The Structural Dynamics of Nitrided Ferritic 439 Grade Stainless Steel Plates

by

Muhammad Fawwaz bin Mohamad Lawi

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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A project dissertation submitted to the
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Approved by,

____

(Associate Professor Dr. Patthi bin Hussain)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
January 2014

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.

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MUHAMMAD FAWWAZ BIN MOHAMAD LAWI

ABSTRACT

439 Stainless steel is widely known around the world for its anti-corrosive characteristics. Because of its abundance and cost effectiveness, it is widely used in the industry. However, because of the stiffness and the natural frequency of this material, it limits the usage of the 439 stainless steel.

This paper is basically a study on how nitriding process can improve the stiffness and natural frequency of the stainless steel. The nitriding process consists of two parts: which are the low temperature nitriding and high temperature nitriding. It contains the step-by-step process on how the both nitriding process will be done to the 439 stainless steel and the improvement in stiffness and natural frequency will be observed and studied after both low temperature nitriding and high temperature nitriding.

From the results of this study, it is hoped that 439 stainless steel can be used more on the field that it has never used before because of its limitation and hence, some cost will be saved.

ACKNOWLEDGEMENT

I would like to start by first giving credit to both of my supervisors; Ir. Idris Bin Ibrahim and Dr. Patthi bin Hussain who have been helping me in assessing and giving their advice and guidance in order for me to able to complete this project. I really appreciate it. The experience I get is really meaningful to be practiced in my life.

The acknowledgement of the project should also be credited to lecturers that share their knowledge and give some idea and comments for the development of this project. I also want to thank the technicians and post graduate students who have been helping me by sharing their knowledge and opinion in improving the project. Last but not least, I also would like to thank my friends who also supporting me during the laboratory works when conducting the experiments.

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CHAPTER 1

INTRODUCTION

1.0 Background of study

Stainless steel is the universal name for several types of steels used for their anti-corrosive element. Stainless steel is made using chromium. Usually, it consists of 10.5% to 11% chromium content by mass, the amount needed to prevent the formation of rust in unpolluted atmospheres [1]. There are also other elements that being used to make stainless steel which are nickel, nitrogen and molybdenum. There are four types of stainless steel; austenitic, ferritic, martensitic and duplex.

Case hardening is the process of hardening the surface of a metal. This is by making the metal deeper to stay soft, while allowing the forming of harder metal layer ("case") at the surface. There are many types of case hardening procees. For example, flame and induction hardening, carburizing, nitriding, cyaniding, carbonitriding and ferritic nitrocarburizing. Each type of case hardening is suitable for certain types of material. Case hardening allows the interior of the steel retains its original properties only the outer surface is hardened.

Nitriding is a highly specialized surface hardening treatment that produces a thin but high hardness case on different type of steels, The nitriding process involves the diffusion of nitrogen into the base steel. Ammonia gas can also be used for nitriding process.

Nitriding process theoretically will affect the structural dynamics of a material such as the stiffness and the natural frequency. Stiffness by definition is the rigidity of the object, or in other words the ability of the object to take away the force and return to its original position.

Stiffness is calculated by using the following formula:

$k=F/\delta$

where,

F is the force applied on the body

δ is the displacement produced by the force along the same degree of freedom (for instance, the change in length of a stretched spring).

Increasing stiffness will also increase the natural frequency of the object

1.1 Problem Statement

Ferritic 439 Grade Stainless Steel is not the most commonly used materials in industrial application as compared to the austenitic SS316/SS304 grade stainless steel because of its low in stiffness and also low in natural frequency. To improve the characteristic of these metal by increasing the stiffness and natural frequency, the case hardening process needs to be done by using nitriding process. The nitriding process should be done to increase the stiffness and natural frequency because industrial application exposes the material to vibratory motion which could be at an extreme amplitude and frequency. By doing the nitriding process, the stainless steel will not easily break down.

Therefore, a study is required to investigate the structural dynamics of nitrided ferritic 439 Grade Stainless Steel plates and establish the dynamic properties which are the material stiffness, natural frequency and mode shape of the motion. The result of this study will help built dynamic characteristic data of the nitride ferritic 439 stainless steel and widen its industrial application.

1.2 Objective of the study

To study the structural dynamics of nitrided ferritic 439 grade stainless steel plates and establish its dynamic properties such as material stiffness, natural frequency and mode shape of the motion.

The nitriding process is divided into two categories:

1) High Temperature Nitriding
2) Low Temperature Nitriding

By doing the study, the material stiffness, the natural frequency, and mode shape of the motion of the stainless steel before and after both low and high temperature nitriding process can be compared.

The project starts with the establishment of the chemical compostion and microstructure profile of the non-nitrided ferritic 439 Grade Stainless Steel and also low temperature and high temperature nitrided ferritic 439 Grade Stainless Steel.

1.3 Scope of study

This study will cover the analysis of data and data collection from articles, journals, books, websites, research papers and thesis. The study will be specific on the chemical compositon, microstructure profile, and the dynamic properties such as material stiffness, natural frequency and mode shape of the motion of the base and nitrided 439 grade stainless steel plate as well as the testing method to examine their characteristics and properties. Then all data from the experiments and analysis will be compiled into a report.

CHAPTER 2

CRITICAL LITERATURE REVIEW

439 Stainless Steel & Relationship between Nitriding with Stiffness and Natural Frequency

400 series stainless steel, which is ferritic stainless steel, has good corrosion resistance. The heat conduction performance of this stainless steel is better than austenitic, and the thermal expansion coefficient is smaller than austenitic [13]. 439 stainless steel which is one of the 400 series stainless steel, is well known for its corrosion-resistant and superior formability capabilities characteristics, and there are being widely used in automotive industry to produce difficult to form exhaust system components, tubular manifolds, and mufflers. For appliances, they being used to make hot water tanks, and residential furnaces. And for power generation, 439 being used to make heat exchanger tubing [2]. But their low stiffness which means their ability to take away force is low, and poor resistance limits their industrial applications. The other problem is that this stainless steel cannot be exposed to vibratory motions with high amplitude and frequency. To solve this problems, this research will be done to increase their stiffness, to increase their natural frequency, decrease in friction coefficient and increase in their wear resistance [3]. To increase the stiffness and the natural frequency of the stainless steel, surface-modification techniques or case hardening should be done.

The relation between stiffness and modulus of elascity is given by the following formula:

$$E = \frac{kL^3}{48I}$$

Where, E= modulus of elasticity (GPa)

k = stiffness (N/mm)

L = length (m)

I = second moment of area (m^4)

From this formula, as the stiffness increase, the modulus of elasticity will also increase.

The relationship between stiffness and natural frequency is shown on the formula below, which shows that natural frequency increases as stiffness increases:

$$\omega_n = \sqrt{\frac{k}{m}}$$

Where, ω_n=natural frequency

k=stiffness

m=mass

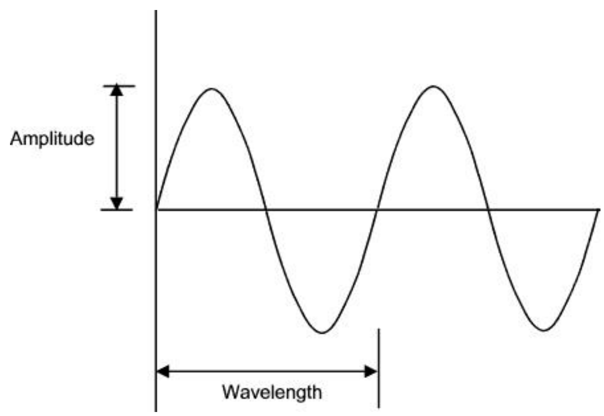


Figure 2.0: Vibration Cycle

Based on figure 2.0 above, one wavelength is equal to one vibration cycle. According to [22], one cycle is equal to 0.5cm, which is equal to 0.5 second. Using formula below, the natural frequency of the ferritic 439 Grade Stainless Steel can be determined:

$f = \frac{1}{T}$, where

f = frequency in Hz

T = time in second

Case hardening of Ferritic Stainless Steel

One of the example of case hardening is nitriding process. Nitriding is done and to increase the stiffness of the material, and to improve wear and friction properties by surface microstructure modification while maintaining adequate substrate properties [4]. There are many types nitriding process which are plasma, gas and salt-bath nitriding [5]. High-temperature gas nitriding is usually applied to Cr based austenitic, martensitic and duplex stainless steels, which have high nitrogen solubility in the austenite phase [6].

In this project, low temperature and high temperature gas nitriding will be applied to AISI 439 ferritic stainless steel. Gas nitriding is a thermochemical surface treatment in which nitrogen is transferred from an ammonia atmosphere into the surface of steels at temperatures within the ferrite and carbide phase region and forms a nitrogen solid solution or nitrides [7,8]. Ferritic stainless steels are chromium-containing alloys with body-centered cubic crystal structures which is shown in Figure 2.1, and the content of the chromium-containing alloys are between 10.5 to 30% [1]. Ferritic stainless steel is ferromagnetic, which means they have good ductility and formability, but high-temperature strengths are relatively poor compared to the austenitic grades [17,18]. Their toughness might be limited at low temperatures and in heavy sections. The standard ferrite stainless steels are types 405, 409, 429, 430, 430F, 430F-Se, 434, 436. 439, 444, and 446. [9, 19]

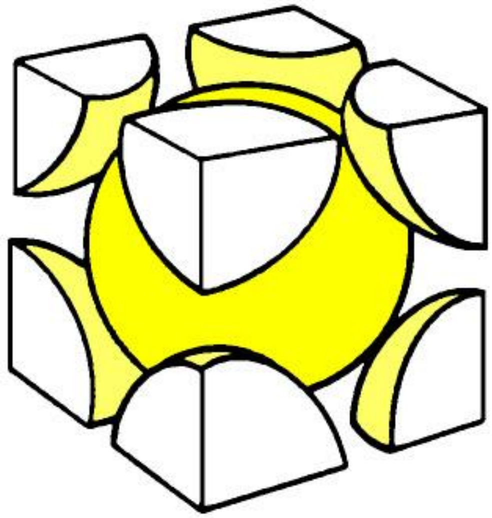


Figure 2.1 : Body-centered cubic structure

High Temperature Gas Nitriding Process to 400 Series Stainless Steel

According to article [6], the optimum temperature for high temperature gas nitriding to 20mm x 50 mm x 1.2mm dimension of 400 series stainless which is the AISI 430 ferritic stainless steel is determined.

Figure 2.2 shows optical micrographs image of the cross-section through the surface and the interior of the AISI 430 steel after the HTGN treatment. For Figure 2.2a, after the high temperature gas nitriding at 1100 ◦C/15 min, it is observed that there is 130 μm of martensite near the surface layer, and in the interior there is ferrite being observed. For Figure 2.2b, after high temperature gas nitriding at 1100 ◦C/10 h, it can be observed that the depth of the martensite phase is increased until the whole 1.2mm thickness was changed into the martensite phase. For Figure 2.2c, relatively fine grain size is observed, and the whole thickness of the stainless steel is consisted of martensite phase.

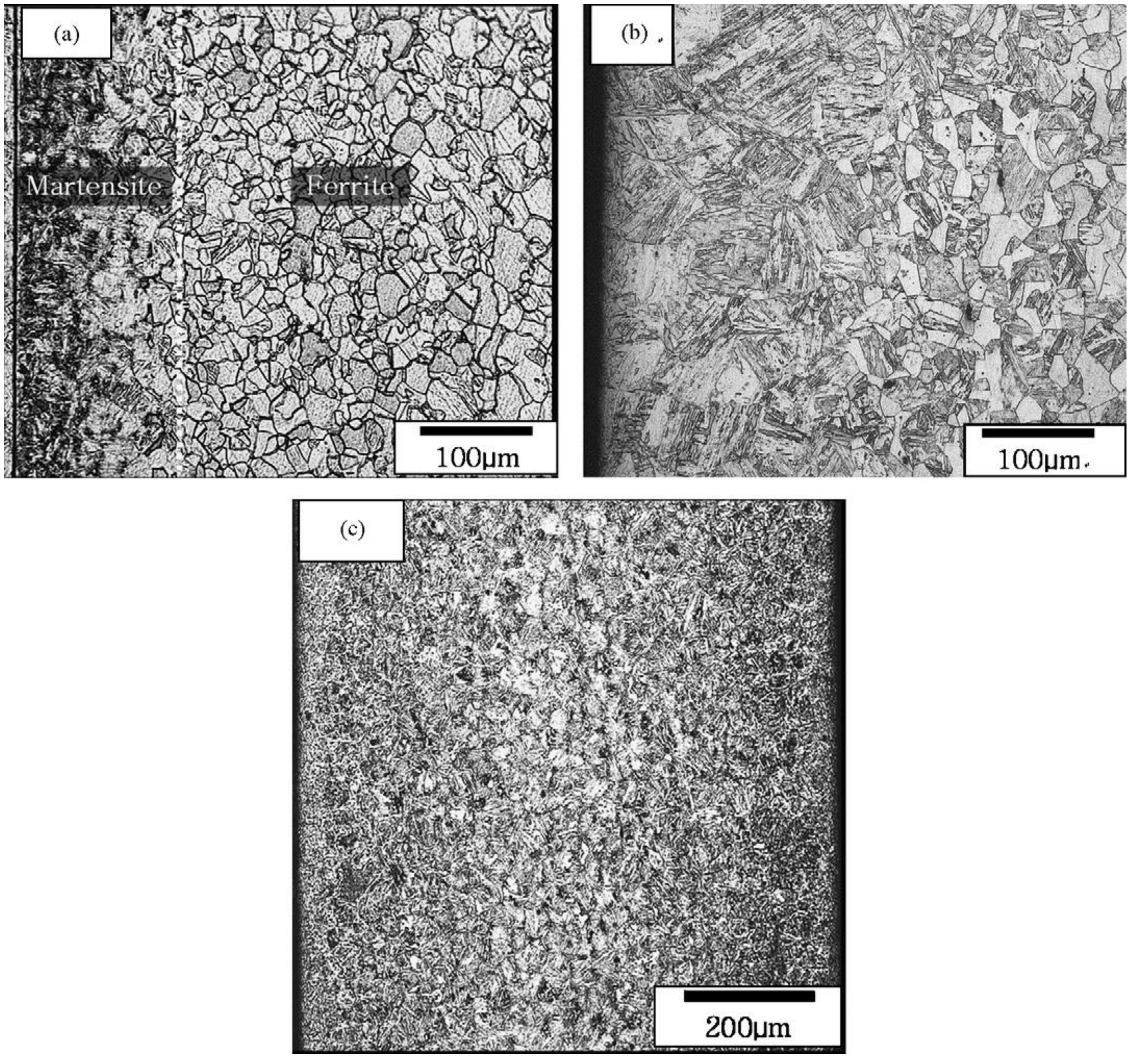


Figure 2.2: Optical micrographs of AISI 430 steel after the HTGN treatment at 1100 ◦C and 1050 ◦C in various time. (a) 1100 ◦C, 15 min; (b) 1100 ◦C, 10 h; (c) 1050 ◦C, 10 h.

Figure 2.3 shows the nitrogen content schematized along depth below the surface. After the high temperature nitriding process at 1100 ◦C/15 min, it can be observed the nitrogen content is decreasing gradually with increasing depth, which reached 0% N at 160 μm from the surface. However, after 10 hours of high temperature gas nitriding treatment at 1050 ◦C and 1100 ◦C, the nitrogen content is almost constant because the of nitrogen has diffused through the whole thickness. It can be observed that nitrogen content at the 10μm below the surface is the highest after the treatment in 1050 ◦C/10 h (0.54%) and 0.14% and 0.43% were observed for material after treatment in 1100 ◦C/15 min and 1100 ◦C/10 h, respectively.

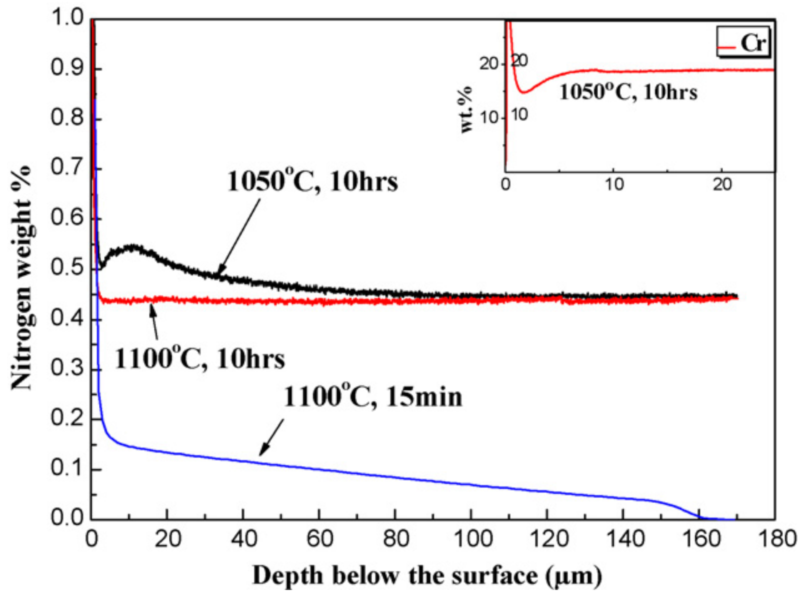


Figure 2.3 : Changes of the nitrogen content as a function of depth below the surface after the HTGN treatment for 10 h.

The results from this study can be summarized as the graph in Figure 2.4 as follows:

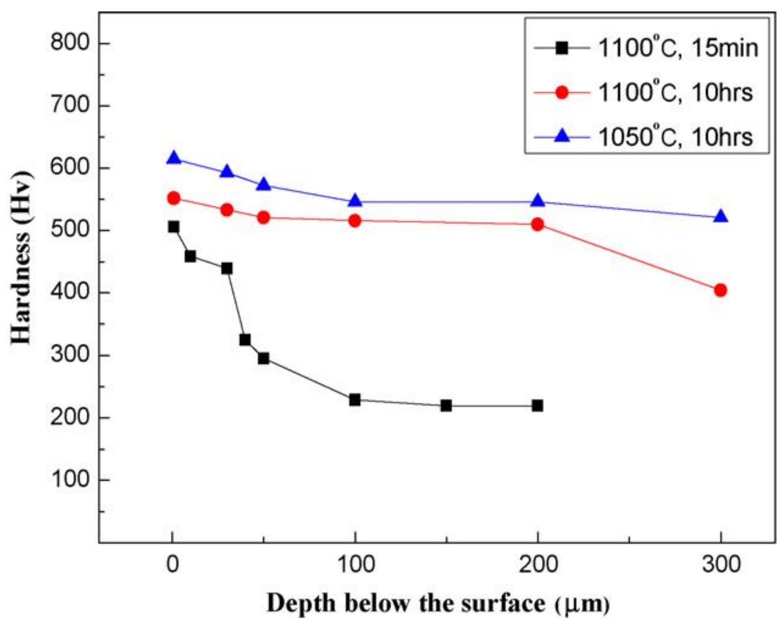


Figure 2.4: Hardness as a function of the depth below the surface after the High Temperature Gas Nitriding for 10h.

From this study [6], it can be concluded that if the stainless steel is nitrided at 1050 C, the hardness will be better than if it is nitrided at 1100 C.

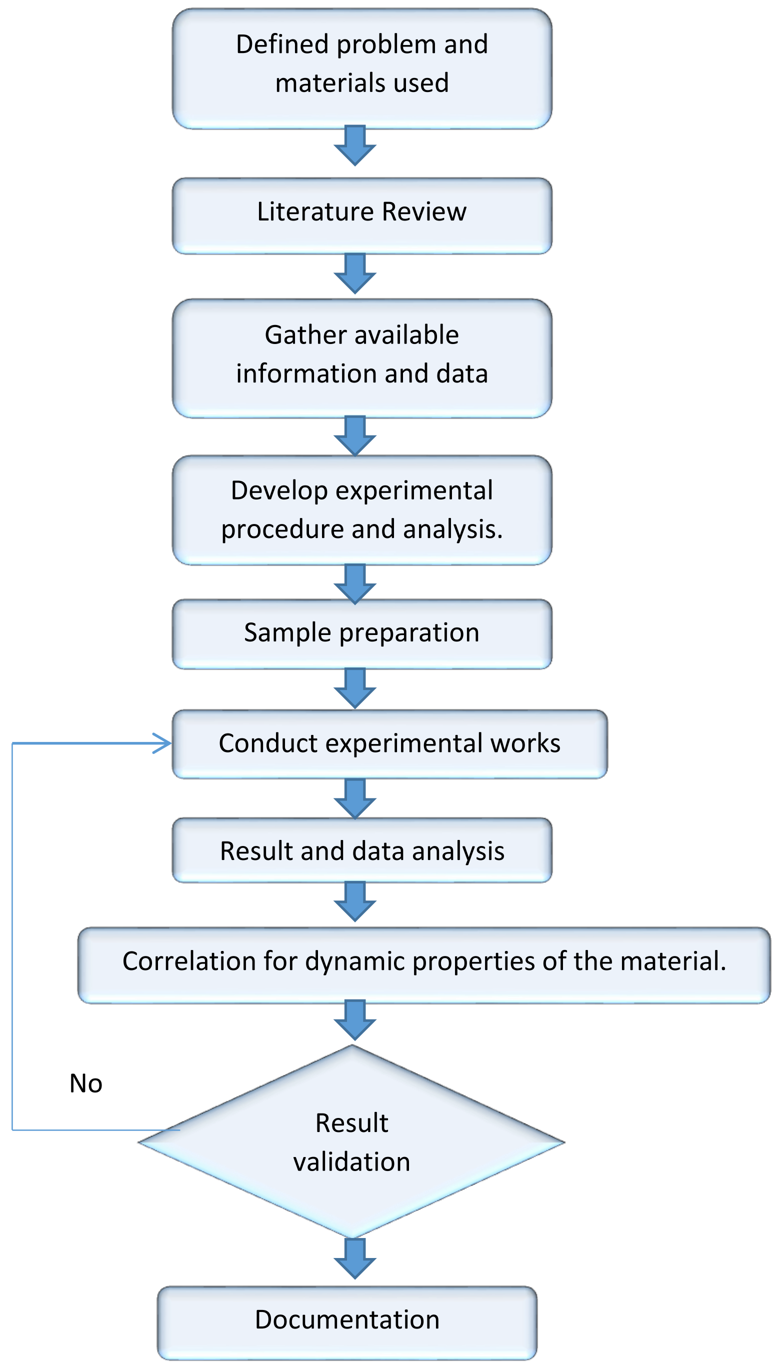
Low Temperature Gas Nitriding to 400 Series Stainless Steel

The process of low temperature nitriding involves the temperature between 350-500 °C. The process of low temperature nitriding will super-saturates the surface of the steel and expands the lattice. This expanded layer is called as “S-Phase” [21]. There is no new phase formed, but the properties of the new formed layer is unique. The thin hard layer formed from the low temperature nitriding process increases the wear resistance, chemical resistance, fretting resistance, corrosion performance, and other properties that plague stainless steels in demanding applications.

CHAPTER 3

METHODOLOGY AND PROJECT ACTIVITIES

3.0 Flow Chart



Ferritic 439 Grade stainless steel Plate Sample Size

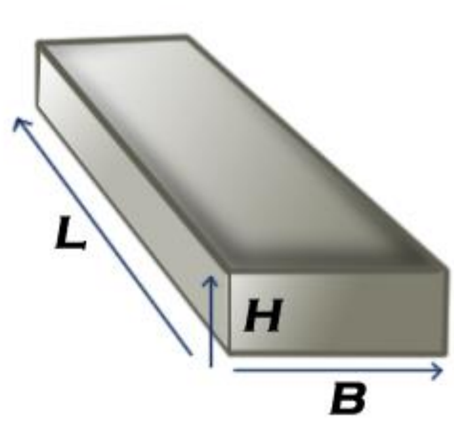


Figure 3.0: SS439 Plate Dimension

L = 111.13mm

B = 13.63mm

Thickness = 1.46mm

3.1.0 Metallography Methodology

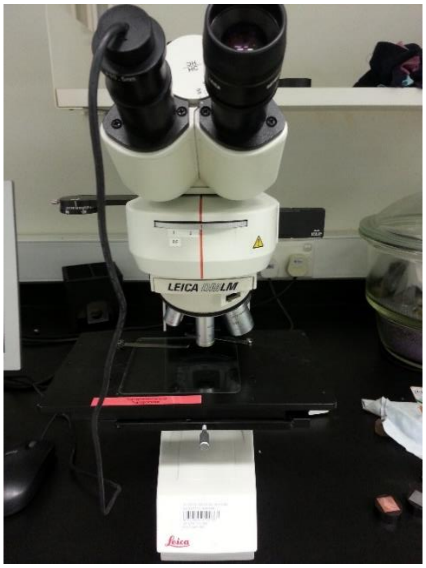


Figure 3.1 : Leica DM LM Microscope

1. The 439 Stainless Steel Plate is sectioned into 12mm x 12mm using abrasive cutter.
2. The sample is then hot mounted using Automatic Mounting Press and Buehler Phenolic Black Powder for ease of handling.
3. Grinding is done to the sample using rotating disc covered with 400,800, 1200 grit silicon carbide paper and using water as lubricant. Light pressure is applied at the center of the sample. Ensure the flatness of sample surface is maintained throughout the grinding steps
4. Polishing is done using rotating discs covered with soft cloth impregnated with micro-particles of diamond. “Rough” and “final” polishing is done to the sample.
5. Etching is done using ferric chloride etchants. The polished sample is etched by swabbing a cotton tip dipped in etchant.
6. The etched sample is then observed under microscope.
7. Image recording is done.
8. The steps is repeated for non-nitrided stainless steel, the high temperature nitrided, and the low temperature nitrided.

3.1.1 Nitriding Process Methodology

High Temperature Nitriding

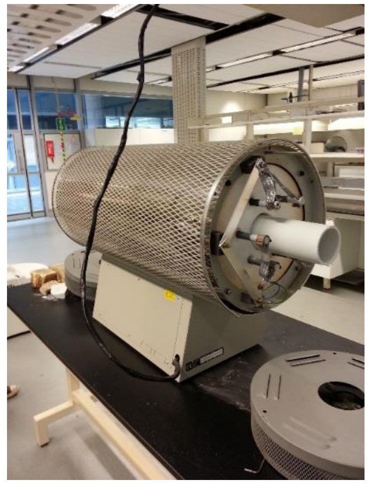


Figure 3.2 : Carbolite STF horizontal tube furnace

According to [12], the nitriding process was carried out in a Carbolite STF horizontal tube furnace. The N_2 gas is used. The procedures used in [12] are as follow:

1. 5 samples of AISI 439 ferritic stainless steel are prepared in 111.13mm X 13.63 mm X 1.46mm dimension. The samples will be washed with acetone before each experiment being carried out to remove any impurities on the surface of the samples.
2. A gas flow meter will be attached to the tube furnace to adjust the flow rate and to maintain constant flow rate during the treatment.
3. The gas outlet tube will be connected to a Drechsel bottle.
4. Five millimeters of the outlet tube length will be inserted into the water to slightly increase the gas pressure flown in the furnace.
5. Two samples will be placed in alumina boat and then be inserted into the heating zone.
6. The samples will be nitrided at 1050 °C for 10 hours.

Low Temperature Nitriding

1. 5 samples of AISI 439 ferritic stainless steel are prepared in 111.13mm X 13.63 mm X 1.46mm dimension. The samples will be washed with acetone before each experiment being carried out to remove any impurities on the surface of the samples.

2. A gas flow meter will be attached to the tube furnace to adjust the flow rate and to maintain constant flow rate during the treatment.

3. The gas outlet tube will be connected to a Drechsel bottle.

4. Five millimeters of the outlet tube length will be inserted into the water to slightly increase the gas pressure flown in the furnace.

5. Two samples will be placed in alumina boat and then be inserted into the heating zone.

6. The samples will be nitrided at 500 °C for 10 hours.

3.1.2 Stiffness Test Methodology

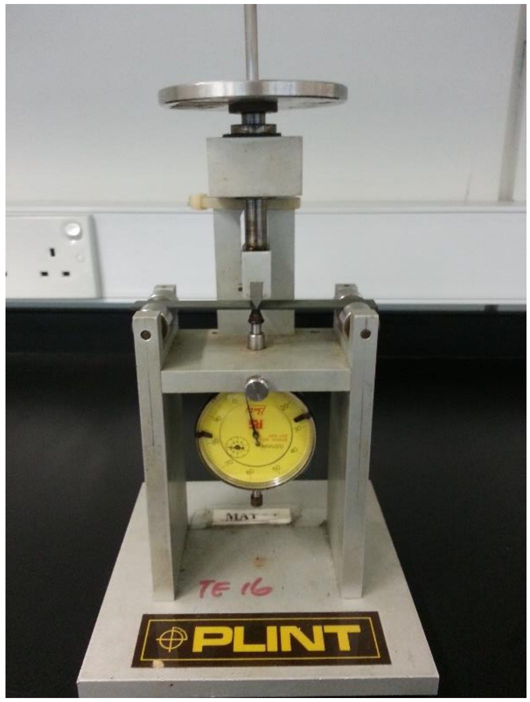


Figure 3.3 : Three point bend apparatus

1. The height and thickness of the specimen will be measured using vernier calliper and recorded.
2. The size of the specimen is 111.13mm x 13.63 mm x 1.46 mm.
3. The specimen will be placed on the supports of the apparatus.
4. The reading of dial gauge displacement indicator will be calibrated to zero.
5. The 200g load is put on top of the apparatus.
6. The deflection readings are recorded and 200g of increment for each reading will be added until the weight of the load reached 2.6kg.
7. The stiffness will be determine from the graph of Load (Kg) VS Deflection (mm)

3.1.3 Natural Frequency and Mode of Shape Methodology

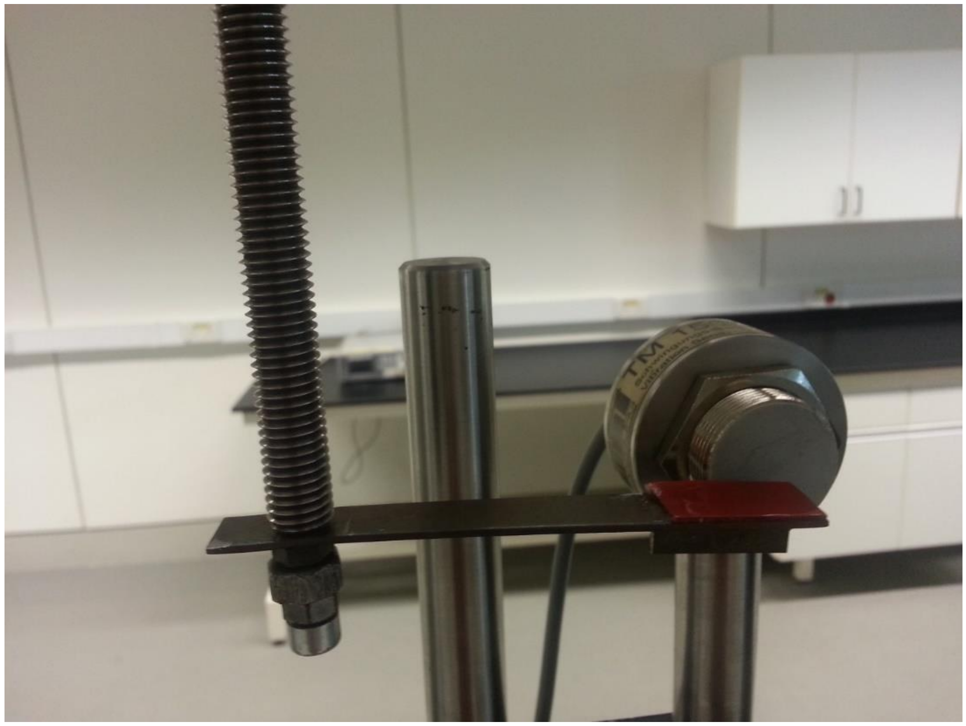


Figure 3.3 : Vibration Test Apparatus

1. The stainless steel plate will be put at the fixed mount.
2. The sensor vibration will be connected at the end of the stainless steel.
3. Recorder will be started and the stainless steel will be deflected about 1.5cm and it is allowed to come to rest.
4. The recorder will be stopped.
5. The experiment will be repeated for non-nitrided SS439, low temperature nitrided SS439, and high temperature nitrided SS439.

3.2.1 FYP I Gantt Chart

Project Activities	Week													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Project draft														
Literature review														
Preparation of extended proposal														
*Extended proposal submission														
Experiment procedure development														
SS 439 ferritic purchase and samples preparation														
*Proposal defense														
Preparation of interim report														
*Interim report submission														

Key milestone

3.2.2 FYP II Gantt Chart

Project Activities	**Week**														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Project Work Continues															
Submission of Progress Report															
Project Work Continues															
Pre-SEDEX Poster & Presentation															
Submission of Draft Report															
Submission of Dissertation (soft bound)															
Submission of Technical Paper															
Oral Presentation															
Submission of Project Dissertation (hard bound)															

Key milestone

3.3 Project Activities

FYP I

Event or Deliverable	Target Date	Responsibility
1) Project charter/draft preparation	Week 3-4	Discussion of the feasibility of the project.
2) Literature reviews	Week 3-14	Studies of the articles, journals, and etc. Data from the studies will be collected and analyzed.
Extended proposal	Week 6	Submission of the extended proposal to supervisor and also to FYP 1 coordinator.
Proposal defense	Week 9	Presentation of proposal to supervisor and examiner.
Interim report	Week 10-14	Submission of interim report to supervisor and to FYP 1 coordinator

FYP II

Event or Deliverable	Target Date	Responsibility
1) Project Works Continuation	Week 1-7	Involves mainly in: -High Temperature Nitriding of SS439 Plates (5 samples) -Low Temperature Nitriding of SS439 Plates (5 samples)
	Week 8-10	Metallography, Stiffness Test, and Natural Frequency Test for Non Nitrided, Low Temperature Nitrided, and High Temperature Nitrided SS439 Plates
Pre-SEDEX Poster & Presentation	Week 11	Poster presentation of project to internal examiner.
Submission of Draft Dissertation	Week 12	Submission of the draft dissertation to the supervisor.
Submission of Dissertation & Technical Paper	Week 13	Submission dissertation (3 soft bound copies) & Submission of technical paper to the supervisor.
Oral Presentation	Week 14	Oral presentation to 2 examiners & supervisor.
Submission of Dissertation	Week 15	Submission of dissertation (hard bound)

CHAPTER 4

RESULT & DISCUSSION

4.0 MICROSTUCTURE

4.0.1 Microstructure of Non Nitrided SS439 Plate

Figure 4.0: Non-Nitrided SS439 Plates

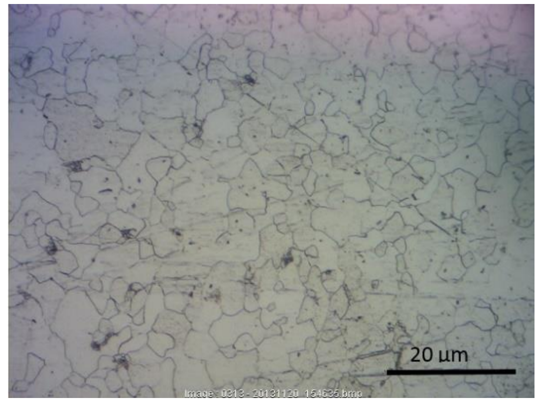


Figure 4.1: Non-nitrided SS439 Plate Microstructure

Figure 4.0 shows the non-nitrided SS439 plates and figure 4.1 shows the non-nitrided SS439 plate microstructure. The microstructure is taken from cross-section view of the plate with 100 times magnification. From this microstructure, the grain boundaries can be seen. There are just clear grain boundaries before any insertion of nitrogen particles.

At this state, the 439 stainless steel plate is just performing at its basic performance. Next, nitriding will be done to improve the material.

4.0.2 Microstructure of Low Temperature Nitrided SS439 Plates

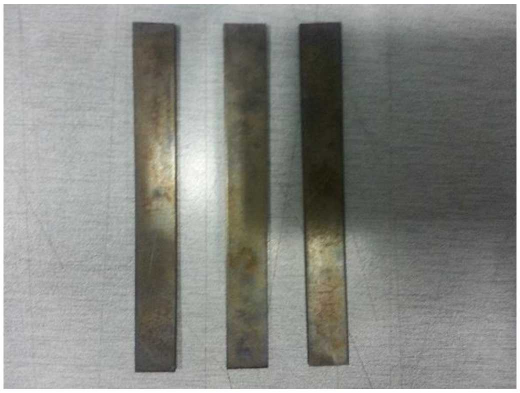


Figure 4.2: Low Temperature-Nitrided SS439 Plates

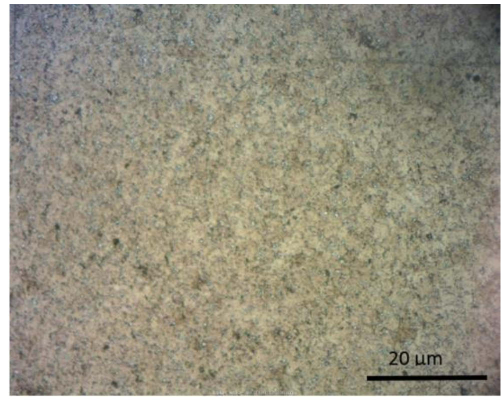


Figure 4.3: Low Temperature-Nitrided SS439 Plates Microstructure

Figure 4.2 shows the SS439 Plates after being low temperatre nitrided at 500°C for 10 hours and 4.3 shows the microstructure of the plates from cross section view at surface of the plate. As can be seen from the microstructure, the nitrogen particles have diffused into the grain boundaries. It can be observed also that the nitrogen particles have diffused throughout the plates, and create some light yellowish colour at the grain boundaries.

4.0.2 Microstructure of High Temperature Nitrided SS439 Plates

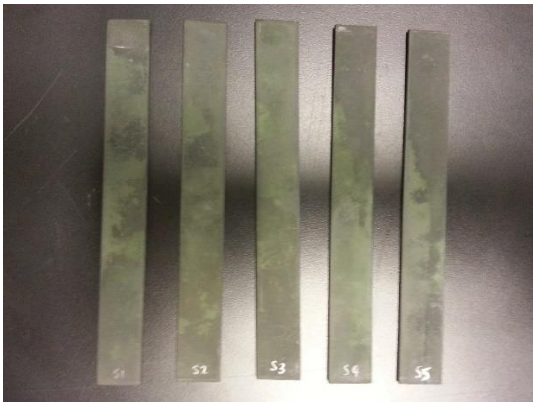


Figure 4.4: High Temperature-Nitrided SS439 Plates

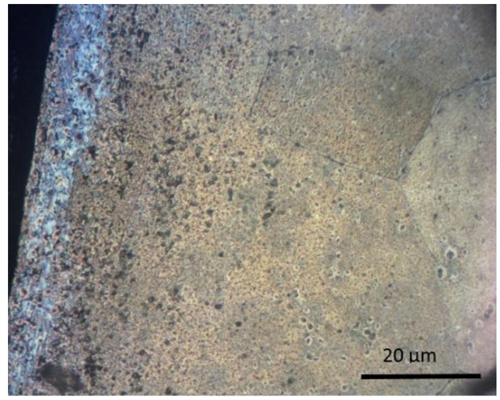


Figure 4.5: High Temperature-Nitrided SS439 Plates Microstructure

Figure 4.4 shows the SS439 Plates after being high temperatre nitrided at 1050°C for 10 hours and 4.5 shows the microstructure of the plates from cross section view at surface of the plate. As can be seen from the microstructure, at the surface of the plate, the microstructure has turned into martensitic phase. It can observed that nitrogen particles has diffused throughout the plate and the colour of the grain boundaries are darker than the previous low temperature nitride grain boundaries.

4.1 STIFFNESS TEST RESULT

4.1.1 Non-nitrided SS439 Plate

Load (kg)	Deflection (mm)					
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average Deflection
0	0	0	0	0	0	0
0.2	0.04	0.04	0.045	0.045	0.045	0.043
0.4	0.08	0.08	0.09	0.09	0.08	0.084
0.6	0.12	0.13	0.135	0.13	0.125	0.128
0.8	0.16	0.165	0.18	0.17	0.165	0.168
1	0.2	0.205	0.22	0.2	0.21	0.207
1.2	0.24	0.25	0.27	0.255	0.25	0.253
1.4	0.28	0.285	0.31	0.29	0.29	0.291
1.6	0.33	0.34	0.355	0.34	0.33	0.339
1.8	0.375	0.39	0.4	0.38	0.365	0.382
2	0.42	0.43	0.44	0.425	0.405	0.424
2.2	0.46	0.475	0.485	0.47	0.45	0.468
2.4	0.5	0.52	0.525	0.505	0.495	0.509
2.6	0.55	0.56	0.575	0.55	0.53	0.553

Table 4.0 : Deflection of Non-Nitrided SS439 Plates

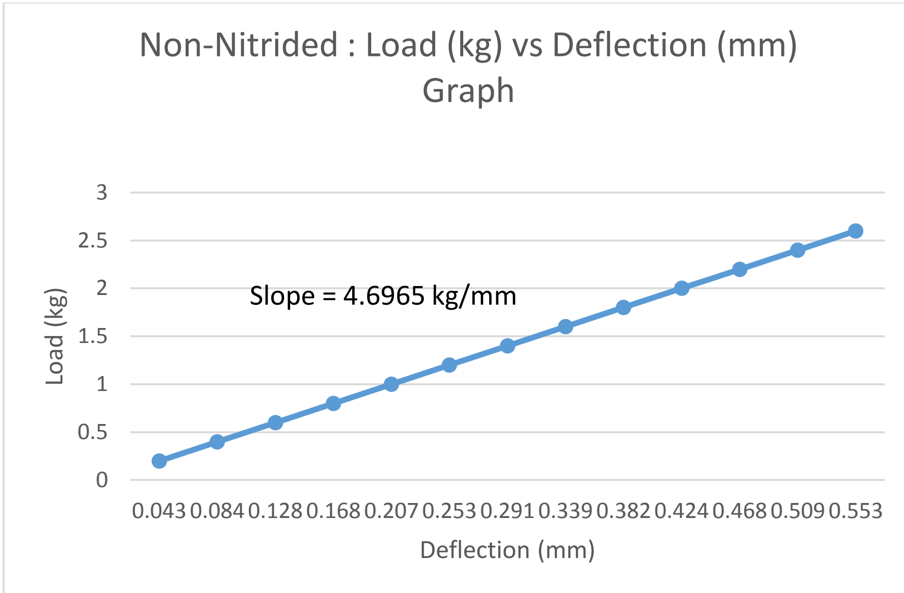


Figure 4.6: Load (kg) vs Deflection (mm) Graph of Non-nitrided SS439 Plates

<u>Calculation for Non – Nitrited SS439</u>

So, k (stiffness) = 4.6965 kg/mm x 9.81 m/s^2

= 46.0732 N/mm

= 46073.2 N/m

L = 111.13mm

B = 13.63mm

H = 1.46mm

Second Moment of area: $I_{x-x} = \frac{BH^3}{12}$

$$= \frac{(13.63\times10^{-3})(1.46\times10^{-3})^3}{12}$$

$$= 3.53\times10^{-12}\, m^4$$

Modulus of Elasticity: $E = \frac{kL^3}{48I}$

$$= \frac{(46073.2\ N/m)(111.13\times10^{-3}\, m)^3}{48(3.53\times10^{-12}\, m^4)}$$

= 372.67 GPa

4.1.2 Low Temperature Nitrided SS439 Plates

Load (kg)	Deflection (mm)					Average Deflection (mm)
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	
0	0	0	0	0	0	0
0.2	0.04	0.05	0.05	0.04	0.045	0.043
0.4	0.085	0.09	0.08	0.085	0.08	0.084
0.6	0.135	0.125	0.13	0.13	0.125	0.128
0.8	0.175	0.165	0.175	0.175	0.17	0.168
1	0.22	0.205	0.215	0.21	0.2	0.207
1.2	0.255	0.25	0.26	0.255	0.24	0.253
1.4	0.305	0.295	0.31	0.3	0.28	0.291
1.6	0.345	0.34	0.355	0.35	0.32	0.339
1.8	0.39	0.385	0.395	0.39	0.37	0.382
2	0.43	0.425	0.435	0.435	0.405	0.424
2.2	0.48	0.465	0.485	0.475	0.45	0.468
2.4	0.52	0.51	0.53	0.515	0.485	0.509
2.6	0.57	0.56	0.58	0.565	0.54	0.551

Table 4.1 : Deflection of Low Temperature-Nitrided SS439 Plates

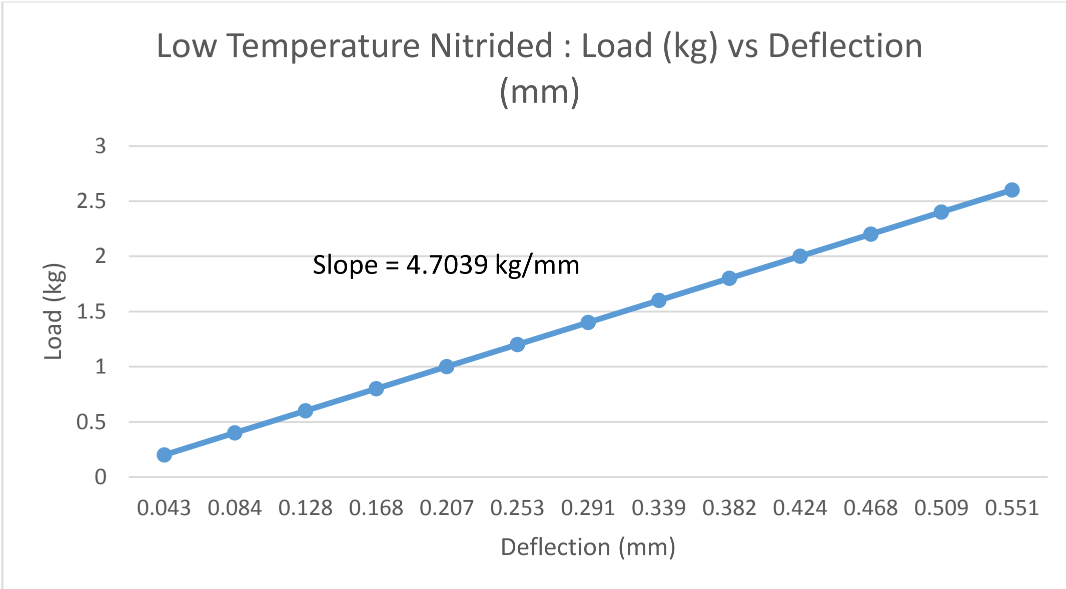


Figure 4.7: Load (kg) vs Deflection (mm) Graph of Low temperature-nitrided SS439 Plates

Calculation for Low Temperature Nitrided SS439

So, k (stiffness) = 4.7039kg/mm x 9.81m/s^2

= 46.1450 N/mm

= 46145.0 N/m

L = 111.13mm

B = 13.63mm

H = 1.46mm

Second Moment of area: $$I_{x-x} = \frac{BH^3}{12}$$

$$= \frac{(13.63\times10^{-3})(1.46\times10^{-3})^3}{12}$$

$$= 3.53\times10^{-12}\,m^4$$

Modulus of Elasticity: $$E = \frac{kL^3}{48I}$$

$$= \frac{(46145.0\ N/m)(111.13\times10^{-3}\,m)^3}{48(3.53\times10^{-12}\,m^4)}$$

= 373.25 GPa

4.1.3 High Temperature Nitrided SS439 Plates

Load (g)	Deflection (mm)					
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average Deflection
0	0	0	0	0	0	0
0.2	0.05	0.05	0.05	0.05	0.04	0.048
0.4	0.095	0.08	0.09	0.085	0.09	0.088
0.6	0.13	0.13	0.13	0.13	0.13	0.13
0.8	0.175	0.175	0.175	0.18	0.17	0.175
1	0.22	0.22	0.21	0.21	0.205	0.213
1.2	0.265	0.26	0.26	0.255	0.25	0.258
1.4	0.3	0.305	0.3	0.3	0.28	0.297
1.6	0.35	0.345	0.35	0.33	0.33	0.341
1.8	0.39	0.38	0.38	0.37	0.37	0.378
2	0.43	0.415	0.415	0.41	0.4	0.414
2.2	0.49	0.46	0.46	0.45	0.45	0.462
2.4	0.52	0.5	0.5	0.49	0.49	0.5
2.6	0.56	0.54	0.54	0.54	0.53	0.542

Table 4.2 : Deflection of High Temperature-Nitrided SS439 Plates

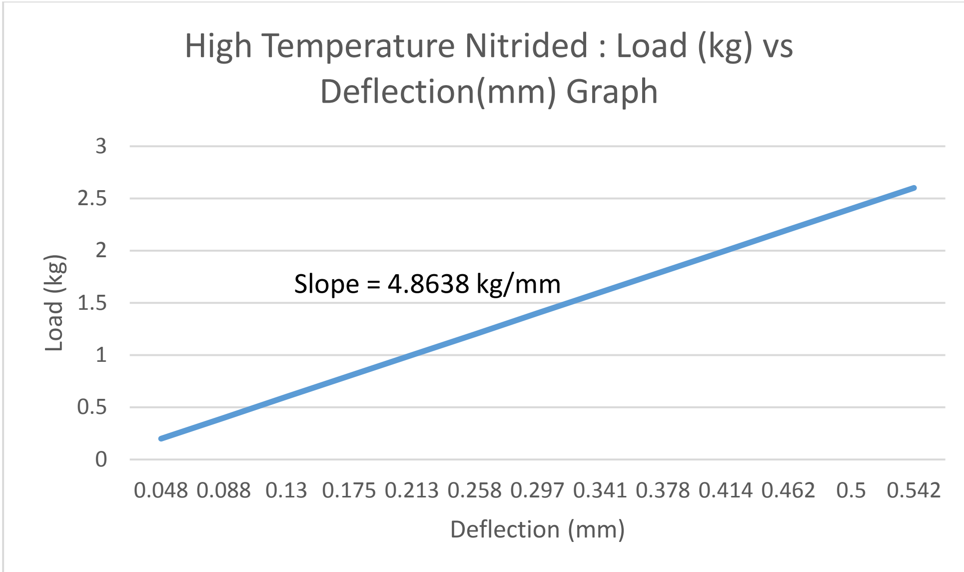


Figure 4.8: Load (kg) vs Deflection (mm) Graph of High temperature-nitrided SS439 Plates

Calculation for High Temperature Nitrided SS439

So, k (stiffness) = 4.8638 kg/mm x 9.81m/s^2

= 47.7140 N/mm

= 47714.0 N/m

L = 111.13mm

B = 13.63mm

H = 1.46mm

Second Moment of area: $I_{x-x} = \dfrac{BH^3}{12}$

$$= \frac{(13.63\times10^{-3})(1.46\times10^{-3})^3}{12}$$

$$= 3.53\times10^{-12}\,m^4$$

Modulus of Elasticity: $E = \dfrac{kL^3}{48I}$

$$= \frac{(47714.0\ \ N/m)(111.13\times10^{-3}\,m)^3}{48(3.53\times10^{-12}\,m^4)}$$

= 385.95 GPa

Stiffness Result Discussion

From the calculation for the stiffness of non-nitrided, low temperature nitrided, and high temperature nitride SS439, the results can be summarized as the table below:

Sample	Stiffness, K (N/mm)	Modulus of elasticity, E (Gpa)
Non-nitrided	46.0732	372.67
Low Temperature Nitrided	46.1450	373.25
High Temperature Nitrided	47.7140	385.95

Table 4.3: Stiffness, k and Modulus of elasticity, E of SS439 (Non-nitrided, Low temperature nitrided, High Temperature Nitrided)

From the table above, it can be seen that the stiffness is increasing from non-nitrided to low temperature nitrided, which is from 46.0732 N/mm to 46.1450 N/mm. Significant increases of the stiffness is shown from low temperature nitrided to high temperature nitrided which is 46.1450 N/mm to 47.7140 N/mm. This indicates that the material stiffness increases as the nitriding is done from low to high temperature. The higher the temperature, the better the case hardening of a material. 1050°C temperature is the best temperature to nitride the ferritic 439 grade stainless steel to increase its stiffness.

From the graphs of load(kg) vs. deflection, all samples(non-nitrided and nitrided) have linear deflection towards the load applied. This shows that as long as the load is applied in the elastic region, all materials used has the elastic capability and will behave elastic. From all the samples, the high temperature nitride SS439 plates has the highest stiffness which is 47.7140 N/mm.

4.2 NATURAL FREQUENCY TEST

4.2.1 Natural Frequency Non-Nitrided SS439 Result

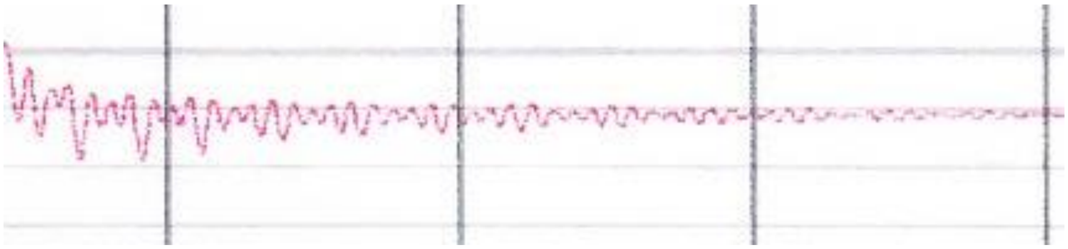


Figure 4.9 : Vibration Cycle of Non-Nitrided SS439

1wavelength, Π = 5mm = 0.5s

For Non-Nitrided SS439:

1 wavelength = 2mm

Thus, T= 0.2 s

$$F = \frac{1}{T}$$

$$F = \frac{1}{0.2s} = 5Hz$$

4.2.2 Natural Frequency of Low Temperature Nitrided SS439 Result

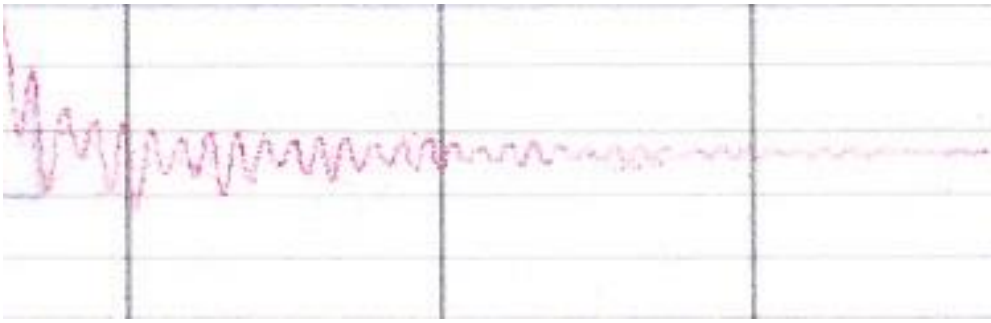


Figure 4.10 : Vibration Cycle of Low Temperature Nitrided SS439

1wavelength, Π = 5mm = 0.5s

For Low Temperature-Nitrided SS439:

1 wavelength = 1.6mm

Thus, T= 0.16 s

$$F = \frac{1}{T}$$

$$F = \frac{1}{0.16s} = 6.25Hz$$

4.2.3 Natural Frequency of High Temperature Nitrided SS439 Result

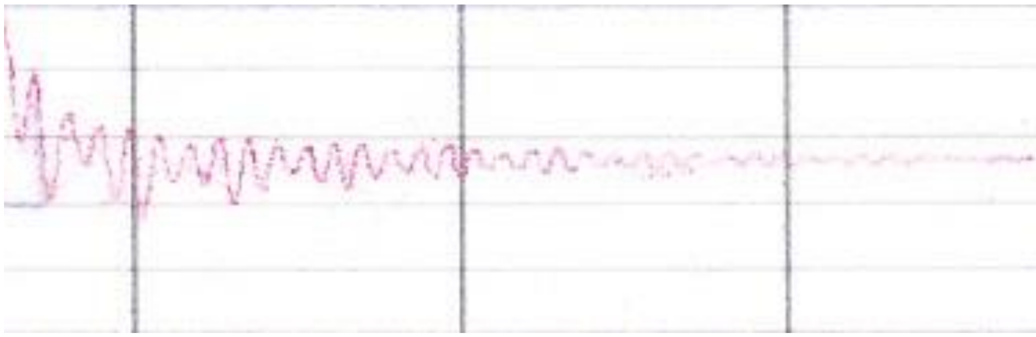


Figure 4.11: Vibration Cycle of High Temperature Nitrided SS439

Calculation :

1wavelength, Π = 5mm = 0.5s

For High Temperature-Nitrided SS439:

1 wavelength = 1mm

Thus, T= 0.1 s

$$F=\frac{1}{T}$$

$$F=\frac{1}{0.1s}= 10Hz$$

Discussion For Natural Frequency

The result for natural frequency of non-nitrided, low temperature nitrided, and high temperature nitrided SS439 can be summarized as the table below:

Sample	Natural Frequency, Hz	Increment, Hz
Non-nitrided SS439	5	-
Low Temperature Nitrided SS439	6.25	1.25
High Temperature Nitrided SS439	10	5

Table 4.4: Natural Frequency of Non-Nitrided, Low Temperature Nitrided, & High Temperature Nitrided SS439

Based on the table above, when the SS439 is nitrided at low temperature, which is 500˚C, there is only slight increment in natural frequency which is 1.25 Hz compared to the non-nitrided SS439. While for the high temperature nitrided SS439 at 1050˚C, the increment is 5 Hz compared the non nitrided which makes its natural frequency become 10 Hz.

This shows that the high temperature nitriding process has succeed and more effective compared to low temperature nitriding process in order to increase the natural frequency of Ferritic 439 Grade Stainless Steel.

This increment in natural frequency will allow the material to be used in more vibratory environment, and thus will expand the usage of the Ferritic 439 Grade Stainless Steel.

CHAPTER 5

5.0 CONCLUSION

In a conclusion, this project has delivered the results based on what has been stated in literature review. After the low temperature and high temperature nitriding process, the stiffness of the stainless steel 439 has increased. The best nitriding process to increase the stiffness is by high temperature nitriding process at 1050˚C for 10 hours because the results show a big difference in the modulus of elasticity of the material which is from 372.67GPa for non-nitrided to 385.95GPa for high temperature nitrided. Based on the following formula:

$$\omega_n = \sqrt{\frac{k}{m}}$$

Where, ω_n=natural frequency

k=stiffness

m=mass

As the stiffness increases, the natural frequency will also increase. This has been proven from the natural frequency test. After both low temperature and high temperature nitriding process, the natural frequency has increased. But the more significant increase in natural frequency can be seen after the high temperature nitriding process when the natural frequency increases from 5Hz for non-nitrided to 10Hz for high temperature nitrided SS439.

It can be concluded that the high temperature nitriding process is better than the low temperature nitriding process as the Ferritic 439 Grade Stainless Steel shown significant increase in stiffness and natural frequency during the high temperature nitriding process compared to low temperature nitriding process.

5.1 RECOMMENDATION

To expand the usage of Nitrided SS439

The stainless steel 439 is widely used because of its corrosion resistant characteristics and also its reasonable cost to the industry. After this study is done, it is hoped that this nitrided stainless steel can be used in conditions that the nitrided stainless steel being exposed to the vibratory motion which could be at an extreme amplitude and frequency. This project will expand the usage of this precious material by perfecting it using high temperature nitriding process.

To use ANSYS Simulation Software

To further the study of the structural dynamics of the nitrided ferritic 439 grade stainless steel, simulation software like ANSYS. Structural analysis solutions from ANSYS can provide the ability to simulate every structural aspect of the nitride ferritic SS439, including linear static analysis that simply provides stresses or deformations, modal analysis that determines vibration characteristics, through to advanced transient nonlinear phenomena involving dynamic effects and complex behaviors. Due to time constraint, author has no opportunity to perform the ANSYS Simulation to the nitrided ferritic SS439.

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