Study on the Wear Resistance of Duplex Stainless Steel after Undergo Nitrogen Diffusion Process Varies With Time

by

Mohammad Firdaus b Shahrom

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

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Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved by,

(Associate Profeesor Dr. Pathi bin Hussain)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2011

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 FIRDAUS B SHAHROM

ABSTRACT

This report basically discusses the research **study on the wear resistance of duplex stainless steel after undergo nitrogen diffusion process varies with time.** This report consists of the project's background, objectives, and problem statements, scope of work, literature review, methodology or the flow of the project, result & discussion and last but not least the conclusion. In this work the author report a study on the wear resistance of duplex stainless steel (DSS) after undergo nitriding process which will be conducted in a horizontal tube furnace and being conducted at four different times. Nitriding is one of the traditional thermochemical treatments for surface engineering that can be utilized in order to harden the duplex stainless steel surface to resist any failure. It wills also affecting the wear resistance of the steel. Wear characteristics are more to system properties rather than material properties. Contact type, the operating conditions, environment, the material characteristics of the test material and the mating material are the main factors for operating wear mechanism. In order to conduct the nitriding process, it is crucial to highlight the important of its variables such as time, temperature and gas velocity. However, for this project, the author will investigate and identify the effect of changing the time for nitriding process towards the wear resistance. Therefore, the result for before (raw sample) and after nitriding sample which are varies in time (1.0 hour, 2.5 hour, 4.5 hour) will being compared and observed. This objective will be achieved by a series of laboratory tests which is "wear test" using pin-on-disk method will be used to analyze the wear characteristic using DUCOM Multi Specimen Tester. To prove and verify that the nitriding process is successfully, metallographic study which using XRD machine will be done.

ACKNOWLEDGEMENT

First and foremost, I would like to express my praises to ALLAH for His blessing.

My deepest appreciation and gratitude is extended to my supervisor, AP Dr. Patthi Hussain for being very encouraging, supportive and responsive throughout the whole process of completing this final year project to fulfill the university requirement. Without his constant supervision and guidance, I may not be able to complete this project successfully.

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CHAPTER 1
INTRODUCTION

1.1 Project Background

Stainless steel has a good corrosion resistance, where they possess a low hardness, wear resistance. By case hardening the stainless steel, the hardness can be increased. Surface hardness can be increased by diffusion of carbon or nascent nitrogen. The gas nitriding is done at 1100 °C for three different specimens.

Nitriding is done in which hard complex nitrides are formed which improves the surface hardness. Non treated duplex stainless steel specimen was used as a reference material. Wear test were carried out for comparision. The layers were characterized by optical microscope, scanning electron microscope and X-Ray Diffraction (XRD). Wear test were conducted to characterize the tribological wear behaviour.

1.2 Problem Statement

Duplex Stainless Steel is used in industry since it has a two-phase microstructure consisting of grains of ferritic and austenitic stainless steel. It has a good corrosion resistance with high strength but it is also brittle. Wear characteristics are more to system properties rather than material properties. Contact type, the operating conditions, environment, the material characteristics of the test material and the mating material are the main factors for operating wear mechanism.

So, by nitriding process, it can improve the wear resistance of the steel. We need to determine the effect of increasing and changing the nitriding temperature towards the wear resistance. Nitriding will involve in heating the samples at high temperature with nitrogenous gas that will be diffused to the surface of each samples. Besides, we are required to identify and investigate the effect of using variations value of nitriding times to the samples in terms of its microstructure changes and composition. Not to forget, while the author varied the time values, the temperature constraint used is 1100 °C , constant which is for each experiment.

1.3 Objective and Scope of Study

Objective of this project is:

- To determine the effect of using variation in time towards the wear resistance.

Scope of study of this project is mainly in the form of laboratory experiments. This project cover on the conducting the gas nitriding at high temperature on the duplex stainless steel or for this case using LDX 2101, identify the effect of variation of nitriding times on the wear resistance. Non treated duplex stainless steel specimen was used as a reference material.

The conventional high temperature gas nitriding process (HTGN) will be conduct in a horizontal tube furnace for four different times. This gas nitriding process will be following strictly to ASTM A355 standard specifications.

Therefore, the wear resistance of the material are expected to be improved. After that, the author will use XRD to obtain the phase formation of nitrides. Not to forget, all these observation and identification will highlight the significance relationship of utilizing variations of nitriding times which could affect the result compiled.

After the required data is acquired, the project is considered as complete. The result obtained can be used for future work.

CHAPTER 2

LITERATURE REVIEW

Throughout the chapter 2, the review on the materials and also the information related to the materials which being used will be discuss more detailed. The purpose is to know more details about the materials being reserched and also the process will be involved throughout the project.

2.1 Stainless Steel

Steel is an alloy of iron and carbon, containing less than 2 % carbon.
Stainless steel contains a maximum of 1.2 % carbon, a minimum of 10.5% chromium (standard EN 10088-1) and other alloying elements. The presence of chromium confers on stainless steel its principal quality: its corrosion resistance [1]. Their remarkable resistance to corrosion is due to a chromium-rich oxide film which forms on the surface [2].

The alloying elements, depending on their percentages, give stainless steels their physical, chemical and mechanical properties. The presence of alloying elements is the starting point for obtaining the desired properties, various production processes facilitating this. The carbon and iron steel base, together with the addition of various alloying elements, provide the balance of each grade and dertermine which stainless "family" it belongs. Despite their relatively simple microstructure stainless steels have a rather complex alloy
chemistry that may cause a number of difficulties during processing and usage [3].

Table 2.1: Metal classification table

Classification of material	Composition	% carbon
Cast iron	iron, carbon	› 2 %
Carbon steels	iron, carbon	‹ 2 %
Special steels	iron, carbon and chromium or nickel or molybdenum (min 5%)	‹ 2 %
Stainless steels	iron, carbon and chrome >10.5% (standard EN 10088-1)	‹ or = 1.2 %

2.1.1 Type of Stainless Steel

There are several types of stainless steel – FERRITIC, MARTENSITIC, AUSTENITIC and DUPLEX. The ferritic steels are magnetic, have a low carbon content and contain chromium as the main alloying element, typically at the 13% and 17% levels. The martensitic steels are magnetic, containing typically 12% chromium and a moderate carbon content. They are hardenable by quenching and tempering like plain carbon steels and find their main application in cutlery manufacture, aerospace and general engineering. The austenitic steels are non-magnetic and, in addition to chromium typically at the 18% level, contain nickel, which increases their corrosion resistance. They are the most widely used group of stainless steels. Duplex steels are used where combinations of higher strength and corrosion resistance are needed. Super austenitic grades and precipitation hardened grades of steel are also available [4].

Table 2.2: Relative price for different stainless steel grades, March 2009 [13]

Grade			Structure	Yield strength* MPa	PRE	Relative price
Outokumpu	EN	ASTM				
4307	1.4307	304L	Austenitic	170	18	1
LDX 2101	1.4162	S32101	Duplex	450	26	1.2
2304	1.4362	S32304	Duplex	400	26	1.6
4404	1.4404	316L	Austenitic	170	24	1.6
2205	1.4462	S32205	Duplex	450	35	2.0
4432	1.4432	316L	Austenitic	170	25	2.5
4438	1.4438	317L	Austenitic	205	28	2.7
2507	1.4410	S32750	Duplex	550	43	3.1
904L	1.4539	904L	Austenitic	220	34	3.9
254 SMO	1.4547	S31254	Austenitic	310	43	5.0

* Min values according to ASTM A240.

2.2 Duplex Stainless Steel

Duplex stainless steel are a family of grades combining good corrosion resistance with high strength and ease of fabrication. Their physical properties are between those of the austenitic and ferritic stinless steel but tend to be closer to the ferritics and to carbon steel [5].

Duplex stainless steels are called "duplex" because they have a two-phase microstructure consisting of grains of ferritic and austenitic stainless steel. The picture shows the yellow austenitic phase as "islands" surrounded by the blue ferritic phase. When duplex stainless steel is melted it solidifies from the liquid phase to a completely ferritic structure. As the material cools to room temperature, about half of the ferritic grains transform to austenitic grains ("islands"). The result is a microstructure of roughly 50% austenite and 50% ferrite [6].

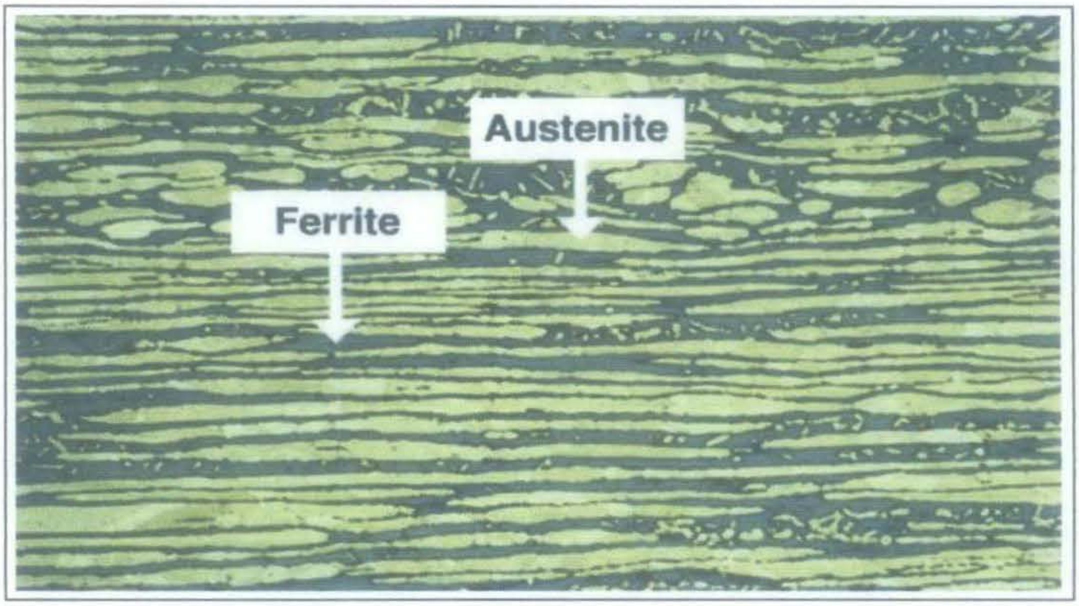


Figure 2.1: Duplex Stainless Steel Phase [6].

2.3 Nitriding

Nitriding is a thermochemical process by which the surface of a ferrous metal is enriched with nitrogen to improve the wear resistance of the component [7]. There are several attempts to increase the surface hardness and wear resistance of stainless steel by conventional surface treatment such as nitriding and nitrocaburising process [12].

It is being done by heating the material at high temperature under nitrogenous atmosphere. Nitrogen diffuses into the steel and increases the hardness during the treatment. For improving the hardness the technique is widely applied for austenitic , ferritic , duplex and martensitic stainless steels [11].

This technique is of great industrial interest, because it forms a unique composite structure with a hard surface (a layer of Fe-nitride compounds) and a tough interior, so that the global mechanical performance and wear/corrosion resistance of alloys and steels can be greatly improved [8]. However, nitriding processes are performed at high temperatures (500°C) for a long duration (~20 to 80 hours) (1, 2) and may induce serious deterioration of the substrate in many families of materials [8].

In gas nitriding the donor is a nitrogen rich gas, usually ammonia (NH_3), which is why it is sometimes known as ammonia nitriding [9]. When ammonia comes into contact with the heated work piece it disassociates into nitrogen and hydrogen. The nitrogen then diffuses from the surface into the core of the material.

There are several types of nitriding process which are :

1) Gas nitriding and nitrocaburising

2) Plasma and nitrocaburising

3) Salt bath nitrocaburising

Ion nitriding and ion nitrocarburizing improve the surface properties of engineering components made of various sintered powder metallurgy (PM) ferrous alloys including stainless steels providing very hard, tough surface with improved corrosion properties and fatigue strength without affecting part dimensions. Ion (also called plasma) nitriding and ion nitrocarburizing can be used in applications where good wear, antigalling properties and erosion resistance of engineering components and products are required. Ion nitriding improves fatigue and frictional properties of components, and also, in many situations, enhances corrosion resistance. [9].

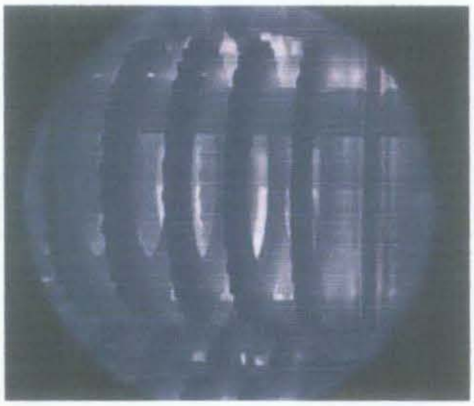


Figure 2.2 : Parts undergoing ion nitriding surface treatment in process chamber [9]

2.3.1 High Temperature Gas Nitriding (HTGN)

High temperature gas nitriding (HTGN) of stainless steels is a thermochemical treatment, in which nitrogen is absorbed from a N2 gas atmosphere leading to nitrogen dissolution in austenite at 1273 – 1473 K. High nitrogen cases with excellent corrosion resistance and tribological properties can be obtained [10]. The high temperature (azc)Actransformation is driven by nitrogen supersaturation built up during nitriding. The same treatment can be applied to austenitic and duplex stainless steels, obtaining fully austenitic cases with superior corrosion and tribological properties.

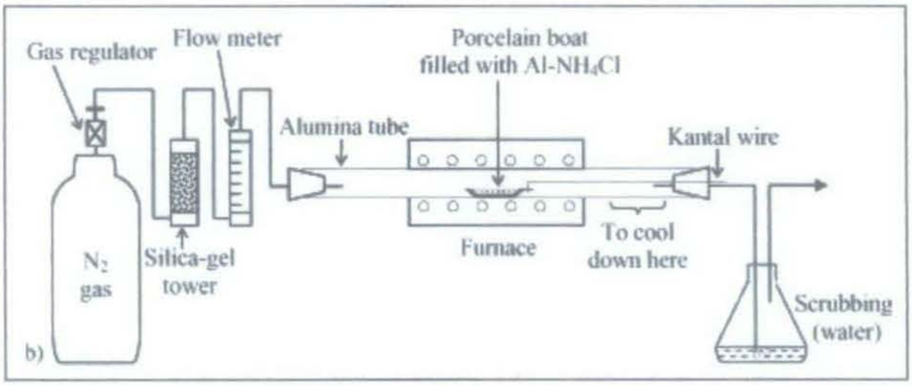


Figure 2.3 : Schematic picture of horizontal tube furnace and its apparatus [12]

2.4 Previous study

2.4.1 Study done by RAM.SUBBIAH, Dr.RAJAVEL on Dry Sliding Wear Behaviour Analysis of Nitrided 316LN Grade Austenitic Stainless Steels Using Gas Nitriding Process

The study involved Austenitic Stainless Steel (AISI 316LN) where it has been cut off into cylindrical specimen with a dimension of 50 mm diameter , 10 mm height used. The diameter of the pin is 8mm and length is 30 mm. The gas nitriding is done at 450 – 5400 C for three different specimens. Before the nitriding process begin, the specimens were sand blasted, pickled in 15% sulphuric acid for 20 minutes. The gas nitriding process were done in a bell type furnace at 4500 C (14 hours), 500 0 C (20 hours), 5400 C (72 hours) and named as GN 1, GN 2, and GN 3 respectively.

The author is using a standard pin on disc machine, with the parameters are, test pin rotated at 1460 rpm, with a load of 15 Kg was applied for a fixed period of 7 minutes under dry conditions. Calculation on the wear rate was being done by determining the weight loss and the time was recorded when the sample is before and after tested. Wear loss is being given by the difference between the specimen before and after testing.

After the experiment, which are gas nitriding process and wear test, the results are:

GN 3 sample results inferior wear performance. Thus the wear rate of untreated specimen is specified to be lower that of nitride material. Hence good surface hardness is obtained. High temperature gas nitriding results in good wear performance to relative case depth, which improves wear resistance.

2.4.2 Scanning Elctron Microscope Result:

Figure 2.4: Untreated PIN Specimen

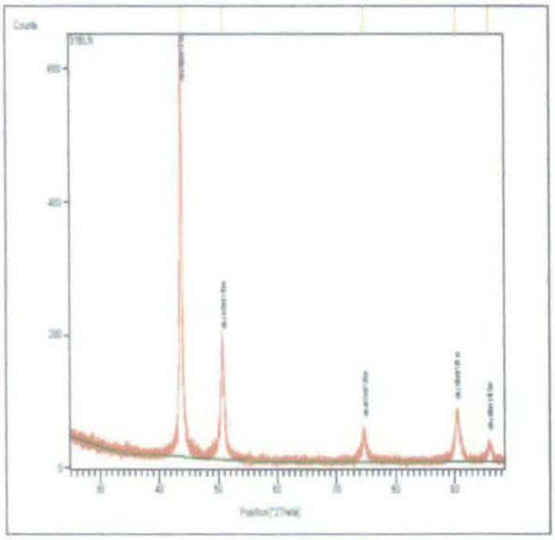
Figure 2.5: GN1 PIN Specimen

Figure 2.6: GN2 PIN Specimen

Figure 2.7: GN3 PIN Specimen

The author stated that, from the figure 2.4,2.5,2.6 and 2.7 it is seen that, the specimens were compared with untreated specimen. The peel of material is very high in untreated specimen. The wear of material is high. As the case depth increases, wear loss of the material decreases. In GN 3 the wear loss of material is less when compared to GN 2 and GN1. From SEM images it is proved that GN 3 specimen improves its wear resistance. It was found that volume wear loss was low and specific wear rate was very low.

2.4.3 X-Ray Diffraction Analysis



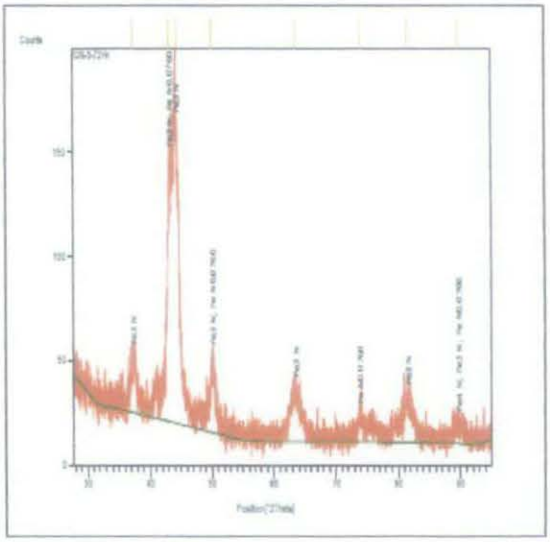


Figure 2.8 : XRD of Untreated Specimen   Figure 2.9 : XRD of GN3 Specimen

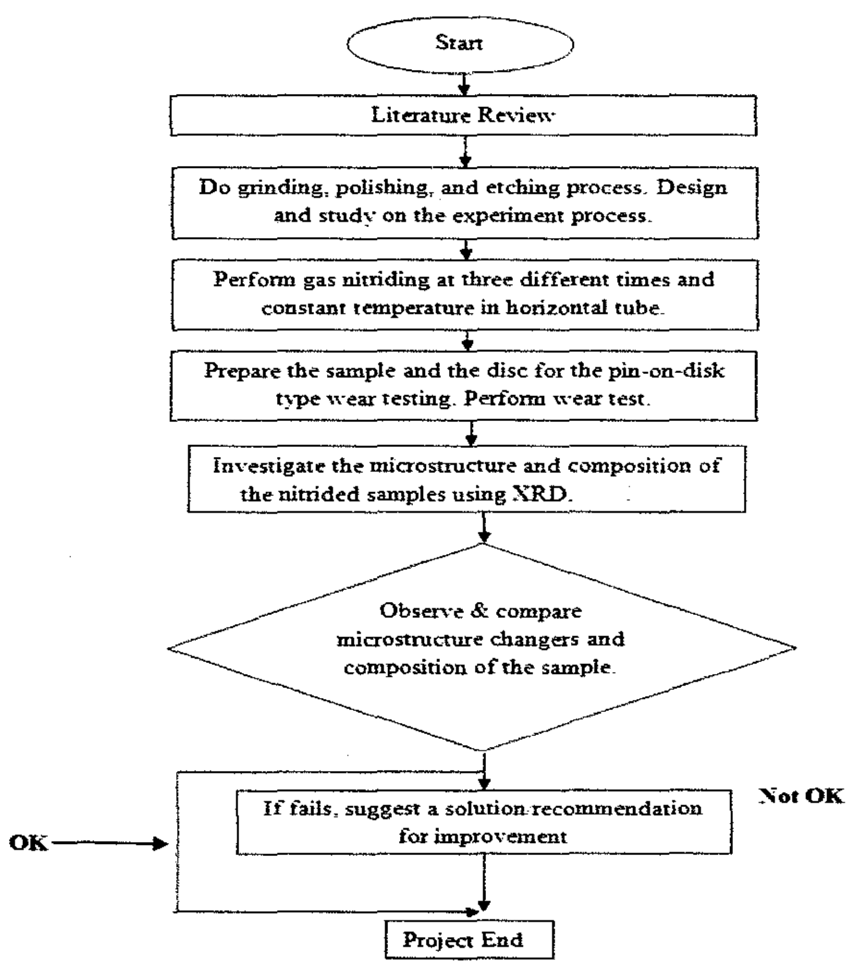
Based figure 2.8 and 2.9 XRD analysis, the phase formation of nitrides were obtained. From The XRD pattern, it was observed that iron nitrides are formed at the peaks with nitrogen formation. The formation of Cr-Ni-Fe-Celement, siderozot, and roaldite in GN 3 improves the wear resistance of the material. As it was found that, no presence of nitrogen compounds in the untreated specimen.

CHAPTER 3

METHODOLOGY

3.1: Project Flow Chart

Initially, the author had read some journals and articles for the literature review in order to enhance the understanding on mechanical properties, microstructure changes and the growth rate of the nitride layer. Not to forget, the author have been recognized and introduced to all equipments that can be used on her project. After some research, the author got some basic overview of what she is going to do. Below shows the several steps which will accomplish by the author for this project:



3.2 Procedures

For completing this project, a few steps and procedures need to be taken to make sure that the objectives of the project are fullfilled.

3.2.1 Research Methodology

The project began with the literature study, deciding and discovering the objective and do further study on the phases of duplex stainless steel and also the nitriding process. Nitriding process can be divided into several ways which are:

- Gas nitriding
- Plasma nitriding
- Ion nitriding

For this project, high temperature gas nitriding is been choosen. After the technique to be used is being finalised, literature review is being done on how to formulate and modelling the data being obtained after the experiment being done. The study also being done on the effect of nitriding process towards the mechanical and physical properties of duplex stainless steel were done from previous paper. Literature review being done continuosly by referring to books, and from the previous journals.

3.2.2 Experiment Procedures

1) Determine the shape and dimension of the sample

2) Microstructure conformation and observation before and after nitriding using metallographic technique.

a) Sample selection

b) Specimen preparation using metallographic technique:

- Sectioning – specimen is cut into small size (20mm x 20mm)
- Mounting - specimen is encapsulated in polymeric matrix
- Grinding - surface damages introduced by previous operation are removed
- Polisihing – to produce scratch-free surface with mirror-like finish

- Etching – to make "visible" the microstructure surface under microscope during inspection. For LDX 2101 of D.S.S, the etching agent is Fry's Reagent which is prepared using 30ml H_2O, 25ml ethanol, 40ml HCl, 5g C_uCl_2 (Copper Chloride).

3) Perform High Temperature Gas Nitriding

a) Tube furnace is use and will be connect with the nitrogen supply, flow meter and cone flask. Cone flask will be filling up with water with the intention that the bubble can be observed as a way to confirm the flow of nitrogen besides using the flow meter.

b) A specific time interval and temperature to perform nitriding are decided.

c) For this project, the nitriding temperature is divided to three different time interval which are 1.0 hour, 2.5 hour and 4.5 hour and the temperature are constant which is 1100 °C.

d) The HTGN is performed as in procedures below :

i. Carried out in Carbolite Horizontal Tube Furnace

ii. Sample is cleaned using acetone

iii. The sample is placed in alumina boat and inserted into the heating zone

iv. Air in furnace is purging with nitrogen for 15 minutes.

v. Heating at 5°C/min will start immediately after purging complete

vi. The required cycle, segment, temperature and nitriding period are set.

vii. The heater will be turn on, and the furnace is heated to temperature of 1100°C for 1 hours.

viii. After 20 minutes, the nitrogen gas tank valve is opened (rotate clockwise) and waited until 1 hours.

ix. The Nitrogen gas (N_2) flow rate is controlled to be 120 mm^3 every time.

x. After 1 hour, the N_2 valve is closed. Wait until no more bubbles in the cone with water.

xi. During opening the tube furnace, PPE must be worn.

xii. The nitrided sample is being taken out after the sample is being cooled down inside the furnace.

xiii. The microstructure is being observed using optical microscope and the phase is being identified.

xiv. The "wear resistance" is being determined using The pin-on-disk method will be used to analyze the wear characteristic of the aluminum matrix reinforced with carbon nanotubes. Wear resistance is determines by using DUCOM Multi Specimen Tester. It was performed according to ASTM Standard G99 (Eyre, 1991).

xv. The parameters fot the wear test are 2.5 kg load,100 rpm, 0.1 hour, and room temperature (23°C).

e) Step i to xv will be repeated for different sample nitrided time which is 2.5 and 4.5 hours.

3.2.3 Testing and Observation

The substrates produces will be test by using equipments. The chemical composition of the nitride sample will be tested by using XRD analysis, and finally wear test will being conducted to determine the wear resistance for each specimen.

3.2.4 Analysis

The result obtained will be analyze which are the nitride layer, nitrogen composition after nitriding, wear resistance and also XRD analysis to determine the chemical composition.

3.3 Hardware and Tools

3.3.1 Raw materials:

- Duplex stainless steel type of LDX 2101

3.3.2 Tools:

Metallographic tools set

1) Wire cut EDM
2) Grinder and emery paper
3) Polisher and diamond paste
4) Etching agent (Fry Reagent)
5) Tube Furnace
6) Optical Microscope (OM)
7) DUCOM Multi Specimen Tester
8) Carbolite Horizontal Tube Furnace
9) X-Ray Diffractiometer (XRD)

Figure 3.1 : DUCOM multispecimen tester

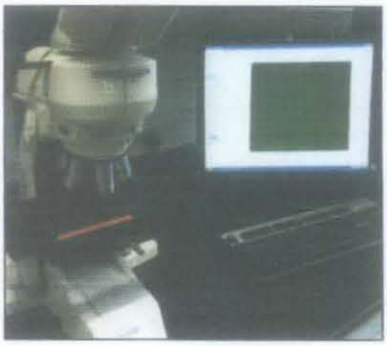


Figure3.2: Optical Microscope

Figure 3.3 : Tube Furnace

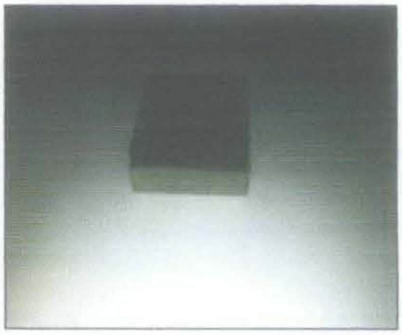


Figure 3.4:Duplex Stainless Steel Specimen

Table 3.1 : List of equipment/tool

EQUIPMENT/TOOL	DESCRIPTION
Optical Microscope	Magnifies an image by sending a beam of light through the object. The condenser lens focuses the light on the sample and the objective lenses (10X, 40X, . . . , 2000X) magnifies the beam, which contains the image, to the projector lens so the image can be viewed by the observer.
DUCOM multispecimen tester	The pin-on-disk method will be used to analyze the wear characteristic of the aluminum matrix reinforced with carbon nanotubes. It was performed according to ASTM Standard G99 (Eyre, 1991).
Field Emission Scanning Electron Microscope (FESEM)	Electron Microscope which that images the sample surface by scanning with a high-energy beam of electrons in a raster scan pattern.
X-Ray Diffraction Analysis	Use to investigates crystalline material structure, including atomic arrangement, crystallite size, and imperfections.

3.4 Gantt Chart FYP II

Table 3.2 : Gantt chart for FYP II

Activities	1	2	3	4	5	6	7	Mid Semester Break	8	9	10	11	12	13	14
Project work continues: Grinding,Polishing and Etching															
Experiment: Start Nitriding Process															
Progress Report Preparation															
Fabrication for wear resistance test • Disc (Turning) • Sample (EDM)															
Submission of Progress Report 1									Δ						
Perform Wear Test on fabricated samples															
Analysis using • XRD															
Result gathering															
Poster Exhibition												Δ			
Submission of Dissertation final draft															Δ
Oral presentation															Δ
Submission of Dissertation (hard bound)									7 days after oral presentation						

Δ Key Milestone   Completed Activities

CHAPTER 4
RESULT AND DISCUSSION

4.1 Nitriding Process

Table : 4.1

Time (hr)	Sample's weight (g)		
	Before	After	Difference
1.0	17.336	17.348	0.012
2.5	17.649	17.663	0.014
4.5	17.427	17.440	0.017

Figure 4.1 : Graph weight difference vs time

Based on table 4.1, it can be found that the sample weight difference is being calculated by subtracting the weight before nitriding form the weight after nitriding. From the graph plotted, it can being concluded that as the time for nitriding is increasing, the weight difference is also increasing. This is due to the amount of nitrogen diffuse inside the LDX 2101 is increasing as the time increase.

4.2 Wear Test

Table : 4.2

	Sample's Weight		
	Before (g)	After (g)	Loss (g)
Untreated Stainless Steel	3.0977	2.8778	0.2213
1.0 hour 1100°C	2.9234	2.7134	0.2116
2.5 hour 1100 °C	3.0973	2.9173	0.1803
4.5 hour 1100 °C	3.0535	2.9035	0.1501

Figure 4.2: Graph weight loss vs time

Based on the table 4.2, it can be found that the sample weight loss is being calculated by subtracting the weight of the sample before nitriding from the weight after nitriding. From the graph plotted, it can be concluded that as the time for nitriding is increasing, the weight difference is decreasing.As for the untreated sample, it is being used only as a comparison and reference from the other nitrided sample. This is because, the amount of nitrogen diffuse inside the LDX 2101 increases, the wear resistance is increased thus, the weight loss is reduced.

4.3 Wear Resistance Analysis

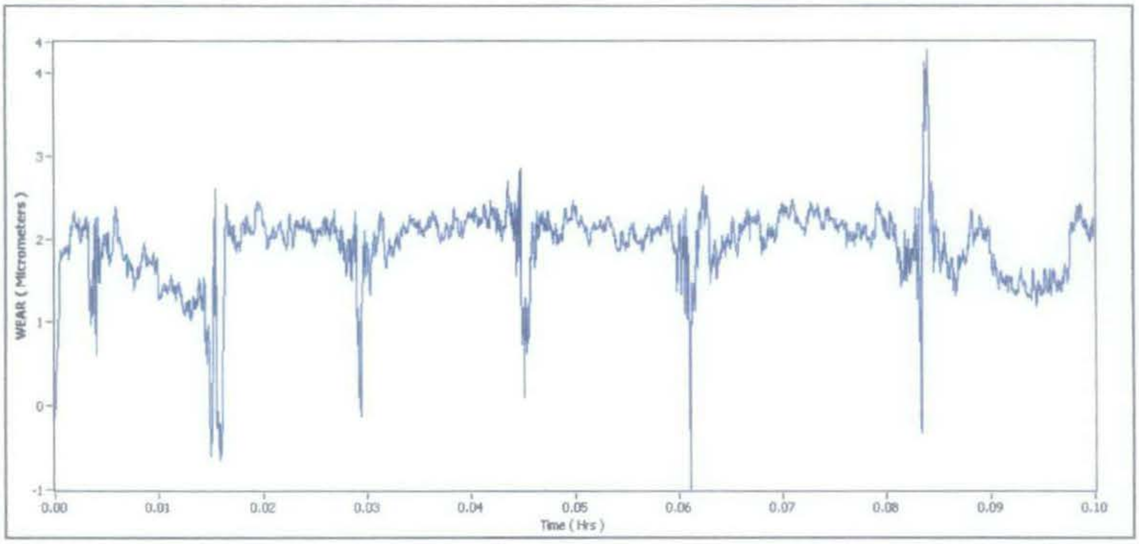


Figure 4.3 : Wear resistance for raw sample

From figure 4.3 above, the approximate rate of the weight loss every 0.01 hours is 2.2 micrometers during the wear test which being conducted about 0.1 hour, 2.5 kg load, 100rpm, and room temperature (23°C) using DUCOM multispecimen tester (pin-on-disk method). The untreated specimen is pure and did not undergo the nitriding process which makes the wear resistance of the sample is the lowest. The rate of weight loss for the raw sample is the highest which is 2.2 micrometers every 0.01 hours.

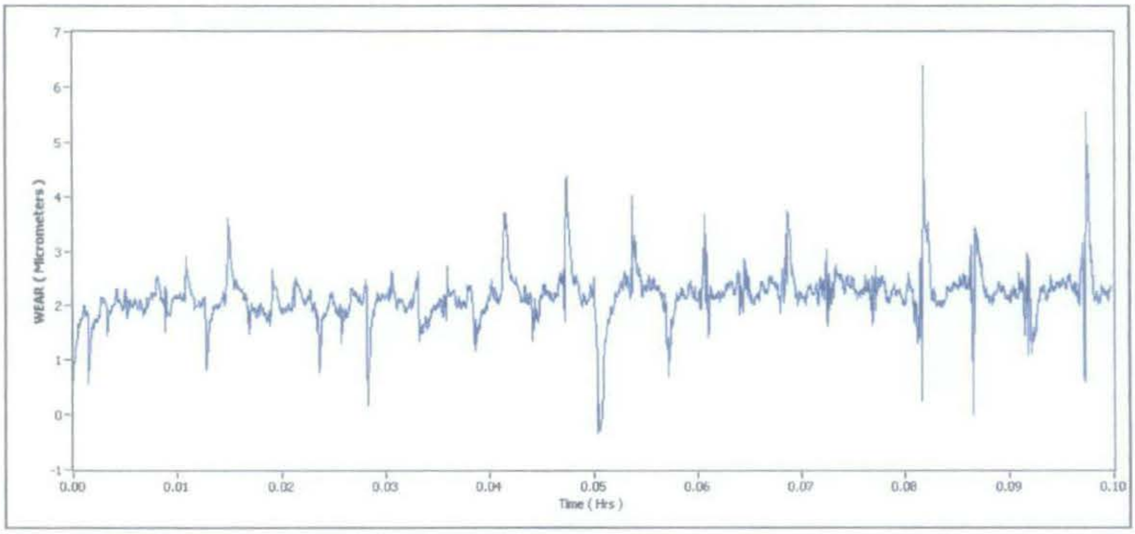


Figure 4.4 : Wear resistance for 1.0 hour nitrided sample

From the figure 4.4 above, the approximate rate of the weight loss every 0.01 hours is 2.1 micrometers during the wear test which being conducted 0.1 hour, 2.5 kg load, 100rpm, and room temperature (23°C) using DUCOM multispecimen tester (pin-on-disk method). The sample was undergo the nitriding process for 1.0 hour and under 1100°C temperature. Nitriding process increases the wear resistance of the sample. So, the rate of weight loss for the specimen nirided for 1.0 hour is 2.1 micrometers every 0.01 hours.

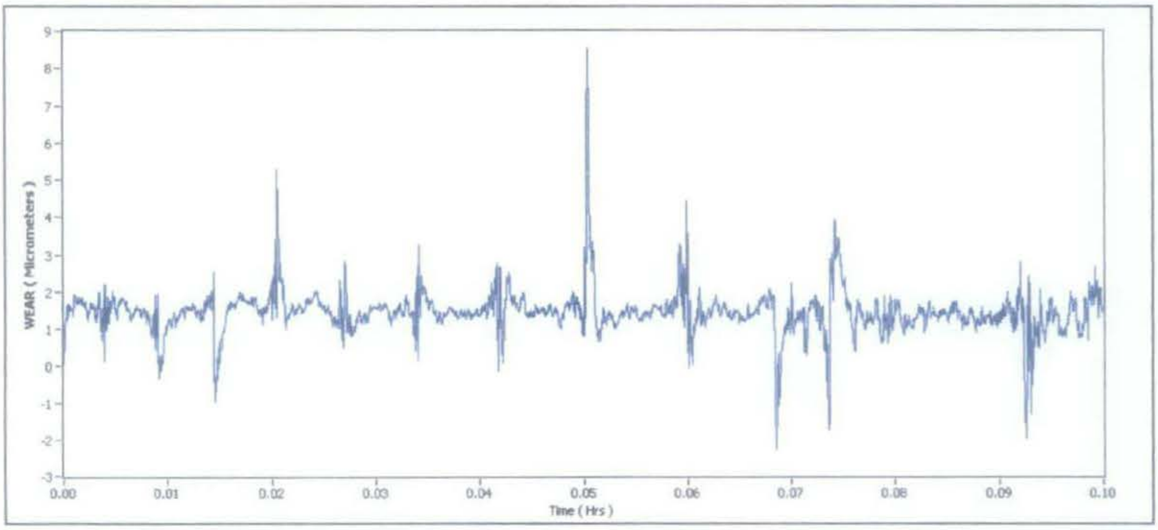


Figure 4.5 : Wear resistance for 2.5 hour nitrided sample

From figure 4.5 above, the approximate rate of the weight loss every 0.01 hours is 1.8 micrometers during the wear test which being conducted for 0.1 hour, 2.5 kg load, 100rpm, and at room temperature (23°C) using DUCOM multispecimen tester (pin-on-disk method).

The sample was undergone the nitriding process for 2.5 hour and under 1100°C temperature.As the time increased, the amount of nitrogen diffused into the sample were increased.Thus, the wear resistance of the sample is higher. So, the weight loss is lower for compared to the sample undergo nitriding process for 1.0 hour which is 1.8 micrometers every 0.01 hour.

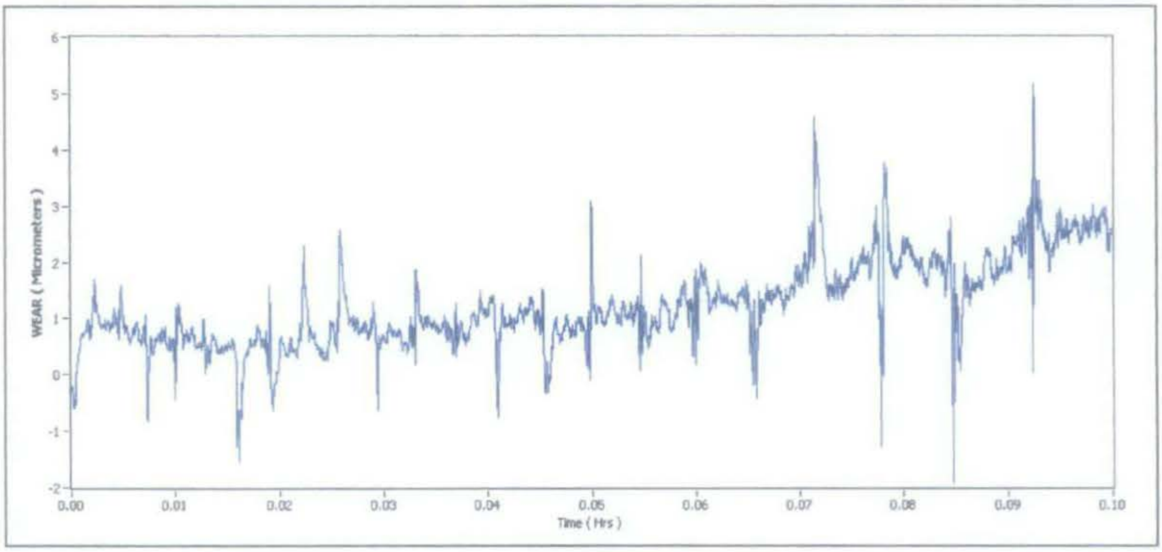


Figure 4.6 : Wear resistance for 4.5 hour nitrided sample

From figure 4.6 above, the approximate rate of the weight loss every 0.01 hours is 1.5 micrometers during the wear test which being conducted 0.1 hour, 2.5 kg load, 100rpm, and room temperature (23°C) using DUCOM multispecimen tester (pin-on-disk method). The sample was undergone the nitriding process for 4.5 hour and under 1100°C temperature. As the time increased, the amount of nitrogen diffused into the sample were increased and thus the wear resistance of the sample is the highest. So, the rate of weight loss for every 0.01 hours is the lowest which is 1.5 micrometers.

Based on the four graph obtained from the wear test, it shows that the sample which has been nitrided for 4.5 hours have the lowest rate of weight lost for every 0.01 hour (higher wear resistance) compared to the other sample which is approximately 1.5 micrometers for every 0.01 hour. It follows by the 2.5 hour nitrided sample (1.8 micrometers for every 0.01 hour),1.0 hour nitrided sample (2.1 micrometers for every 0.01 hour) and the untreated specimen (2.2 micrometers for every 0.01 hour). It shows that when the time is increase, the amount of nitrogen gas diffuse into the LDX 2101 also increase and will improve the wear resistance of the LDX 2101.

4.4 XRD Result

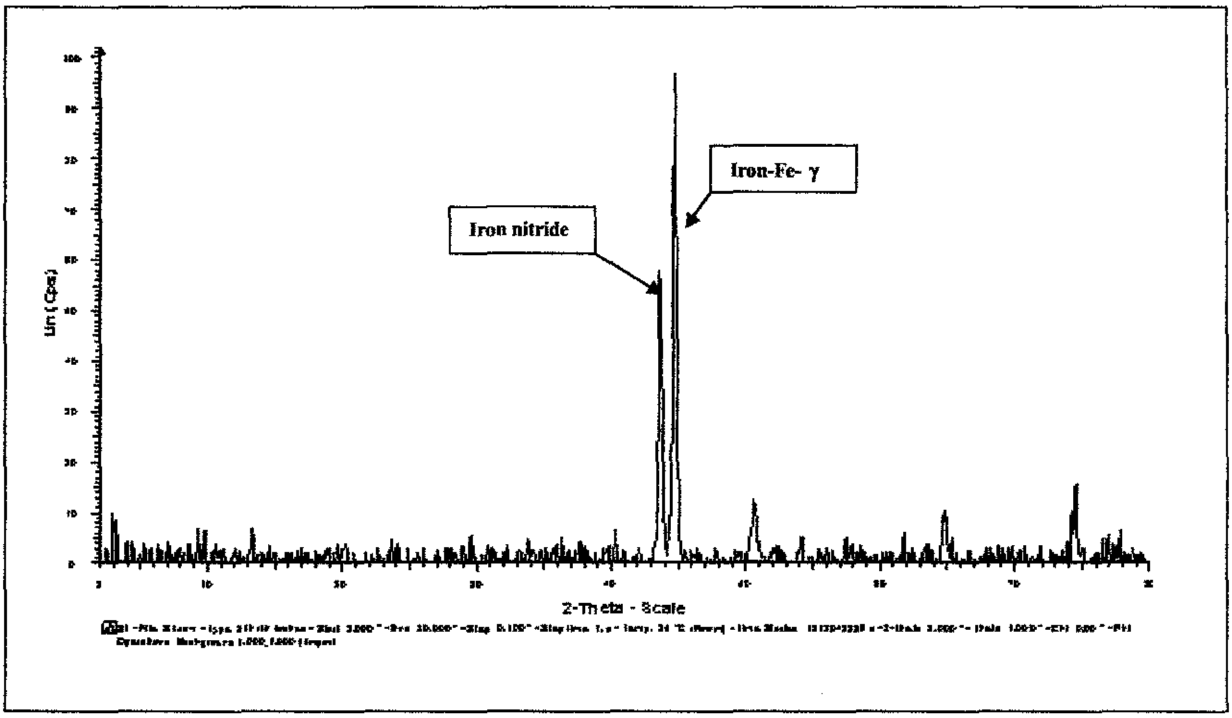


Figure 4.7 : XRD result for untreated sample

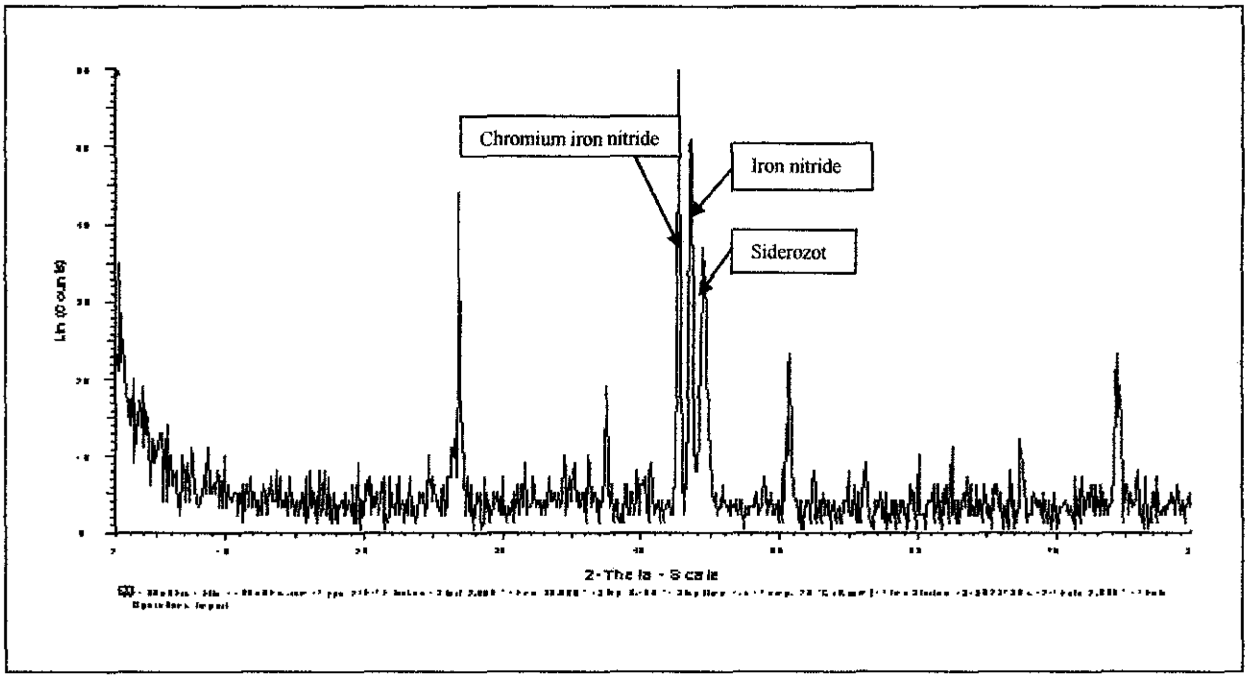


Figure 4.8 : XRD result for 4.5 hour nitrided sample

It was found that, less of nitrogen compound presence in the untreated specimenas shown in Figure 4.7. From Figure 4.8, the phase formations of nitrides were obtained. From the XRD pattern, it was observed that iron nitrides are formed at the peaks with nitrogen formation. The formation of Cr-Ni-Fe-C elements such as siderozot, iron nitride and chromium iron nitride in sample 4.5 hour improves the wear resistance of the material.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The research on the **study on the wear resistance of duplex stainless steel after undergo nitrogen diffusion process varies with time** is succesfully. All the experimental work for this research is accomplished within the time.The nitriding process is done for the three different nitriding time which are 1.0 hour, 2.5 hour and 4.5 hour while the temperature is constant, 1100°C. After the nitriding process completed, the sample undergo the wear test using the pin-on-disk method. The parameters are 2.5 for the load, 100 rpm, 0.1 hour and room temperature. From the graph being obtained after the wear test, sample which being nitrided 4.5 hour has a very good wear resistance. It showed that, as the time of nitriding increases, weight loss decreases.Weight loss have significance in wear resistance which is the lower weight reduced during the wear test means that the higher wear resistance. XRD confirms the presence of nitride compounds like iron nitride, roaldite, siderozot and magnetite. Among these three specimens,4.5 hour nitrided has improved the wear resistance and hence the life of the material is increased.

5.2 Recommendation

For further research, it is highly recommended that the specimen undergo wear testing using disc fabricated from the metal which have the higher properties since every specimen have their own properties and the wear rate will be different.

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