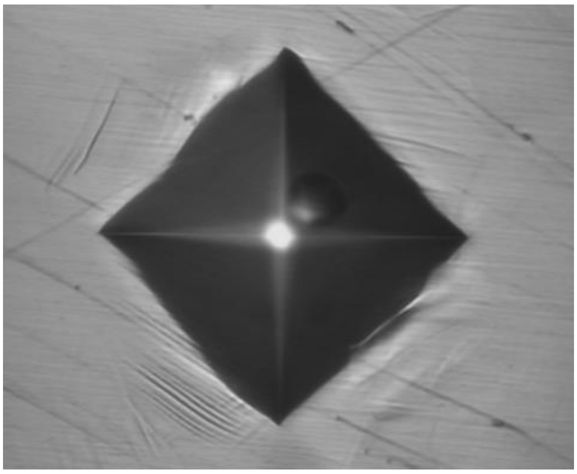
- Middle indentation mark

- Outer indentation mark



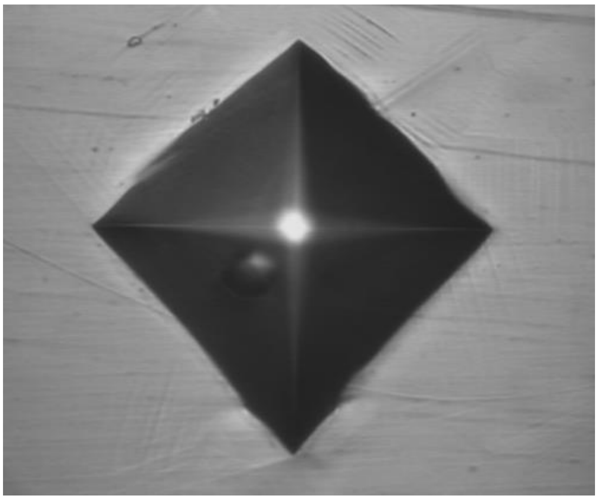
Microhardness indented marks on specimen with thickness 2.0 mm

- Inner indentation mark



- Middle indentation mark

- Outer indentation mark



Gantt Chart for Final Year Project I (FYP 1), semester 7, 2016

No.	Tasks	Weeks													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Search for related journals	■	■	■	■	■	■	■	■						
2	Literature Review 2.1 Read and Review				■	■	■	■	■						
3	Progress Report 3.1 Progress report 1				■	■	■	■	■						
	3.2 Draft final report								■	■	■	■	■	■	■
4	Specimen 4.1 Hand Grinding								■	■					
	4.2 Polishing								■		■	■	■		
	4.3 Microscopy inspection								■		■	■	■		
5	Testing 5.1 Microhardness Profile								■					■	■
	5.2 Surface Morphology analysis								■					■	■

■ **Midsem break**

Gantt Chart for Final Year Project I (FYP 1I), semester 8, 2017

		Gantt Chart of PSM II																
No.	Task	Week																
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Sample preparation	🟨							⬛									
		🟩							⬛									
2	Grinding specimens	🟨	🟨						⬛									
		🟩							⬛									
3	Polishing specimens	🟨	🟨						⬛									
		🟩							⬛									
4	Microhardness test			🟨	🟨	🟨	🟨	🟨	⬛									
			🟩	🟩	🟩	🟩			⬛									
5	Surface Morphology Analysis								⬛	🟨	🟨	🟨	🟨	🟨				
						🟩	🟩	🟩	⬛	🟩								
6	Interpret data/results			🟨	🟨	🟨	🟨	🟨	⬛	🟨	🟨	🟨	🟨	🟨				
			🟩	🟩	🟩	🟩			⬛	🟩								
7	Implement the results and discussion								⬛	🟨	🟨	🟨						
									⬛	🟩	🟩							

8	Review results and discussion by supervior								⬛				🟧	🟧	🟧			
									⬛			🟩	🟩	🟩				
9	Complete the report								⬛							🟧		
									⬛						🟩			
10	Prepare for Presentation slides								⬛							🟧		
									⬛							🟩		
11	Presentation PSM II								⬛								🟧	
									⬛								🟩	

🟧 Actual	🟩 Planning	⬛ Midsem break