## SUPERVISOR DECLARATION

"I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Structure & Materials)"

Signature :
Supervisor : DR. RAFIDAH BINTI HASAN
Date :

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**DECLARATION**

"I hereby declare that the work in this thesis is my own except for summaries and quotations which have been duly acknowledged."

| | | |
|---|---|---|
| Signature | : | |
| Author | : | SHAHIDATUL MOUNA MAULAT SHAHIDAN |
| Date | : | |

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I would like to dedicate this research to my beloved parents, who always keep supporting and praying for my success.

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## ABSTRACT

The main purpose of this study is to analyze the effect of boronizing heat treatment on stainless steel by using two parameters (time and temperature). This treatment was conducted using a furnace. This process is carried out at temperatures from 850 - 950°C (1123 - 1223 K) for three various duration times which are 2, 4 and 6 hours. From the experiment, ball bearing of AISI316L with 10mm diameter are used. This experiment also been conducted for different boronizing temperature with each duration time selected. The unboronized and boronized specimens at different value of temperatures and times will be analyzed in term of their friction and wear through ball on disc testing apparatus. The wear of the specimen will be analyze through CCD camera that determine the size of the scar. In discussion, findings show that as the hardness increase, the wear and friction will decrease with given time and temperature. For conclusion, boronizing process has made the stainless steel less friction and wear due to hardness of the specimen.

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# ABSTRAK

Tujuan utama kajian ini dijalankn adalah untuk membincangkan kesan-kesan penyusukboronan terhadap logam stainless steel dengan menggunakan dua pembolehubah (masa & suhu). Penggunaan kebuk relau diperlukan dalam kajian ini. Prosess ini dijalankn menggunakan suhu 850 - 950°C (1123 - 1223 K) untuk tiga durasi masa iaitu 2, 4 dan 6 jam. Galas bebola AISI 316L berdiameter 10mm dipilih untuk eksperimen ini. Eksperimen ini juga dijalankan menggunakan suhu dan masa yang berbeza berdasarkan parameter yang dipilih. Logam asas dan logam yang telah disusukboronkan akan dianalisis. Tahap geseran akan dikaji menggunakan alatan bebola pada cakera manakala tahap hakisan pula akan dikaji menggunakan kamera CCD. Di dalam perbincangan, menunjukkan bahawa apabila kadar kekerasan meningkat, kehausan dan geseran akan berkurang, bergantung kepada diberi masa dan suhu. Penyusukboronon menjadikan logam keluli tahan karat tahan geseran serta mengurangkan kadar hakisan terhadap bahan kajian.

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# CHAPTER 1

# INTRODUCTION

## 1.0 INTRODUCTION

The surface of industrial component may require treatment to enhance their surface characteristics. Type of surface hardening which involved the process of introducing a metal or alloy to boron is called boronizing or boriding. In this process, boron atoms are diffused into the surface of a metal component and produces surface which contains metal borides. As the result, these metal borides have extremely high hardness 1400HV-2600HV, wear resistance and often will last two to five times longer than components which are treated with conventional heat treatments. Also, the other properties of the borocoat layer are high abrasion resistance, resistance against cold welding and has excellent thermal stability.

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Boronizing of ferrous materials is generally performed at temperatures ranging from 840 to 1050˚C. The process can be carried out in solid, liquid or gaseous medium. The powder-pack boronizing has the advantages of simplicity and cost-effectiveness in comparison with other boronizing processes (Kayacan, Ö., Sahin, S., & Tastan, F., 2010). Metallic borides have relatively high hardness. The hardness achieved by boronizing increases the resistance to abrasive wear. Boronized layers have good tribological characteristics at high temperatures (Kayacan, Ö., Sahin, S., & Tastan, F., 2010). Very low coefficient of friction and high hardness are obtained on boronized surfaces. Since boron is reactive to oxygen, borides have thin oxide films on their surfaces, which lower the coefficient of friction (Kayacan, Ö., Sahin, S., & Tastan, F., 2010). In this project, metal used is stainless steel and the specimen is packed with boronizing mixture and heated from various temperatures from 850℃ to 950℃ and various time for 2 hours, 4 hours, and 6 hours.

The main advantage of the boronizing process is to improve the metal hardness. Hardness is a criterion of how resistant solid matter is to various kinds of permanent shape change when a compressive force is applied resistant to permanent deformation. Therefore there are different measure of rigorousness such as scratch hardness, indent hardness, and rebound hardness. Hardness is dependent on ductility, elastic stiffness, plasticity, strength and viscosity. However, the disadvantage of boronizing is the brittleness of boronized layers. To lessen this brittleness, the production of multi element and composite boride layers is applied. The applications for boride components are shown in the Table 1.1.

Table 1.1 : Applications for boride components(Internet sources, 2014)

| Applications for boride components | |
|---|---|
| Automotive components. | Tools making and metal forming technology. |
| Burner nozzles. | Steam turbine components. |
| Gears. | Power plant engineering. |
| High wear pumps. | Plastics processing. |

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## 1.1 PROBLEM STATEMENT

Surface hardening is necessary to develop a high surface hardness on a steel part in many industrials purpose nowadays. It is important so that the steel can abide scratch and wear. This surface hardening can be achieved by sustaining the surface treatment such as boronizing or boriding process. This process need to be studied extensively before undergoes boronizing process on the pin on disc speciment; hence this study focuses in the investigation on factors that influence the pack of boronizing process and also to design and fabricate suitable container for the boronizing powder pack.

## 1.2 OBJECTIVES

The purposes of this project are :

1. To develop a pack of boronizing process using FKM UTeM facilities.
2. To evaluate factors which are affecting the pack boronizing process.
3. To design and fabricate suitable container for boronizing process.
4. To conduct boronizing experiment with boronizing time and temperature factors.

## 1.3 SCOPE

The scope of this study is :

To develop a new process using FKM UTeM facilities and to carry out experiments with variable parameters in order to study the factors that are affecting the process.

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## 1.4 PLANNING AND EXECUTION

The experiment planning is shown in the Gantt chart provided in Table 1.2 and Table 1.3.

Table 1.2 : Gantt Chart for Semester 1.

| Activity | Week | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| Title selection | ■ | | | | | | | | | | | | | |
| Title Confirmation | | ■ | | | | | | | | | | | | |
| Chapter 1 | | | ■ | ■ | | | | | | | | | | |
| Literature Review | | | | | ■ | ■ | | ■ | ■ | ■ | ■ | ■ | | |
| Poster Preparation | | | | | ■ | ■ | | | | | | | | |
| Methodology Study | | | | | | | | ■ | ■ | | | | | |
| Material Preparation :<br>Fabrication of container.<br>Preparation of specimen. | | | | | | | | | ■ | ■ | | | | |
| Experimental Setup<br>Boronizing experiment. | | | | | | | | | | ■ | ■ | ■ | | |
| Results and Analysis | | | | | | | | | | | ■ | ■ | | |
| Final Seminar | | | | | | | | | | | | | ■ | |
| Draft Report Preparation | | | | | | | | | | | | ■ | ■ | ■ |
| Draft Report Submission | | | | | | | | | | | | | | ■ |

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Table 1.3 : Gantt Chart for Semester 2.

| Activity | Week | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| Experimental Setup<br>Boronizing experiment. | | | | | | | | | | | | | | | | |
| Progress Report | | | | | | | | | | | | | | | | |
| Experimental Setup<br>Pin on Disc experiment. | | | | | | | | | | | | | | | | |
| Experimental Setup<br>Determining the wear scar diameter. | | | | | | | | | | | | | | | | |
| Result and Analysis | | | | | | | | | | | | | | | | |
| Draft Report Preparation | | | | | | | | | | | | | | | | |
| Draft Report Submission | | | | | | | | | | | | | | | | |
| Final<br>Seminar | | | | | | | | | | | | | | | | |

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# CHAPTER 2

# LITERATURE REVIEW

## 2.1 BACKGROUND OF STAINLESS STEEL

Inox steel is a steel alloy, which is another name to stainless steel in metallurgy, contains a minimum of 10.5 % of chromium by mass. The content or amount of chromium present is the factor that differentiate between carbon steel and stainless steel. When exposed to air and moisture, unprotected carbon steel can promptly rust. This iron oxide film is active and accelerates corrosion by forming more iron oxide and because of the higher volume of the iron oxide, this tends to flake and fall away. Stainless steel contain sufficient amount of chromium to form a detached film of chromium oxide, which avoids further surface consumption by blocking oxygen diffusion to the steel surface and blocks erosion from spreading into the metal's internal structure, and because of the comparative size of the steel and oxide particles, they bond strongly and stay attached to the surface (Internet reference, 2012).

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Stainless steel is thoroughly used in real-life applications in which to prevent corrosion. The material is also expected to have a tough, scratch-resistance surface in many end-uses. Surface engineering proposes solutions when improved wear resistance is required (Alenka Kosmac, 2013).

## 2.2 TYPE OF STAINLESS STEEL

There are five families of stainless steels and their percentage of usage of each type are as shown in the Table 2.1.

Table 2.1 : Percentage Usage Of Each Type Of Stainless Steels

(Source : www.worldstainless.org, retrieved October, 23 2014).

| Percentage Usage Of Each Type Of Stainless Steels. |
|---|
| • Austenitic Stainless Steel – 200 series and 300 series (72%) |
| • Ferritic Stainless Steel – 400 series (24%) |
| • Martensitic Stainless Steel (2%) |
| • Precipitation Hardening (1%) |
| • Duplex Stainless Steel (0.6%) |

### 2.2.1 Ferritic Stainless Steel

These steels have a similar microstructure to carbon and low carbon steels and are based on Chromium with small amounts of Carbon usually less than 0.10% (BSSA Guide, 2013). With an amount between 10.5% - 27% of chromium and a very small amount of Nickel, Ferritic Stainless Steel serves have better engineering properties than austenitic grades but have a lower resistant to corrosion. Due to lack toughness in welds and cannot be hardened by heat treatment, they are usually limited in usage to relatively thin sections. In a condition where there is

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present of sea water, high Chromium steels with addition of Molybdenum can be used. Besides that they are magnetic and less expensive. Ferritic steel is less ductile than austenitic steel (Sand Meyer Steels, retrieved October 29, 2014)

### 2.2.2 Austenitic Stainless Steel

Stainless steels have an austenite crystalline structure, which is a face-centered cubic crystal structure. To retain an austenitic structure at all temperature, they contain a maximum of 0.15% carbon, a minimum of 16% chromium and sufficient content of nickel and/or manganese. They cannot be hardened by heat treatment but have the useful property of being able to be hardened to high strength level whilst retaining a useful level of ductility and toughness. By lowering the nickel content and increasing the content manganese will result in weak corrosion resistance (Internal Stainless Steel Forum, 2005).

The austenitic stainless steel is usually more expensive than the ferritic grades. However, they have good formibility and weldability which is generally much better than the ferritic grades. They also excel in the aspect of toughness, even to very low cryogenic temperature and they are not magnetic (BSSA Guide, 2013). Table 2.2 shows the major alloy element composition of austenitic stainless steels.

Table 2.2 : Major Alloy Element Composition Of Austenitic Stainless Steels.

(Source : Gedge et. al. (2008))

| Steel Designation | | Alloy Composition (Min%) from EN 10088 | | |
|---|---|---|---|---|
| EN 10088 | ASTM International | Chromium | Nickel | Molybdenum |
| 1.4301 | 304 | 17 | 8 | - |
| 1.4404 | 316 L | 16.5 | 10 | 2 |
| 1.4435 | 316 L | 17 | 12.5 | 2.5 |

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### 2.2.3 Martensitic Stainless Steel

Martensitic stainless steels is somehow almost similar to ferritic stainless steels which was based on Chromium but have up to 1 % of Carbon level these allow them to be tempered and hardened. Tempered martensite will result in hard and tough steel (Akhavan Tabatabaei, Behnam; 2009). But on the other hand, martensitic is low on the ability to be weld and formability since its durability is reduced and make it brittle. It is quenched and magnetic.

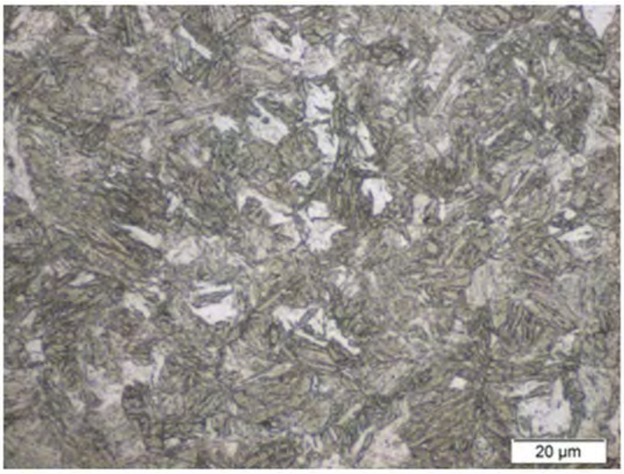


Figure 2.1 : Microstructure for Martensitic Steel MS 950/1200.
(Source : www.worldautosteel.org, retrieved 2014)

### 2.2.4 Duplex Stainless Steel

Duplex stainless steel have a microstructure of approximately 50% austenitic and 50% ferritic. Duplex stainless steel combines the properties of austenitic and ferritic stainless steels due to its Austenitic-Ferritic microstructure which are more-resistant to stress corrosion cracking, adequate formability and weldability, and have higher strength than either ferritic or austenitic steels (Cabrera *et al*., 2003). Figure 2.2 shows the micrograph of a duplex stainless steel while Table 2.3 list the alloying composition of duplex stainless steel.

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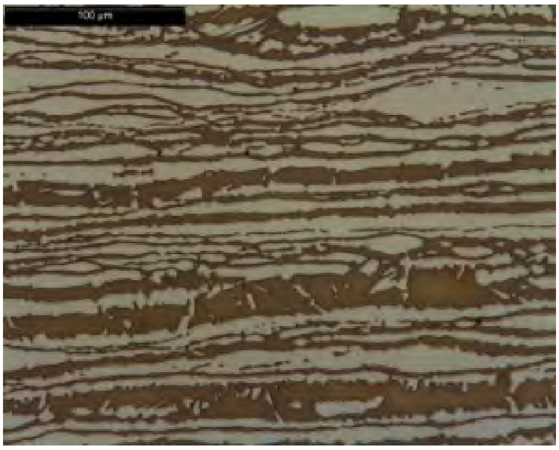

Figure 2.2 Micrograph of a duplex stainless steel. The dark area phase is α-ferrite and the light area phase is γ-austenite. (Michael, P., retrieved 2014).

Table 2.3 : Major Alloy Element Composition of Duplex Stainless Steels.

(Source : Gedge et. al., 2008)

| Steel Designation (EN 10088) | Alloy Composition (Min%) from EN 10088 | | | |
|---|---|---|---|---|
| | Chromium | Nickel | Molybdenum | Nitrogen |
| 1.4462 | 21 | 4.5 | 2.5 | 0.22 |
| 1.4410 | 24 | 6 | 3 | 0.35 |
| 1.4362 | 22 | 3.5 | 0.1 | 0.05 |
| 1.4162 (LDX2101) | 21.5 | 1.5 | 0.3 | 0.22 |

### 2.2.5 Precipitation Hardening Stainless Steel (PH)

Precipitation hardening is a kind of heat treatment technique which was used to increase the yield strength of materials that are malleable. These steels can develop very high strength by adding elements such as Cooper, Niobium, and Aluminium to PH steel,. PH stainless steel have higher corrosion resistance compared to austenitic varieties, and can be hardened to even higher strengths than the other martensitic grades. The most common, 17-4PH, uses about 17% Chromium and 4% Nickel (Callister. 2010).

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## 2.3 APPLICATION OF STAINLESS STEEL

### 2.3.1 Bridges

- Cala Galdana Bridge in Minorca Spain.

It is the first vehicular bridge constructed using duplex stainless steel. The owner decided to replace the existing structural, 18 meter reinforcement concrete bridge due to severe corrosion and settlement in one of its supports. The total length of the bridge is 55 meter and its main span is 45 meter long (Pedelta, 2010).

Figure 2.3 : CalaGaldana Bridge in Minorca Spain. (Source : Pedelta, 2010)

### 2.3.2 Transportation Industry

A wide range of functional and decorative components for transportation vehicles are fabricated from stainless steels. Table 2.4 shows the application of stainless steels in the transportation industry.

Table 2.4 : The Application Of Stainless Steels In The Transportation Industry. (Source : R.A. Lula,1986)

| |
|---|
| Seagoing Chemical Tankers. |
| Aerospace Components Such As Structural Parts, Fasteners, And Engine Cooling Section. |
| Automobile parts such as fasteners, wheel covers, mirror mounts, and exhaust manifolds. |
| Railroad cars and large vehicles such as busses and tanker trucks. |

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