# EFFECT OF HEAT TREATMENT ON HARDNESS AND IMPACT STRENGTH OF STAINLESS STEEL

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**SUPERVISOR DECLARATION**

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

Signature: ……..……..............

Supervisor: ……..…..…………

Date: ….…….…….…………..

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**This report is submitted in fulfilment of the requirements for the award Bachelor of Mechanical Engineering (Structure and Materials)**

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## DECLARATION

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

Signature: ……..……..............

Author:….……..…..…………

Date: ….………….…………..

Special dedicated to

All My Family Members

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# ABSTRAK

Zaman ini, keluli tahan karat digunakan secara meluas dalam banyak bidang kerana ia mempunyai ciri-ciri mekanikal yang diperlukan berbanding dengan bahan lain; oleh itu penambahbaikan ke atas keluli tahan karat perlu dilakukan. Faktor keselamatan sesuatu produk boleh dipertingkatkan dengan mereka struktur yang mempunyai nilai ketahanan dan kebolehpercayaan yang tinggi untuk memastikan keselamatan kepada pengguna. Kajian ini dijalankan untuk menyiasat kesan pemanasan terhadap kekuatan impak, kekerasan and mikrostruktur ke atas keluli tahan karat. Keluli tahan karat akan dipanaskan dan direndamkan dalam pelindapkejutan media yang berlain. Aloi ini akan dipanaskan mencapai suhu 900$^{o}$C mengikut masa pembakaran yang berlainan. Selepas itu, ia akan direndamkan dalam air and minyak. Proses penuaan dijalankan pada suhu 700$^{o}$C yang merupakan suhu yang paling sesuai untuk proses penuaan. Kekuatan impak dan nombor kekerasan diperolehi dengan menggunakan ujian impak Charpy dan ujian kekerasan Brinell. Akhirnya, mikrostruktur specimen akan diperhatikan menggunakan SEM untuk menetapkan sifatnya.

# ABSTRACT

Nowadays, stainless steel is widely used in many field due to its excellent mechanical properties compare to other materials; therefore improvement on stainless steel needed to do from time to time. Factor of safety for products can be improve by designing high durability and reliability structures in order to ensure safety to its users. This study was undertaken to investigate the effect of heat treatment on impact strength, hardness and microstructure characterization of heat treated stainless steel. The stainless steel will be heated in the heat treated conditions, using different quenching media. The alloy will be treated with solution at temperature of 900ºC for different soaking time. Next, it will be quenched using different media such as distilled water and mixed lubricant. Aging process will be conducted at temperature of 700ºC which is suitable elevated temperature for aging process. Impact strength and hardness value will be obtained using Charpy impact test and Rockwell hardness tester respectively. Lastly, microstructure of the material will be observed using SEM (Scanning Electron Microscope) to determine its microstructure.

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$^{o}C$ = Degree Celsius (Temperature)

HRC = Rockwell Hardness Number (Scale C)

kg = Kilogram (Mass)

# CHAPTER 1

# INTRODUCTION

## 1.0 INTRODUCTION

This chapter will show preface for primary idea of research for this project. Topics that will be consisted are research background, problem statements, scope, objectives and summary of entire report.

## 1.1 RESEARCH BACKGROUND

Stainless steel is iron-based alloys with composition of carbon, manganese, phosphorus, sulphur, silicon, chromium, nickel and molybdenum. Stainless steel has the stainless properties due to existence of chromium inside it as one of the main composition. Chromium will form a thin layer of chromium oxide to enhance the resistance of corrosion of this material. Addition of other chemical elements can improve other properties of stainless steel and hence there is various type of it. For instant, the resistance of corrosion properties of stainless steel can be improved by increases the quantity of nickel and molybdenum inside it.

In industry, stainless steel is often applied in making gas turbine, high temperature steam boilers, heat-treating furnaces, aircraft, missiles, and nuclear power generating units. It is also used in hospitals, kitchens, abattoirs and other food processing plants because it is easy to clean which fulfills strict hygiene conditions.

Due to wide application of stainless steel, it is important to improve the mechanical properties of stainless steel in order to enhance properties of it. This is because heat treatment can improve durability and reliability of stainless steel. It will make a step forward in bringing more benefits to user in various application fields.

## 1.2 PROBLEM STATEMENTS

Stainless steel is iron-based alloys with composition of various chemical components which improves the properties of alloys. But, as received material of stainless steel is not yet excellent, therefore heat treatment is done to improve the mechanical properties of it. Once stainless steel is heat treated, it will be tested for mechanical properties namely hardness test, impact strength and microstructure on failure surface.

## 1.3 OBJECTIVES

1. To determine the impact strength of stainless steel after heat treatment solution and aging process based on time batches.
2. To investigate the hardness of stainless steel after heat treatment, quenching and aging process based on time batches.
3. To compare the changes of mechanical properties for stainless steel after heat treatment, quenching and aging process.

4. To determine the relationship between the type of quenching medium and impact strength of stainless steel.
5. To do microstructure observation on the specimens after heat treatment solution and aging process.

## 1.4 SCOPE

The scope of this study is to observed the influence of heat treatment, quenching and aging process on hardness and impact strength of stainless steel compare to as received material. Factors influencing the effectiveness of heat treatment time, quenching medium and aging time will be the main parameters in this project. Impact and hardness test of specimens will be determine in two stages, first is after heat treatment solution and quenching; second stage is heat treatment solution and quenching followed by aging and quenching process again. So, the comparison between the conditions of stainless steel can be concluded based on the result of testing. Besides that, microstructure observation using optical microscope and SEM will be used to study the transformation of microstructure on the failure surface inside stainless steel after heat treatment, quenching and aging process.

## 1.5 SUMMARY

Heat treatment is a common process used to alter physical and mechanical properties without changing the product shape. Stainless steel will be the main research material in this project. Based on heat treatment mechanisms and theory, stainless steel is predicted to behave as brittle material after undergoing solution heat treatment followed by quenching in oil and water. But, if the process is continued with aging followed by another quenching at room temperature and water, stainless steel will exhibit ductile behavior. All of the result of experiment will be check by impact test and hardness test. Microstructure observation using optical microscope and scanning electron microscope (SEM) will helps to investigate the internal structure of stainless steel.

# CHAPTER 2

# LITERATURE REVIEW

## 2.0 LITERATURE REVIEW

In literature review, summary and synthesis of previous researches which related to the topic of this project will be included. This is to obtain accurate prediction and experimental result.

## 2.1 STRENGTH OF MATERIAL

Strength of material can be referring as mechanics of material in related study field. The main concern in this field is the ability of material to withstand stress or strain applied. Material will exhibit changes in original properties after undergoing heat treatment or cold worked. Therefore, mechanical properties of material also concerned such as hardness, impact load will be discussed in following section. Mechanical properties of materials can be studied based on few properties, such as stress-strain diagram, fatigue, creep, hardness and so on. These properties can be tested using respective testing equipment by using appropriate procedures.

Meanwhile, mechanics of material covers more on determining behavior of material when subjected to stress, load or impact. Many researches are done in order to predict accurately the situation on reactions from material as they are receiving external energy. Each material will react differently based on natural or imparted properties inside them. The studies related to material are very important because factors of safety can be enhanced by deep and well understanding of the material.

### 2.1.1 Impact Strength

According to ASTM A370, Charpy V-notch impact test is a dynamic test in which a notched specimen is struck and broken by a single blow in a specially designed testing machine. The measured test values may be the energy absorbed, the percentage strain fracture, the lateral expansion opposite the notch, or a coronation thereof.  Testing temperatures other than room (ambient) temperature often are specified in product or general required specifications. Although the testing temperature is sometimes related to expected service temperature, the two temperatures need no identical.

Impact test will illustrate the ability of the material to endure a sudden applied load and is articulated in terms of energy. Sudden applied load here is refers to pendulum struck the test specimens placed inside the impact tester. From Beer and Johnston (2006), higher volume with a low modulus of elasticity and high material yield strength can increase the impact strength.

### 2.1.2 Hardness

Generally, hardness of material can be obtained by conducting hardness test. There are two common types of hardness test, namely: Brinell Test and Rockwell Test. Hardness test represents the resistance to penetration and is occasionally employed to obtain a quick approximation of tensile strength. Hardness measurement obtained can be converts into relative tensile strength according to appropriate tables provided in ASTM A370. These conversion values have been obtained from computer-generated curves and are presented to the nearest 0.1 point to permit accurate reproduction of those curves.

Nowadays, Rockwell hardness test is applied widely, especially in United States. It is preferable due to its speed, freedom from personal error, ability to distinguish small hardness differences in hardened steel, and small size of indentation. Therefore, the finished heat treated parts can be tested without damage. This test measures the depth of indentation under constant load as a measure of hardness.

A minor load of 10kg is first applied to seat the specimen. This minimizes the amount of surface preparation needed and reduces the tendency of ridging or sinking in by the indenter. Then, major load is applied and the depth of indentation is recorded automatically on a dial gage in terms of arbitrary hardness number. There is no unit for Rockwell hardness number, but the value of the hardness will be presented just in arbitrary with Rockwell hardness scale as shown in Table 2.1. The method to choose a suitable scale is based on material or the processes which have already changed the material properties. In Table 2.2, typical application of Rockwell hardness scales is presented. (Surface Engineering Forum, 2002-2013)

Table 2.1: Typical Application of Rockwell Hardness Scales (Source: Surface Engineering Forum, 2002-2013)

| | |
|---|---|
| HRA | Cemented carbides, thin steel and shallow case hardened steel |
| HRB | Copper alloys, soft steels, aluminium alloys, malleable irons, etc. |
| HRC | Steel, hard cast irons, case hardened steel and other materials harder than 100 HRB |

<table>
<tr><td>HRD</td><td>Thin steel and medium case hardened steel and pearlitic malleable irons</td></tr>
<tr><td>HRE</td><td>Cast iron, aluminium and magnesium alloys, bearing metals</td></tr>
<tr><td>HRF</td><td>Annealed copper alloys, thin soft sheet metals</td></tr>
<tr><td>HRG</td><td>Phosphor bronze, beryllium copper, malleable irons HRH, Aluminum, zinc, lead</td></tr>
<tr><td>HRK</td><td rowspan="7">Soft bearing metals, plastics and other very soft materials</td></tr>
<tr><td>HRL</td></tr>
<tr><td>HRM</td></tr>
<tr><td>HRP</td></tr>
<tr><td>HRR</td></tr>
<tr><td>HRS</td></tr>
<tr><td>HRV</td></tr>
</table>

Table 2.2: Rockwell Hardness Scales (Source: Surface Engineering Forum, 2002-2013)

| Scale | Indenter | Minor Load *F0* kgf | Major Load *F1* kgf | Total Load *F* kgf | Value of *E* |
|---|---|---|---|---|---|
| A | Diamond cone | 10 | 50 | 60 | 100 |
| B | 1/16" steel ball | 10 | 90 | 100 | 130 |
| C | Diamond cone | 10 | 140 | 150 | 100 |
| D | Diamond cone | 10 | 90 | 100 | 100 |
| E | 1/8" steel ball | 10 | 90 | 100 | 130 |
| F | 1/16" steel ball | 10 | 50 | 60 | 130 |
| G | 1/16" steel ball | 10 | 140 | 150 | 130 |
| H | 1/8" steel ball | 10 | 50 | 60 | 130 |
| K | 1/8" steel ball | 10 | 140 | 150 | 130 |
| L | 1/4" steel ball | 10 | 50 | 60 | 130 |
| M | 1/4" steel ball | 10 | 90 | 100 | 130 |
| P | 1/4" steel ball | 10 | 140 | 150 | 130 |
| R | 1/2" steel ball | 10 | 50 | 60 | 130 |
| S | 1/2" steel ball | 10 | 90 | 100 | 130 |
| V | 1/2" steel ball | 10 | 140 | 150 | 130 |

## 2.2 INTRODUCTION TO HEAT TREATMENT

From Callister (2008), heat treatment is defined as controlled heating and cooling of metals to alter their physical and mechanical properties without changing the product shape. Sometimes it is done indirectly due to manufacturing processes which either heat or cool the metal such as welding or forming.

Meanwhile, metals and alloys will develop requisite properties by heat treatment which is very important in achieving desired microstructure that imparts the desired characteristics in a given material. Basic knowledge of physical metallurgy is crucial for understanding the theory of heat treatment. Heat treatment of metals is significant process in the final fabrication process of many engineering components. The aim in this stage is to make the metal better suited, structurally and physically, for some specific applications. For instant, heat treatment has huge impact on steels, and their properties may be changed considerably by definite heating and cooling cycles.

Heat treatment is done to achieve the following objectives:

i. Improvement in ductility;
ii. Relieving internal stresses;
iii. Refinement of grain size;
iv. Increasing hardness or tensile strength and achieving changes in chemical composition of metal surface as in the case of case-hardening;
v. Improvement in machinability;
vi. Alteration in magnetic properties;
vii. Modification of electrical conductivity;
viii. Improvement in toughness; and
ix. Development of recrystallized structure in cold-worked metal.

Heating rate will affecting the final result obtained from the process. It should be noted that the larger the size of object, the lower the rate of heating. This is to avoid development of internal stresses due to thermal gradient and ensure homogeneity of the structure and reduce holding time at heat treatment temperature.

For alloy steel heating process, heating temperature can be slightly higher temperature for homogenization of austenite.

### 2.2.1 Solution Heat Treatment/Annealing

By referring to Materials and Engineering Research Institute of Sheffield Hallam University (2002-2012), austenitic stainless steel cannot be hardened by heat treatment because they will harden instantly by cold work. Solution heat treatment or also known as annealing is not just recrystallized the work hardened grains inside material, they will bring back chromium carbides which precipitated at grain boundaries in sensitized steels into solution in the austenite. Solution heat treatment for stainless steel is normally set above 1040$^{o}$C, but melting point of stainless steel has to be identified before solution heat treatment. Grains size refinement is the main objective in doing annealing; therefore good prediction of temperature set in annealing is important. Time controlled in placing test specimens in heating furnace has to be set carefully to avoid uneven grains growth.

As a reminder, when conducting solution heat treatment process, surface of test specimens must be clean to free from oil, grease and other carbonaceous residues. This is because such residues will leads to carburization during heat treating and degrades corrosion resistance. Moreover, preheating before austenitising is advice to avoid cracking occurred in high-carbon types and in complex sections of low-carbon types. Common way of preheating is done by set temperature of preheating as 790$^{o}$C and heating to austenitising temperature.

### 2.2.2 Quenching

By referring to Materials and Engineering Research Institute of Sheffield Hallam University (2002-2012), quenching is known as a process where subjected of a heated metal above the recrystallization phase into rapid cooling process. The quenching of steel will becomes martensite. Quenching medium is used to cool heated metal. There can be water, saltwater, air and oil which are common quenching medium used.

Martensitic stainless steel owns huge hardenability because of their high alloy content. Air cooling from the austenitizing temperature is usually sufficient to produce full hardness final product, but larger sections will use oil quenching. Parts have to be tempered once they have reached ambient temperature to avoid delayed cracking if oil quenching is used. Tempering at temperatures above 510$^{o}$C should be followed by relatively rapid cooling to below 400$^{o}$C to avoid embrittlement.

Some precipitation-hardening stainless steel requires more complicated heat treatments than standard martensitic types. For examples, semi-austenitic precipitation-hardening type may require annealing, trigger annealing (to condition austenite for transformation on cooling to room temperature), sub-zero cooling (to complete the transformation of austenite) and ageing (to fully harden the alloy). Besides that, martensitic precipitation-hardening types often require nothing more than a simple aging treatment.

### 2.2.3 Age Hardening/Ageing

From definition of Bodycote heat treatment, ageing which also known as age-hardening or precipitation hardening. Some alloys including aluminium alloys, beryllium copper and special stainless steel are capable of being hardened by solution heat treatment followed by ageing process. The ageing process is conducted in the temperature range from 100$^{o}$C to 200$^{o}$C for aluminium and copper alloys. For other steels, suitable temperature range is from 400$^{o}$C to 700$^{o}$C. Optimum strength is obtained by the use of lower temperature and longer treatment time. In order to carry out manufacturing operations on these alloys, it is often necessary to soften them by re-solution treatment or over-ageing at a temperature which is intermediate between the solution and ageing temperature. The required mechanical properties may then produce by ageing without re-solution heat.