Study of Plain Dent on Seamless Mild Steel Pipe

by

Nabilah Binti Amir Hamzah

Dissertation submitted in partial fulfilment of

the requirements for the

Bachelor of Engineering (Hons)

(Mechanical Engineering)

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Universiti Teknologi PETRONAS
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CERTIFICATE OF APPROVAL

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Approved by,

....
(AP Dr Othman Mamat)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

July 2010

CERTIFICATION OF ORIGINALITY

This is to clarify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons

....
(NABILAH BINTI AMIR HAMZAH)

ABSTRACT

In Malaysia, there is Pipeline Gas Utilities (PGU) that operates which is owned by PETRONAS. There are onshore and offshore pipeline in the system. It is very dangerous if the system in not good condition. Therefore, pipeline integrity is very important in maintaining the pipeline in order to prolong the service of the equipment. Unfortunately, uncertainty event might happen due to the third parties who intrude the system.

Plain dent defect is one of the dent defect categories. It is the most common defect that appear to the pipeline surface structure which is due to the third party. As the defect produce on the structure, it may disturb the strength condition of pipeline.

Therefore, the aim of this project is to investigate the effect of plain dent defect on the physical and mechanical properties of carbon steel pipe. The carbon steel that used in this project is mild steel which has low carbon content. The pipe will be introduced an artificial defect in order to create the dent defect by using free-fall method. The weight of the load is constant. The variable of creating the artificial defect is by having different height to release the loads. The artificial dent defect shows the percentage of failure increasing as the height of load is increasing during free-fall and producing fracture to the structure of the pipe.

The samples will go through two testing in order to measure the physical properties of the material. The testing is Rockwell hardness test and microstructure analysis using Optical Microscopy. All procedure had been done and the analysis of the data had been analyzed.

ACKNOWLEDGEMENT

First and foremost, I would like to praise Allah the Almighty for with His blessings and guidance I am able to successfully complete my final year project. My appreciation goes to my Supervisor, AP Dr Othman Bin Mamat for the advice, plans, and also for the knowledge and experiences shared during my attachment under him. His guidance had developed my interest in plain dent which helped me to develop during my final year in UTP.

My gratitude is extended to all lecturers for their respective professionalism and all the knowledge shared. Also, a million thanks to all staffs and technicians at lab for the continuous help, support and guidance from the beginning of the final year project until the end.

Heartfelt appreciation is given to Universiti Teknologi PETRONAS (UTP) and Mechanical Engineering Department for equipping students with essential skills and excellent theoretical as well as practical work. To final year project coordinator, I would like to raise many thanks for keeping the supervision in great control.

Finally, my acknowledgement is considered incomplete without thanking all my fellow colleagues, and family who have been giving great support and encouragement for me to complete the program.

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CHAPTER 1

1. INTRODUCTION

1.1 PROJECT BACKGROUND

The most common causes of damage and failures in onshore and offshore in oil and gas transmission pipeline are external interference from the third party. Dent is one of the defects that exist at a point where mechanical damage happen in the pipeline. Assessment methods are needed to determine the severity of the defects when the defects are detected in pipelines.

Detects usually occurring during the fabrication of the pipeline and assessed against recognized and proven by quality control limits. However, a pipeline will consistently contain larger defects at some stage during its life. Therefore, it needs a 'fitness-for-purpose' assessment in order to determine the severity of the defects.

Nowadays, there are several institution who done the research about the dents effects in the pipeline. They have been introduced the best method which is compile in the Pipeline Defect Assessment Manual (PDAM) to determine the severity of the defects. PDAM is the compilation of all the full scales test data used in the development and validation of existing pipeline defects assessment methods.

1.2 PROBLEM STATEMENT

Most of the oil and gas transmission pipelines were placed either laying under seawater or buried underground for onshore. The mechanical damage might happen at upper shelf or bottom shelf of the pipeline.

At upper shelf, dents usually occur when there are external interference occur in the pipeline. Most of the external interference happen to the pipeline is by puncture using indenter which is hard, sharp and the bearing load is high. The activity of excavating which is lack of supervision usually is the cause of dent defects occur at onshore pipeline. The marine activity such as the laying of the anchor of the ship is one of the causes of dent defects occur at offshore pipeline.

Therefore, there is some interference of the system when there are defects occur in the pipeline. The severity of the defects must be measured before any incident happen to the public because the system for oil and gas transmission is very critical.

1.3 OBJECTIVE

The main objective of this project is to analyze the dent defect on;

i. the hardness of the sample at different load;
ii. surface structure of the sample after introducing the artificial defect.

1.4 SCOPE OF STUDY

The failures of the pipeline are divided into two sections which are mechanical damage and corrosion. Mechanical damage is the selected section of pipeline integrity by the author for her Final Year Project.

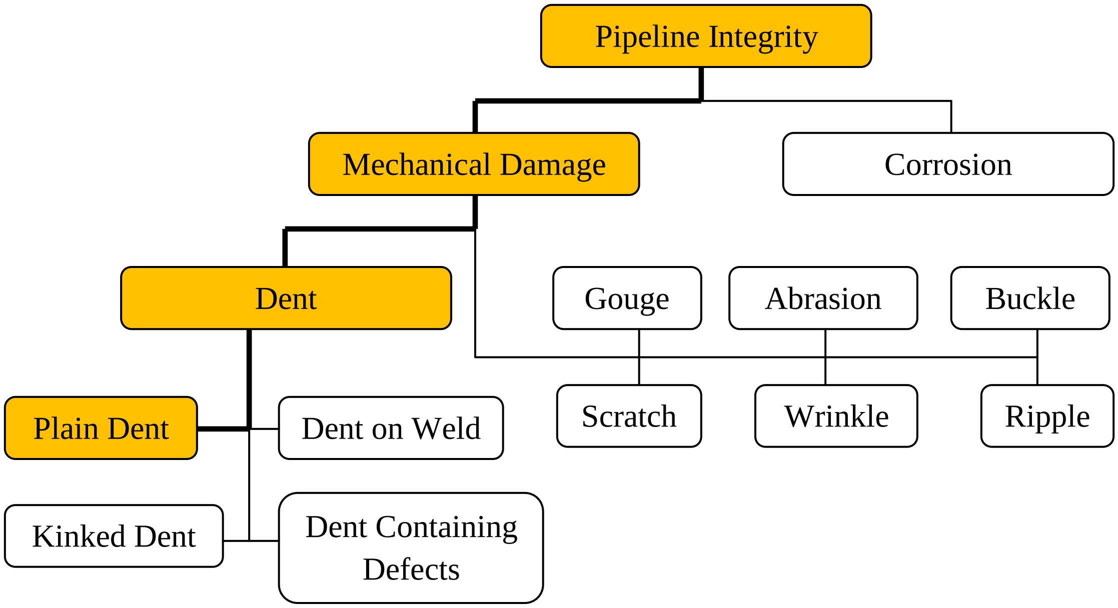


Figure 1-1 : Scope of Study in Pipeline Integrity

Mechanical damage is the loss of the material due to the mechanical action. There is lots of mechanical damage due to the third part in oil and gas industry. The mechanical damage that usually found in pipeline is dent, gouge, scratch, buckle, abrasion, wrinkle and ripple. The scope of mechanical damage in the industry is too big. Therefore, the author only will be focused in dent defect only.

In dent's family tree, it is consist of several type of dent defect. There are plain dent, kinked dent, dent on weld and dent containing defects. In this project, the author was interested in plain dent defect. Therefore, this project is about the study of plain dent in pipeline.

The result for this project will not specific to oil and gas transmission pipeline. The bright side of this project is the result outcome also can be related to any pipeline that have plain dent problem.

CHAPTER 2

2. LITERATURE REVIEW

2.1 WHAT IS DENT DEFECTS?

The definition of dent is a permanent plastic deformation of the circular cross-section of the pipe. A dent is a gross distortion of the pipe cross-section. Dent depth is defined as the maximum reduction in the diameter of the pipe compared to the original diameter [3]. The dent depth also includes both the local indentation and any divergence from the nominal circular cross-section (i.e. out-of-roundness or ovality).

The dent defects can be differentiating due to the differences of physical damage and behavior. Below are the types of dent defects occur in the pipeline [3].

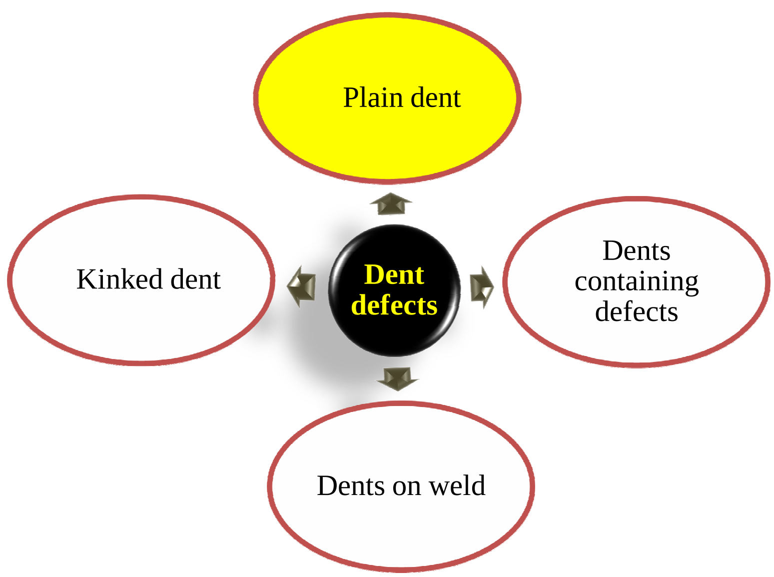


Figure 2-1 : Types of Dent

The dent defects will show a different behavior when the pipe in zero pressure and internal pressurized. The behavior that dents usually happen in the defected pipeline is spring back or re-rounds behavior [3]. After an external interference remove from the surface of the pipe, the structure of the pipe have the tendency fix back to the original geometry of the structure. This behavior occurs because the condition of pipeline has internal pressure in the system. The high pressure in the system will push outward the structure to the original shape in a certain degree.

The spring back and re-rounding behavior of a dent depends upon the pipe geometry, the material properties, the condition of the pipeline whether pressurized or unpressurized, and the shape of the dent.

2.2 RELEVANT STANDARD

There are several methods to perform this project which published in Pipeline Defect Assessment Manual (PDAM). General procedures for assessing flaws in structure, based on fracture mechanics were given in BS 7910 [1] and API 579 [2]. The methods that can be used to assess the defects are stated in the APPENDIX I. The details that contain in Appendix 1 were taken from a journal [3].

Other standard uses for this project are tabled below;

Table 2-1 : Code and Standard

CODE	TITLE
ASTM E18-07	Standard Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials.
API 579 / ASME FFS-1 2007	Fitness-for-service.
ASME B36.10	Welded and Seamless Wrought Steel Pipe.

2.3 DENT DEFECTS

The effects of dent in the pipeline are very broad context that able to discuss in this projects. Due to the time constraint given to the author, the scope of dent should be narrow to one type dent defect only. Refer to APPENDIX I [3], the author had done some literature review from a journal written by Andrew Cosham and Phil Hopkins about the difference types of dent in detail.

2.4 REQUIREMENT

There are components should be considered before performing the assessment of a dent. The component [2] satisfied the following requirements.

a. The component is a cylindrical shell with a geometry that satisfied Equation (2.1) and (2.2)

$$168\ mm\ (\ 6.625\ in.\ ) \leq D \leq 1050\ mm\ (42\ in.) \qquad (\ 2.1\ )$$

$$5\ mm\ (\ 0.20\ in\ ) \leq t_c \leq 19\ mm\ (\ 0.75\ in.\ ) \qquad (\ 2.2\ )$$

b. The component is subject only to internal pressure (i.e. supplemental loads are assumed to be negligible).

c. The component material is carbon steel with specified minimum yield strength (SMYS) that satisfied **Equation (2.3),** and an ultimate tensile strength (UTS) that satisfied **Equation (2.4).** The limit on SMYS only applied to the static assessment of dent-gouge combinations, and the limit on UTS only applied only applies to the fatigue assessment of dents and dent-gouge combinations.

$$SMYS \leq 482\ MPa\ \ (\ 70\ ksi\ ) \qquad (2.3)$$

$$UTS\ \ \leq 711\ MPa\ \ (\ 103\ ksi\ ) \qquad (2.4)$$

d. The dent or dent-gouge combination is an inward deviation of the shell cross section.
e. The assessment procedures only apply to isolated dents and dent-gouge combinations. In this context, isolated is defined as two times the limit permitted in the assessment procedures for L_{msd}.

CHAPTER 3

3. METHODOLOGY

3.1 PROJECT FLOW

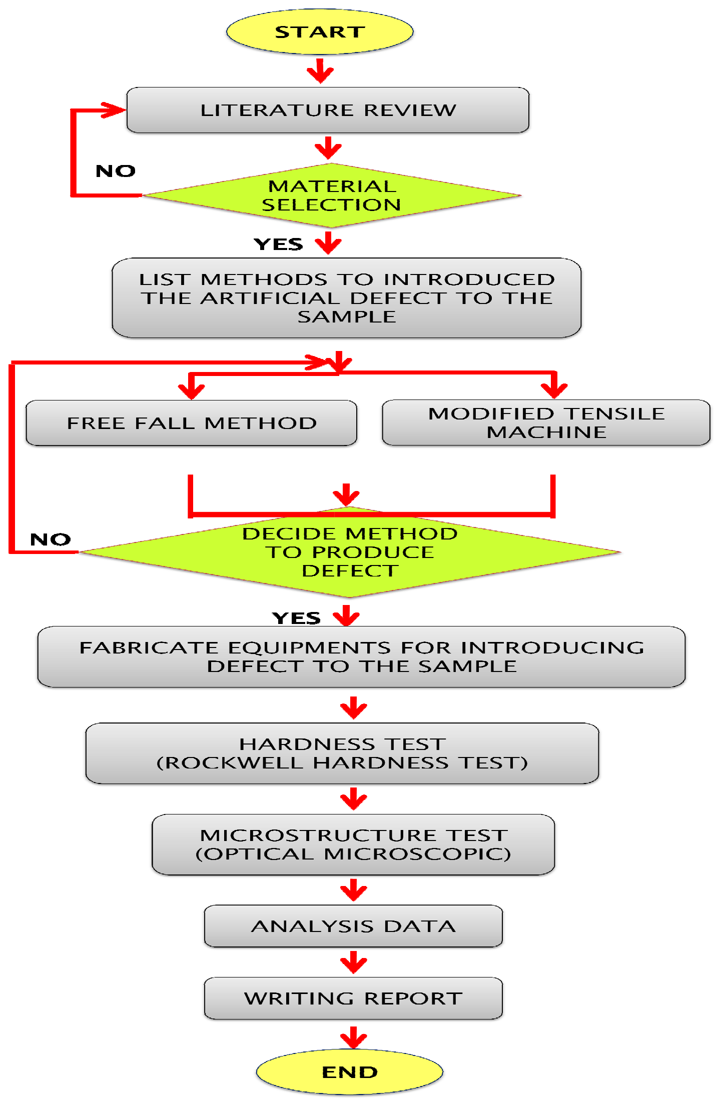


Figure 3-1 : Project Flow

3.2 PROJECT ACTIVITIES

Based on Figure 3, the author had done research for this project. This project will be divided into five (5) sections. The sections are material selection for the sample, selection of method for introducing artificial defect on the sample, fabrication the equipment to setup the free-fall, testing used on the sample before and after created the artificial defect and material preparation before observing the structure using Optical Microscopic.

3.2.1 Material selection.

The problem statement of this project was taken from PETRONAS Gas Berhad (PGB). The pipeline material used in gas transmission in Malaysia which is owned by PETRONAS is high tensile carbon steel grade X70. It is a high tensile carbon steel which have high percentage of carbon in the material of the pipeline. The purpose of having a high strength material for their pipeline in order the material of the pipeline has a long period of services.

In this project, there author will be used the mild steel which is a low-carbon steel as specimens in conducting the experiments. Mild steel is the most commonly available of the cold-rolled steels. Other than that, the price of the material is relatively low while it provides the acceptable material properties for many applications. The chemistry component and the material properties are in table below.

Table 3-1 : Material Properties and Chemical Component of Mild Steel.

Minimum Properties	Ultimate Tensile Strength, σ_{uts} , MPa	439.89
	Yield Strength, MPa	370.25
	Elongation	15%
	Rockwell Hardness	B71
Chemistry	Iron (Fe)	98.81 – 99.26 %
	Carbon (C)	0.18%
	Manganese (Mn)	0.6 – 0.9%
	Phosphorous (P)	0.04% max
	Sulfur (S)	0.05% max

The material dimension and specification for the sample is listed below.

a. Diameter Nominal = 32 *mm* (1 ¼ *inch*)
b. Schedule = Standard 40.
c. Outside diameter, *D* = 42.164 *mm*
d. Wall thickness, *t* = 3.555
e. Inside diameter, *d* = 35.052 *mm*
f. Inside area = 9.650 cm^2
g. Length = 4 *inch.*

Mild steel is a suitable material to use in this experiment because it meets one of the requirements in **Equation (2.4)** at **section 2.4.** The specimen of this project will have the same material, thickness and diameter.

3.2.2 Introducing Artificial Defect

An artificial defect will be created on the specimen to perform the test on the structure of the pipe. The sample will be given a difference load by using indenter equipment in order to create an artificial defect.

After an artificial defect create to the sample, there are few parameter must be taken to perform assessment of the defect in the size of dent produce. The parameters are depth of the dent, the length of the dent and the width of the defect [2].

Introducing an artificial defect to the specimen is the most crucial stage of this project. If the sample do not have correct defect which is plain dent defect, the project could not proceed. Therefore, the author will introduced two alternative methods to conduct an experiment to produce an artificial dent defect. Besides that, this project is a small-scale laboratory experimental.

Two alternative methods of introducing an artificial dent defect onto the sample are:

a. Modifying the tensile test machine by attaching an indenter to the machine.
b. Create a free-fall method by using indenter.

3.2.2.1 Modified Tensile Test Machine

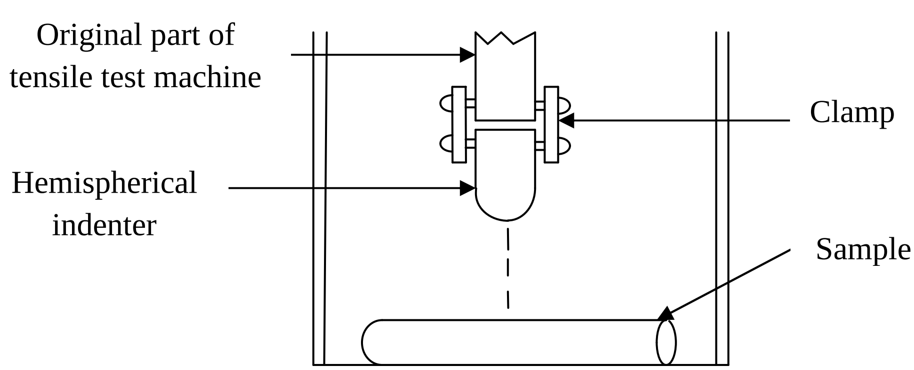


Figure 3-2 : Modified Tensile Test Machine

One of the alternatives to introduce a dent to the sample is by modifying the tensile test machine. The additional component that will be attached to the original part of tensile machine is the hemispherical indenter by clamping to the original part of tensile machine.

The hemispherical indenter will be fabricated by using CNC lathe machine that are available in UTP laboratory. The material used for fabricating the indenter must be harder than the mild steel itself which is cast iron. Cast iron has a higher amount of carbon in their structure where make the material is harder than the mild steel. The amount of carbon in the cast iron is between 2.1% to 4% where is higher that mild steel, 1.8% carbon content.

The clamp component also is an additional component to the tensile test machine in order to perform this project. The clamp will be fabricated in UTP's workshop by using a plate of steel and attach the nut and bolt to the clamp. The purposes of adding the clamp to the tensile test machine is to hold the original tensile component and the hemispherical indenter. By holding these two components, it will prevent them from slipping during the experiment is conducted.

The specimen will be in zero pressure condition during conducting the experiment. The maximum depth of denting, $(\delta/D_o)_{max,}$ is set between 1% up to 10% from the original diameter of the specimen. The denting speed is set at 0.1 *mm/min.*

3.2.2.2 Free-fall Method.

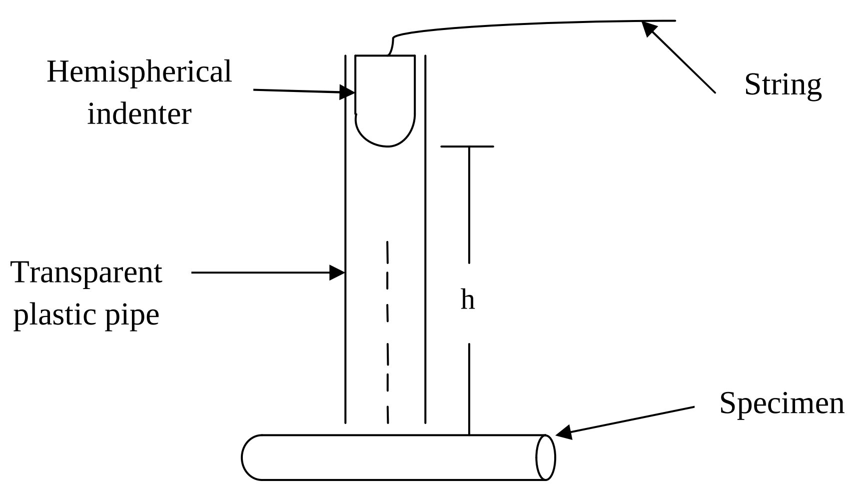


Figure 3-3 : Free Fall Method - Equipment Arrangement.

The free-fall test is another alternative method to introduce a dent defect to the sample. The components involve in this method are hemispherical indenter, transparent plastic pipe, a string, and a specimen's holder.

The hemispherical indenter used in modified tensile test must be fabricated which will be fitted the original part of tensile machine. Furthermore, the difference between this method and the method by modifying tensile test machine is there are options in selecting material or body shape of hemispherical indenter. The options are either fabricate the hemispherical indenter in laboratory or purchase a hammer which their head have hemispherical shape.

It is a simple method to conduct the experiment. For this method, the author able to calculates the force being applied to the hemispherical indenter from a certain height, **Equation 4.1** [8] and force between the specimen and hemispherical indenter, **Equation 4.2** [7].

$$F = mg \qquad (4.1)$$

F = *force an object, N*

m = *mass of the object, kg*

g = *gravitational acceleration , 9.81 m/s*^{2}

$$F = G\,\frac{m_1+m_2}{h^2} \qquad (4.2)$$

F = *force between two object.*

m_1 = *mass of the first object, kg*

m_2 = *mass of the second object, kg*

h = *distance between object, m*

G = *gravitational constant,* 6.673×10^{-11} *Nm*^{2}*/kg*^{2}

3.2.2.3 Advantages and disadvantages

The author has introduced two methods to conduct an experiment to produce the artificial dent defect to the specimen. Both methods have their own pros and cons in conducting the experiment. The advantages and disadvantages of both methods are listed below.

Table 3-2 : Advantages and Disadvantages of Two Methods in Introducing an Artificial Defect.

Method	Advantages	Disadvantages
Modified Tensile Test Machine	• Easy to conduct. • More accurate • Able to control the indentation.	• Difficult to access to the laboratory • Slipping effect during experiment. • Limitation of the facilities
Free-fall Method	• Easy to fabricate • Easy to conduct • Easy to handle • Cheap • No limitation of place to conduct the experiment.	• Not too accurate • Trial and error method

After considering the advantages and disadvantages of both methods, the author decided to select free-fall method as the method to introduce artificial defect to the sample.

3.2.3 Fabrication

In the second period of the project which is during FYP2, the author started to fabricate the equipments for free-fall method to introduce an artificial defect to the sample. The equipment which is needed to fabricated are listed below;

i. Sample's holder by using electrical saw to cut the wood and face mill to flatten the surface.
ii. PVC pipe for indenter's pathway.
iii. Mild steel pipe for sample.

3.2.4 Testing

The tests that have been conducted in this project are measured the hardness of the material before and after an artificial defect are created and analyzed the structure of the material at defected area.

The first test has been performed for this project is hardness test. The purpose of measuring the hardness of the material was to analyze the changes of the hardness of the material before and after producing an artificial defect.

The type of hardness test applied in this project was Rockwell Hardness test in scale B. This test was conducted based on ASTM E18-07 Standard Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials.

The second stage of testing performed on the sample was analyzing the structure of the material. The purpose of analyzing the structure of the material is to compare the structure of the material before and after an artificial defect created. It's also to test whether the changes of microstructure of the material will affect the strength of the structure by identified any fracture or crack produce on the defect. The test was carried out by using Optical Microscopic (OM) machine.

3.2.5 Material Preparation for Structure Analysis.

The next step after introducing an artificial defect and performing hardness test, the sample must go through material preparation stage before analyze the structure of the sample. The sample that used for OM is very small. Therefore, the defected area will be taken out from the sample and it takes several processes. The process of material preparation is as below;

i. Cutting the cross-section of the defected area by using abrasive cutter.
ii. Mounting the small sample with phenolic resin by using mounting machine.
iii. Grinding and polishing the sample until get the finest surface of material.
iv. Etching the material with nital solution.

After all of above processes had done the sample able to go through microstructure analysis by observing through OM.

3.3 GANTT CHART

Activities	1	2	3	4	5	6	7		8	9	10	11	12	13	14
Selection of project topic + Submission of proposal															
Research on selected topic															
Preparation and submission of Preliminary report				Δ											
Project work : 1. Study on the method of assessment. 2. Develop formulation 3. Preparation the procedure of the testing								**Mid Semester Break**							
Submission of progress report									Δ						
Seminar									Δ						
Project work continue 1. Continue of study the method for testing.															
Submission of interim report final draft															Δ
Oral presentation												During study week			

Δ = Milestone ■ = **Completed task**

Activities	1	2	3	4	5	6	7		8	9	10	11	12	13	14
Project work continues 1. Create artificial defect 2. Hardness test before introduce artificial defects. 3. Measure the parameter of the defect.															
Submission of Progress Report I				Δ											
Project work continues 1. Microstructure test 2. Analysis the data from experimental.															
Submission of Progress Report II								**Mid Semester Break**	Δ						
Seminar										Δ					
Project work continues															
Poster Exhibition											Δ				
Submission of Dissertation final draft															Δ
Oral presentation												During study week			
Submission of Dissertation (hard bound)									7 days after oral presentation						

Δ = Milestone   [orange box] = **Completed task**

3.4 EQUIPMENTS/ MATERIAL USED

The equipments / materials needed for this project are listed as follows:

1. Equipment
   i. Abrasive Cutter
   ii. Face Milling Machine.
   iii. Electronic Saw.
   iv. Hand Saw
   v. Mounting Machine.
   vi. Grind and Polish Machine.
   vii. Indentation Hardness Machine.
   viii. Optical Microscopic.

2. Material
   i. Mild Steel Pipe
   ii. Phenolic Resin Powder
   iii. Nital Solution.
   iv. Ethanol Solution.

CHAPTER 4

4. RESULT & DISCUSSION

4.1 RESULT FROM FREE-FALL METHOD

Free-fall method had been done in order to produce the artificial defect to the sample. Every sample is defected for five (5) times in certain height to get the best result for this project. The height to drop the indenter is starting from 20cm, 60cm, 100cm, 140cm and 180cm.

The author successfully measured the parameter of the sample need for this project by using vernier caliper. The parameters required are stated at the table below.

Table 4-1 : Length and Width of the dent

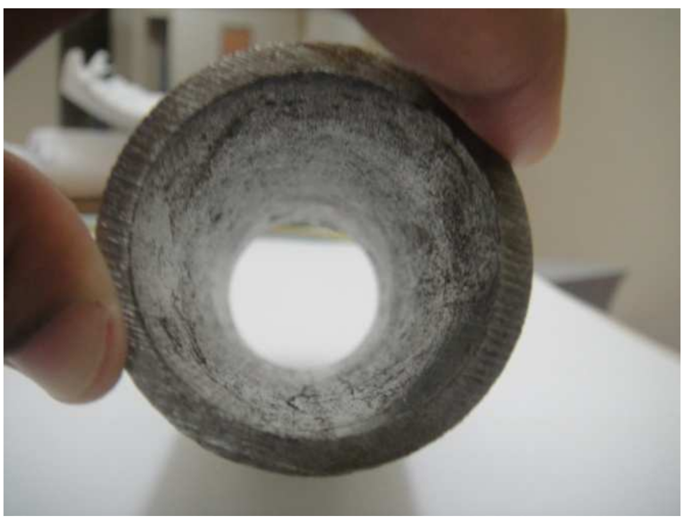
Height (cm)	Parameter	1	2	3	4	5
20	Length (cm)	1.94	3.24	2.82	2.32	1.92
	Width (cm)	1.94	2.06	2.1	1.96	1.36
60	Length (cm)	4.24	4.18	3.54	3.84	3.84
	Width (cm)	3.66	3.2	3.54	3.1	2.64
100	Length (cm)	4.18	3.06	3.58	3.84	3.54
	Width (cm)	3.38	2.7	3.14	3.54	2.86
140	Length (cm)	4.52	4.92	5.66	4.92	5.26
	Width (cm)	3.68	4.44	4	3.68	4.48
180	Length (cm)	5.56	5.34	5.94	5.94	5.92
	Width (cm)	3.74	3.66	3.94	4.32	4.68

The results of drop test by using visual inspection are stated below.

4.1.1 The visual observation from height of 20cm

Outside view

- *The dent produce is very shallow.*
- *The diameter of the dent is very small.*

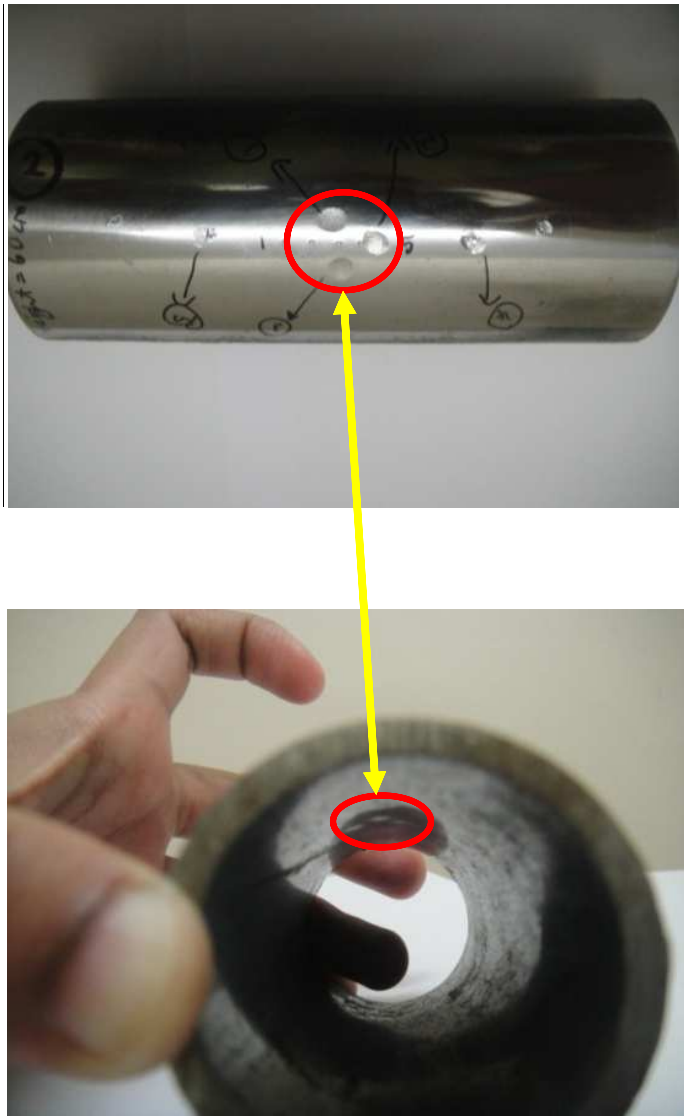


Inside view

- *Cannot visually observe the deformation of structure at the inner wall.*

Figure 4-1 : The sample after drop test (height = 20cm)

4.1.2 The visual observation from height of 60cm



Outside view

- *The dent produce is shallow.*
- *The diameter of the dent is bigger than the diameter at 20cm height.*

Inside view

- *Able to visually observe the deformation of structure at the inner wall quite clear.*

Figure 4-2 : The sample after drop test (height = 60cm)

4.1.3 The visual observation from height of 100cm.

Outside view

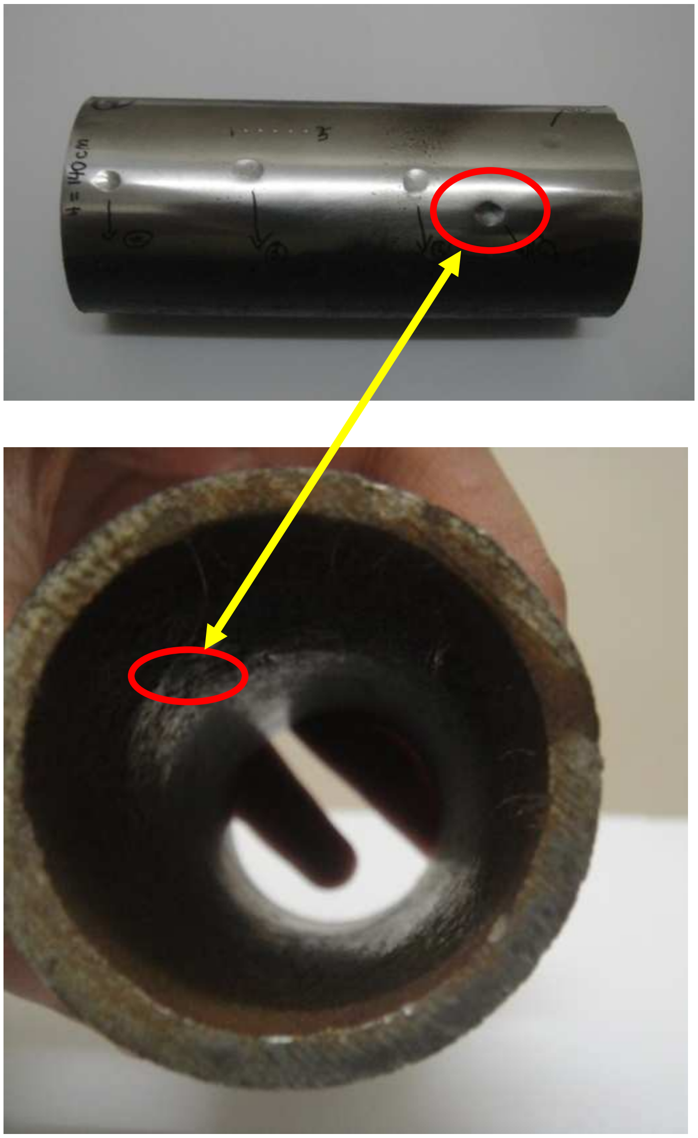
- *The dent produce is quite shallow.*
- *The diameter of the dent is bigger than the diameter at 60cm height.*

Inside view

- *Able to visually observe the deformation of structure at the inner wall quite clear.*

Figure 4-3 : The sample after drop test (height = 100cm)

4.1.4 The visual observation from height of 140cm.



Outside view

- *Deeper dent.*
- *Larger diameter of the dent.*

Inside view

- *Able to visually observe the deformation of structure at the inner wall quite clear.*
- *Not all dent able to defect visually.*

Figure 4-4 : The sample after drop test (height = 140cm)

4.1.5 The visual observation from height of 180cm

Outside view

- *Deeper dent.*
- *Larger diameter of the dent.*

Inside view

- *Deeper dent.*
- *Larger diameter of the dent.*
- *Able to inspect visually and clearly for all dents.*

Figure 4-5 : The sample after drop test (height = 180cm)

4.2 HARDNESS TEST

Hardness test is one of the tests that required for this project. The author used Rockwell Hardness Test type B for this project. It is the most common method used to measure hardness because they are so simple to perform and require o special skills. The standard load for this testing was 100kg. Indenter includes spherical and hardened steel balls having diameter of $\frac{1}{6}$ inch.

The hardness test was selected than any other mechanical test for several reasons:

i. They are simple and expensive – commonly no special specimen need be prepared and the testing apparatus is available at UTP laboratory.
ii. The test is nondestructive – the specimen is neither fractured nor excessively deformed: a small indentation is the only deformation.
iii. Other mechanical properties often may be estimated from hardness data, such as tensile strength.

The data required for hardness test must be taken before and after introducing an artificial defect to the sample. The results of the hardness test before conducting the drop test are collected in the table below.

Table 4-2 : Hardness Test Before Introduce Artificial Defect

Height (cm)	Hardness before drop test (HRB)						
	1	2	3	4	5	Average	Total Average
20	74.9	73.3	77.6	77.7	77	76.1	76.432
60	81.1	81.5	78.2	78.9	79.2	79.78	
100	73.1	78	77.2	75.3	77.6	76.24	
140	70.7	72.9	73.1	72.3	72.6	72.32	
180	75.7	77.9	79.4	78.2	77.4	77.72	

Table 4-3 : Hardness Test After Introduce Artificial Defect

Height (cm)	Point	Hardness (HRB)					Average (HRB)	Total Average (HRB)
		1	2	3	4	5		
20	1	73.6	72.7	74.7	-	-	73.6667	73.2467
	2	74.3	69.6	78.2	-	-	74.0333	
	3	65.4	66.9	75.5	-	-	69.2667	
	4	65.3	68.8	80.5	-	-	71.5333	
	5	78.7	76.8	77.7	-	-	77.7333	
60	1	79.7	82.2	84.6	87.4	79.4	82.66	86.68
	2	78.7	81.5	93.1	94.7	81.3	85.86	
	3	78	77.1	94	90.6	89.3	85.8	
	4	80.3	93.6	79.6	104.4	64.5	84.48	
	5	82.6	91.1	93.2	117.5	88.6	94.6	
100	1	82.4	80.3	91.9	104	82.1	88.14	86.62
	2	71.2	83.6	93.7	94.2	80.9	84.72	
	3	81.9	89.8	89.5	88.8	89.4	87.88	
	4	79.3	83.7	88.4	87	90.4	85.76	
	5	78.8	90.6	83.5	80.7	99.4	86.6	
140	1	65.4	80.3	80.7	83.8	94.5	80.94	84.416
	2	78.1	81	93.2	107.7	78.6	87.72	
	3	85.5	89.3	79.9	84.2	91	85.98	
	4	86.7	97.3	80.3	69.3	73.3	81.38	
	5	89.1	97.7	74.6	90.6	78.3	86.06	
180	1	75.7	84.3	85.4	82.4	82	81.96	81.476
	2	79.3	84.4	81.9	53.6	84.6	76.76	
	3	77.1	83.8	80.5	81.8	73.7	79.38	
	4	80.2	81.6	84.1	87.8	90.4	84.82	
	5	85.2	82.6	81.6	84.8	88.1	84.46	

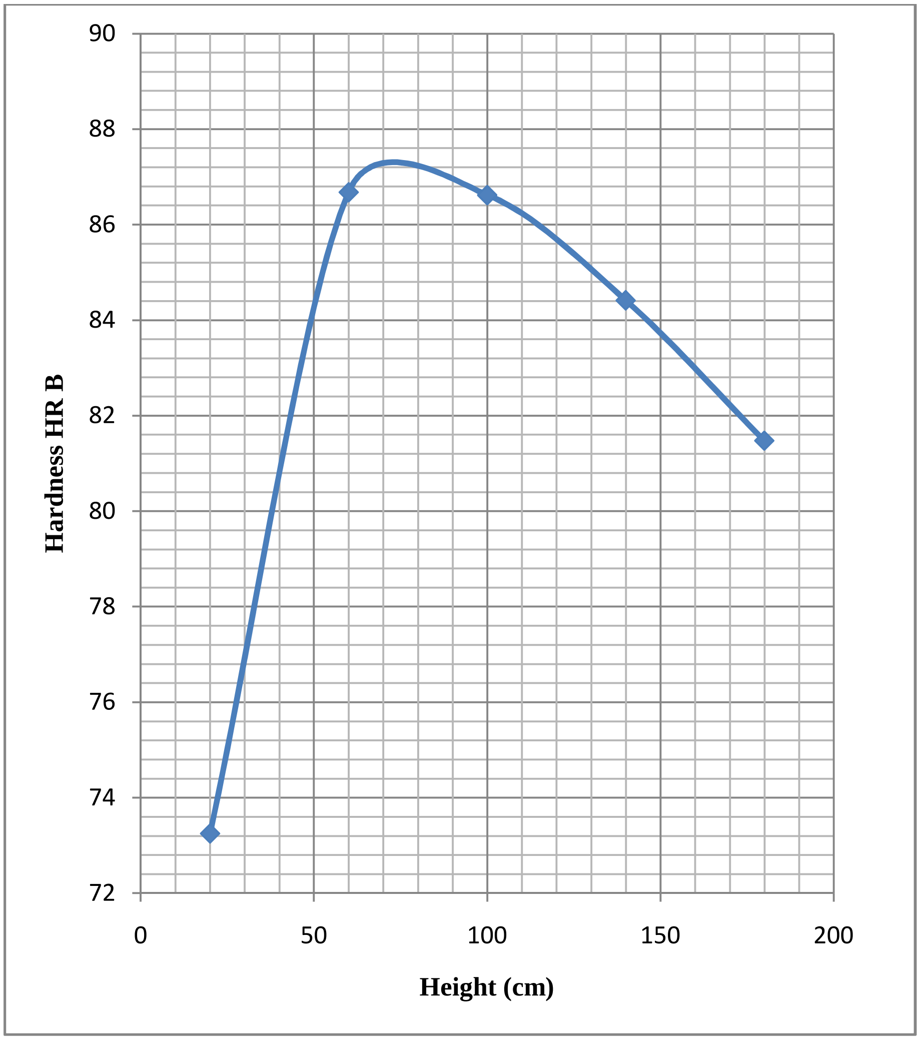


Figure 4-6 : Hardness Test

In **Figure 4-6**, hardness data shows that the material experience plastic deformation and started to fail at certain value. The curve also shows that the sample is a brittle material. Even though the material is brittle, it's not fail immediately. The material reduce the as the height of the indenter is increasing. It is due to the material of sample which is a metal.

4.2.1 Correlation between Hardness and Tensile Strength.

Based on the reason hardness test was selected for this project due to the availability of hardness data to estimate the tensile strength of the defects. Both tensile strength and hardness is indicator of a metal's resistance to plastic deformation. As a rule of thumb for most steel, the tensile strength of mild steel can be estimated based on HB by using the following **Equation (4)** [7] **;**

$$TS\ (MPa) = 3.45 \times HB \qquad (4)$$

Table 4-4 : Correlation between Hardness and Tensile Strength

Height (cm)	Average hardness (HRB)	Average hardness (HB)	Tensile Strength (MPa)
20	73.2467	131	451.95
60	86.68	170	586.5
100	86.62	170	586.5
140	84.416	163	562.35
180	81.476	149	514.05

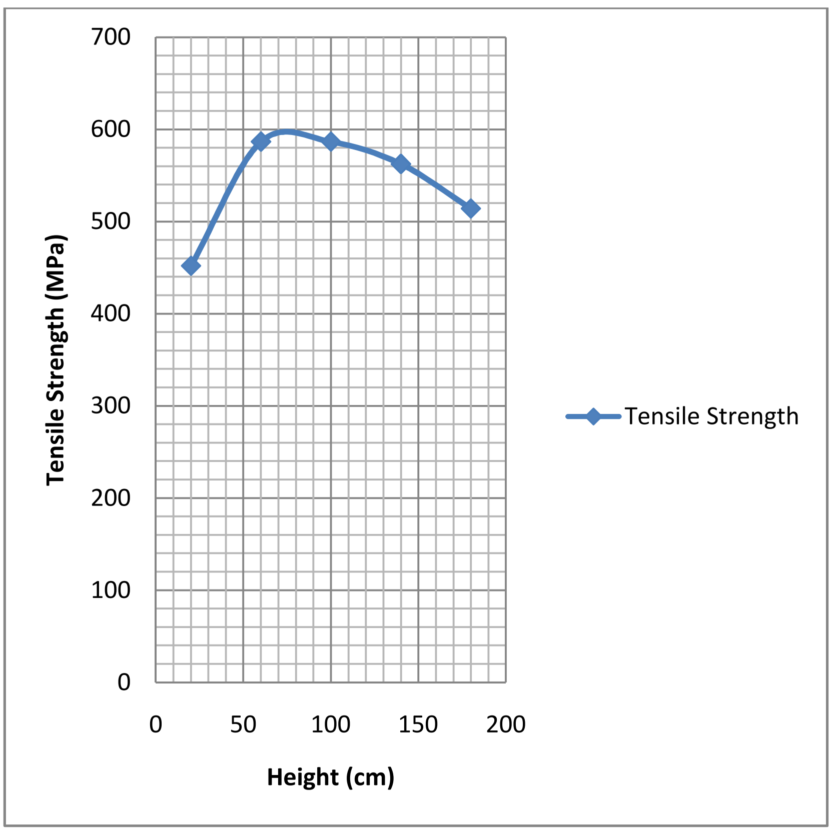


Figure 4-7 : Tensile Strength vs. Height

The calculation of tensile strength by correlating the hardness data shows the similar pattern of graph with picture in **Figure 4-6** and **Figure 4-7**. From **Figure 4-7**, it proved that the sample started to fail after reach the ultimate tensile strength of the material. The structure starts to fail at height of 70mm by having 87.2HRB.

Therefore, the author able to calculate the percentage of failure to the structure after introduce artificial defect.

Table 4-5 : Percentage of Failure

Height (cm)	Average Hardness (HRB)	% of Failure
0	76.43	-12.35
20	73.25	-16.00
60	86.68	0.60
100	86.62	0.67
140	84.42	3.19
180	81.48	6.56

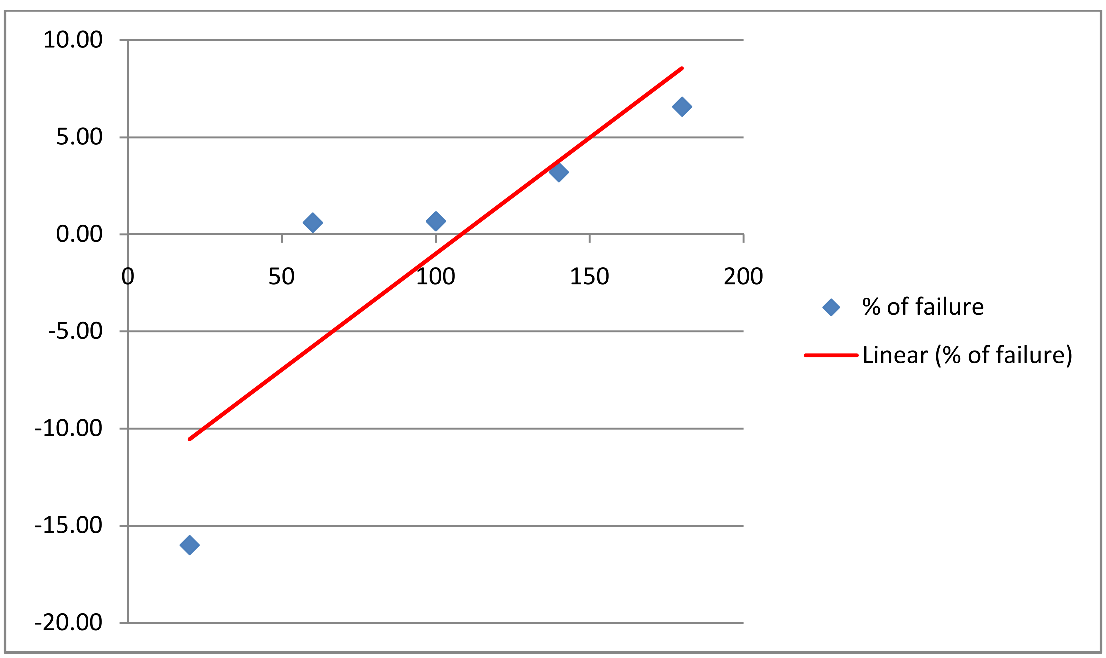


Figure 4-8 : Percentage of Failure

In **Figure 4-8**, the failure percentage of the structure is increasing linearly and reaching 10% of failure. As the failure percentage reaching 10%, the severity of the defect is very high [3].

4.3 MICROSTRUCTURE ANALYSIS

The microstructure analysis for this project is to identify the changes of the structure after introducing the artificial dent defect to the sample. Previously during FYP1, the author had planned to analyze the microstructure of the sample by using Scanning Electron Microscopic (SEM). Unfortunately during the FYP2, the SEM machine was not available due to the machine breakdown for the whole semester. Therefore, the author had to change the method of analyzing microstructure by using Optical Microscopic.

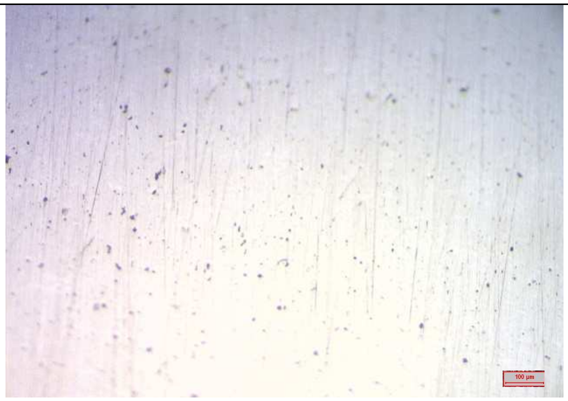
As the method was changes, the author decided to take the microstructure at the cross-section of dent defect. By observing the microstructure at the cross-section, it would get a result of changes in grain boundaries and intergranular crack at the dent's area. As the sample gone through material preparation, the author faced difficulties in cutting the sample into small pieces before mounting process. There are several ways to cut the sample at the cross-section. The alternative methods are by using Wire Electrical Discharge Machining (WEDM), abrasive cutter, hand saw and bend saw machine. The author had used all the method to cut the sample. But unfortunately, all of the method are either not available or not giving the best result of cutting surface of the sample. Therefore, the result of the microstructure is not good.

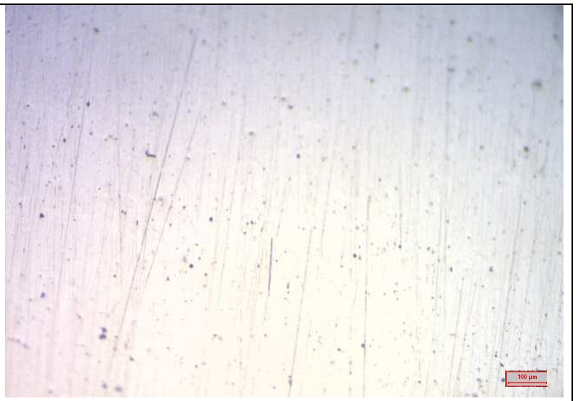
Next, the author decided to take the microstructure at the surface of the dent defect. From the top view of the defect, the author was able to identify if there are any micro-crack, scratch, fracture or changes on the structure of the sample.

The pictures of the microstructure were taken from various magnifications. There are 5x, 10x, 50, 100x and 150x magnification of picture using the Optical Microstructure.

4.3.1 Optical Observation Results

4.3.1.1 Result at Zero Defects





- All the pictures at 100x magnification at different area.
- All picture above shows that the surface structure is smooth without any defects.
- The vertical lines are the result of not very good surface finishing during polishing the surface of the sample. It is not consider as defect to the structure

Figure 4-9 : Optical Observation at Zero Defect

4.3.1.2 Result at height of 20mm

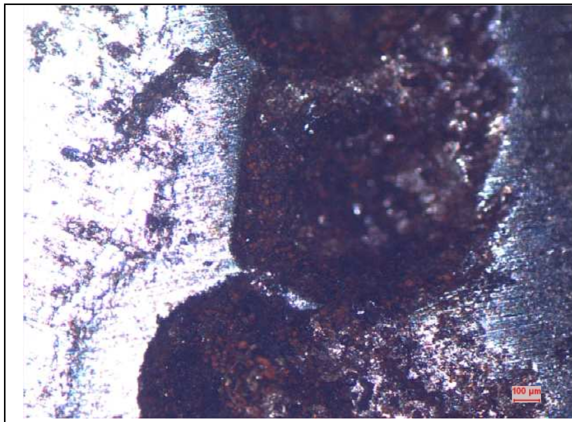
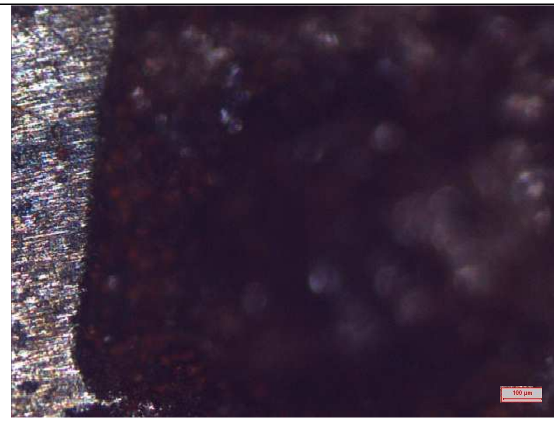
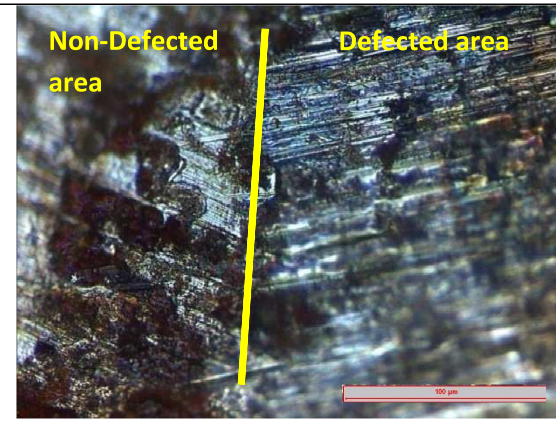
		
• The picture at 50x magnification. • No appearance of fracture around the defect area.	• The picture at 100x magnification. • Clear line of defected are without any fracture or defect.	• The picture at 500x magnification • There are changes in the orientation of the structure between the defected area and non-defected area.

Figure 4-10 : Optical Observation at height of 20cm

4.3.1.3 Result at height of 60mm

<table>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>

The picture at 50x ma magnification.
The crack starting at the indentation of the hardness test.
The crack is not straight, so it cracks along the grain boundary.

</td>
<td>

The picture at 100x magnification.
Appearance of two cracks from different initial sources of crack.
The plastic deformation of the material producing the crack which reducing the strength of the structure

</td>
</tr>
</table>

Figure 4-11 : Optical Observation at height of 60cm

4.3.1.4 Height = 100mm

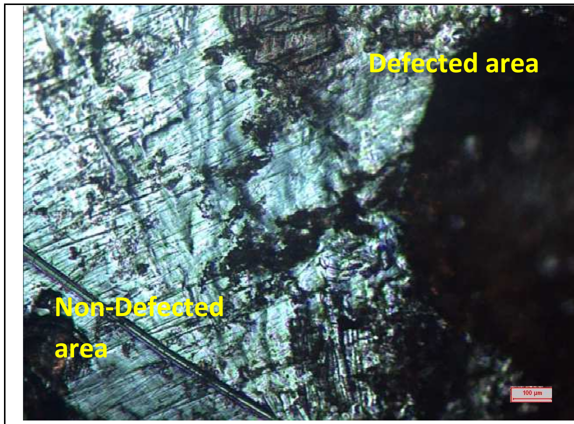
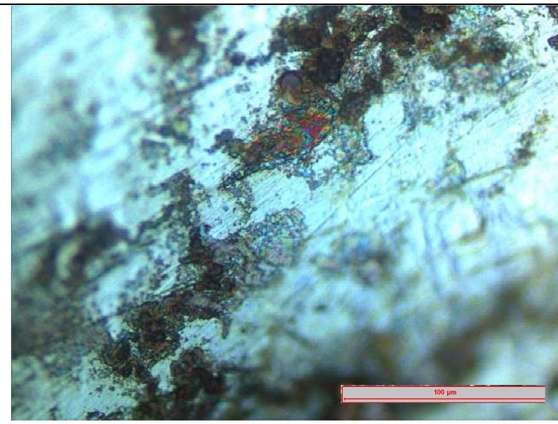
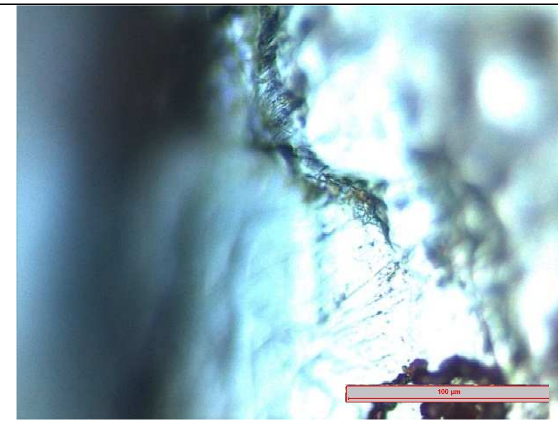
<table>
<tr>
<td>
</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The picture at 100x magnification.
Able to differentiate between dented area and non-dented area.
The dented area seems that the grain boundaries had been pressed.</td>
<td>The picture at 500x magnification.
There black spot like pitting.</td>
<td>The picture at 500x magnification.
Able to identify crack at the dent area
There also black spot around the crack’s area.
The shape of the black spot is like producing along the grain the boundary.</td>
</tr>
</table>

Figure 4-12 : Optical Observation at the height of 100cm.

4.3.1.5 Height = 140mm

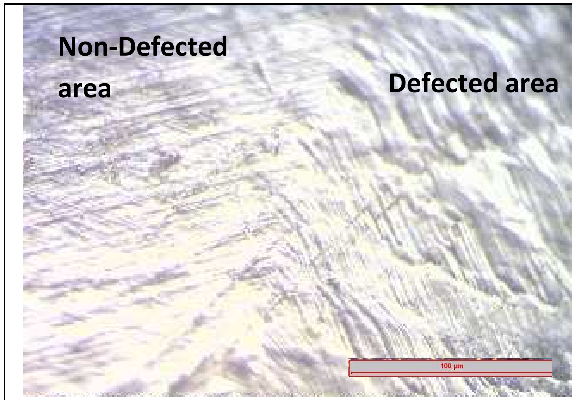
		
• The picture at 500x magnification. • Able to differentiate between dented area and non-dented area. • The orientation of the structure at the defected area, it likes the material had been pressed by a load.	• The picture at 500x magnification. • There are existed of small crack at the defected area.	• The picture at 500x magnification. • There is loss of metal at dented area.

Figure 4-13 : Optical Observation at the height of 140cm

4.3.1.6 Height = 180mm

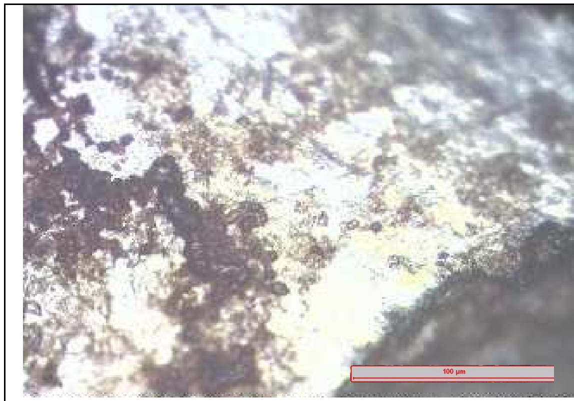
<table>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• The picture at 500x magnification</td>
<td>• The picture at 1000x magnification</td>
<td>• The picture at 1500x magnification</td>
</tr>
<tr>
<td colspan="3">• At all picture, there are production of stress concentration.
• At all picture, there are black spot created along the grain boundaries.</td>
</tr>
</table>

Figure 4-14 : Optical Observation at the height of 180cm.

CHAPTER 5

5. CONCLUSION & RECOMMENDATION

5.1 CONCLUSION

From the study of plain dent on seamless mild steel pipe, the following conclusions of can be made from hardness and structure observation's point of view.

From the hardness results, the hardness of the material increase to the maximum point – at height of 70cm by giving the value of 87.2HRB. After reached the maximum point, the hardness of the material started to decrease. By correlating the hardness data with tensile strength, the maximum point was referred to the yield strength of the material.

From the optical observations is the orientation of the material changed after introducing artificial defect on the sample. The macro crack on the dent was also observed.

5.2 RECOMMENDATION

The study of plain dent is very wide scope of project as has been by someone before. As time given to finish this project is very little and limited, there are more mechanical properties that could be studied. Therefore, the author will list the future work expansion for this project:

i. In this project, the author used mild steel pipe as the sample. The used of low carbon steel in this project due to the cost limitation to the author. In future, it will be more precise to use high tensile carbon which has the similar carbon content that used in oil and gas industry.

ii. The author suggest to modify the tensile test machine for introduce the dent defect. This method is not chosen as the method to introduce the dent for this project due to the laboratory limitation. Therefore, it is good initiative to modify the tensile test machine in order to get a better result in introducing the artificial dent defect in the future project.

iii. Other than hardness test and microstructure analysis, burst strength test and fatigue life of plain dent also could be conducted for future work expansion.

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[3] Andrew Coshama, Phil Hopkins. *The effect of the dents in pipeline – guidance in the pipeline defect assessment manual*. International Journal of Pressure Vessels and Piping 81 (2004) 127-139.

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[6] ASTM, "E18 Standard Test Method for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials," Annual Book or ASTM Standard, American Society for Testing and Materials, Vol. 3.01.

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APPENDIX I

Title : The Effect of Dents in Pipelines – Guidance in the Pipeline Defect Assessment Manual
Author : Andrew Cosham , Phil Hopkin
Journal : International Journal of Pressure Vessels and piping 81 (2004) 127 – 139

Aspects	Plain dent	Dents on weld	Dents containing defects	Kinked dent
Terminology	A smooth dent that contains no wall thickness reduction (such as a gouge or a crack) or other defects or imperfections (such as a girth or seam weld) • Not significantly reduce the burst strength of the pipe.	The dent exist on the welded area of the pipe	The dent on the pipe contains other defects than dent.	A dent which causes an abrupt change in the curvature of the pipe wall (radius of curvature in a any direction) of the sharpest part of the dent is less than 5 times the wall thickness).[1]
Effect	• Reduce the static and cyclic strength of the pipe	• Reduce the static and cyclic strength of the pipe	• Reduce the static and cyclic strength of the pipe	•

Method in PDAM 1) Internal pressure (static) longitudinally oriented 2) Internal pressure (fatigue)	1. Dent depth less than 7-10% of the pipe diameter. [1] 2. European pipeline Research Group (EPRG)	1. No method 2. No method	1. Dent-gouge fracture model. 2. No method	1. No method 2. No method
Burst strength	• The effect of dents on the failure characteristics of linepipe, Battelle Columbus Laboratories, NG18, Report No. 125, May, 1981. • Effect of smooth and rock dents on liquid petroleum pipeline. Final report to API, SES, Inc., Keifner Associated, 10 October 1997, API Publication 1157, Nov; 1997. • The resistance of gas transmission pipeline to mechanical damage, paper VIII-3. International conference on Pipeline Reliability, Calgary, Canada, June 1992. • Residual strength of dented pipeline, DNV test result. Tenth international Conference on Offshore and Polar engineering	• Very low burst pressure. • Min ; 7% of the SMYS (specific minimum yield strength). • Low burst strength - Cracking during indentation. - Spring back or reround. - Presence of welding defects. • Dent weld usually repair/ removed if found in a pipeline.	No research report or literature that describes experimental studies of the behaviour of smooth dent containing a defect.	No research report or literature that describes experimental studies of the behaviour of kinked dents.

	(ISOPE 2000) Seattle, USA, 28 May – 2 June; 2000. • Dents in pipeline. Oil Gas J 1958;56;155-61. • The significance of mechanical damage in pipelines. 3R International, 21, Jahrgang, Heft, 7 July;1982. • Recent studies of the significance of mechanical damage in pipelines. The American Gas Association and European Pipeline Research Seminar V, San Francisco, USA, September;1983. • The effect of mechanical damage on fracture initiation in linepipe; part 1 – dents. Report ERP/PMRL 82-11 (TR), Canada: Canadian Centre for Mineral and Energy Technology (CANMET) January 1982. • The significance of dents and defects in transmission pipelines, paper C376/049.			

	Proceedings of International Conference on Pipework, Engineering and Operation, London: Institution of Mechanical Engineers Feb; 1989. • Repair of dents containing minor scratches , paper 9. Ninth Symposium on Line Pipe research, Houston, texas: Pipeline research Committee of the American Gas Association ; 1996. (*all the full scale test on plain dent, the dent depths were measured at zero pressure after spring back.)			
Analyze	• No published analytical methods for assessing the burst strength. • **British Gas -** <8% of Øpipe / up to 24%, has little effect on the burst strength of pipe. • **EPRG -** <7% of Øpipe, measured at pressure are acceptable provided	No method of assessment published.	No method of assessment published.	No method of assessment published.

	they are not subjected to internal pressure fluctuating. • **Recent test data** – 10% including a factor of safety on the dent depth. • **Currently research** effort to develop limit for plain dents based on strain. • **PDAM –** limit of 10% of Øpipe for the depth of an unconstrained plain dent at zero pressure / constraint plain dent subject to static internal pressure loading. • **ASME B31.8 -** limit of 6% of Øpipe includes operational considerations. •			
Result	***Limit from Burst test*** • Lowest toughness = 20J (15ftlbf) [3] • Max wall thickness = 12.7mm (0.500 in.) [3] ***Limit from Fatigue test*** • Lowest toughness = 14J	***Limit from Burst test*** • Lowest toughness = 38J (28ftlbf) [3] • Max wall thickness = 16.8mm (0.661 in.) [3] (*no measurements of the weld toughness) ***Limit from Fatigue test***	No result	No result

	(10 ftlbf) [3] • Max wall thickness = 17.4mm (0.685 in.) [3]	• Lowest toughness = 19J (14 ftlbf) [3] • Max wall thickness = 16.8mm (0.661 in.) [3] (*no measurements of the weld toughness)		
Fatigue life	• The fatigue life decrease as the dent depth increase. • Larger the dent depth, the larger the stress & strain concentration in the dent. • The higher the mean stress for a given cyclic stress range , the longer the fatigue life. • **SES –** constrained plain dent have least or same fatigue life of an unconstrained plaint dent of the same depth. • **Empirical -** to predict the fatigue life subject to cyclic pressure loading develop - **EPRG** i) based on S-N curve for the fatigue life of (longitudinal) submerged arc welded pipe in	Containing dented seam weld & dented girth weld. • Lower than plain dent/ weld in undented pipe. •	No method of assessment published.	No method of assessment published.

	DIN 2413. ii) Function of the dent depth and the pipeline geometry. iii) Dent depth after spring back measured at zero pressure. iv) **Recommended** by PDAM to use the original EPRG plain dent fatigue model. - **SES** **i)** S-N curve & stress concentration. **ii)** Stress Concentration factor develop from elastic-plastic finite element analyses. - **Rosenfeld** Required data not given in the published test data. - **Shell**. Required data not given in the published test data.			

behaviour - Spring back & reround • **System -** Introduced into pressurized pipe more than unpressurized pipe • **Pressure -** Reround as internal pressure increase. • **Affected** – nature of the lateral support around the pipe during indentation. • **Thickness -** Thinner wall pipe more easy to spring back than thicker wall pipe.	Empirical spring back correction factor developed by • Battelle (include internal pressure) • The EPRG (easily used and recommended by PDAM) • Gasunie (transverse dents) Based on the depth of the dent and do not address all the factors that would be expected to be relevant. Semi-empirical rerounding model develop by **Rosenfeld** • But, data is not available in the published test data (although in principle , it more accurate that empirical correction factor)	Less than smooth dent
Long dent	• Maximum stress & strain – at the base of the dent. • Greater • Fatigue crack – longitudinally oriented in the middle of the dent. • **More** springback&reround	
Short dent	• Maximum stress & strain – occur on the flanks of the dent. • Lower • Fatigue crack – longitudinally oriented on the flank of the dent. • **Less** springback&reround.	
Quantitative information	Full scale test for **Spring back & rerounding** behaviour of dents • Battelle • EPRG • Det Norske Veritas • Gasunie • Stress Engineering Services (SES) The **ONLY PUBLISHED** quantitative information	

	• Stress Engineering Services (SES)
Other	Minimum toughness – 2/3 specimen thickness upper shelf Charpy V-notch energy. [3] Toughness decrease the burst strength of the defect will decrease. Failure due to plastic collapse , then flow stress should be the ultimate tensile strength. Leis – full size equivalent upper shelf Charpy impact energy between 60 to 75 ftlbf (81 J and 102 J) [3].

[1] this is an approximation definition of a kinked dent.