Nitriding of A316 Stainless Steel Pipe with Improvement of Corrosion Resistance

by

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16290

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
Mechanical Engineering

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CERTIFICATION OF APPROVAL

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Approved by,

(Assoc. Prof. Dr. Patthi Hussain)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2016

CERTIFICATION OF ORIGINALITY

This is to certify 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.

(MOHAMMAD FADZIL BIN YOUSOF KUNJU)

ABSTRACT

Nitriding process is a process that can enhance mechanical properties as well as the corrosion rate of steels. Hence due to this reason, nitriding had become one of the desirable method used for surface treatment in producing material with high quality of performance. The main purpose of this project is to enhance the corrosion resistance of austenitic stainless steel which used normally in oil and gas industry. This project is mostly concentrating on conducting the gas nitriding process and investigation is made to define the effect of nitriding process on the pipe in terms of corrosion resistance and microstructure. The high temperature gas nitriding process was subjected on A316L austenitic stainless steel at the temperature of 1200°C for 8 hours holding time. The samples were undergoing the metallography process to see and compare of the microstructure of treated and untreated AISI 316. The microstructures of the nitrided stainless steel were found they are twin formation which can be can divided into two patterns which is suspended twin and transgranular twin. Besides that, the samples undergo Energy Dispersive Spectrometer (EDS) test in order to check the nitrogen content after the stainless steel was nitrided. The nitrogen content is expressed in duration curve which shows that the diffusion of the nitrogen throughout the whole pipe after nitriding process are uniformed. Moreover, the immersion test was carried out to compare the corrosion rate before and after nitriding. The Immersion Test on the stainless steel shows the decrease in corrosion rate on the nitrided stainless steel hence it shows increased in corrosion resistant.

ACKNOWLEDGEMENT

First and foremost, I would like to express my greatest gratitude to Allah S.W.T for His blessings during my strenuous times and for His gift of the health and the ability for me to complete this Final Year Project. In these two semesters, I have been received generous supports from several persons who contributed in different ways to the process of completion of this project.

I would like to take this opportunity to express my profound gratitude and deep regard to my supervisor, Assoc. Prof. Dr. Patthi Bin Hussain for his exemplary guidance, monitoring and constant encouragement throughout the course of this project. The blessing, guidance and help given by him time to time shall carry me a long way in the journey of life on which I am about to embark.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Stainless steels are widely used in the Oil and gas industry because of its attributes in withstanding highly corrosive environment and also of its excellent mechanical properties. In addition, stainless steel also have a wide temperature ranges that makes stainless steels become highly available in upstream and downstream applications from productions to transport and storage, refineries, LNG plants and petrochemical units. Because of this, stainless steel has replaced traditional carbon steel in many applications. These iron-based alloys contains high level of chromium which will form an invisible, adherent, protective and self-healing chromium-rich oxide on the surface of the metal in order to prevents further corrosion by blocking oxygen diffusion into the metals internal structure.

However, the normal phase of stainless steel have a poor mechanical properties in certain conditions and environments. Hence, nitrogen is diffused into the surface of the stainless steel to enhance mechanical properties as well as the corrosion rate of steels. This process are called Nitriding process and there are three main method normally used including Gas Nitriding, Salt Bath Nitriding and Plasma Nitriding

1.2 PROBLEM STATEMENT

Through oil is not corrosive in itself, but the production takes place in a very highly corrosive environments. Working tube piping is used for transport of flammable oil and gas from the reservoir to the downstream area are under continuous exposure to harsh marine environment. Even though austenitic stainless steel are commonly used in offshore subsea conditions, there have been reports of wear and corrosion under conditions where these were not expected. Figure 1 below shows the tertiary recovery method of Enhanced Oil Recovery (EOR) where working tubes are used to connect the oil bank to the production well.

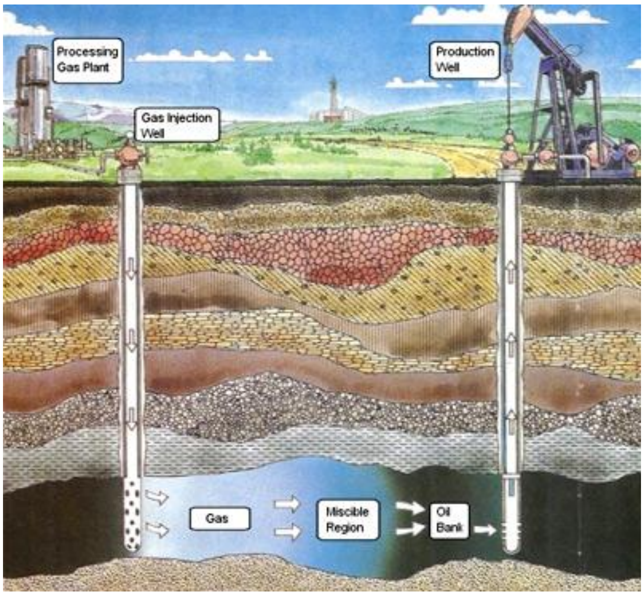


Figure 1: Gas Injection Method

This stainless steel used as the working tube is exposed to CO_2 and H_2S gases that contain in the crude oil which leads to sweet and sour corrosion. Meanwhile, unpredictable presence of chlorine containing environment such as sea water also leads to pitting and crevice corrosion. High operating temperature during operation which leads to formation of intermetallic phase, sensitization and weld decay. This is the reason why nitrogen is been introduced into the surface of stainless steel in order to increase the hardness as well as the corrosion and wear resistance.

1.3 OBJECTIVES

The objectives of this project are:

- To enhance the corrosion resistance of austenitic stainless steel by using Nitriding method.
- To identify the uniformness of the nitrogen diffusion during the gas nitriding process.
- To compare the microstructure of the materials before and after been nitride.

1.4 SCOPE OF STUDY

This project is mainly focusing on conducting the gas nitriding on the A316 Austenitic Stainless Steel pipe in order to improve corrosion resistance. During the experiment, the uniformness distribution of the nitrogen been diffused will be observed. The study are made to determine the effect of nitriding process on the pipe in terms of corrosion resistance and microstructure. The evaluation will be made by comparing the nitrided pipe with the unnitrided pipe.

CHAPTER 2

LITERATURE REVIEW

2.1 STAINLESS STEEL

Stainless steels are considered as the back bone of modern industry as it is widely used in Oil and Gas, Medical, Pharmaceutical, Transport and other industries for corrosion or oxidation resistant purposes. Stainless steel is an alloy made up of iron and a minimum of 10.5% Chromium. The Chromium acts as the ‘passive layer’ where it forms an oxide layer on the surface of the steel [6]. This layer will help in preventing any further corrosion take place on the surface of the material. Higher percentage of chromium in the stainless steel causes it to have a higher resistance to corrosion [5]. Besides, Stainless steel also contains a different amount of carbon, silicon, manganese and other alloying elements [9]. Alloying elements such as nickel, titanium, copper and molybdenum are mixed into the steel to enhance its properties such as strength, cryogenic toughness, corrosion resistance and formability.

Stainless steel was discovered by Sheffield metallurgist Harry Brearleyin 1913. The experiment was done to uncover new technologies for weapon materials that are used to prolong the life of gun barrels which were corroding away quickly. Brearley found that 13% of Chromium steel had not corroded after few months and decided to call his new discovery as ‘Rustless Steel’. Stainless steels can generally be categorized into 5 categories which are Ferritic, Austenitic, Martensitic, Duplex, and Precipitation-Hardening [6].

Ferritic Stainless steel cannot be hardened by heat treatment and not as formable as austenitic stainless steels. For Austenitic Stainless Steel, their microstructure is formed from the combination of Manganese, Nickel and Nitrogen [9]. These combinations will cause the steel to have a better weldability and formability characteristics. On the other hand, Martensitic stainless steels have up to 1% of carbon and a chromium composition as same as the Ferritic steels. Therefore, it allows them to tempered and hardened while having generally low weldability and formability. Both Ferritic and Martensitic are magnetic.

Duplex is simply explained as half ferritic and half austenitic. Thus, it has a higher strength as compared to the other two. Lastly, Copper, Niobium and aluminium are added to steel in order to form Precipitation-Hardening stainless steel. This type of stainless steel has a very high strength and designed to be formable in the solution annealed condition.

2.1.1 AUSTENITIC STAINLESS STEEL

There are a number of groups exist in stainless steels. The main group stainless steels is austenitic stainless steels where it can be classed into five different groups, Cr-Mn grades, Cr-Ni grades, Cr-Ni-Mo grades, high performance austenitic grades and high temperature austenitic grades [9]. It has high corrosion resistance in most environments. They also have a good formability, weldability and good impact strength at low temperature making them useful in cryogenic applications [4]. Cold working can strengthen austenitic stainless steels significantly.

Austenitic stainless steels contain between 16 to 25% of Chromium and nitrogen in solution [6]. This two elements contribute to high corrosion resistance to the materials. Austenitic stainless steel is in the face-centered cubic (F.C.C) atomic structure. It is formed from the addition of nickel into the ferrite stainless steel. Thus, this structure increases the ductility property of stainless steel.

Austenitic Stainless steel classified as 200 and 300 series. For 300 series, Type 316 and Type 304 grades are differed by its physical and chemical properties. So does straight grades, L grades and H grades.

Straight grades is define when the material consist maximum of 0.08% of carbon while L grades shows that the stainless steel is a low carbon material [9]. For H grades, the composition of the carbon is within 0.04% to 0.10%. Usually, H grade is used for high temperature application where high carbon act to increase the strength of the stainless steel [4]. Typical applications of Austenitic Stainless steel are pipe, structural supports, architectural uses and fasteners. However, it is the most expensive type of stainless steel due to the higher alloy content.

2.2 CORROSION IN STAINLESS STEEL

Even though stainless steel is proven more resistant to corrosion than other ordinary carbon or alloy steels, in certain condition it still can be corroded. Therefore, a sharp acumen is used to choose the best grade of stainless steel and the appropriate material for a given applications. The corrosion happen when the materials react with the environment as they being unstable thermodynamically [5]. In the oil and gas industry, the most common form of corrosion occurs when the stainless steel comes in contact with the aqueous environment and rusts [2]. The corrosion rate is depend on the corrosivity of the environment which either corrode severely or corrode at a very low rate due to the formation of passive film particularly stainless steel. The corrosion in Oil and Gas Pipelines usually influenced by the CO_2 and H_2S gasses content, temperature, water chemistry, compositions, flow density and conditions of steels [1]. These types of materials fail to perform with expected strength and corrosion resistance when there is destruction of the passive film either uniformly or at a localized spot. Hence, the breakdown of the passive film will lead to various types of corrosion such as pitting, crevice, stress corrosion cracking, intergranular corrosion and corrosion fatigue at the stainless steel.

Crevice corrosion is a major problem to stainless steel since the occurrence is unpredictable in chlorine containing environments such as in the sea water and other environments used in oil and gas industries [5]. Other than that, stress corrosion cracking is a relatively rare form of corrosion which often occurs in a very specific combination of tensile stress, temperature and corrosive stress. This is known as stress corrosion cracking. One of the examples is sulphide stress cracking where it contains hydrogen sulphide. While for the intergranular stress corrosion, it is usually happen in the heat affected zone such as at the welding region. Corrosion problem will leads to material degradation and hence will also result in the loss of mechanical properties such as hardness, strength and so on [3].

2.3 GAS NITRIDING PROCESS

Nitriding is a surface hardening process, where the steel surface or the metal parts are being diffused with nitrogen at relatively low temperature [8]. This process can enhance mechanical properties as well as the corrosion rate of steels. In nitriding process, it does not require any phase change and the molecular structure of the materials does not change as well. There are three main methods used for nitriding process which are, gas nitriding, salt bath nitriding and plasma nitriding.

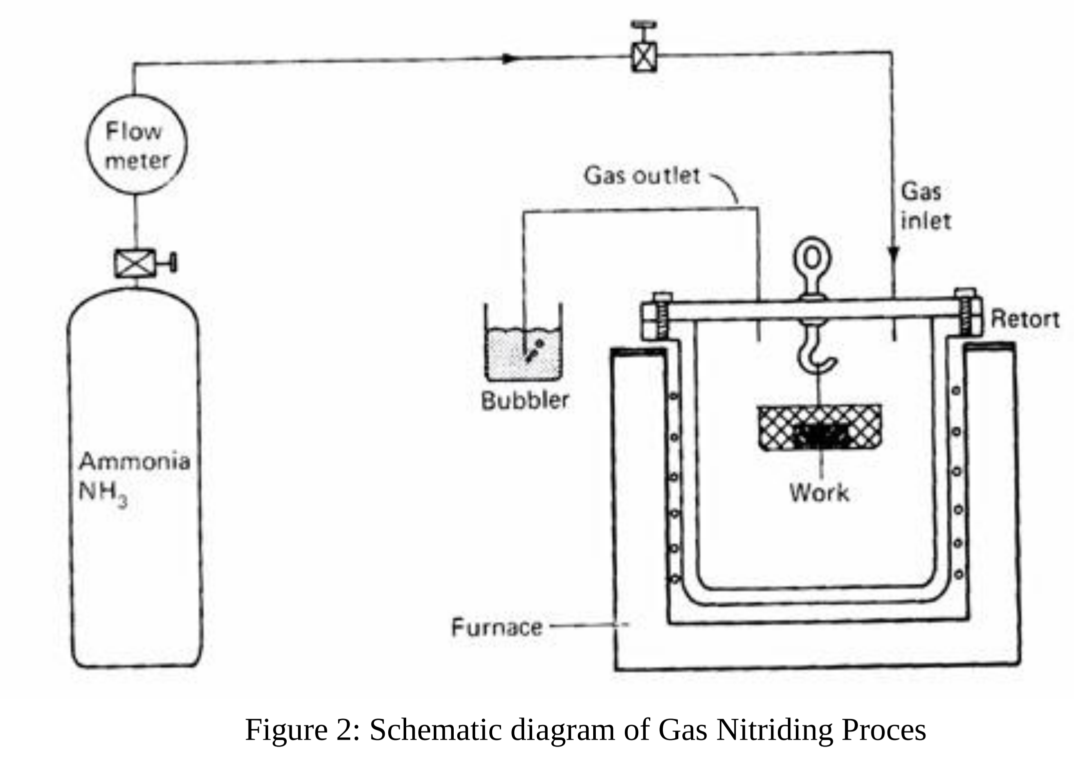


Figure 2: Schematic diagram of Gas Nitriding Proces

In gas nitriding, ammonia (NH_3) is usually used as the donor in nitrogen rich gas. Therefore this type of nitriding is known as ammonia nitriding process. When ammonia are heated, it will dissociates into nitrogen and hydrogen. Later, nitride layer is formed when the nitrogen diffuses on the steel surface [8]. The thickness and phase constitution of the resulting nitriding layers can be selected and the process optimized for the particular properties required [7]. After nitriding, a compound layer and an underlying diffusion zone are formed near the surface of the steel. The compound layer, also known as the white layer, consists predominantly of Fe_3N and Fe_4N phases and can greatly improve the wear and corrosion resistances [7].

The temperature of nitriding process is lower than the alloy steels transformation temperature. Firstly, heat is applied to the parts to be nitride followed by hot active nitrogen which is between 450-590℃ [8]. The temperature used is lower than the final steel temperature. This is to ensure that the nitriding process will not affect the mechanical properties of the base metal and to produce a very good wear resistance steel. Conventional nitriding at temperature higher than 773 K (450°C) degrades the corrosion resistance of the steels by the chromium nitrides formation which consumes the dissolved chromium for a passive state. As a result, the steel produced are of a very high strength with extremely good wear resistance. Furthermore, the nitride specimens with composition of Fe_3N and Fe_4N phases were found having an increase in hardness, wear and corrosion rate, and fatigue limit [8].

CHAPTER 3

METHODOLOGY

3.1 FLOW CHART

Figure 3 below shows the project flow chart.

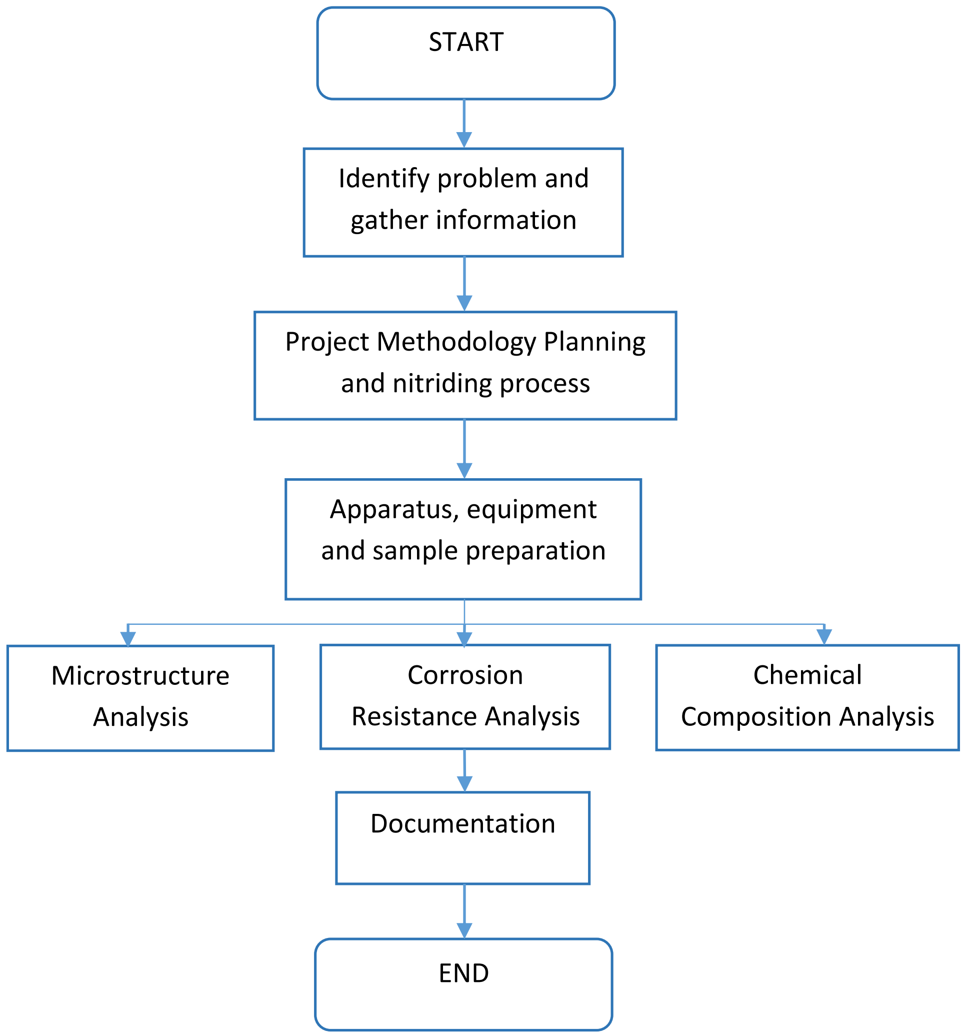


Figure 3: Project Flow

3.2 GANTT CHART AND KEY MILESTONE

Table 1: Gantt chart

No	Activities	Due Date	Semester 1 (FYP 1)													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Material Purchase	2 weeks														
2	**Start Lab Work (Sample Preparation)**	Week 11														
3	Nitriding of A316 Stainless Steel Pipe	3 weeks														
No	Activities	Due Date	Semester 2 (FYP 2)													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
3	Optical Microstructure Analysis	Week 1														
5	SEM Cross Section Analysis with EDS	Week 2														
6	Corrosion Rate Analysis	Week 3														
7	Result Analysis	3 weeks														
8	Report Completion	4 weeks														

Table 2: Project Key Milestone

Deliverable	Target Week	Responsibility
Material Purchase	Week 9- Week 10	Material with dimension of 1 metre should be purchased.
Lab Work Start	Week 11	Sample should be cut into 2 pieces with dimension of 50mm each.
Nitriding of the samples	Week 12- Week 14	All samples should be nitride using furnace chamber for 8 hour.
Result Analysis	Week 6- Week 8	All the result obtain during the Analysis process should be gathered and analyse.
Report Completion	Week 12- Week 14	Submit the completed report to course coordinator and supervisor for grading.

3.3 METALLOGRAPHY

The project are actually a laboratory-based experiment and sequence of methodology have been set in order to achieve the objective of the project. Therefore the methodology compromises of:

3.3.1 SECTIONING

Equipment : Abrasive Cutter

Procedure : 1. Abrasive cutter is used to cut the pipe into 5 pieces.

2. Before the cutting process start, the pipe is clamped and locked.

3. For the safety purposes, the machine cover is closed.

4. After the cutting process finished, the pipe is taken out.

Figure 4: Abrasive Cutter Machine

3.3.2 HIGH TEMPERATURE NITRIDING PROCESS

Equipment : Tube Furnace

Procedure :

1. The pipe is immersed into Hydrochloric Acid solution for 15 minute to remove the native oxide layer.
2. The temperature of the furnace is set to 1200℃ and the process took around 8 hours.
3. Nitrogen gas is flowed into the furnace once the temperature reach 1200℃ and the gas valve is closed and the furnace is left to cool down once complete.
4. After the process is done, the specimen is heated up to 700℃ to avoid from sensitization.
5. The furnace is opened and the sample is taken carefully.

Figure 5: Tube Furnace

3.3.3 MICROSTURCTURE INVESTIGATION

Equipment : Optical Microscope (OM)

Procedure : 1. The optical microscope and computer system is switched on.

2. The sample is placed under the magnifying glass.

3. The image is focused, captured and saved in the computer.

4. The optical microscope and computer system is switched off.

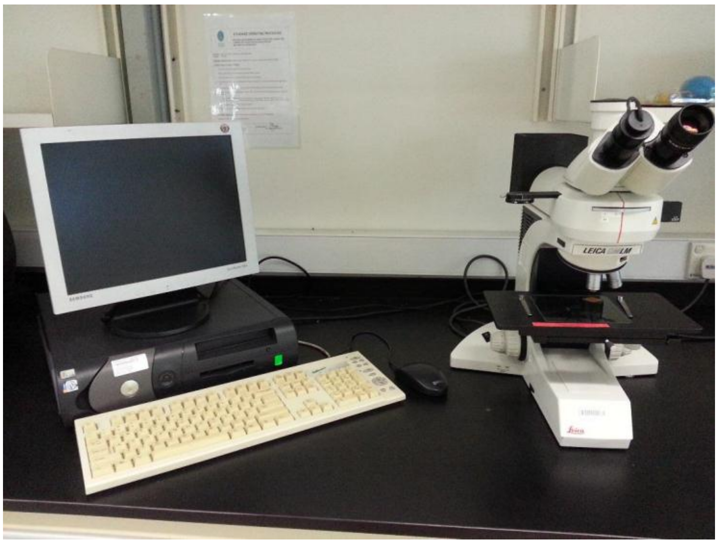


Figure 6: Optical Microscope

3.3.4 SEM CROSS SECTION ANALYSIS WITH EDS

Equipment : Scanning Electron Microscope (SEM)

Procedure : 1. The sample is placed in the machine.

2. Using camera magnifications, the thickness, microstructure and chemical compositions are obtained.

3. The collected data is saved.

3.3.5 CORROSION RATE ANALYSIS

Equipment : Immersion Test (Weight Loss)

Procedure : i. Preparation of samples (Based on ASTM G48)

1. Austenitic Stainless Steel is cut into 1 cm (length) x 1 cm (width) x 0.5 cm (height).

2. 2 experiments are conducted where each experiment requires 1 sample (Immersion test).

3. 2 samples are cut using abrasive cutter.

4. The samples are later rinsed with alcohol and acetone.

5. The samples are put in the vacuum chamber to prevent corrosion.

ii. Preparation of Solution (Based on ASTM G48)

1. 600mL of distilled water will be filled into a beaker.

2. 6% wt of FeCl will be measured using the weighing machine. (6% FeCl = 68.72 g)

3. The 68.72g NaCl is put into the 600mL distilled water and stirred by using magnetic stirrer.

4. Then, 1% of HCl is added into solution. (1% HCl = 16mL)

5. The solution is put into a glass cell.

iii. Immersion Test (Based on ASTM G48)

1. The weight and total surface area of the samples were measured before immersion test.

2. After immersion test for 48 hours, the sample was removed from solution.

3. Cleaning process was carried out and the weight loss was measured.

Figure 7: Immersion test

CHAPTER 4

RESULT AND DISCUSSION

4.1 METALLOGRAPHY ANALYSIS

In this project, The A316 stainless steel welded pipe was used to be the samples. The specification of the pipe is as in Table 3 below.

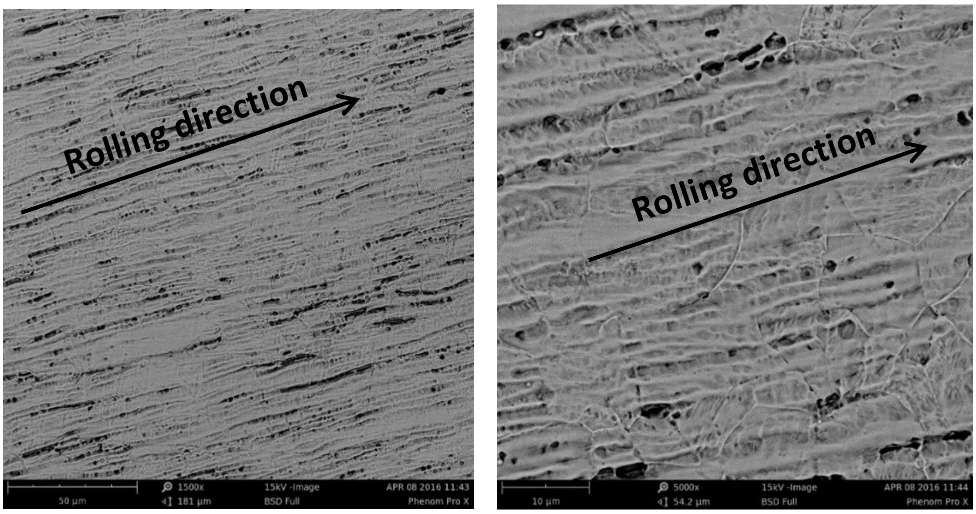
Table 3: Sample Specification

Specification	Dimension (mm)
Length	50
Diameter	33.4
Thickness	3.8

The A316 austenitic stainless steel were nitrided with NH_3 for 8 hours. In order to make the comparison between nitride and unnitrided pipe, the samples are prepared. The preparation of the samples includes the sectioning, grinding, polishing and mounting processes. The samples were cut into pieces which quantify around 1 mm and prepared as Figure 8.

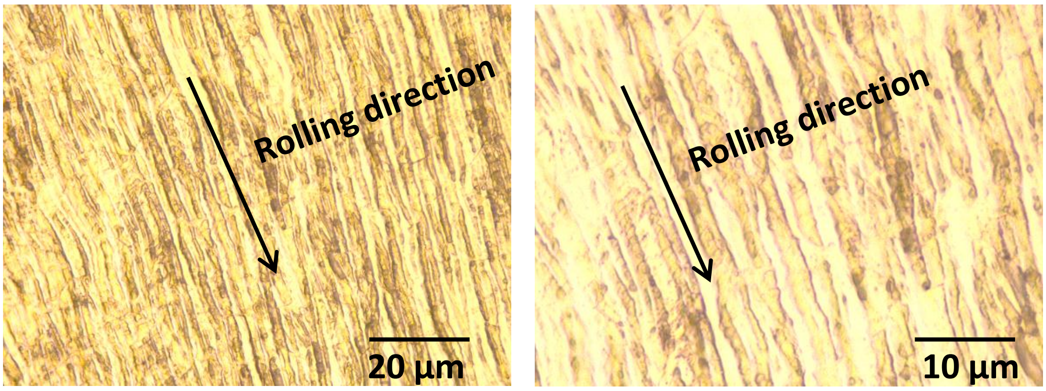
Figure 8: The prepared samples for the analysis

Figures 9 and 10 below show the microstructure images of the unnitrided and nitrided A316 stainless steel pipe under various magnifications.



(a) (b)

Figure 9: Microstructure of the unnitrided Stainless Steel using SEM

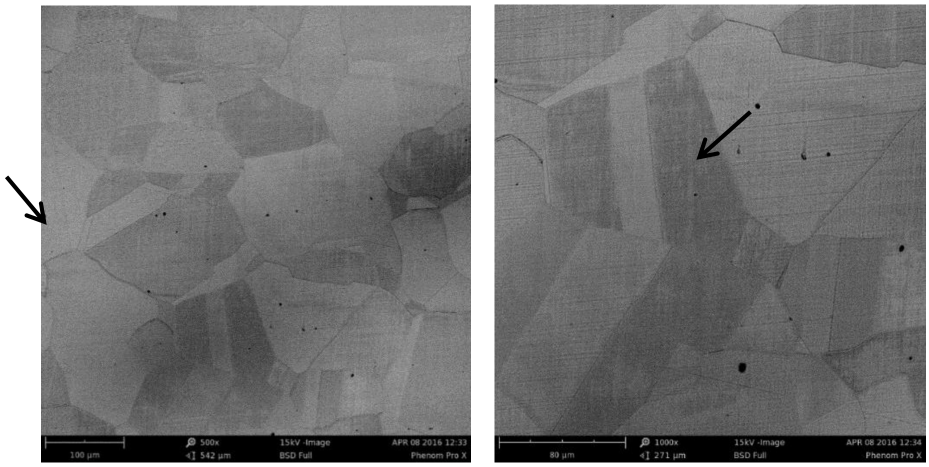


(a) (b)

Figure 10: Microstructure of the nitrided Stainless Steel using OM

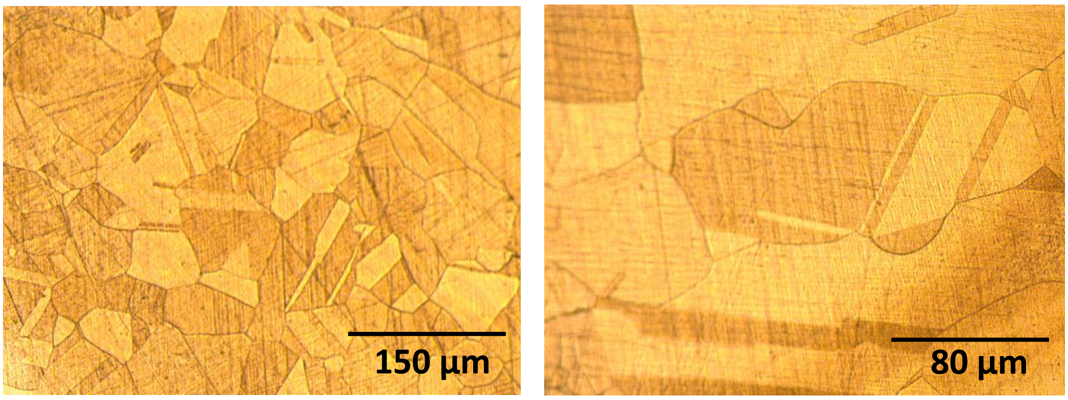
The Figure 9 and 10 show the microstructure of unnitrided sample of A316. The rolling effect of cold working can be seen and due to the poor surface preparation, the optical microscopy failed to reveal the microstructure of the sample. The cold work means to mechanically deform a metal at a temperature below the recrystallization temperature to reduce in cross-sectional area or thickness of the metal by processes such as rolling. Meamwhile, from the figures above it can be clearly seen that there are voids on the surface of the unnitrided Stainless Steel.

Figures 11 and 12 below show the microstructure images of the nitrided A316 stainless Steel Pipe under certain magnification. From the microstructure images, the comparison between both nitride and unnitrided stainless steel were made.



(a) (b)

Figure 11: Microstructure of the nitrided Stainless Steel using SEM



(a) (b)

Figure 12: Microstructure of the unnitrided Stainless Steel using OM

Figure 11 and 12 show the microstructure of the nitrided A316 which is a typical structure for austenitic stainless steel when being treated in this condition. The twin formation is observed in the microstructure of the austenitic stainless steel. The formation of twinning is observed in multiple slip systems especially in low stacking fault energy (SFE) face-centered cubic metal like A316 stainless steel. Twinning is generally considered as a deformation mechanism for the low SFE metals such as ASS or TWIP steel. Grains without mechanical deformation twins contain a high density of planar dislocation structures.

Besides the twin formation, based on the microstructure of the samples with nitriding method, the size of grain is increasing compare to the size of grain before it was nitrided. This means all of nitrogen absorbed into the specimen was in solid solution of austenite without precipitating any nitrides. On heating steel through its critical range, transformation to austenite takes place. The austenite grains are extremely small when first formed, but grow in size as the time and temperature increased during the nitriding. Grain size can be measured using an optical microscope on a transverse metallographic mount (because rolling elongates the grains) by counting the number of grains within a given area, by determining the number of grains that intersect a given length of a random line, or by comparison with reference pictures. Finally, from the result above it is clearly seen that all the voids on the unnitrided stainless steel were removed once nitriding took place.

4.2 UNIFORMNESS ANALYSIS

In order to determine the uniformness of nitroges gas diffusion throughout the whole pipe, the energy dispersion spectrometre (EDS) analysis was carried out using scanning electron microscope (SEM). This instrument was used to analyse the chemical composition of the stainless steel. The nitrided pipe was cut into 5 samples which are as shown in the Figure 13 below.

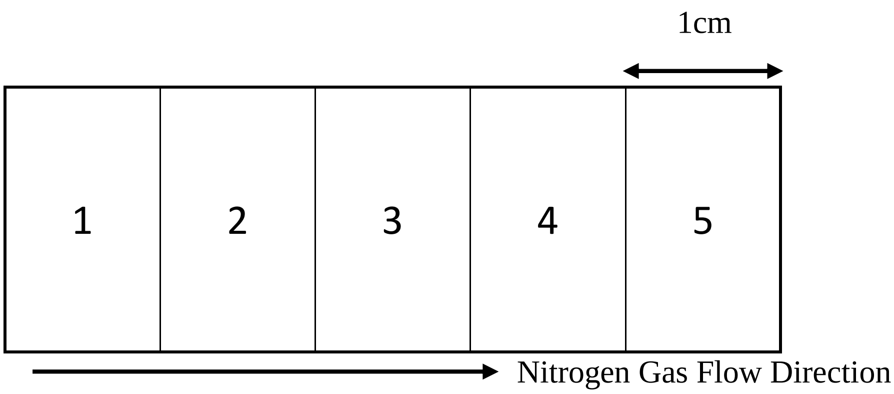
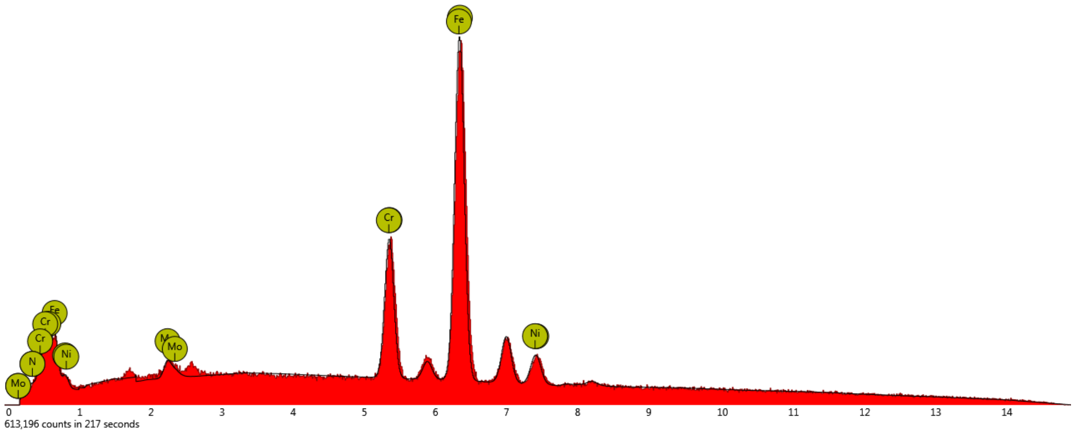


Figure 13: Nitrided sections of SS316 pipe which is separated into 5 samples

Sample 1

Table 4: Chemical Composition of Sample 1



Element	Symbol	Percentages
Iron	Fe	69.1
Chromium	Cr	16.4
Nickel	Ni	10.2
Molybdenum	Mo	2.1
Nitrogen	N	2.0

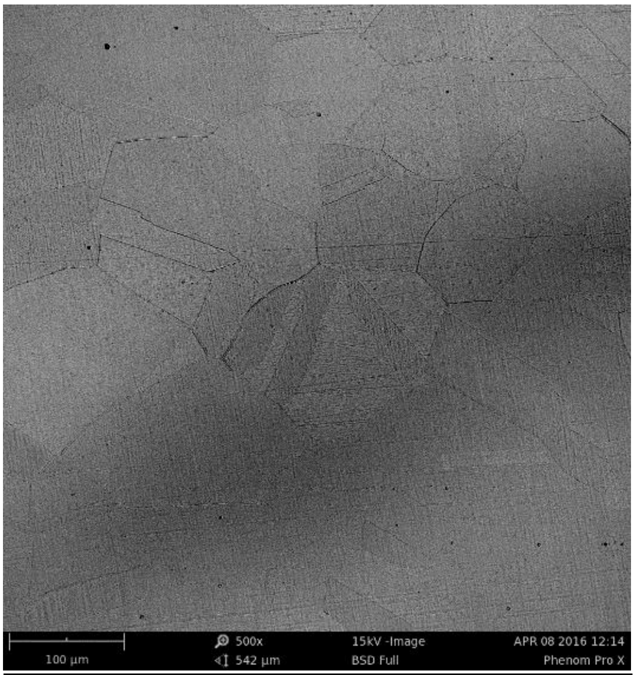
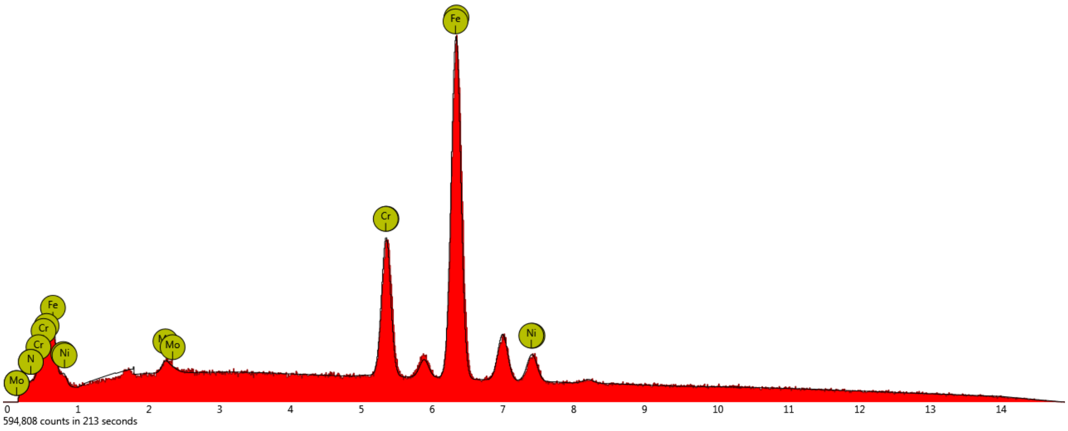


Figure 14: Microstructure of Sample 1

Sample 2

Table 5: Chemical Composition of Sample 2.



Element	Symbol	Percentages
Iron	Fe	69.2
Chromium	Cr	16.2
Nickel	Ni	10.1
Molybdenum	Mo	2.1
Nitrogen	N	1.8

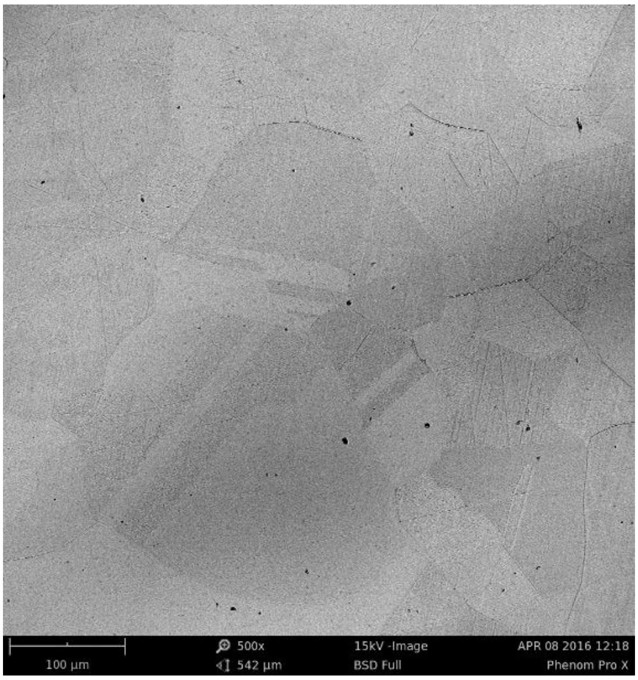
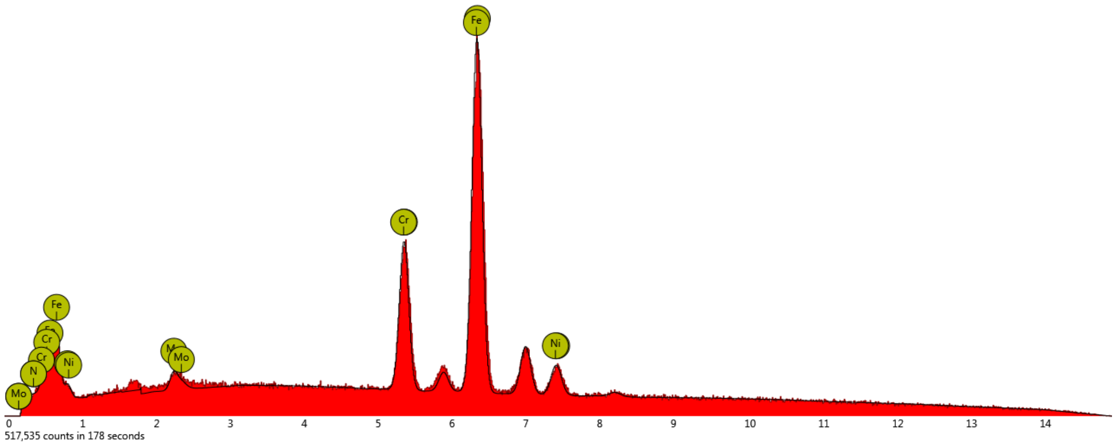


Figure 15: Microstructure of Sample 2.

Sample 3

Table 6: Chemical Composition of Sample 3.



Element	Symbol	Percentages
Iron	Fe	68.2
Chromium	Cr	16.6
Nickel	Ni	10.7
Molybdenum	Mo	2.7
Nitrogen	N	1.9

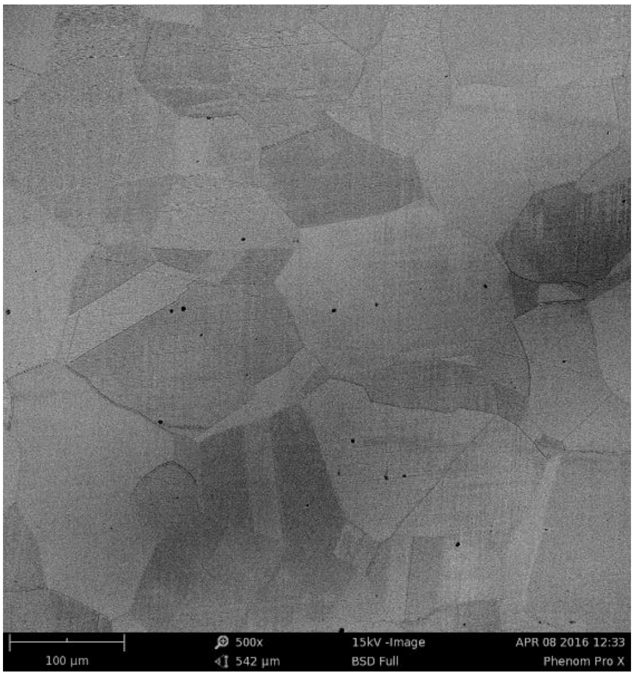
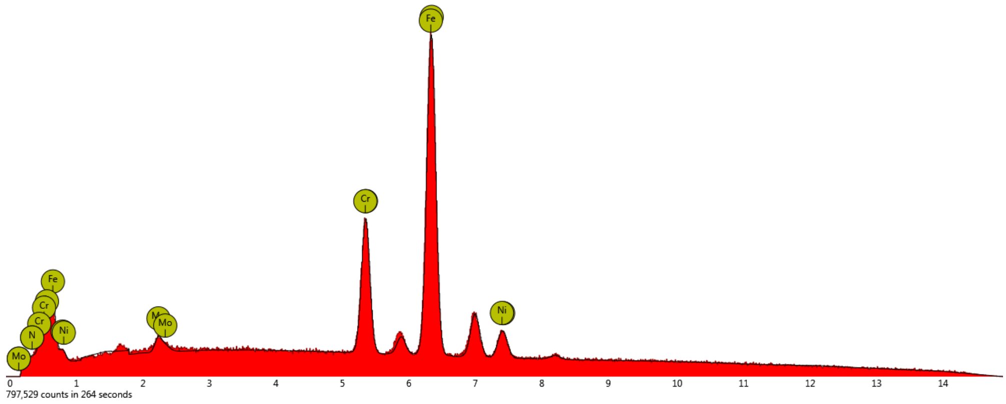


Figure 16: Microstructure of Sample 3.

Sample 4

Table 7: Chemical Composition of Sample 4.



Element	Symbol	Percentages
Iron	Fe	67.7
Chromium	Cr	16.5
Nickel	Ni	10.6
Molybdenum	Mo	2.7
Nitrogen	N	1.9

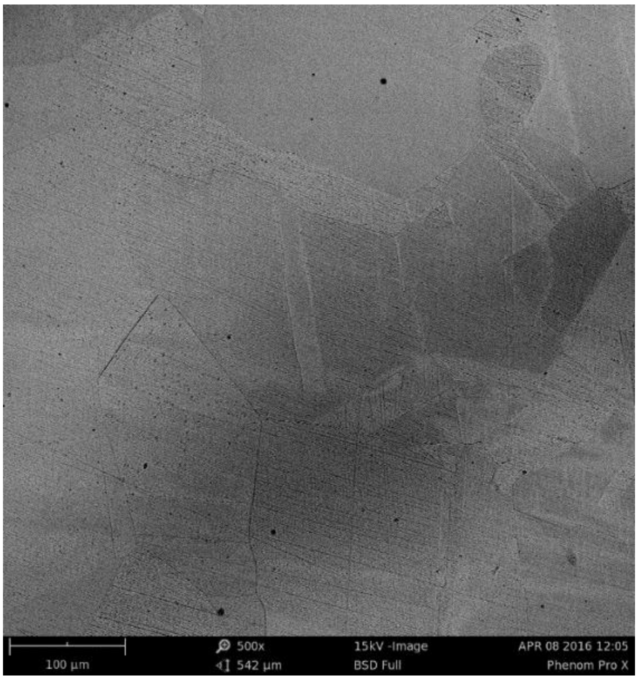
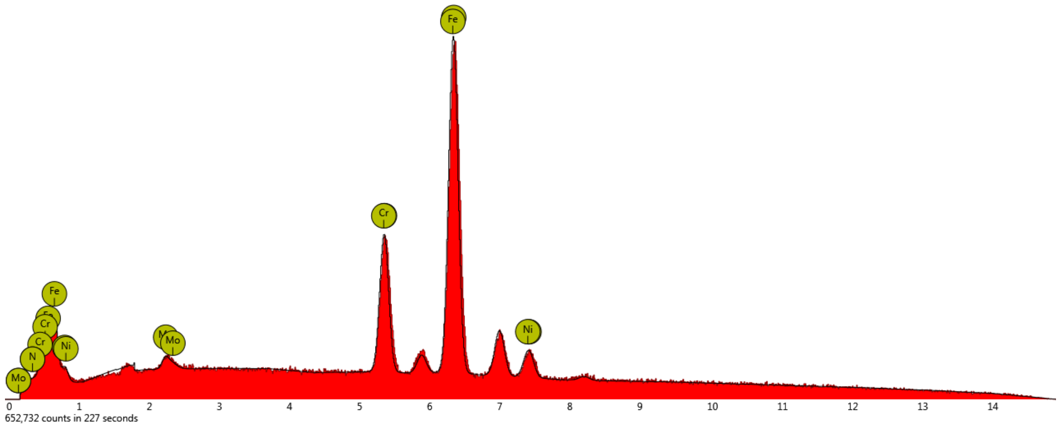


Figure 17: Microstructure of Sample 4.

Sample 5

Table 8: Chemical Composition of Sample 5.



Element	Symbol	Percentages
Iron	Fe	68
Chromium	Cr	16.2
Nickel	Ni	10.9
Molybdenum	Mo	2.9
Nitrogen	N	2.0

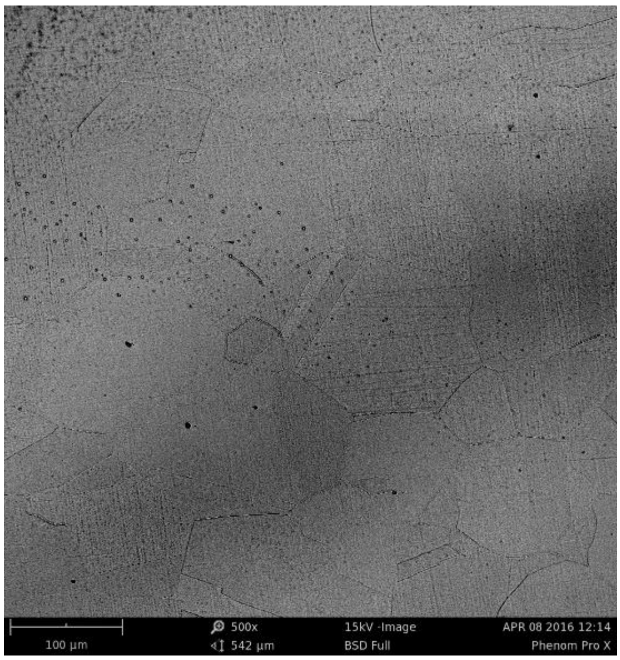


Figure 18: Microstructure of Sample 5.

Based on the experimental result, the nitrogen composition is selected and the curve fitting is done which are as below.

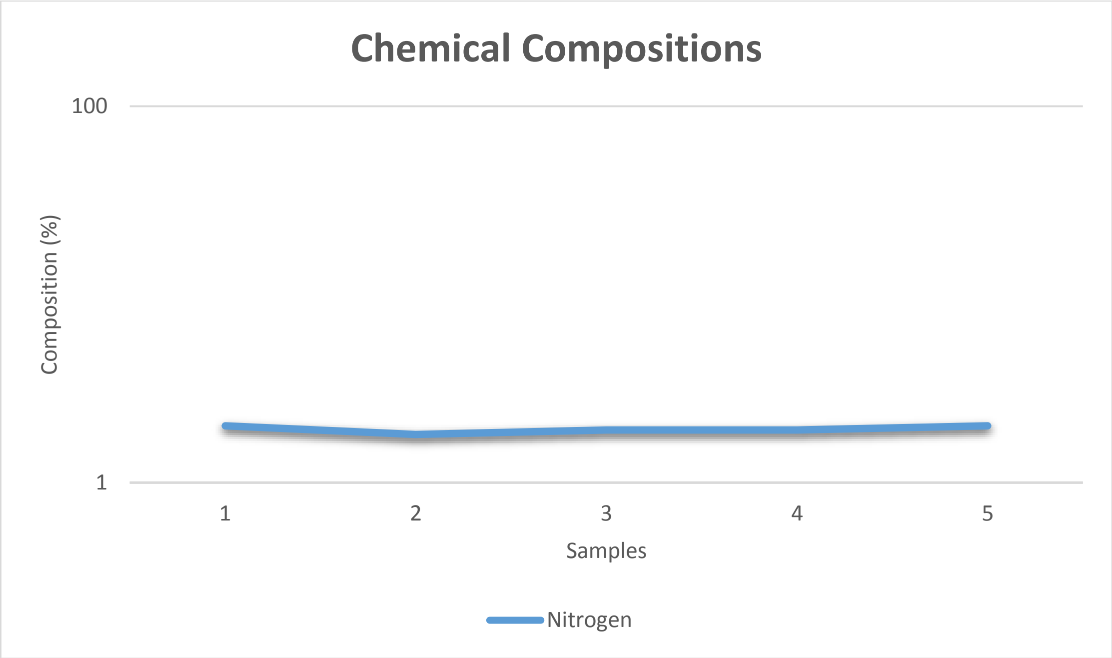


Figure 19: Chemical Composition of nitride Stainless Steel

From the result obtained, it can be obviously seen from the chemical composition of all 5 samples, the diffusion of nitrogen gas throughout the whole nitride pipe are almost similar. Besides that, from the microstructure images obtained, it shows clearly that the size of grain boundary of the samples is approximately similar. Hence, these prove that the diffusion of nitrogen into A316 stainless steel is uniformed. The uniformed distribution of nitrogen by using gas nitriding method shows that the uniformed increase in hardness and mechanical properties of the treated stainless steel.

4.3 Corrosion Analysis (Immersion Test)

The corrosion testing was done to compare the different of corrosion rate in both nitrided and unnitrided Stainless Steel. As the corrosion definitions is the degradation of material due to the reaction with the environment, the test was carried out to analyse the weight loss of the material by using immersion test where the result of weight loss is observed and calculated as below. In order to gain the corrosion rate (CR), this formula was used:

$$CR = \frac{W \ x \ k}{D \ x \ A \ x \ t} \qquad \text{eq. 1}$$

where:

W = weight loss in grams

k = constant (22,300)

D = metal density in g/cm3

A = coupon area (inch2)

t = time (days)

Unnitrided Stainless Steel

Table 9: Corrosion rate calculation of Unnitrided pipe

Formula	**K*W**	**A*T*D**	**(K*W)/(A*T*D)**
corrosion rate (mm/yr)	7.78E+04	2.77E+03	**28.04709453**
	Area ,A	7.2	cm^2
	density ,D	8.03E+00	g/cm^3
	K	8.76E+04	

Table 3: Weight Loss of Unnitrided pipe.

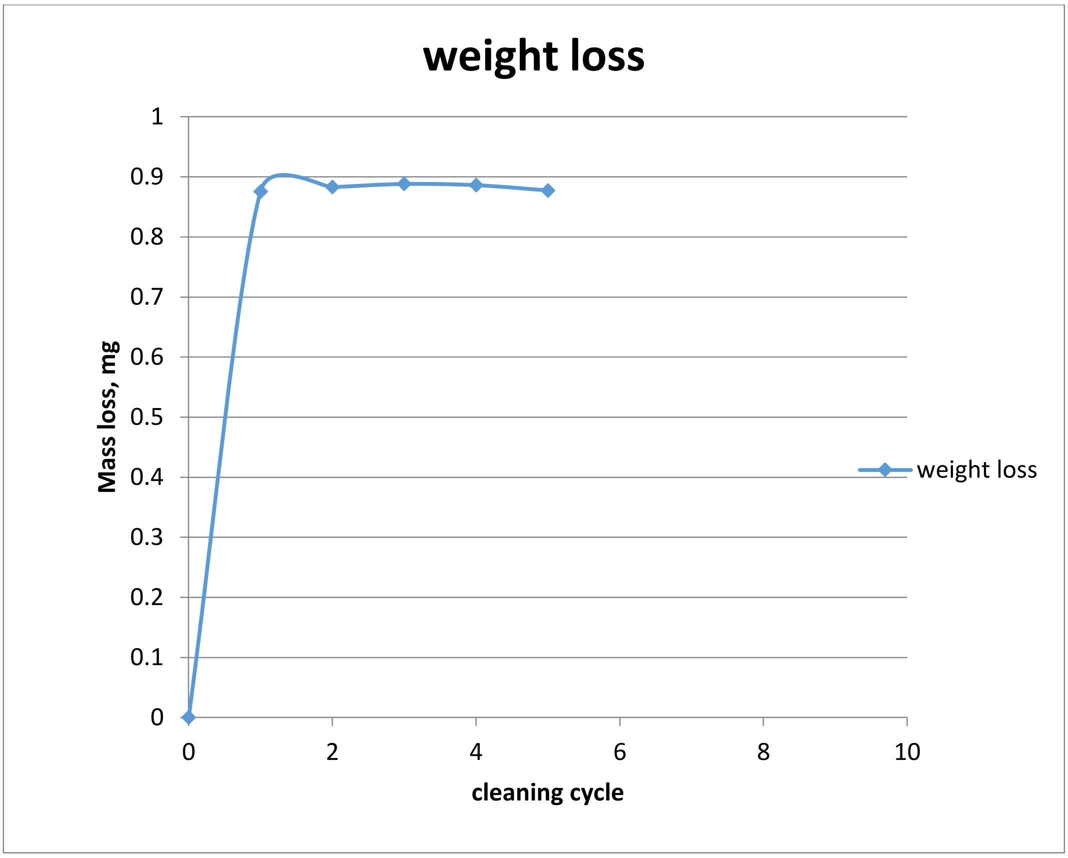


Figure 20: Weight Loss of distribution Unnitrided pipe

Nitrided Stainless Steel

Table 10: Corrosion rate calculation of Nitrided pipe

Formula	K*W	A*T*D	(K*W)/(A*T*D)
corrosion rate (mm/yr)	1.00E+05	4.78E+03	**20.9700778**
	Area ,A	12.4	cm^2
	density ,D	8.03E+00	g/cm^3
	K	8.76E+04	

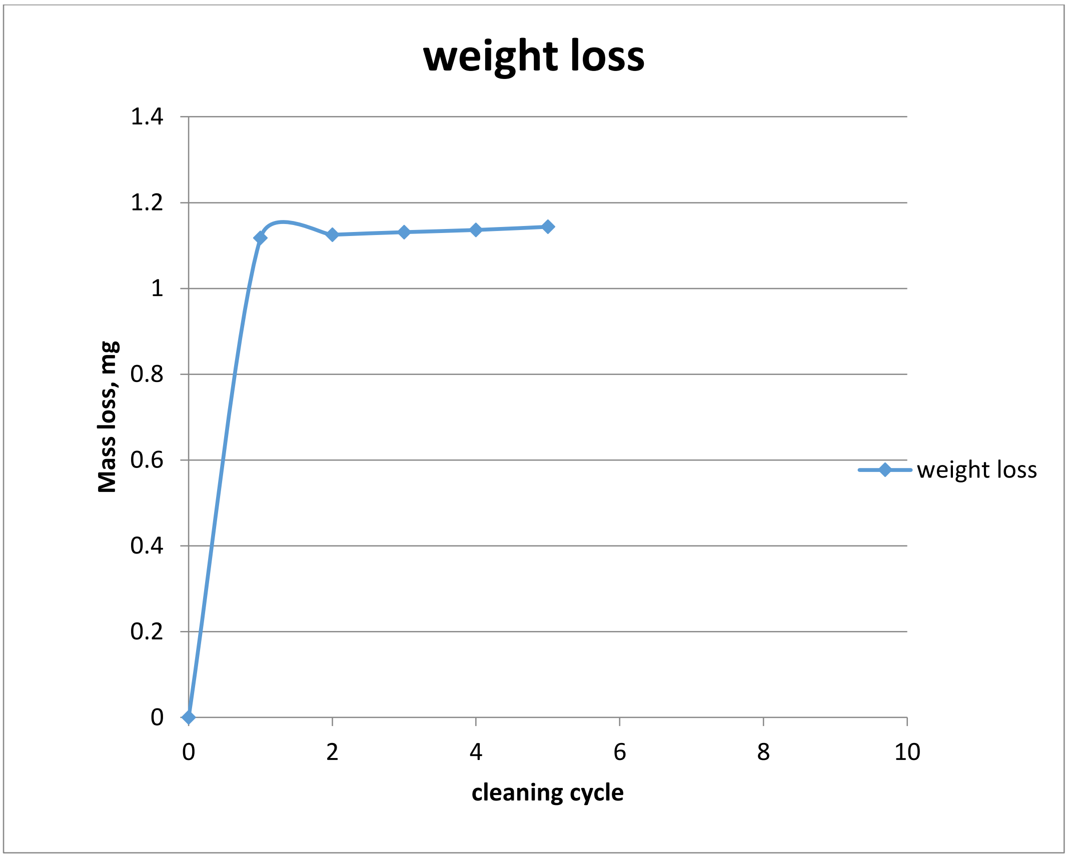


Figure 21: Weight Loss of distribution Unnitrided pipe

Based on the calculated value from the table above, the corrosion rate of nitrided stainless steel is found less than the unnitrided stainless steel. This shows that there are increased in corrosion resistance as the value of corrosion rate of the unnitrided is 28.05 mm/yr. Meanwhile, for the nitrided stainless steel is 20.97 mm/yr. This concludes that the corrosion rate is decreased when the stainless steel is nitrided

CHAPTER 5

CONCLUSION AND RECOMMEDATION

5.1 CONCLUSION

As a conclusion, this project research was carried out to improve the corrosion rate of the pipe by using nitriding method. Hence, from the result it can be proved that the nitrided A316 austenitic stainless steel have a better corrosion resistance compare to the unnitrided samples. Besides, the Immersion Test on the stainless steel shows the decrease in corrosion rate on the nitride stainless steel. The increasing in the corrosion resistance is due to the high nitrogen concentration in the stainless steel pipe. Besides that, the grain size of the microstructure of the A316 tends to be enlarged when nitrogen is introduced to it. The twin formation can be divided into two patterns which are the suspended twin and transgranular twin. Other than that, nitriding also help the untreated pipe to recover from any voids problem. Finally, based on the experimental result of the chemical compositions, the nitrogen content of nitrided stainless steel is expressed in duration curve. By observing the curve, the diffusion of the nitrogen throughout the whole pipe after nitriding process were found uniformed.

5.2 RECOMMENDATION

The recommendations for this project are as follow:

I. The grain size should be measure to know the exact value of the enlargement of the grain size after subjected to the gas nitriding process.

II. The nitrogen content in the surface of the samples should be analyzed by using the X-Ray Diffraction (XRD)

III. The number of the samples should be increased by using more than 1 parameter

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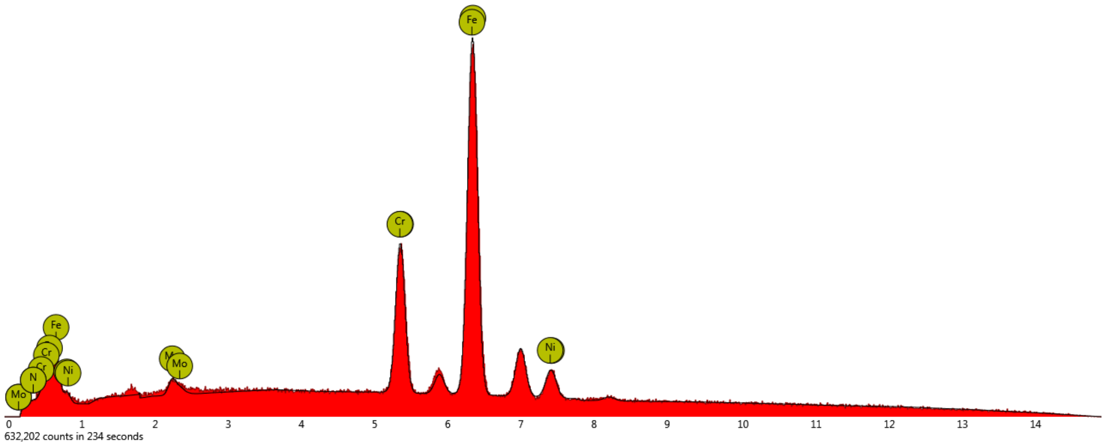
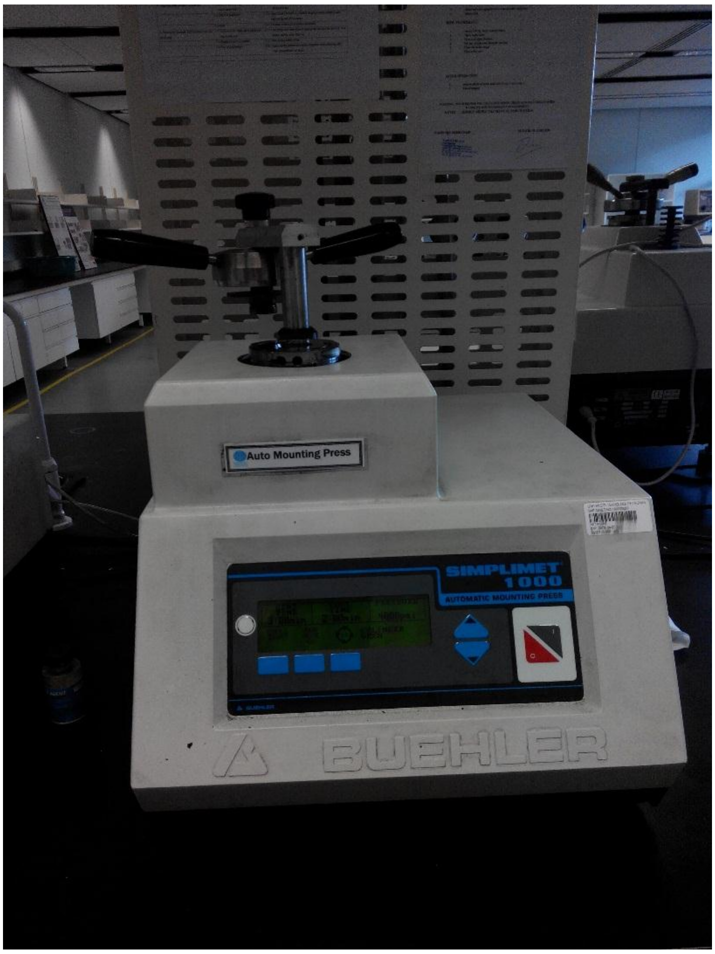
APPENDICES



EDS result for Untreated Stainless Steel

Samples that have been cut into 10 pieces.

Sample before it is mounted.



Mounting machine which used to mount the sample.