Effects of Titanium Addition on Mechanical and Corrosion properties of 316L Stainless Steel Developed through Powder Injection Molding Process.

By

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13942

Dissertation submitted in partial fulfillment of
the requirement for the
Degree of Engineering (Hons)
(Mechanical Engineering)

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CERTIFICATION OF APPROVAL

Of Research Project

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(MECHANICAL ENGINEERING)

Approved by,

____

(AP Dr. Faiz Bin Ahmad)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
MAY 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.

(MOHD TARMIZI BIN WAHABI)

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ABSTRACT

Titanium is be used to enhance mechanical and corrosion properties of stainless steel 316L. The stainless steel (316L) powder water atomized (PWA) is reinforced with titanium powder and green parts are produced by powder injection molding (PIM). Various weight percentages of titanium which are 0%, 0.5%, 1.0% and 1.5% are used to study the effects of titanium into 316L stainless steel (SS). Then, the green samples are sintered in argon environment in three different temperature which are 1300 ^{o}C, 1345 ^{o}C, 1390 ^{o}C. Characterization of the samples were done through morphological analysis under scanning electron microscope (SEM). While tensile test was done to measure the mechanical properties of the stainless steel after enhancement with titanium. Also, the corrosion test is done to check the corrosion resistance of samples in Ringer’s solution.

ACKNOWLEDGEMENT

Final year project (FYP) is a subject that focusing on individual capability and intellectual to solve problems either theoretically or experimentally. Student will be given a title or propose a title for their project. Duration for this project is two semester which are Final Year Project 1 and Final Year Project 2. For the last eight months, I, Mohd Tarmizi Bin Wahabi, student ID 13942 from Mechanical Engineering Programme had been finished my project entitled Effects of Titanium Addition on Mechanical and Corrosion Properties of 316L Stainless Steel Developed through Powder Injection Molding Process successfully.

Alhamdulillah, I had finished my final year project which is partially fully an important task before graduating from Universiti Teknologi PETRONAS. Thanks Allah for giving me helps and sent me a good supervisor, AP Dr. Faiz Bin Ahmad, who is expert in this area of research. Without his guidance, I will not know how to execute this project until the end.

Also, I would like to thanks Mr. Aslam, doctorate student who the one that help me during my experiment. He also had showed me what I supposed to find and focus for my project.

Much appreciation also I dedicated to all the devoted and supportive committee of the Final Year Project under the coordinator, AP Dr. Azmi Bin Wahab who is the person that facilitating and managing this encouraging FYP course. My deepest gratitude shall be given to all technician and staff of Universiti Teknologi PETRONAS for their support and cooperation to me in order to complete my project.

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CHAPTER 1 : INTRODUCTION

1.1 Background Study

High mechanical and corrosion properties are the most vital characteristic in materials selection for a project. Engineers must select for the stronger element and the capability of the element to withstand the corrosion. Nowadays, stainless steel is the common metal used in the industries because it high mechanical and corrosion properties in working environment. There are many types of stainless steel in the current market such as stainless steel (SS) 403, SS 316, SS316L and many more. The difference of each stainless steel is their compositions. For example SS 316L has 16% - 18% of Chromium, 10% - 14% of Nickel, 0.03% max of Carbon, 2.0% max of Manganese, 0.045% max of Phosphorus, 0.03% max of Sulfur, 10% of silicon, 2.0% - 3.0% of Molybdenum [1]. However, in this project, the stainless steel 316L will be reinforced with titanium.

Titanium is an element on earth that has great mechanical properties compare to iron. Moreover, this element also has high strength -to –weight ratio which is widely used in industries [1]. Combination of the titanium with the stainless steel could increase the mechanical and corrosion properties of stainless steel 316L.

In last 20-30 years, powder metallurgical process had improved the mechanical and corrosion properties of metal effectively [2]. Furthermore, by using powder metallurgy techniques, fine grain size can be produced which increase the homogeneity of the materials [3].

1.2 Problem Statement

Stainless steel is corroded while it is used in specific environment for a long period of time. In order to avoid corrosion and improve its mechanical properties, surface treatment is often used to improve the properties. However, surface coating is an expensive technique and has its own limitations. Thus improvement in corrosion resistance and mechanical properties of 316L SS is required to make it more compatible with the desired environment.

1.3 Objective

- To investigate the effects of titanium on mechanical and corrosion properties of 316L stainless steel developed through powder injection molding.
- To study the effects of temperatures during sintering process on the samples.
- To examine the morphological structure of titanium admixed 316L stainless steel.

1.4 Scope of Study

The current study is focused on the mechanical and corrosion properties of the stainless steel 316LSS which is alloyed with titanium. In this research, several tests will be conducted to measure the corrosion and mechanical properties of 316LSS alloy.

1.5 Feasibility of Studies

This project must be completed within 28 weeks (2 Semester of studies) with the complete report. Also it required experimental work from manufacturing the samples until testing the properties. Procedures made will ensure the accuracy of the project progress within the time limit.

CHAPTER 2 : LITERATURE REVIEW

Alloy metals are combination of various types of chemical composition such is iron, carbon, phosphorus, sodium and many more. The purpose of alloying metal is to increase the mechanical properties and also to enhance the corrosion properties. Corrosion occurs at all materials on earth because the materials need to achieve its stable condition. What makes the differences between each material is the corrosion rate.

Powder metallurgy process can show a wide spectrum of alloys composition and produce extensive range of mechanical and corrosion properties [4]. To achieve that, the new materials must have austenite and ferrite microstructure where a balance of austenite and ferrite in the microstructure will help in achieving the highest pitting corrosion resistance [5]. This shows that the mixture's composition and its microstructure will determine the corrosion resistance [6]. Thus, a proper sintering process must be done in order to create austenite and ferrite microstructures of stainless steel.

There are low and high carbon steel. Low carbon steel which will referred to 'L' at the end of it type like 316L and 304L, contain small amount of element carbon which is 0.03 wt%. The purpose of the made of low carbon steel is to increase the resistance to intergranular corrosion [7]. In order to reduce the carbon composition in the stainless steel, argon sintering process is introduced. Inside the furnace, argon gas is injected through the stainless steel to remove the carbon and sulfur elements. Typically for low carbon steel, the sulfur is around 0.005 wt% because low sulfur composition is quite beneficial to hot machinability [7].

Table 2-1: Mechanical Properties of 316L SS [8] and Titanium [9]

Mechanical Properties	316L SS	Titanium
Tensile strength	558 MPa (min)	246-370 MPa
Yield strength 0.2% Proof	290 MPa (min)	100-225 MPa
Elongation	50 % in 50mm (min)	15 %
Hardness Brinell	217 HB max	716 HB
Hardness Rockwell B	79 HRB max	100 HRB

Table 2-2: Physical Properties of 316L SS [8] and Titanium [9] [10]

Properties	316L SS	Titanium
Melting Temperature	1371-1399 ^oC	1668 ^oC
Density	7.99 g/cm^3	4.43 g/ cm^3
Modulus of Elasticity in Tension	193 GPa	116 GPa
Thermal Expansion Coefficient	$19.9 \times 10^{-6} K^{-1}$	$8.6 \times 10^{-6} K^{-1}$
Thermal Conductivity	16.2 W/m.K	21.9 W/m.K

Table 2-1 and Table 2-2 above are explaining the mechanical and physical properties of 316L SS and titanium.

Previous study shows that the suitable temperature for gas-atomized sintering is above 1350^{o}C where the best microstructures formation that high mechanical and corrosion properties [11]. Basically there are two types of powder that can be used in the powder injection molding process which are water atomized and gas atomized powder. However, gas atomized could be sintered to 99% of the theoretical density while water atomized powder can be sintered to a maximum of 97% of theoretical density [12].

During the sintering process, there will be shrinkage on the samples. Thus, there are parameter and calculations to be considered to control sintering shrinkage in order to obtain the desired final dimensions [13]. However, the complexity of the sintering process makes dimensional control a very challenging job [14].

In addition, corrosion by definition is deterioration of a material or its properties because of reaction with its environment [15]. Rate of corrosion increased first but then reduced with time [16]. There are several studies on corrosion behaviour of 316L stainless steel [17]. It shows the important of corrosion prevention of the materials used for biomedical implant. Allergic and hypersensitivity are some of the common problem as the effects of the corrosion composition inside the human body.

CHAPTER 3 : METHODOLOGY

<u>Experimental Methodology</u>

1) Preparing the raw materials
2) Sample Preparation

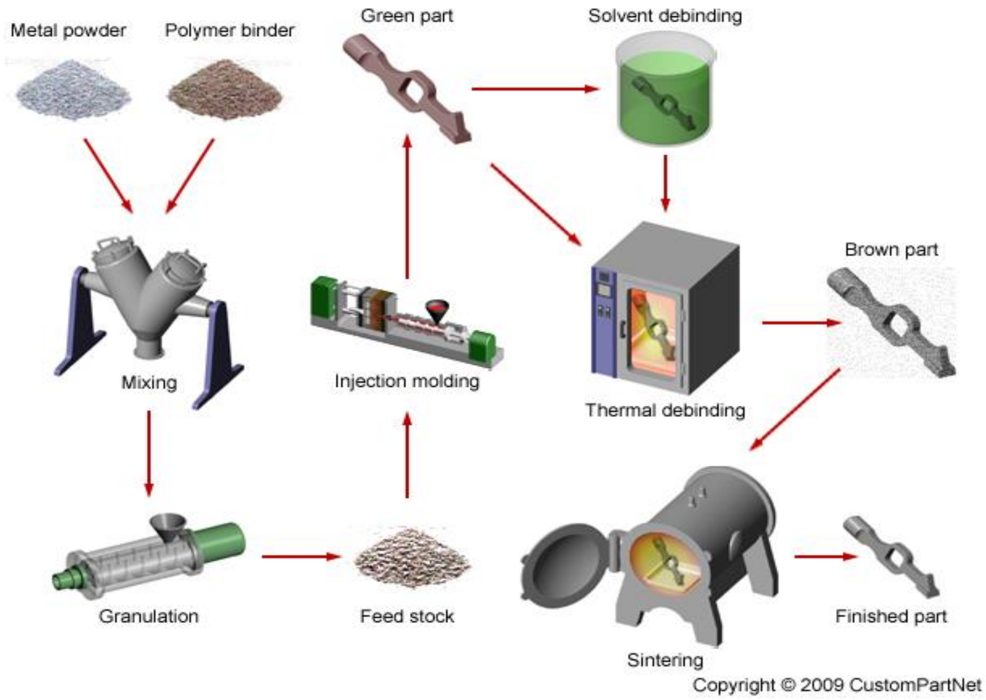


Figure 3-1: Schematic Diagrams of the Fabrication of Samples *[18]*

3) Testing Characterization
   i. Mechanical Properties
      - Tensile Test
   ii. Microstructure Analysis
      - Scanning Electron Microscopy (SEM)
      - EDS
   iii. Corrosion Test

3.1 Feedstock Preparation

➢ Material

Figure 3-2: Ratio of powder used in the each sample

Sample	Powder (total 65% wt)	Binder (total 35% wt)		
		Polypropylene	Steric Acid	PW
1	316L SS (100% wt)	25	5	70
2	316L SS (99% wt) + 1% wt Ti	25	5	70

➢ Equipment

1. Type : Z-blade mixer
2. Rate : 60 rpm
3. Temperature : 175 ^{o}C
4. Time : 90 min

3.2 Sample Preparation

Figure 3-3: Vertical Injection Molding MCP HEK-GmBH

Figure 3-4: Components of injection molding

3.2.1 Injection Molding Procedure

a. Firstly, the temperature was set to 180oC.
b. The vertical injection molding was switched on.
c. Next, the granule was poured inside into the hopper.
d. The granule was melted for about a few seconds until all the melted granule was squeezed out from the nozzle as shown in **Figure 3-5**.
e. Step 3 to 4 was repeated 3 times in order to remove the gases inside the granule.
f. Finally, the mold was inserted directly below the nozzle.
g. The nozzle was aligned with the mold.
h. After re-melt process, the mold was taken out from the machine.
i. The product was taken out from the mold by pushing the pin slowly from the outside of the mold as shown in **Figure 3-6**.

Figure 3-5: Purging process

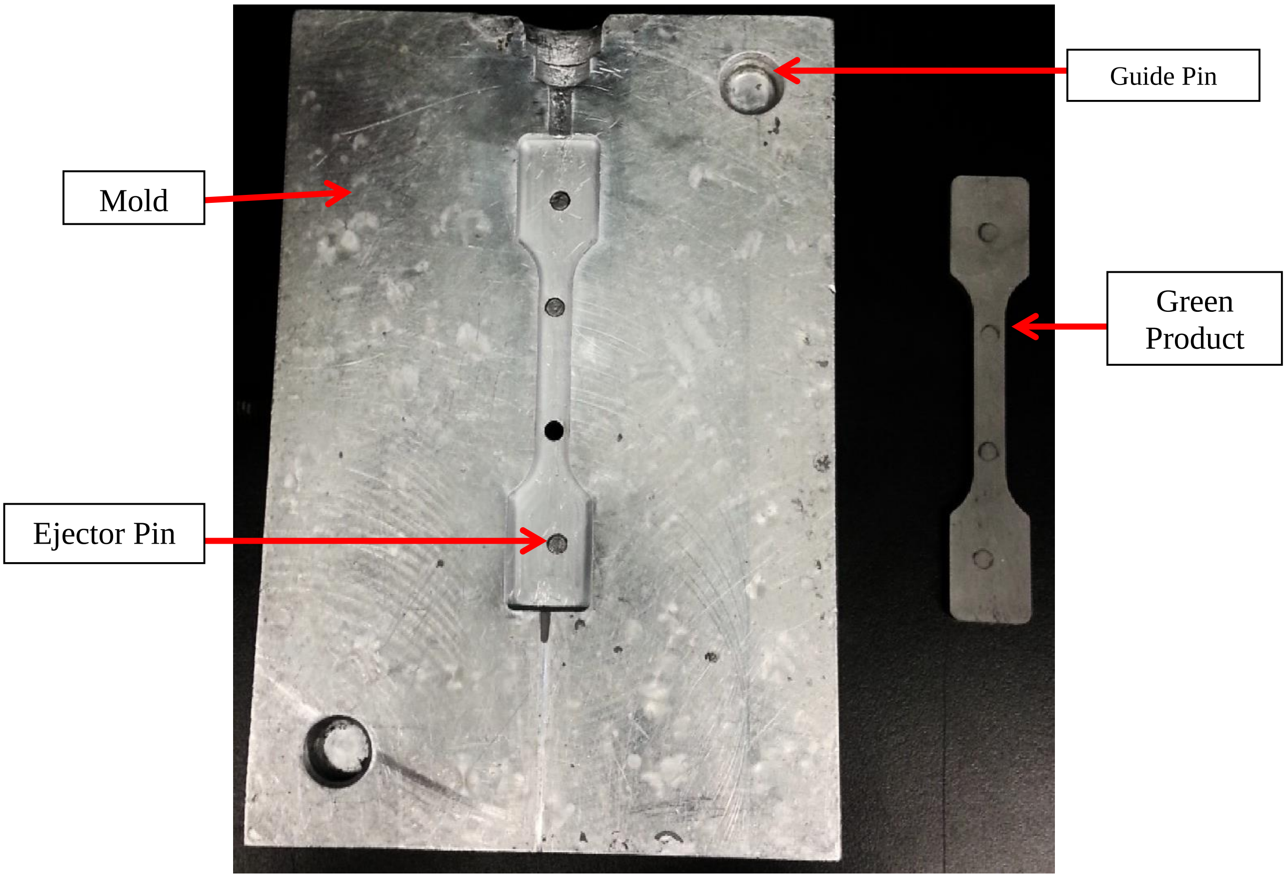


Figure 3-6: Mold used

Figure 7 shows completed product after removed from the mold. The product has good finishing based on visual inspection on the edges and surface. It is safe to say that the compound mixture ratio is well balanced.

3.2.2 Solvent Debinding

Solvent Debinding is a process to remove the binder by using n-heptane liquid. The samples were immersed in the solution for five hours. Also the solution must be in 60 ^{o}C.

Figure 3-7: Green Samples

3.2.3 Sintering Process

The purpose of the process is to increase the density of green samples. According to Liu, Loh and etc [14], various temperatures and sintering atmosphere will determine the final density. So these factors must be characterized and optimized perfectly in order to get high density final product. Since the temperature used were 1300 – 1400 ^{o}C, the student had used alumina tube furnace which was in Block N.

Figure 3-8: Tube Furnace

Table 3-1: Parameter for sintering process

Parameters	**Value**
Temperature	1300°C, 1345°C, 1390°C
Time	12 hours times 3 cycles
Pressure	50 – 100 mmHg
Gas	Purified Argon
Temperature rate	As per cycle
Flow rate	1000 cm^3/min

Table 3-2: Temperature used for sintering process

No. of samples	Temperature (°C)
3	1300
3	1345
3	1390

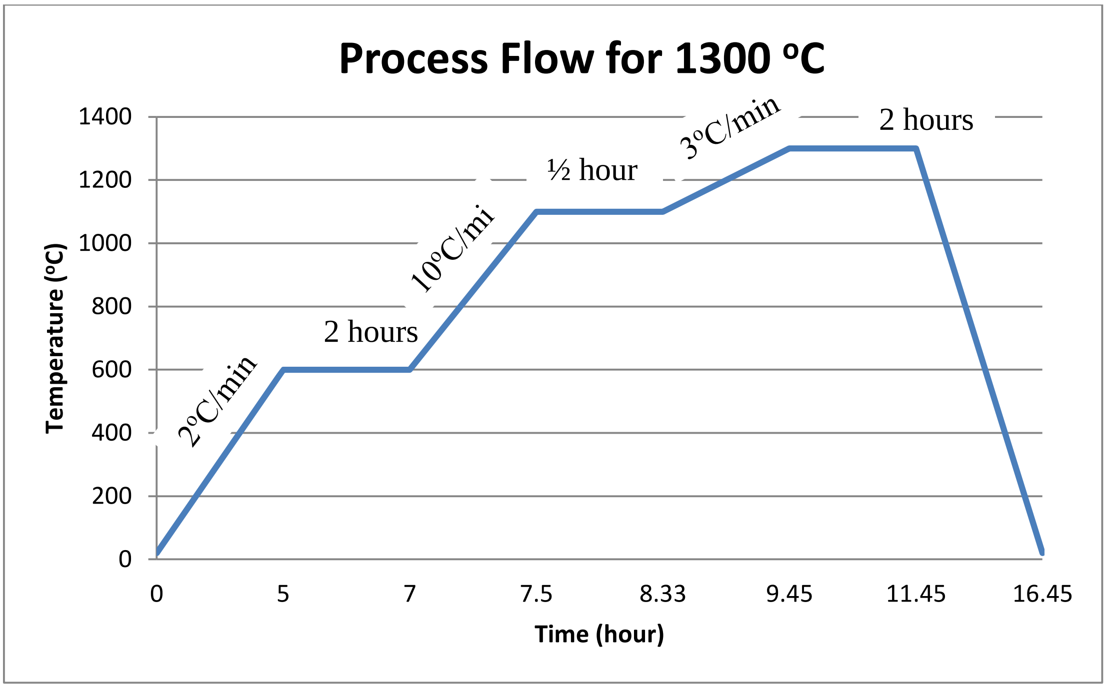


Figure 3-9: Sintering cycle for temperature 1300 ºC

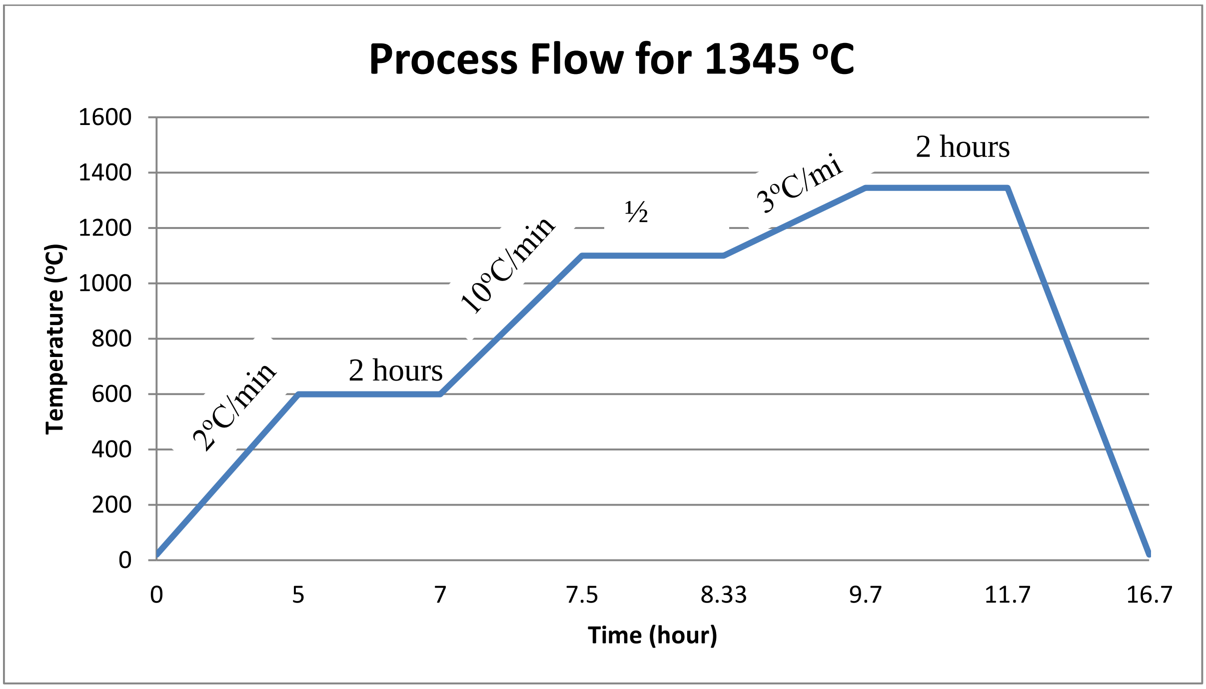


Figure 3-10: Sintering cycle for temperature 1345 ºC

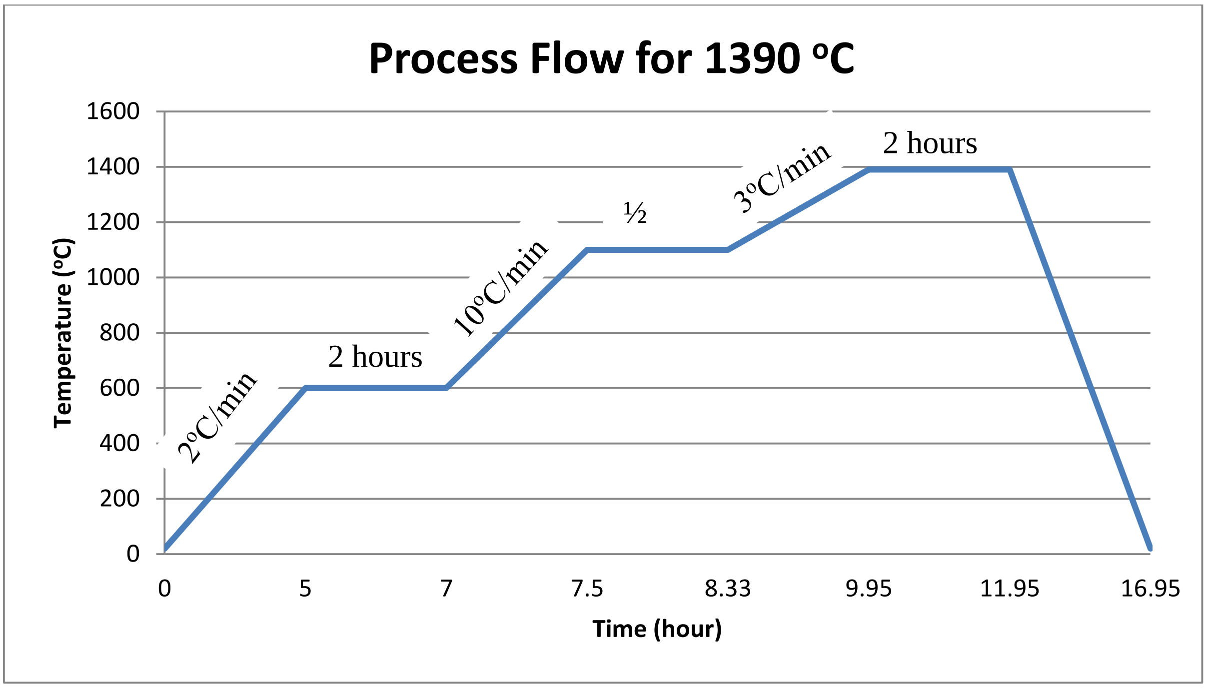


Figure 3-11: Sintering cycle for temperature 1390 oC

Figure 3-12: Green samples for Argon sintering

Figure 3-13: Sintered samples in Argon environment

3.3 Testing Characterization

3.3.1 Mechanical Testing

Metals Tensile Testing Standard – ISO 6892 – 1 ASTM E8/8M

Apparatus

Figure 3-14: Universal Testing Machine (UTM)

Procedure

1. Each sample is labelled with a marker pen. ID format is given to indicate the material and temperature differences.
2. The diameter of the specimen is measured at three locations along the gage length. The average of these measurements are recorded in the table provided.
3. The gage length is marked and the distance between gage length marks are measured.
4. The sample is mounted at the universal testing clamps by the technician. An extensometer will be placed on the sample to measure displacement.

5. Once the machine has been initialized, the test will begin. The hydraulic ramp is slowly pull the sample. The load and corresponding displacement is recorded into a data file created at the beginning of the initialization stage.
6. After the sample has been stretched to a displacement of about 1 mm, the test will be put on hold. The extensometer is removed. This is done to prevent damage to the extensometer in the event of sample fracture.
7. The test is continued at a slightly higher rate of loading. The load is only recorded in order to determine the maximum and fracture loads.
8. After the sample is fractured and the test is stopped, the sample is removed from the UTM.
9. A printout of the stress-strain curve will be made available.
10. Repeat for another material.

3.3.2 Microscopic Examination

Table top scanning electron microscope (SEM) is used in conducting microscopic examination onto the mounted sample which is newly available at Block 17. It is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that can be detected and that contain information about the sample's surface topography and composition including external morphology (texture), chemical composition, and crystalline structure and orientation of materials making the sample.

Figure 3-15: Table top Scanning Electron Microscope

3.3.3 Corrosion Test

For this test, three solutions need to be prepared which are 1M of nitric acid, 1M of sodium hydroxide and Ringer's solution. The specimens will be immersed for 30 days to get the corrosion result.

a. Preparation of 1 litre of 1 Molar HNO_3 [19]
   - 63ml of 16M concentrated acid is measured in the fume chamber before it is mixed with 937 ml of distilled water. Then, the stick is used to stir the solution gently.

b. Preparation of 1 litre of 1M NaOH [20]
   - 40 grams of NaOH is measured before mixed with distilled water until it reached one litre using cylindrical cylinder.

c. Preparation of Ringer's solution [21].
   - 7.2g sodium chloride - NaCl
   - 0.37g potassium chloride - KCl
   - 0.17 g calcium chloride - $CaCl_2$

     1. The reagents are dissolved into distilled water.
     2. Distilled water is added to bring the final volume to 1 L.
     3. The pH is adjusted to 7.3-7.4 by using pH meter

Weight Loss Method

According to ASTM G1-03, Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimen, corrosion rate can be calculated by the following equation:

Corrosion Rate, CR = $\frac{KW}{DAT}$ [22]   Equation 3-1: Corrosion Rate

K = Constant (mm/year = 87600, mpy = 3450000)

T = Time of exposure in hours

D = Density in grams/cm^3

A = Area in cm^2

W = Weight loss in grams

Table 3-3: Gantt chart for FYP 1

No.	Items	Weeks													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Topic Selection														
2	Background study on the project														
3	Writing up the extended proposal														
4	Discussion with lab technicians														
5	Manufacturing the specimen 5.2 Making the green samples														
	5.3 Gas-Sintering														
6	Proposal Defences														
8	Writing interim report														
9	Submitting interim report														

Planning
Milestone

Table 3-4: Gantt chart for FYP 2

No.	Items	Weeks													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Tensile test														
2	Mounting														
3	Grinding & Polishing														
4	Optical Microscope														
5	Progress Report							★							
6	Scanning Electron Microscope														
7	Corrosion Test														
8	Submission of draft report														
9	Submission of dissertation and technical paper														
10	Oral presentation														

Planning
★ Milestone

CHAPTER 4 : RESULT & DISCUSSION

4.1 Mechanical Test

Table 4-1: Result Tensile Test

Sintering Temperature / Vol%	1300°C	1345 °C	1390 °C
0.0	543.235	539.530	523.548
0.5	563.542	560.305	557.700
1.0	550.322	542.368	535.908
1.5	521.344	523.651	518.150

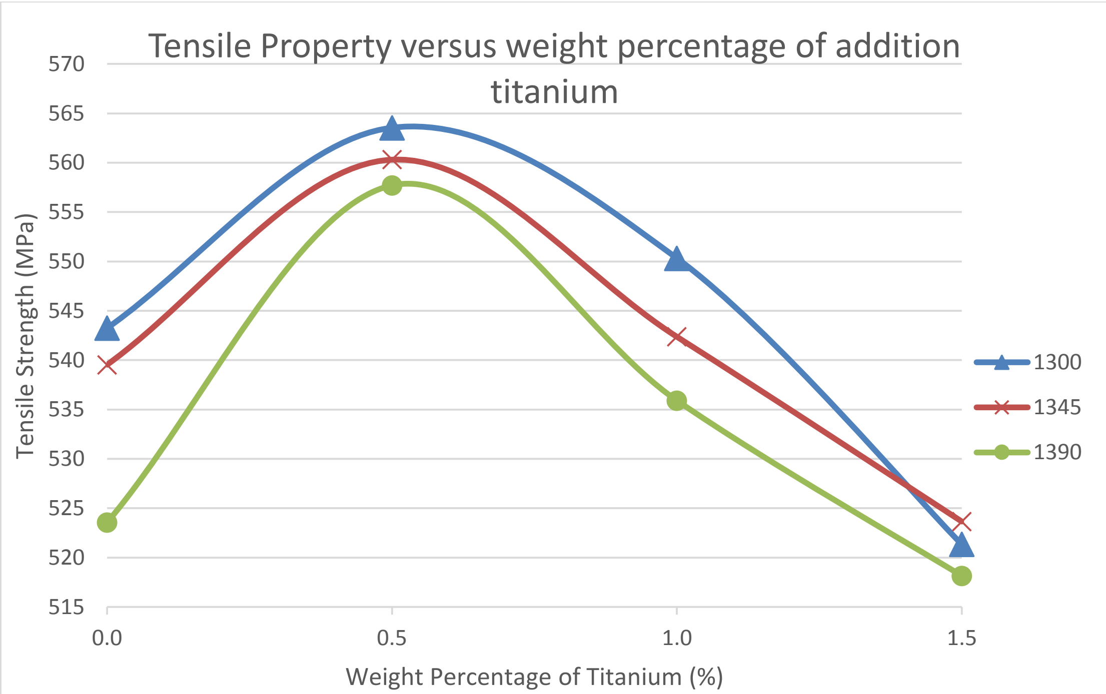
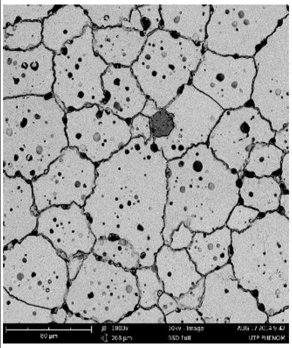
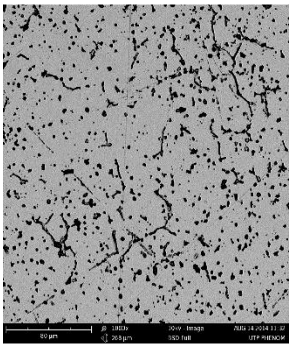
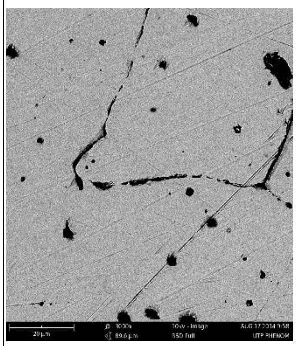
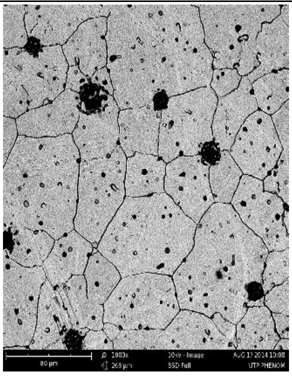
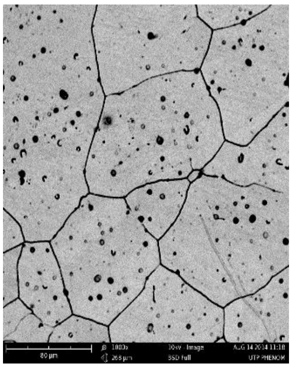
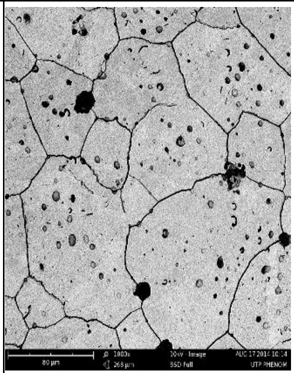
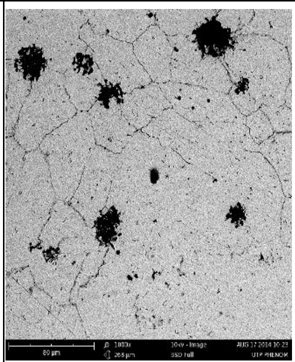
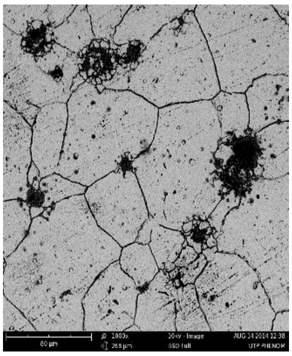
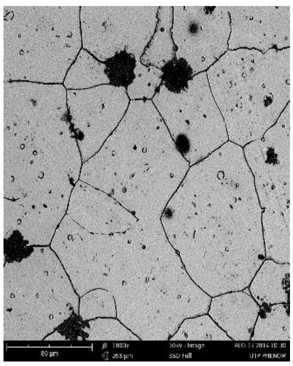
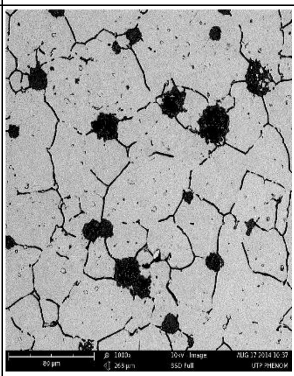
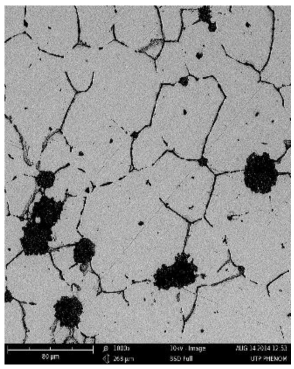
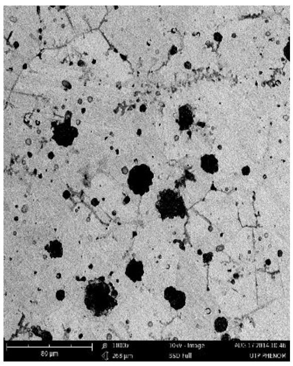


Figure 4-1: Graph of tensile Tests

Referring to the above graph, 1300°C is the best sintering temperature that can give high tensile strength compare to the other higher temperatures which are 1345 °C and 1390 °C. The reason behind the result is that at higher sintering temperature, the size of grains increasing and become larger. Larger grains size will reduce the mechanical strength of the materials. This can proved by looking at the microscopic examination through Scanning Electron Microscope (SEM) in table 4 below.

Table 4-2: SEM micrograph results

Percentage of Titanium	1300°C	1345°C	1390°C
0%			
0.5%			
1.0%			
1.5%			

Incremental of weight percentage of titanium from 0% to 0.5% in the composition of 316L stainless steel has increase the strength of the material. However, when the titanium had been increased more, the mechanical strength drop rapidly. It can be explained as Ostwald Ripening phenomenon (ORP). This phenomenon occurred due to different thermal expansion coefficient between titanium and the stainless steel. As the result, titanium tended to move to the grain boundaries and formed larger in size of porosity. Hence, it reduced the strength of the material.

Below are the results of EDS at 0%Titanium sintered at 1345^{o}C which will explain the composition on the porosity surface. There are four locations done to check the composition of elements.

<u>0% Titanium at 1345^{o}C</u>

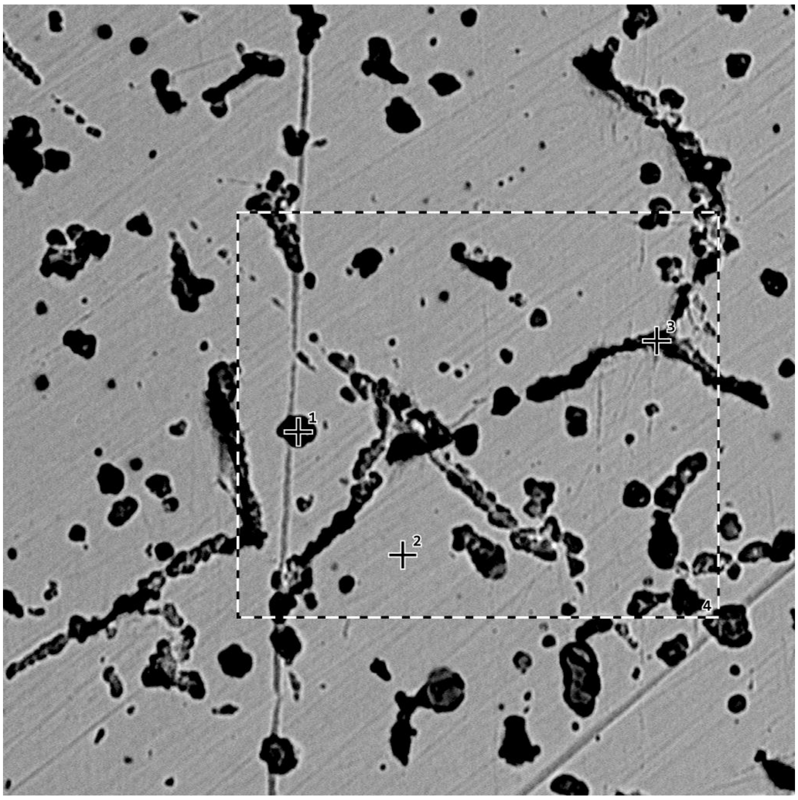


Figure 4-2: SEM micrograph of 0% Titanium sample

1. Black spot

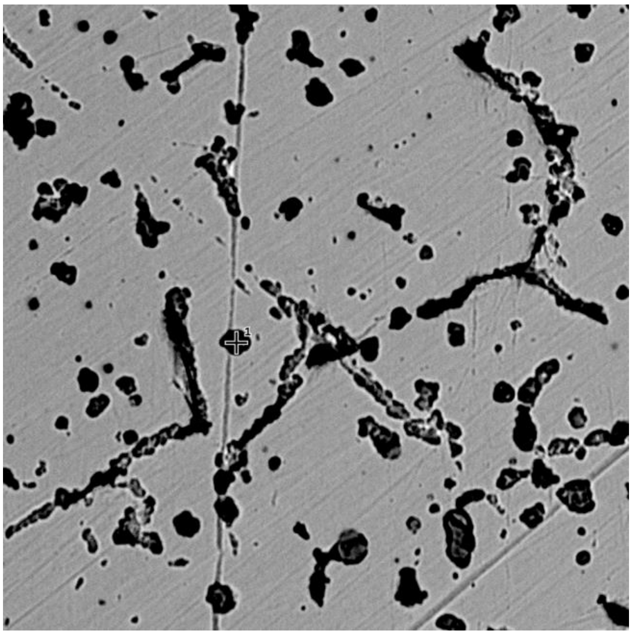


Figure 4-3: SEM micrograph of the black spot of 0% Titanium sample

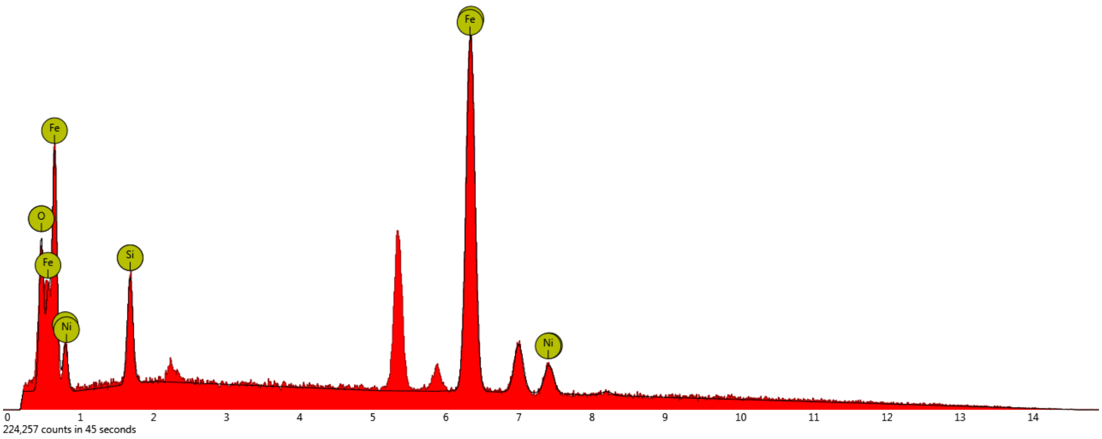


Figure 4-4: EDS analysis of the black spot of 0% Titanium sample

Table 4-3: Elements of composition of the black spot of 0% Titanium sample

Element Number	Element Symbol	Element Name	Confidence	Concentration (%)
26	Fe	Iron	100.0	57.9
8	O	Oxygen	100.0	25.8
14	Si	Silicon	100.0	8.1
28	Ni	Nickel	100.0	8.2

2. Surface Spot

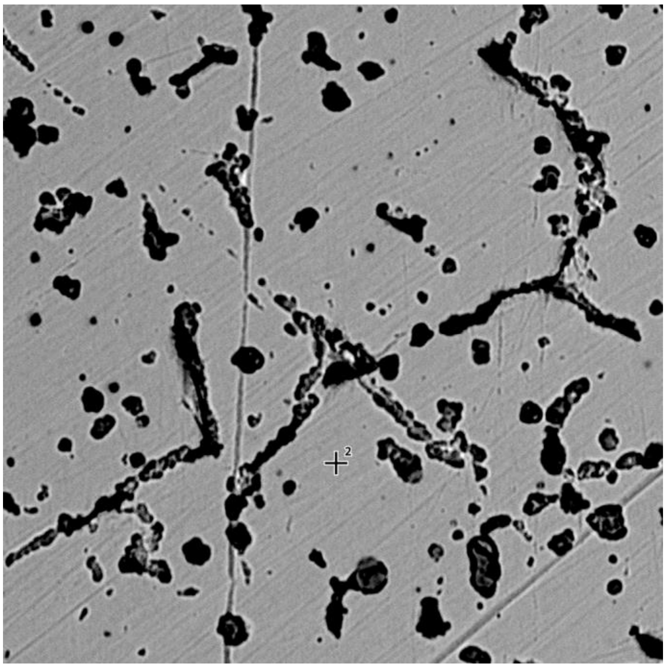


Figure 4-5: SEM micrograph of the surface spot of 0% Titanium sample

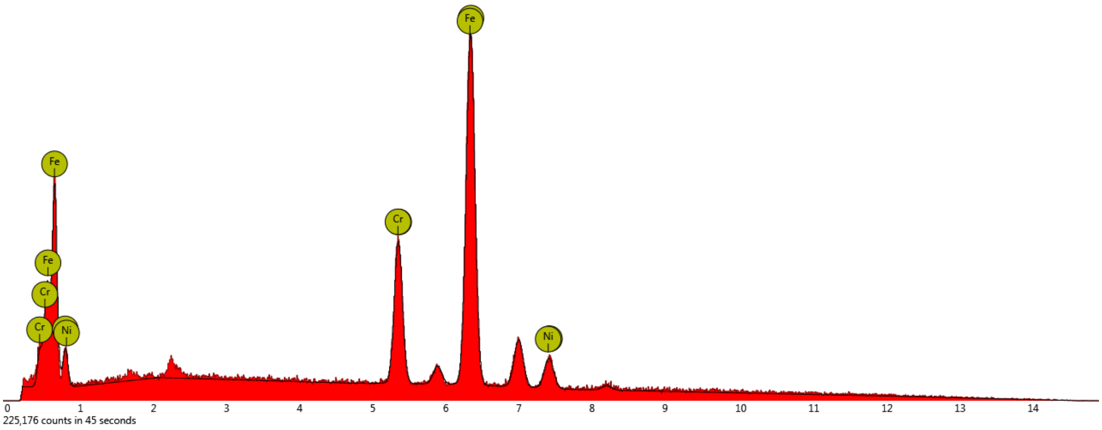


Figure 4-6: EDS analysis of the surface spot of 0% Titanium sample

Table 4-4: Elements of composition of the surface spot of 0% Titanium sample

Element Number	Element Symbol	Element Name	Confidence	Concentration (%)
26	Fe	Iron	100.0	72.3
24	Cr	Chromium	100.0	16.5
28	Ni	Nickel	100.0	11.2

3. Grain Boundary

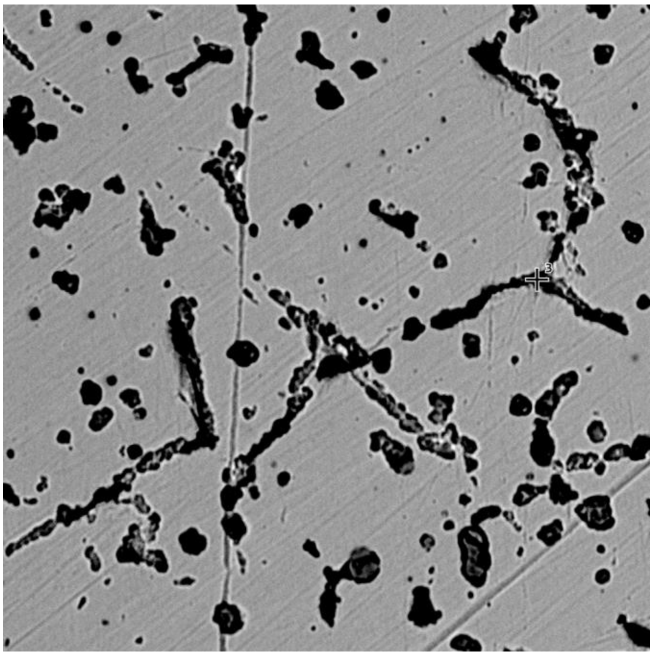


Figure 4-7: SEM micrograph of the grain boundary of 0% Titanium sample

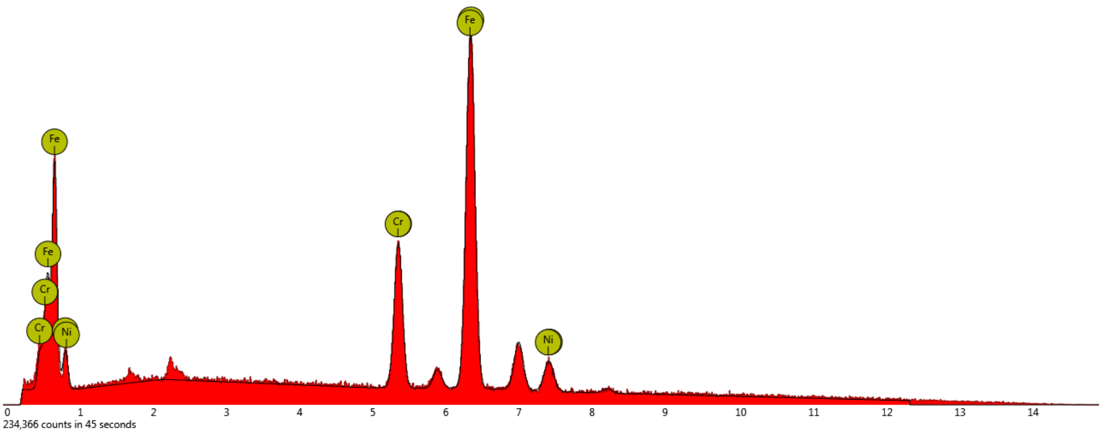


Figure 4-8: EDS analysis of the grain boundary of 0% Titanium sample

Table 4-5: Elements of composition of the grain boundary of 0% Titanium sample

Element Number	**Element Symbol**	**Element Name**	**Confidence**	**Concentration (%)**
26	Fe	Iron	100.0	72.3
24	Cr	Chromium	100.0	16.7
28	Ni	Nickel	100.0	11.0

4. Mapping area

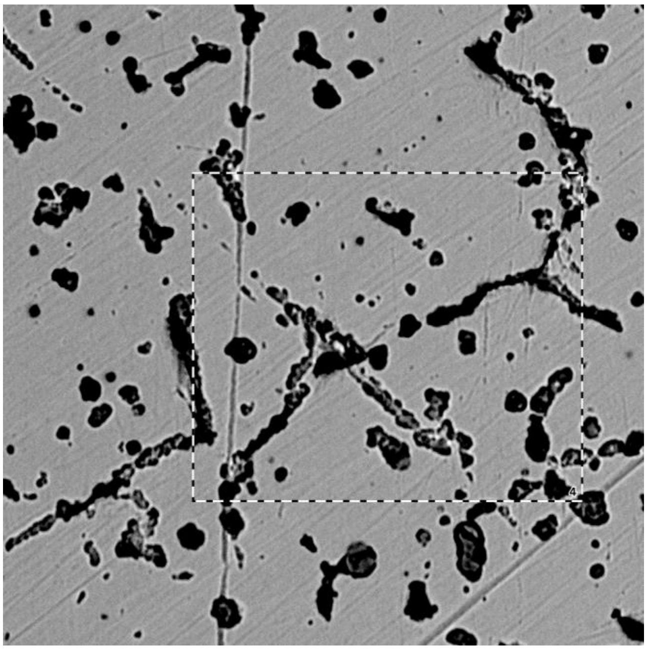


Figure 4-9: SEM micrograph of the mapping area of 0% Titanium sample

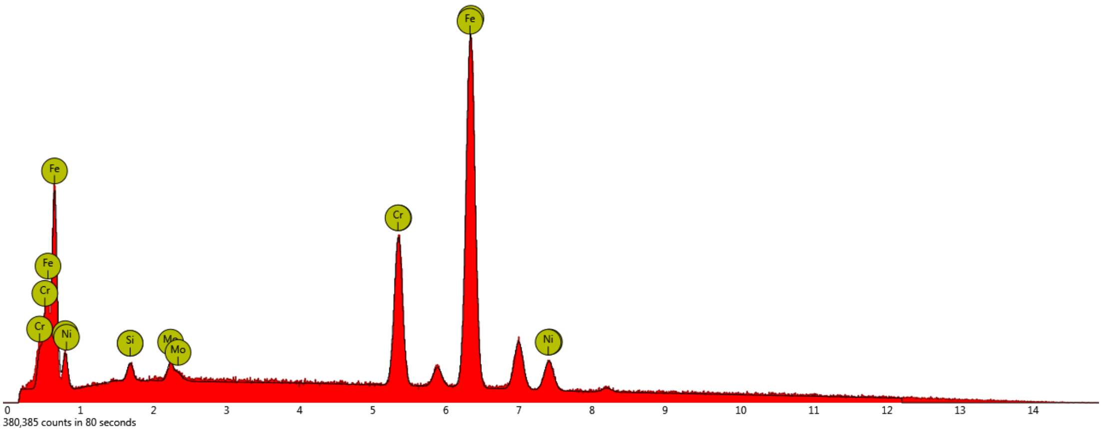


Figure 4-10: EDS analysis of the mapping area of 0% Titanium sample

Table 4-6: Elements of composition of the mapping area of 0% Titanium sample

Element Number	**Element Symbol**	**Element Name**	**Confidence**	**Concentration (%)**
26	Fe	Iron	100.0	68.2
24	Cr	Chromium	100.0	16.4
28	Ni	Nickel	100.0	10.0
42	Mo	Molybdenum	100.0	3.6
14	Si	Silicon	100.0	1.8

Below are the results of EDS at 1%Titanium sintered at 1345^{o}C which will explain the composition of the porous area. There are four locations done to check the composition of elements.

1.0 % Titanium at 1345^{o}C

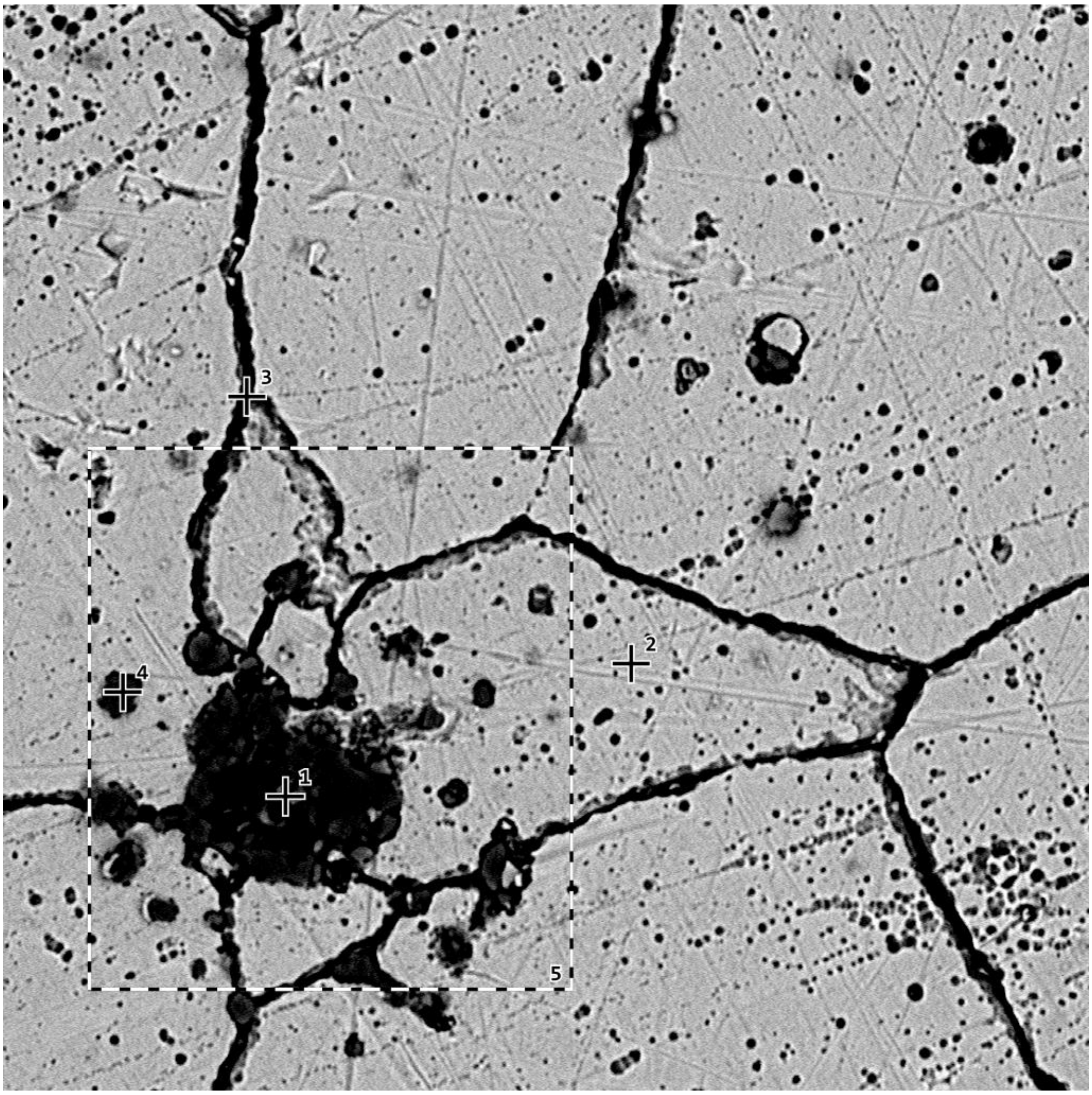


Figure 4-11: SEM micrograph of the 1.0% Titanium sample

i. Black Spot (Large)

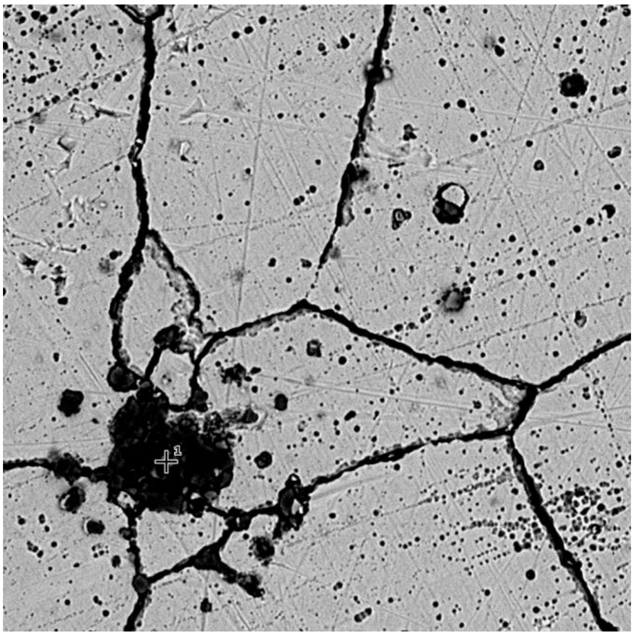


Figure 4-12: SEM micrograph of the black spot of 1.0% Titanium sample

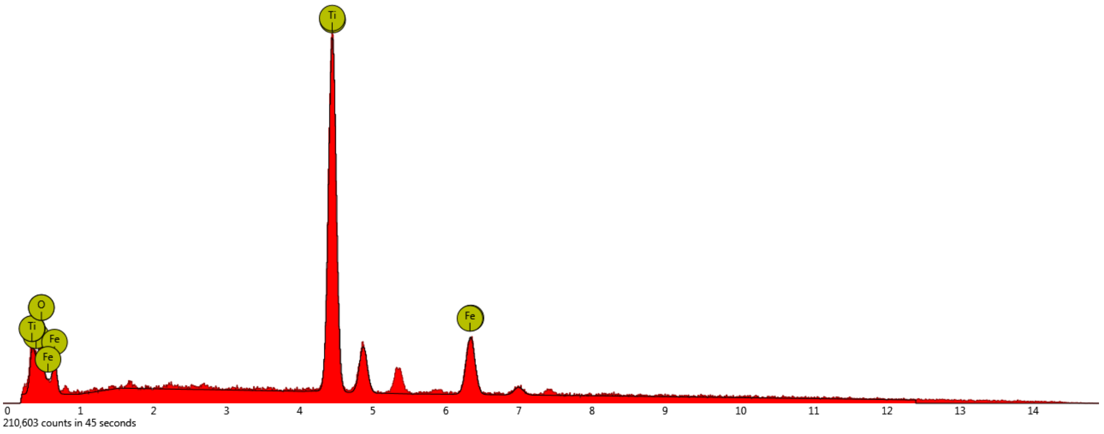


Figure 4-13: EDS analysis of the black spot of 1.0% Titanium sample

Table 4-7: Elements of composition on the black spot of 1.0% Titanium sample

Element Number	**Element Symbol**	**Element Name**	**Confidence**	**Concentration (%)**
22	Ti	Titanium	100.0	40.5
8	O	Oxygen	100.0	44.7
26	Fe	Iron	100.0	14.8

ii. Surface Spot

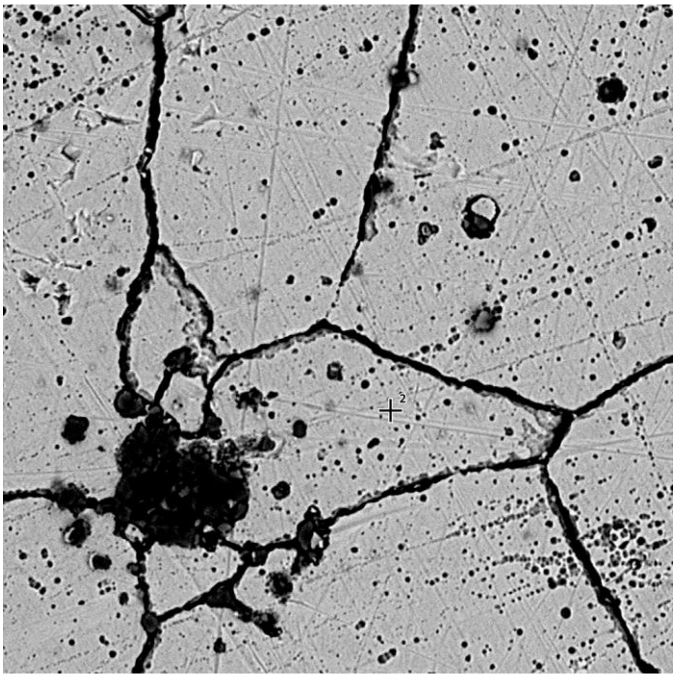


Figure 4-14: SEM micrograph of the surface spot of 1.0% Titanium sample

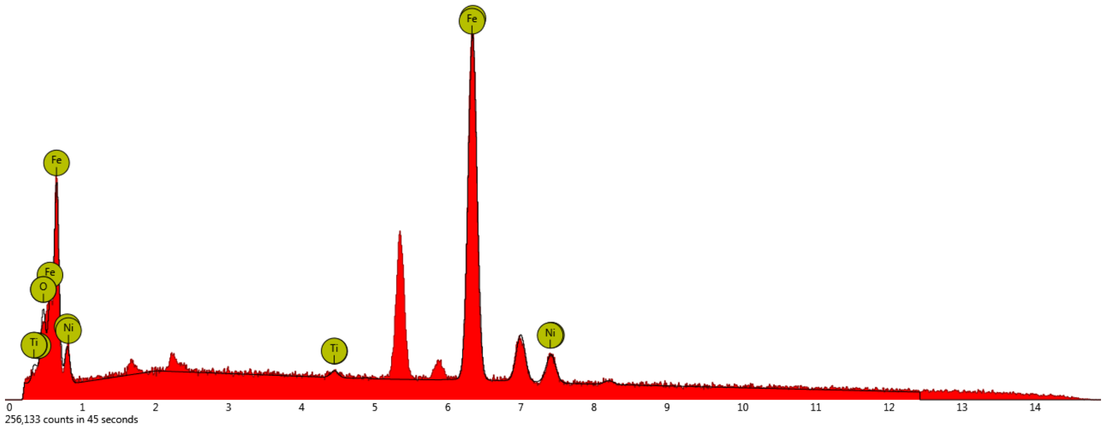


Figure 4-15: EDS analysis of the surface spot of 1.0% Titanium sample

Table 4-8: Elements of composition on the surface spot of 1.0% Titanium sample

Element Number	**Element Symbol**	**Element Name**	**Confidence**	**Concentration (%)**
26	Fe	Iron	100.0	72.2
8	O	Oxygen	100.0	16.2
28	Ni	Nickel	100.0	10.9
22	Ti	Titanium	100.0	0.7

iii. Grain Boundary

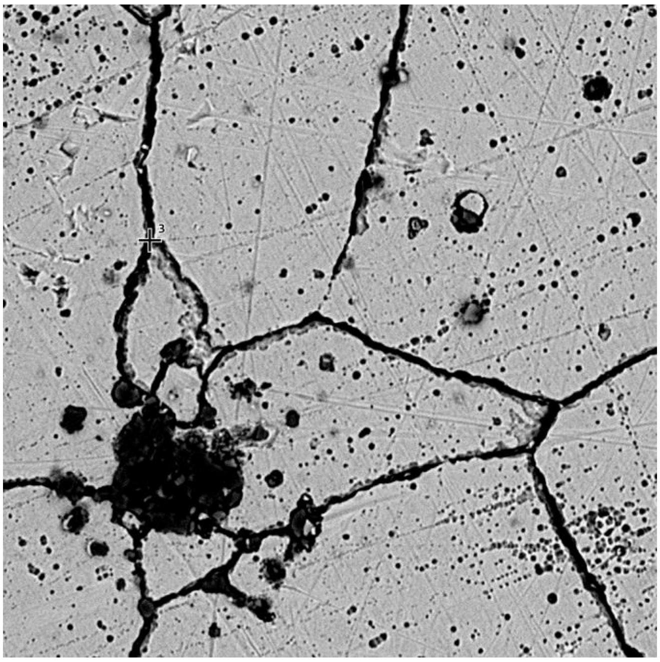


Figure 4-16: SEM micrograph of the grain boundary of 1.0% Titanium sample

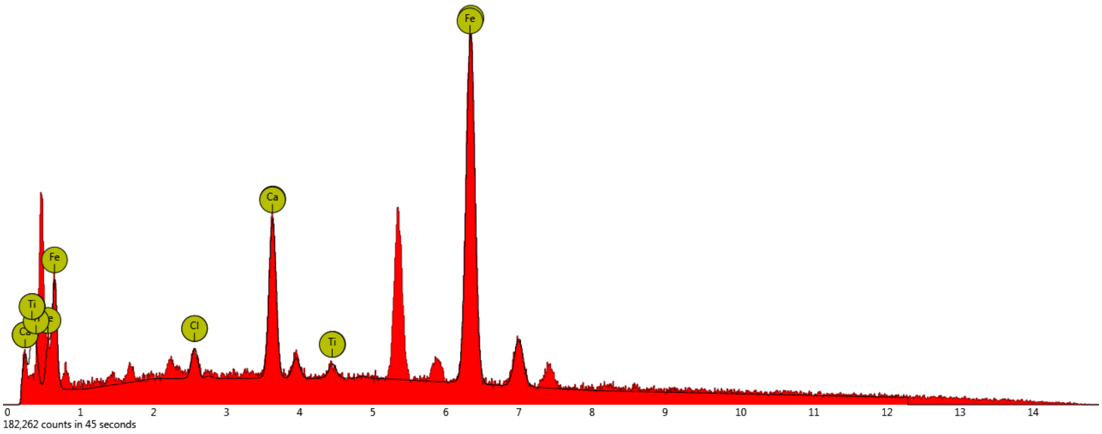


Figure 4-17: EDS analysis of the grain boundary of 1.0% Titanium sample

Table 4-9: Elements of composition of the grain boundary of 1.0% Titanium sample

Element Number	**Element Symbol**	**Element Name**	**Confidence**	**Concentration (%)**
26	Fe	Iron	100.0	82.0
20	Ca	Calcium	100.0	13.4
17	Cl	Chlorine	100.0	2.7
22	Ti	Titanium	100.0	1.8

iv. Black Spot (Small)

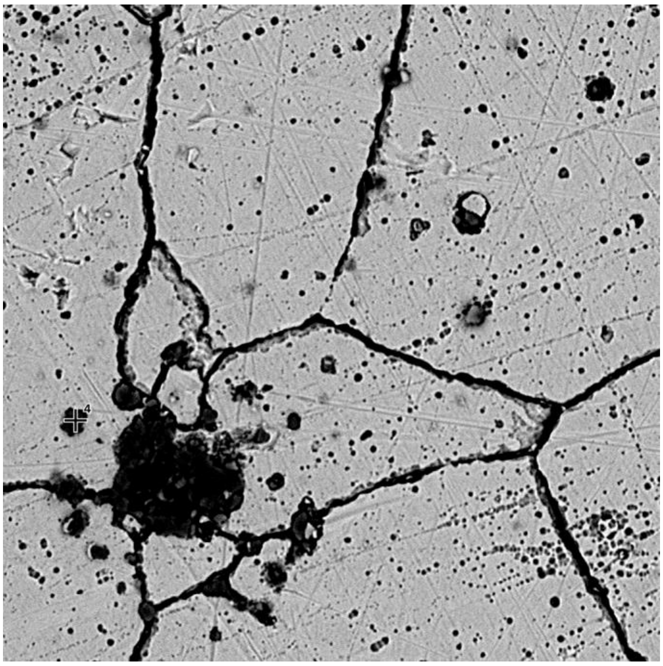


Figure 4-18: SEM micrograph of the small black spot of 1.0% Titanium sample

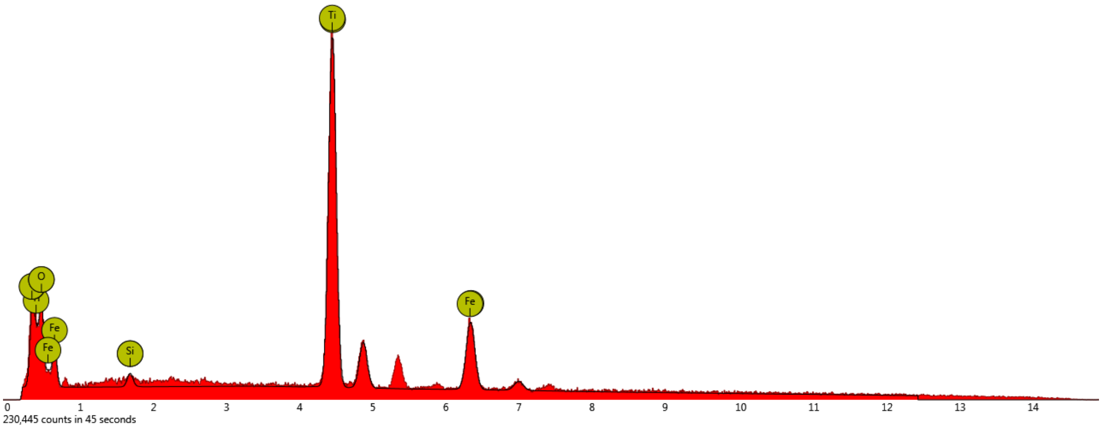


Figure 4-19: EDS analysis of the small black spot of 1.0% Titanium sample

Table 4-10: Elements of composition of the small black spot of 1.0% Titanium sample

Element Number	**Element Symbol**	**Element Name**	**Confidence**	**Concentration (%)**
22	Ti	Titanium	100.0	34.4
8	O	Oxygen	100.0	49.9
26	Fe	Iron	100.0	14.7
14	Si	Silicon	100.0	0.9

v. Mapping area

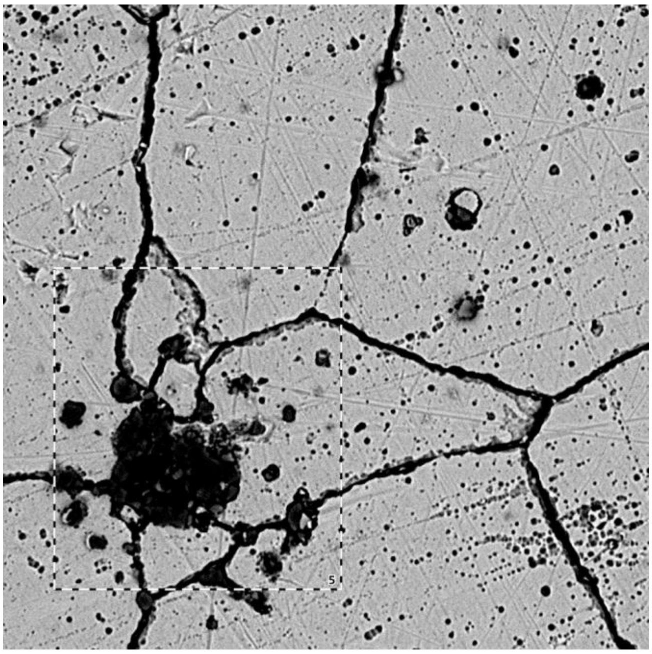


Figure 4-20: SEM micrograph of the mapping area of 1.0% Titanium sample

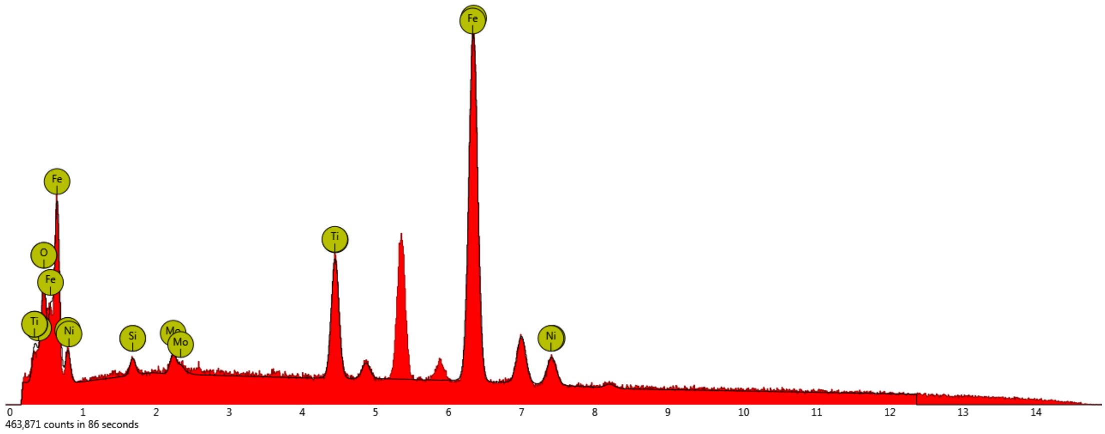


Figure 4-21: EDS analysis of the mapping area of 1.0% Titanium sample

Table 4-11: Elements of composition of the mapping area of 1.0% Titanium sample

Element Number	Element Symbol	Element Name	Confidence	Concentration (%)
26	Fe	Iron	100.0	53.9
8	O	Oxygen	100.0	25.3
22	Ti	Titanium	100.0	9.3
28	Ni	Nickel	100.0	7.4
42	Mo	Molybdenum	100.0	2.9
14	Si	Silicon	100.0	1.2

Explanation:

Titanium had accumulated on the grain boundaries and at the large black spots. These show that titanium failed to mixed well with the elements of 316L SS. Thus, it had led to the mechanical failure of the materials. The formation of titanium oxide occurred during sintering process where there were leakages on the furnace. So, oxygen entered the furnace and oxidized the titanium.

4.2 Corrosion Test

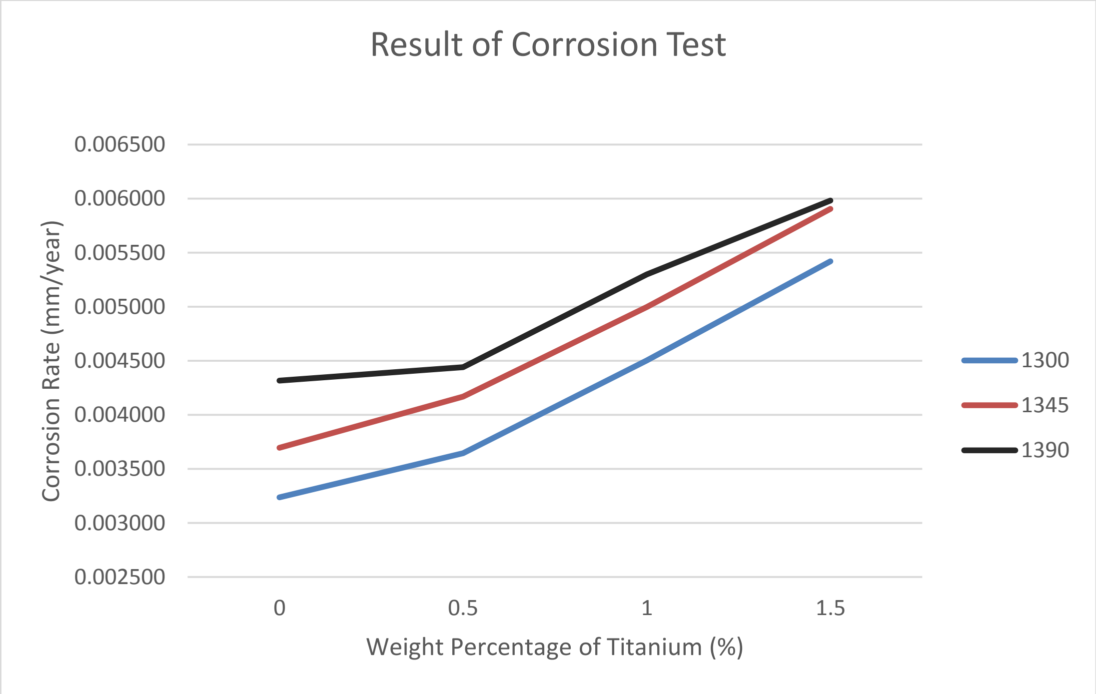


Figure 4-22: Graph of Corrosion Measurement

Graph above shows that there are no significant benefit by adding titanium into the 316L SS. 0% Titanium had gave the best corrosion resistance compare to other compositions. The reason is galvanic corrosion occurred due to presence of different metals in the composition. It can be proved by EDS on the corroded part as below.

Table 4-12: Parameter of samples for corrosion test

Sample Name	Thickness	Length	Height	Initial Weight (g)	Final Weight (g)	Weight Loss	Total Area	Total Area in cm2	Corrosion Rate (mm/yr)	Corrosion Rate (mpy)
PWA 65% VOL 0% Ti 1300	2.67	8.86	5.12	0.913196	0.912845	0.000351	165.3796	1.653796	0.003236	0.127262
PWA 65% VOL 0% Ti 1345	2.77	8.41	5.15	0.878012	0.877620	0.000392	161.7454	1.617454	0.003695	0.145321
PWA 65% VOL 0% Ti 1390	2.70	8.70	5.16	0.909123	0.908657	0.000466	164.628	1.646280	0.004316	0.169729
PWA 65% VOL 0.5% Ti 1300	2.68	7.98	5.25	0.819873	0.819503	0.000370	154.7028	1.547028	0.003646	0.143409
PWA 65% VOL 0.5% Ti 1345	2.64	8.56	5.28	0.881498	0.881051	0.000447	163.4688	1.634688	0.004169	0.163963
PWA 65% VOL 0.5% Ti 1390	2.68	7.97	5.23	0.807035	0.806586	0.000449	154.1182	1.541182	0.004442	0.174689
PWA 65% VOL 1.0% Ti 1300	2.69	8.84	5.25	0.913774	0.913276	0.000498	168.6242	1.686242	0.004503	0.177086
PWA 65% VOL 1.0% Ti 1345	2.70	8.32	5.30	0.861424	0.860894	0.000530	161.74	1.617400	0.004996	0.196486
PWA 65% VOL 1.0% Ti 1390	2.71	8.40	5.24	0.875554	0.874991	0.000563	161.9608	1.619608	0.005300	0.208436
PWA 65% VOL 1.5% Ti 1300	2.71	8.73	5.26	0.894488	0.893892	0.000596	167.6654	1.676654	0.005420	0.213146
PWA 65% VOL 1.5% Ti 1345	2.69	8.32	5.25	0.862165	0.861544	0.000621	160.3666	1.603666	0.005904	0.232194
PWA 65% VOL 1.5% Ti 1390	2.69	8.45	5.20	0.871534	0.870901	0.000633	161.317	1.613170	0.005983	0.235287

a. 0 % Titanium at 1300 ^{o}C

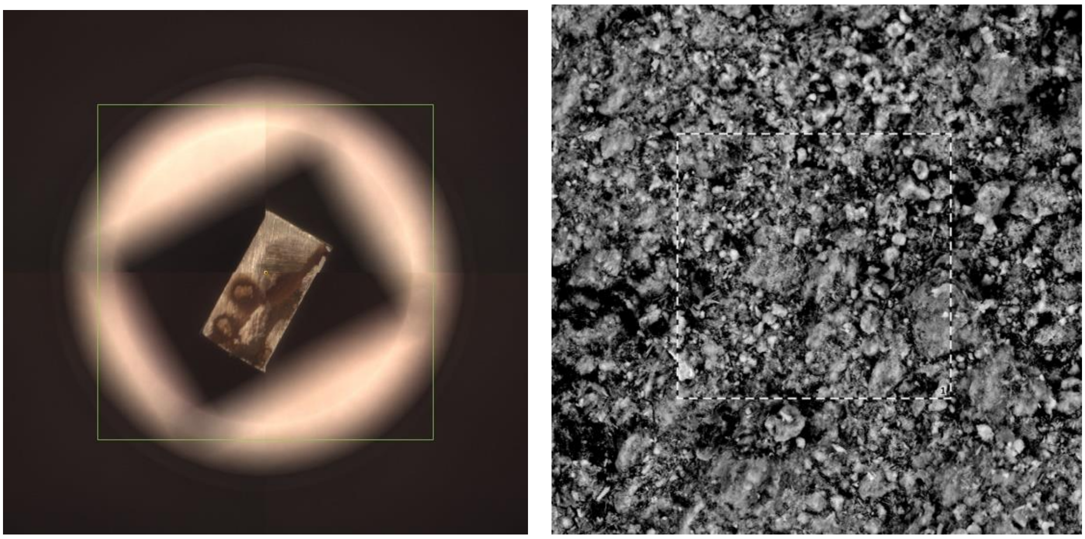


Figure 4-23: SEM micrograph of the corroded part of 0% Titanium sample

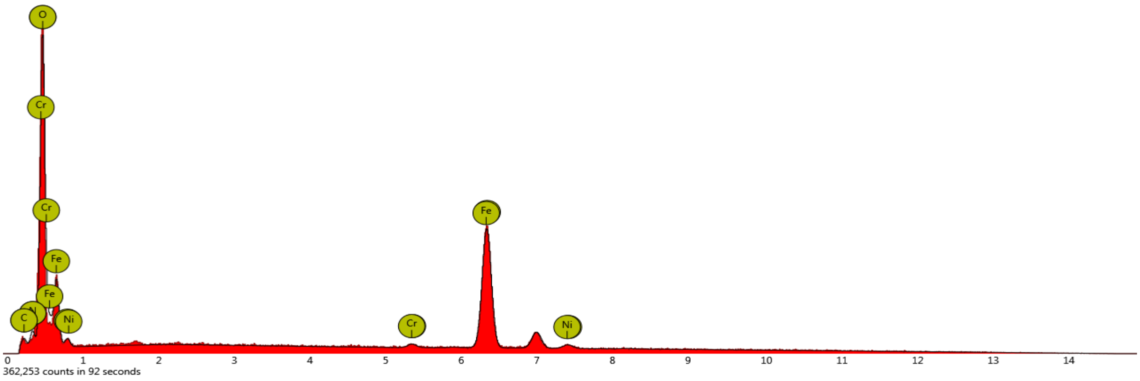


Figure 4-24: EDS analysis of the surface spot of 0% Titanium sample

Table 4-13: Elements of Composition of the corroded part of 0% Titanium sample

Element Number	**Element Symbol**	**Element Name**	**Confidence**	**Concentration**
8	O	Oxygen	100.0	62.2
26	Fe	Iron	100.0	32.8
7	N	Nitrogen	100.0	2.2
6	C	Carbon	100.0	0.5
28	Ni	Nickel	100.0	1.7
24	Cr	Chromium	100.0	0.6

b. 1.5% Titanium at 1300ºC

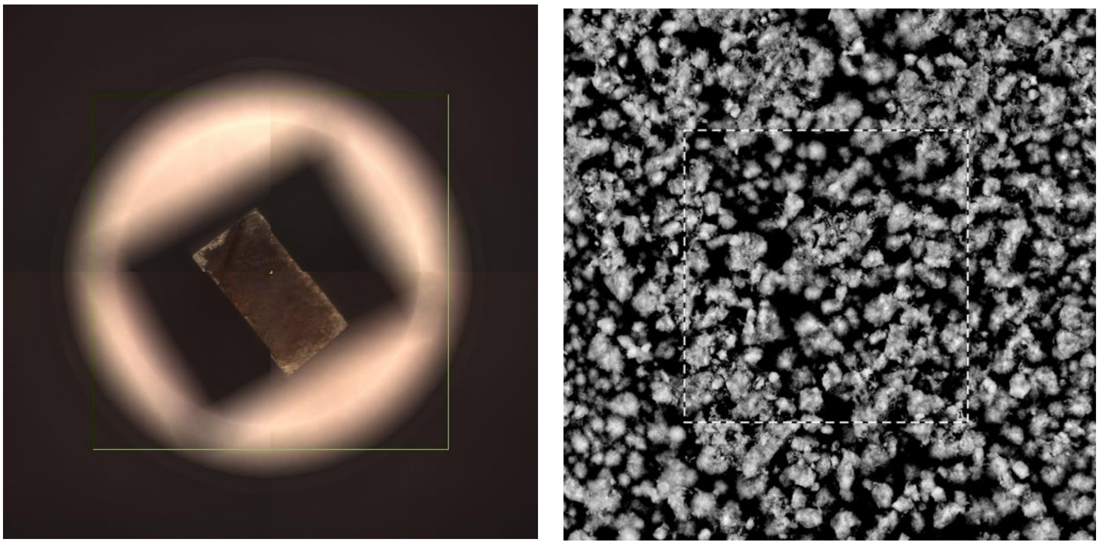


Figure 4-25: SEM micrograph of the corroded part of 1.0% Titanium sample

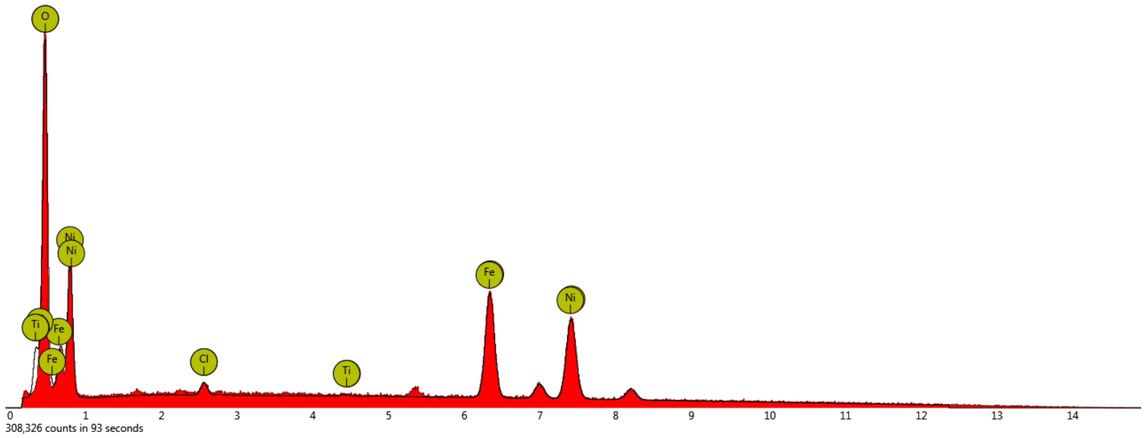


Figure 4-26: EDS analysis of the corroded part of 1.0% Titanium sample

Table 4-14: Elements of Composition of the corroded part of 1.0% Titanium sample

Element Number	**Element Symbol**	**Element Name**	**Confidence**	**Concentration**
8	O	Oxygen	100.0	54.4
26	Fe	Iron	100.0	19.4
28	Ni	Nickel	100.0	25.1
22	Ti	Titanium	100.0	0.2

CHAPTER 5 : CONCLUSION & RECOMMENDATION

For mechanical properties, 0.5 % Titanium in the 316L SS gave the best result and it as the optimum weight percentage allowable if only focusing on mechanical properties. But formation of titanium oxide on the grain boundaries not within the grains particles had make the materials failed and fractured.

Composition of 316L SS without titanium gave the best result for the corrosion test compare to additional of titanium. Galvanic corrosion was the reason of the failure of additional titanium in 136L SS. The presence of two difference metals in the composition had led the galvanic corrosion.

Some recommendations can be implemented for further studies.

i. Sintering process should be conducted in vacuum furnace instead of using argon during sintering process so no oxidation can occurred on the samples.
ii. Atomic level mixing powder is recommended for PIM process.
iii. Bimodal approach can be used to enhance the mechanical and corrosion properties of 316L SS.

CHAPTER 6 : REFERENCES

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