EFFECT OF PRECIPITATE HARDENING TREATMENT ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF CAST ALUMINUM SILICON ALLOY (A356)

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BORANG PENGESAHAN STATUS TESIS

JUDUL: EFFECT OF PRECIPITATE HARDENING TREATMENT UPON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF ALUMINUM SILICON CASTING ALLOY (A356)

SESI PENGAJIAN: 2011/2012

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I hereby declare that I have read this report and in my opinion this report is sufficient in term of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Manufacturing Engineering.

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EFFECT OF PRECIPITATE HARDENING TREATMENT ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF CAST ALUMINUM SILICON ALLOY (A356)

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A report submitted in partial fulfillment of the requirements for the award of the degree of Bachelor of Mechanical Engineering with Manufacturing Engineering

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JUNE 2012

STUDENT DECLARATION

I declare that this thesis entitled *"Effect of Precipitate Hardening Treatment on Microstructure and Mechanical Properties of Cast Aluminum Silicon Alloy (A356)"* is the result of my own research except as cited in the references. The thesis has not been accepted for my degree and is not concurrently candidature of any other degree.

Signature : ………………………..

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To my Beloved Mother and Father

TINA MAGABEE

BINDAMIN KIMPOOK

ACKNOWLEDGEMENTS

I would like to acknowledge and extend our heartfelt gratitude to my supervisor Dr. Syarifah Nur Aqidah Syed Ahmad Lecturer of Faculty Mechanical Engineering for his continues support, helpful advice and valuable guidance throughout my thesis. This thesis could not have been done without her who not only served as my supervisor but also encouraged and guide me through the writing up thesis process by giving her best effort. I also wish to express my sincere appreciate to the lecturers, technical staffs of Faculty Mechanical Engineering, University Malaysia Pahang for their teaching and help during the period of the project.

I also wish to express sincere appreciation to all my friends for their advice to do the study. I benefited greatly from the comments and wisdom these reviewers generously shared with me.

Most importantly, I would like to thank to my family especially my parents, Mr. BINDAMIN KIMPOOK and Mrs. TINA MAGABEE, have guided me throughout my life. They have always sacrifices their time and continuous support me to achieve my dreams and goals. I would like to thank them for all support and encouragement they done for me. Besides that I also want to express my appreciation to my friend SYAHRIL AZEEM ONG for giving an idea, support, and help throughout this thesis writing. I truly could not have done my thesis without him.

ABSTRACT

The main objective of this work was to study the influence of the precipitate hardening treatment of the A356 aluminum silicon sand cast alloy. The experiment process was separated into three parts which was foundry laboratory, material laboratory, and inspection. In the foundry laboratory, the cast alloys was prepared by sand casting process and was melted in a diesel furnace. In the material laboratory, the casting was then treated with precipitate hardening treatment and followed by machining. The inspection was done to observe microstructure, tensile properties and hardness properties. The effect of the solution heat treatment and artificial aging holding time on the microstructure, tensile properties, and hardness properties of the alloy was analyzed. Three specimens were heat treated with a solution treatment at a same temperature of 540°C, was quenched in room temperature water followed by artificial aging at a same temperature of 170°C. The different parameters were holding times which were solution at 2 hours and aging 2 hours, solution at 2 hours and aging 6 hours, solution 6 hours and aging 6 hours. The microstructure were investigated and tested by optical microscope, tension test and Rockwell hardness test respectively. The result found was at 2 hours solution of 540 °C homogenization and saturation of magnesium and silicon in Į(Al) phase, spheroid of eutectic Si phase occurred. After solution treatment, 2 hours artificial aging at 170 °C produced hardening precipitates. Samples treated at 6 hours solution and 6 hours artificial aging achieved even higher tensile strength and hardness. The increased of holding time for solution and artificial aging increased precipitate hardening.

ABSTRAK

Objektif utama kajian ini adalah untuk mengkaji pengaruh rawatan haba pengerasan mendakan aluminium silikon aloi A356. Proses eksperimen telah dibahagi kepada tiga bahagian iaitu dalam makmal faundri, bahan makmal, dan pemeriksaan. Dalam makmal faundri, aloi telah disediakan dengan proses tuangan pasir dan dicairkan di dalam relau diesel. Di makmal bahan, hasil spesimen kemudiannya telah dirawat dengan rawatan haba pengerasan mendakan dan diikuti oleh pemesinan. Pemeriksaan telah dilakukan dengan pemerhatian mikrostruktur, sifat tegangan dan sifat-sifat kekerasan. Kesan rawatan haba penyelesaian dan tempoh masa rawatan penuaan tiruan pada mikrostruktur, sifat tensil, dan sifat-sifat kekerasan aloi telah dianalisis. Tiga spesimen telah dirawat dengan rawatan haba penyelesaian pada suhu 540 ° C yang sama, dicelupkan dalam air pada suhu bilik dan telah diikuti dengan penuaan tiruan pada suhu yang sama iaitu 170 ° C. Parameter yang berbeza adalah tempoh masa iaitu untuk rawatan haba penyelesaian 2 jam dan penuaan 2 jam, haba penyelesaian untuk 2 jam dan penuaan 6 jam, haba penyelesaian untuk 6 jam dan penuaan 6 jam. Mikrostruktur telah dikaji dan diuji oleh mikroskop optik, ujian ketegangan dan ujian kekerasan Rockwell masing-masing. Hasilnya didapati bahawa haba penyelesaian untuk 2 jam pada suhu 540 ° C telah membuat penghomogenan dan ketepuan magnesium dan silikon dalam I (Al) fasa, fasa pembulatan silicon eutektik berlaku. Selepas rawatan penyelesaian, 2 jam penuaan tiruan pada 170 ° C telah dapat menghasilkan pengerasan mendakan. Daripada sampel yang dirawat dengan 6 jam haba penyelesaian dan 6 jam penuaan tiruan mencapai kekuatan tegangan dan kekerasan yang lebih tinggi. Semakin tinggi masa induk untuk penyelesaian dan penuaan tiruan akan meningkatkan mendakan pengerasan.

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ST	Solution treatment
AA	Artificial aging
UTS	Ultimate tensile strength
max	maximum

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CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Aluminum was one of the light and non ferrous metals that widely used today in manufacturing industries. This metal is silvery white in color appearance. Generally, aluminum is remarkable for its light in weight, low density and corrosion resistance. In industrial applications, Aluminum can replace steel in many possible structures that would be too heavy to use steel. Engineer and designers must be fully understand about aluminum so that they can fully utilize the advantages of this material and design to make it perform as expected. This material is very remarkable and yet this metal is also relatively new to our world and only available as a commodity metal for about 60years (Kenneth G. Budinski and Michael K. Budinski, 2010)

Generally, the characteristic of aluminum is it is lighter than any engineering metal except magnesium and beryllium, it has 60% of the conductivity of copper which mean aluminum has higher conductivity than copper, and finally it has good corrosion resistance (Kenneth G. Budinski and Michael K. Budinski, 2010)

In physical, aluminum is soft, durable, lightweight, ductile and nonmagnetic metal. It can be easily cast, extruded and machined. The elements of copper, magnesium, silicon and zinc were added into the aluminum to become aluminum alloy to improve the strength, hardness and fluidity (Ravi, 2006). Aluminum is classified into wrought and cast alloys. One of the cast alloys is aluminum silicon alloy which show excellent castability and good pressure tightness (Ravi, 2006).

Casting is a manufacturing process which involves pouring molten liquid of metal into a mold which contain cavity of desired shape. Sand casting is one of the oldest methods which has been used by the ancient Chinese and still being used today and produce the greatest percentage of casting product (C.W. Ammen, 2000). Aluminum alloys cast are also very easy to handle and it melt easier. However, the quality of cast aluminum alloys product in term of microstructure and mechanical properties usually doesn't meet the expected function requirement.

Today, there are a lot of method to improve the strength of aluminum alloy such as heat treatment, degassing agent, grain refinement and others. One of the methods to improve the mechanical properties of aluminum alloy is by heat treatment the casting product. There are many type of heat treatment used to improve strength such as solid-solution strengthening, strain hardening, grain size refinement, dispersion hardening phase transformations and precipitate hardening. The heat treatment done here is precipitate hardening which is the most effective to improve strength of non ferrous metal (E.Paul DeGarmo, JT.Black, Ronald A. Kohser, Barney E. Klamecki, 2003). The process involves homogenizing or heating then quenching to cool rapidly, and artificial aging.

Homogenizing help to eliminate the consequences of microsegregation and quenching help to increase strength of the casting product. Artificial aging make the grain structure is refined, producing much greater strength properties of the castings. (Vadim S. Zolotorevsky, Nikolai A. Belov, Michael V. Glazoff, 2007). As the result, the mechanical properties and microstructure of the aluminum alloy is changed.

1.2 PROBLEM STATEMENT

Generally, aluminum silicon alloys is the popular material used in sand casting in industry. Among the used of aluminum silicon alloy are the making of cylinder head for engine part in the automotive manufacturing industry.

Today industries, light metal such as cast aluminum alloy have gotten strong attention in engineering design and manufacturing due to strength to weight ratio that deal with some application. However the casting product of aluminum alloys properties sometimes does not meet the required properties. In other to meet the required properties, several treatments have been designed to make aluminum alloys meet the required properties. One of the popular and effective treatments is precipitate hardening by heat treatments. The aim of this study is to investigate the mechanical properties and microstructure of aluminum silicon alloy casting before and after undergoes heat treatment of precipitate hardening. Besides that, this study is to get clear understanding the parameter used in precipitate hardening heat treatment in order to develop optimal mechanical properties and microstructure of the aluminum alloys.ool wear has been a critical issue in metal removal processes. In turning process, tool wear can create parts that are out-of-tolerance and eventually cause tool failure.

1.3 PROJECT OBJECTIVE

The objective of this project was:

a) To investigate the mechanical properties and microstructure of aluminum silicon alloys sand casting product.
b) To investigate the mechanical properties and microstructure changed of aluminum alloys sand casting product undergoes precipitate hardening heat treatment.
c) To identify the effect of parameter in precipitate hardening heat treatment on mechanical properties and microstructure of aluminum silicon alloys sand casting product.

1.4 SCOPE OF PROJECT

In order to reach the project’s objective, the following scopes were identified:

a) The sand casting process was used in this project.

b) The raw materials used are aluminum silicon alloy (A356).

c) The heat treatment done is precipitate hardening.

d) The microstructure and mechanical properties investigation consist of hardness and tensile strength of material without heat treatment.

e) The microstructure and mechanical properties changed investigation consist of hardness and tensile strength of material with different holding time of heat treatment.

1.5 HYPOTHESIS

The expected result for this research is that there will be a difference in terms of microstructure and mechanical properties of cast aluminum alloys product before and after undergoes heat treatment process. The mechanical properties of undergoes heat treatment cast aluminum product will increase in term of hardness and tensile strength.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter discussed the literatures that are related to aluminum silicon alloys, sand casting process, and heat treatment process on aluminum silicon alloys. This chapter will review on microstructure and mechanical properties of cast aluminum silicon alloys product after undergoes heat treatment process based on past study conducted and also review the inspection method for the specimen.

2.2 ALUMINUM

Aluminum is a commercial metal used in industrial design and manufacturing due to its unique properties to perform in certain structure function. Nowadays, aluminum is rank second to steel and the most important nonferrous metal. It is very important in world economy due to its principle uses in transportation, construction, electrical applications, containers and packaging, consumer durable and mechanical equipment (E.Paul DeGarmo, JT.Black, Ronald A. Kohser, Barney E. Klamecki, 2003).

Generally, aluminum properties and characteristic that make it for engineering design and technologies is including its workability, light weight, corrosion resistance and good thermal and electric conductivity as well as easy to recycle. Aluminum has a specific gravity of 2.7 compared to 7.85 for steel which gives aluminum a light in weight advantages. Weakness of aluminum from engineering viewpoint is it has relatively low modulus of elasticity which is also about one third the value of steel (E.Paul DeGarmo, JT.Black, Ronald A. Kohser, Barney E. Klamecki, 2003).

In pure state, aluminum is soft, ductile and not very strong. Therefore, pure aluminum is commonly used for its physical rather than its mechanical properties. Aluminum that contain 99.45% of pure aluminum has electrical conductivity that is 62% that of copper for the same size wire and 200% that of copper on an equal basis. Aluminum alloys is classified into two major groups which is wrought alloys which has characteristic such as low yield strength, high ductility, good fracture resistance, and good strain hardening and cast alloys which has characteristic such as low melting point and high fluidity (E.Paul DeGarmo, JT.Black, Ronald A. Kohser, Barney E. Klamecki, 2003).

2.2.1 Aluminum Casting Alloy

Aluminum alloys is made by adding alloying element to pure aluminum. This alloying element change the characteristic of aluminum as well increase the strength of the alloy. Many popular alloys contain enough silicon to produce eutectic reaction which make the alloy has low melting point and high strength. Silicon also improves the fluidity of the molten metal making it easier to flow through thin sections shape. Effect of having too high silicon contain is producing an abrasive and difficult to cut material. Other alloying element is copper, magnesium, zinc. Table 2.1 show the commercial aluminum casting alloys that use three digit designation of the aluminum association. The first letter indicate a modification of the original alloy, second and third digit identify the particular alloy and last digit separated by decimal point indicate the product form(e.g. casting or ingot) (E.Paul DeGarmo, JT.Black, Ronald A. Kohser, Barney E. Klamecki, 2003). Figure 2.1 shows example of cast aluminum alloy product.

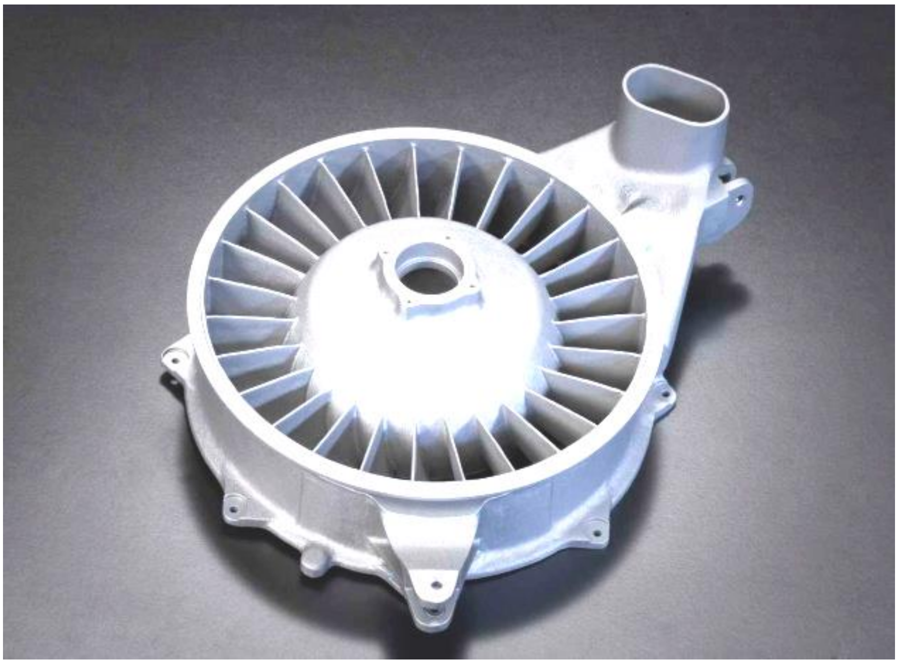


Figure 2.1: Aluminum cast alloy

Source: Thompson Aluminum Casting Co. (TAC) Company

Table 2.1: Cast aluminum alloy designation

Major alloying element	Number series
Aluminum, 99.00% and greater	1xx.x
Copper	2xx.x
Silicon with cu and/or mg	3xx.x
Silicon	4xx.x
Magnesium	5xx.x
Zinc	7xx.x
Tin	8xx.x
Other	9xx.x

Source : E.Paul DeGarmo, JT.Black, Ronald A. Kohser, Barney E. Klamecki, 2003

The percentage of these alloy element in useful aluminum alloys does not exceed about 15% and copper (2xxx), manganese (3xxx), silicon (4xxx), magnesium (5xxx), and zinc (7xxx) are the most important alloying element in aluminum alloy system (Kenneth G. Budinski and Michael K. Budinski, 2010). Each of the alloy elements has an effect toward aluminum alloys whether on microstructure, characteristic property or mechanical properties. Table 2.2 shows the effect of alloy element on aluminum alloy.

Table 2.2: Effect of alloy element

Alloying element	**effects**
Iron	• Naturally occurs as an impurity in aluminum ores • Small percentage increase the strength and hardness of some alloys and reduce hot cracking tendencies in casting • Reduces pickup in die casting cavities
manganese	• Used in combination with iron to improve castability • Alters the nature of the intermetallic compounds and reduces shrinkage • Improve ductility and impact strength in mechanical properties
Silicon	• Increase fluidity in casting and welding alloys and reduces solidification and hot cracking tendencies • Addition in excess of 13% make the alloy extremely difficult to machine • Improves corrosion resistance
Copper	• Increase strength up to about 12% • Higher concentration cause brittleness • Improves elevated temperature properties and machinability • Concentration over 5% reduce ability to hard coat

Magnesium	• Improves strength by solid solution strengthening, and alloys with over about 3% (0.5% when 0.5% silicon is added) will precipitation harden • Aluminum-magnesium alloys are difficult to cast because the molten alloy tend to “skin over” (dross) in contact with air
Zinc	• Lowers castability • High zinc alloy are prone to hot cracking and high shrinkage • Percentage over 10% produces tendencies for stress corrosion cracking • In combination with other element, zinc promotes very high strength • Low concentration in binary alloys (<3%) produce no useful effects
Chromium	• Improves conductivity in some alloys, and in small concentration (<0.35%) it acts as a grain refiner
Titanium	• Naturally occurs as an impurity in aluminum ores, but it is intentionally added to some alloys as a grain refiner
Lead/Bismuth	• Added to some alloys to improve machinability
Zirconium	• Used as a grain refiner in some aerospace alloys
Lithium	• Added to some aerospace alloys (space shuttle fuel tank) to reduce weight. These alloys need a protective atmosphere when being cast

Source: Kenneth G. Budinski and Michael K. Budinski, 2010

2.2.2 Aluminum Silicon Alloy

Aluminum silicon alloys are one of the industrial casting alloys also known as binary alloys. Its contain 4% to 22%of silicon compare to 90% of all casting. These result to its excellent castability and crack resistance. The most important characteristic of this alloys that define why is widely use in industrial are mechanical, corrosion, and casting properties (Vadim S. Zolotorevsky, Nikolai A. Belov, Michael V. Glazoff, 2007).

Other than silicon, these alloys also contain constituent particles such as iron, copper, magnesium, and manganese. The contain of silicon which varies from 4% to 22% can be divided into three range which is 4% to 9%, 10% to 13%, and 14% to 22% (Vadim S. Zolotorevsky, Nikolai A. Belov, Michael V. Glazoff, 2007).

Figure 2.2 shows the phase diagram and microstructure of aluminum silicon alloys respectively with its silicon contain percentage.

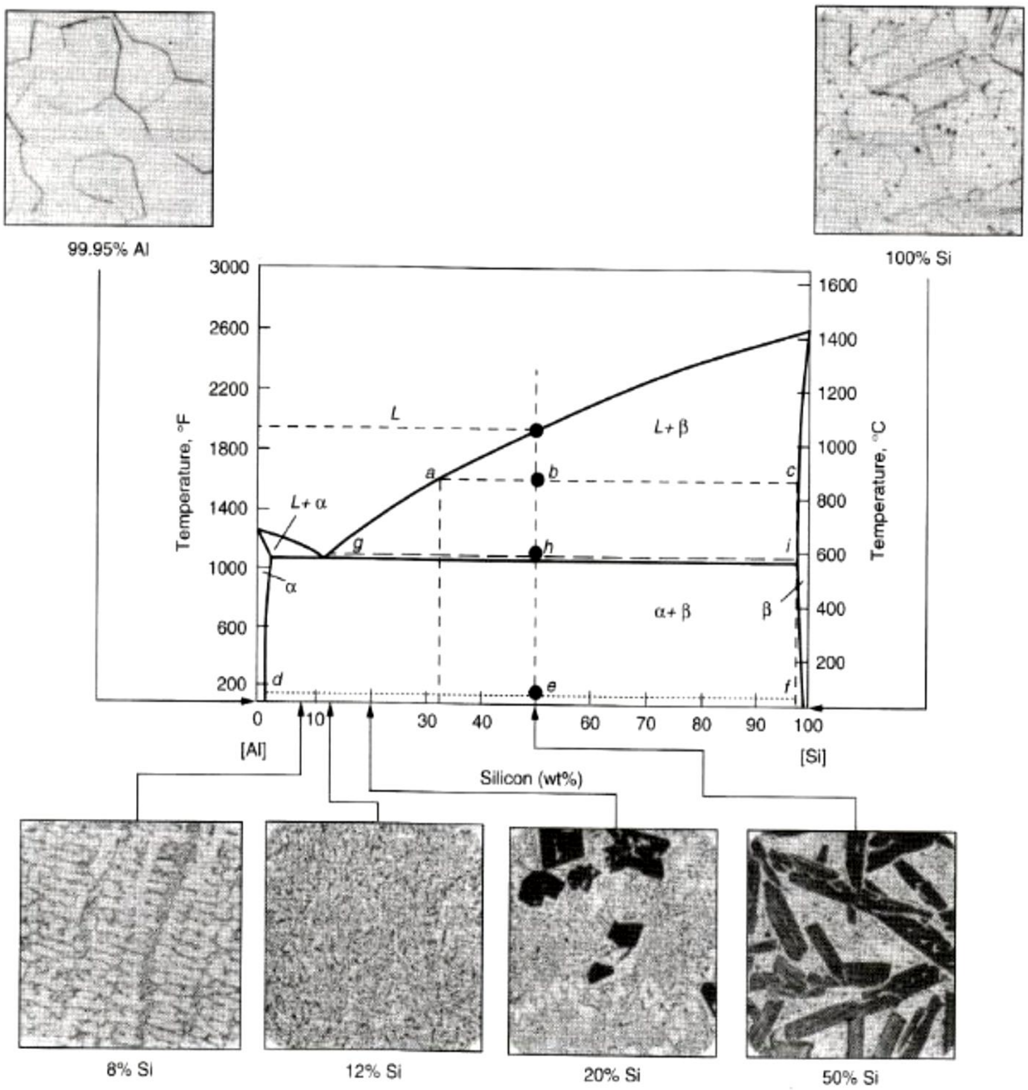


Figure 2.2: Aluminum silicon phase diagram and microstructure

Source: Flake C. Campbell, 2008

Based on the phase diagram in figure 2.2, the microstructure of aluminum silicon alloys when its silicon contain is 4% to 9%, 10% to 13% and 14 to 22% is corresponds to hypoeutectic, eutectic and hypereutectic alloys. Figure 2.3 show the microstructure of this state (Vadim S. Zolotorevsky, Nikolai A. Belov, Michael V. Glazoff, 2007).

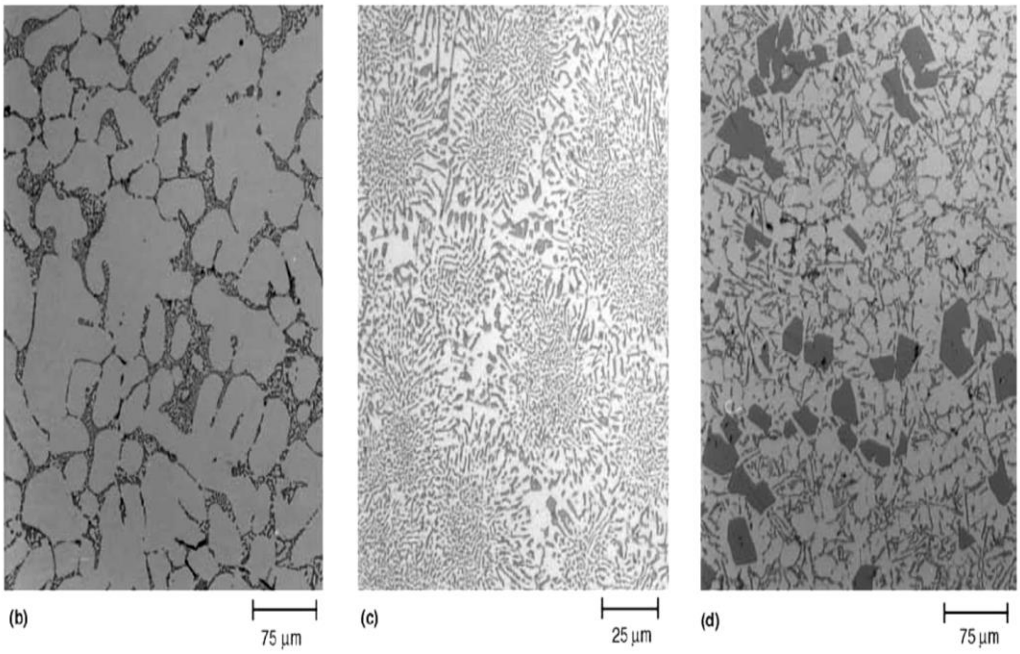


Figure 2.3: Microstructure of hypoeutectic alloy, eutectic alloy, and hypereutectic alloy.

Source: Malgorzata Warmuzek, 2004

2.3 SAND CASTING PROCESS

Sand casting is the oldest and yet still widely use manufacturing process. The process involve in sand casting is making a mould with sand mixture, melting metal into liquid metal and pouring molten liquid metal into the sand mould cavity, solidifies of molten metal liquid in mould cavity and separation of casting product from the mould. The molding material of sand casting is cheap, easy to get and readily to work into suitable mould makes sand casting the most economical method (C.W.Ammen, 2000). Besides that, sand casting also extremely versatile processes where part can be made in almost any size and weight (C.W.Ammen, 2000).

2.3.1 Pattern and mould making

Pattern is an exact replica which takes the shape of the parts intended to be cast. Pattern is a tool to make the cavity in casting molding making process. Design and construction is the first step in making a sand casting .Woods pattern is easy to make and frequently used for small quantities of casting making (E.Paul DeGarmo, JT.Black, Ronald A. Kohser, Barney E. Klamecki, 2003). However, wood dimensionally is not stable and may swell with change in humidity and also tend to wear with repeating in used. This is where metal pattern or hard plastics or other more expensive material have the advantages to use.

Pattern used in the casting industrial has several different types and usually selected based on the number of duplicate casting or the complexity of the part shape. The pattern type is:

a) Solid pattern
b) Split pattern
c) Match plate pattern
d) Cope and drag pattern
e) Loose piece pattern

Solid pattern are the simplest and often the least expensive pattern types. This type is the replica or duplicate of the part to be cast. It is very cheap to make but subsequent molding process is usually slow. Therefore, solid pattern usually used for simple in shape and small quantities of casting (E.Paul DeGarmo, JT.Black, Ronald A. Kohser, Barney E. Klamecki, 2003). Solid pattern is suitable to used for casting simple part like test specimen part.

When solidification process occurs, shrinkage process will happen which the cooling metal will shrink and reduce in size. Therefore, to overcome this problem pattern is made bigger than the size of required casting. This extra size on pattern is called shrinkage allowance. Table 2.3 shows some of various metal shrinkage allowance (C. Elanchezhian, B. Vijaya Ramnath, 2005).

Table 2.3: Various metal shrinkage allowance

Metals	**Shrinkage allowance**
Cast iron	10mm per meter
steel	15mm per meter
Brass	14mm per meter
aluminum	18mm per meter

Source: C. Elanchezhian, B. Vijaya Ramnath, 2005

Core is part of the mould to produce internal cavities within the casting. Core making needed to produce complex part casting and often cost more in casting process. However, core also expand the capabilities of the process and by practice good design, we can facilitate and simplify their use (E.Paul DeGarmo, JT.Black, Ronald A. Kohser, Barney E. Klamecki, 2003).

Gating system is a connecting passage for the whole mould cavities. Gating system makes the delivering of the poured molten metal to all section of mould cavities possible. Gating system function to control speed or rate of metal movement as well the degree of cooling that occurs while it’s flowing. Slow rate of filling result in high loss of heat and cause misruns and cold shuts while rapid rate of filling result in erosion of gating system and mould cavity that cause entrapment of mould material in the final casting (E.Paul DeGarmo, JT.Black, Ronald A. Kohser, Barney E. Klamecki, 2003).

Generally, gating system attached to the thickest sections of a casting to control shrinkage minimize turbulence and splashing. Gating system can also design to trap dross and sand particles and keep them from entering the mould cavity. The specific design for gating system depend on metal being cast such as turbulent sensitive metal like aluminum alloys with low melting point need gating system design that concentrate on eliminating turbulence and trapping dross (E.Paul DeGarmo, JT.Black, Ronald A. Kohser, Barney E. Klamecki, 2003).

2.3.2 Melting and Pouring

Casting process is start by melting process. This process required an equipment called melting furnace. The furnace needed many characteristic for industrial casting. However, for experiment or small casting process, the type of furnace is compose of cupolas, air furnace, crucible furnace, electrical arc furnace or electrical resistance furnace. There are several factors to consider in choosing appropriate melting procedure such as:

a) Temperature needed to melt and superheat the metal
b) The alloy being melted and the form of available charge material
c) The desired melting rate or quantity of metal
d) The desired quality of metal
e) The availability and cost of various fuels
f) The variety of metal or alloy to be melted
g) Melting is to be batch or continuous
h) The required level of emission control
i) The various capital and operating cost

(E.Paul DeGarmo, JT.Black, Ronald A. Kohser, Barney E. Klamecki, 2003)

Crucible furnaces is limited in size and melting rate indirect fuel fired furnace and often used to melt small batches of non ferrous metal. If this furnace received heat from electrical resistance and provides better control of temperature and chemistry. The shape of this furnace usually take shape of holding pots that outer surface heated by flame. Although the stirring action, temperature control and chemistry control of this furnace is poor but these furnace is low in cost (E.Paul DeGarmo, JT.Black, Ronald A. Kohser, Barney E. Klamecki, 2003).

Pouring process is done by pouring the molten metal into the mould cavity. This process usually need pouring device such as ladle to transfer the molten metal from the furnace to the mould. The specific type of ladle is determined by the size and number of casting to be poured and usually in small casting, a handheld, shank type ladle are used for manual pouring (E.Paul DeGarmo, JT.Black, Ronald A. Kohser, Barney E.

Klamecki, 2003). The considerations that need to be taken into account in this process are:

a) To maintain the metal at the proper temperature for pouring
b) To assure that only high quality metal is introduced into the mould

In this process, the most important factor is pouring temperature. This factor serve as controlling factor for the molten metal fluidity which the higher the pouring temperature the higher the fluidity of the molten metal (E.Paul DeGarmo, JT.Black, Ronald A. Kohser, Barney E. Klamecki, 2003).

Fluidity is defined as ability of the molten metal to flow and fill a mould. The important of this ability is it makes sure the liquid metal can flow through the whole region of the mould especially the thin section of the mould cavity. This ability prevent the defect known as misruns and cold shuts where the liquid metal solidify before filling the whole cavity and block the flow of the liquid metal from reaching the other region. However, too high fluidity also need to be avoid as it can permit penetration also a defect where molten metal not only fill the cavity but also fill the small void between the sand particle result in bad surface finish of the casting product. This is where pouring temperature become important to control as it control the fluidity level (E.Paul DeGarmo, JT.Black, Ronald A. Kohser, Barney E. Klamecki, 2003).

2.3.3 Solidification process

Solidification process occurs after molten metal is poured and completely filling the mould cavity. It is a process where the molten metal is allowed to cool inside the mould cavity and became a desired solid shape. One of the importance about this process is many of the structural features that ultimately control the product properties are set during this process. Besides that, many of casting defect such as gas porosity and solidification shrinkage also can be reduced and eliminated by controlling solidification process (E.Paul DeGarmo, JT.Black, Ronald A. Kohser, Barney E. Klamecki, 2003).

There are two important stage in solidification process that need to be control which is nucleation and growth stage. Nucleation stage occurs when stable particle of solid forms from within the molten metal. This stage control process enhance the producing of finer grain of casting product which tend to be beneficial for mechanical properties of the casting material (E.Paul DeGarmo, JT.Black, Ronald A. Kohser, Barney E. Klamecki, 2003).

Growth stage occurs when the heat of fusion is extracted from the liquid metal. Growth control process is like controlling the direction and rate of heat removing or cooling rate. This stage tend to control defect such as shrinkage and when produce faster cooling rate tend to produce finer grain size and superior mechanical properties casting product (E.Paul DeGarmo, JT.Black, Ronald A. Kohser, Barney E. Klamecki, 2003).

Solidification shrinkage is when molten metal undergoes volumetric contraction when it begins to cool and solidify. There are three principle stages in shrinkage:

a) Shrinkage of the liquid
b) Solidification shrinkage as liquid turn into solid
c) Solid metal contraction as the solidified material cools to room temperature (E.Paul DeGarmo, JT.Black, Ronald A. Kohser, Barney E. Klamecki, 2003).

2.4 PRECIPITATE HARDENING HEAT TREATMENT FOR NON-FERROUS METAL

Precipitate hardening is one of the methods in strengthening heat treatment for non ferrous metal which is including aluminium silicon alloy. It is the most effective method of heat treatment to improve strength for non ferrous metals. This method has three steps to process. The first step is solution treatment, second step is quenching and the third step is aging. Precipitate hardening is said extremely effective strengthening mechanism and the reason for attractive engineering properties of many non ferrous alloys (E.Paul DeGarmo, JT.Black, Ronald A. Kohser, Barney E. Klamecki, 2003).

2.4.1 Solution treatment

Solution treatment is a process of heating the material to a certain temperature. Its purpose is to put precipitating element in solid solution (Kenneth G. Budinski, Michael K. Budinski, 2010). In the case of heat treatment of cast aluminium alloy, it also called homogenizing heat treatment and it purpose is to eliminate the consequences of microsegregation that occur during casting solidification process. It can be combined with isothermal tempering (Vadim S. Zolotorevsky, Nikolai A. Belov, Michael V. Glazoff, 2007).

2.4.2 Quenching

Quenching is a process of rapidly cooled the metal from high temperature. In precipitate hardening, quenching is done immediately after solution treatment. Usually the quenching is done in water and it purposes is to suppress diffusion and produced a room temperature supersaturated solid solution (E.Paul DeGarmo, JT.Black, Ronald A. Kohser, Barney E. Klamecki, 2003).

2.4.3 Aging

Aging process is divided into two types which is natural aging and artificial aging. Natural aging is where room temperature is enough to move the unstable supersaturated solution toward the stable two phase structure. Artificial aging required re-heat to elevated temperature to provide necessary diffusion (E.Paul DeGarmo, JT.Black, Ronald A. Kohser, Barney E. Klamecki, 2003).

Aging re-heat temperature is usually lower but the period of heating is longer. The aging time usually determine the tensile properties of material. Too short or too long cycle can result in poor tensile properties. The consideration that needs to be taken is to prevent from over aging (Kenneth G. Budinski and Michael K. Budinski, 2010).

The period of heating and temperature value determine the strength of the material. If longer time and lower temperature is used for aging, higher strength will be produced. Artificially aging is more popular because the ability to lock in the peak properties that occur prior to over aging (E.Paul DeGarmo, JT.Black, Ronald A. Kohser, Barney E. Klamecki, 2003).

2.5 EFFECT OF PRECIPITATE HARDENING ON ALUMINUM CAST ALLOY

In the case of precipitate hardening of aluminum silicon cast alloy, the step is divided into three stages which are solution treatment, quenching, and aging. Each of this stages produce an impact to the aluminum silicon cast alloys. The following will review the impact of each stage in the treatment towards aluminum silicon cast alloy.

2.5.1 Effect on microstructure

The first stage in the precipitate hardening heat treatment process is solution treatment which the main purpose of this treatment for aluminum silicon cast alloy is divided into three major categories which are dissolve soluble phases containing Cu and Mg formed during solidification, homogenize the alloying element, spheroidize the eutectic Si particles (Emma Sjölander et al, 2010). As the solution treatment temperature increase, the three purpose rate will also increase.

The second stages are quenching process which purpose is to suppress precipitation upon cooling of the casting from the high solution treatment temperature to room temperature. If the quench rate is sufficiently high solute is retained in solid solution and a high number of vacancies are also retained. On the other hand if the cooling is too slow, particles precipitate heterogeneously at grain boundaries or dislocations, which results in a reduction in supersaturating of solute and concomitantly a lower maximum yield strength after ageing (Emma Sjölander et al, 2010).

The third stages in precipitate hardening treatment are aging. The objective of ageing is to obtain a uniform distribution of small precipitates or grain refinement which gives a higher strength (Emma Sjölander et al, 2010) or in other words refining the grain structure of aluminum silicon alloy.

The previous study conducted by Xiao Yan Liu on effect of solution treatment on microstructure and mechanical properties of Al-Cu-Mg-Ag alloy provide a clear result the effect of first stage of precipitate hardening which is solution treatment or homogenizing on microstructure. Figure 2.4 shows the microstructure obtained. Based on the result, he explain that a typical ingot structure consisting of dendritic α (Al) phases is present in the as cast microstructure, serious dendritic segregation exists in the ingot and large amounts of intermetallic phases in the interdendritic region are presented. After homogenized, most residual phases are dissolved into the matrix. But there are still little secondary phases both in the grains and along the grain boundaries (Xiao Yan Liu, et al 2010).

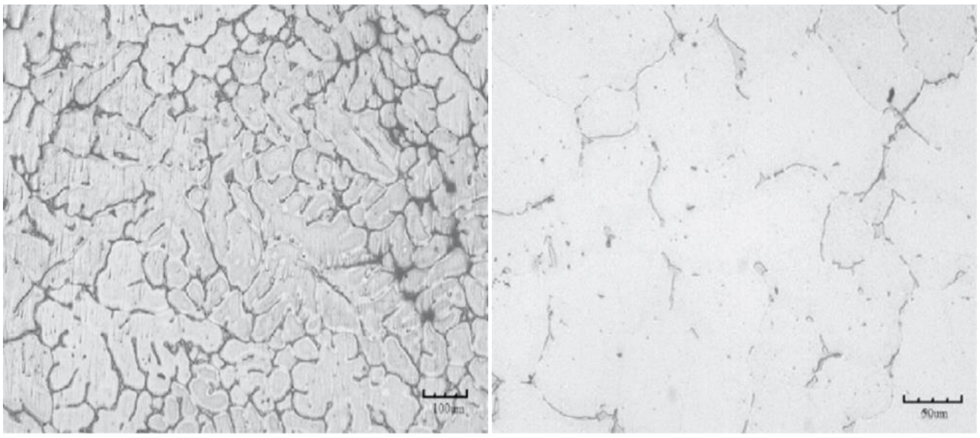


Figure 2.4: Microstructure of Al–Cu–Mg–Ag alloy As-casted and homogenized.

Source: (Xiao Yan Liu, et al 2010)

Meanwhile, another previous study conduct by M.A. Azmah Hanim on the effect of two step solution treatment on microstructure and mechanical properties of aluminum silicon cast alloys show that there is changes happen to the microstructure of as cast and heat treated 332 aluminum silicon cast alloy. Figure 2.5 shows the microstructures of as-cast and after complete heat treatment with single step solution treatment obtained from the study. From the result obtained, she explains that the dark grey phase represents the silicon-rich phase, whereas the light grey matter represents the aluminum matrix. The heat treatments were observed to affect the morphology of the silicon-rich phase. The edges of the silicon-rich phase became more round after the single step solution treatment. From the figure we can see that gradual spheroidisation of the silicon-rich phase and the refinement of the phase (M.A. Azmah Hanim, et al 2010)

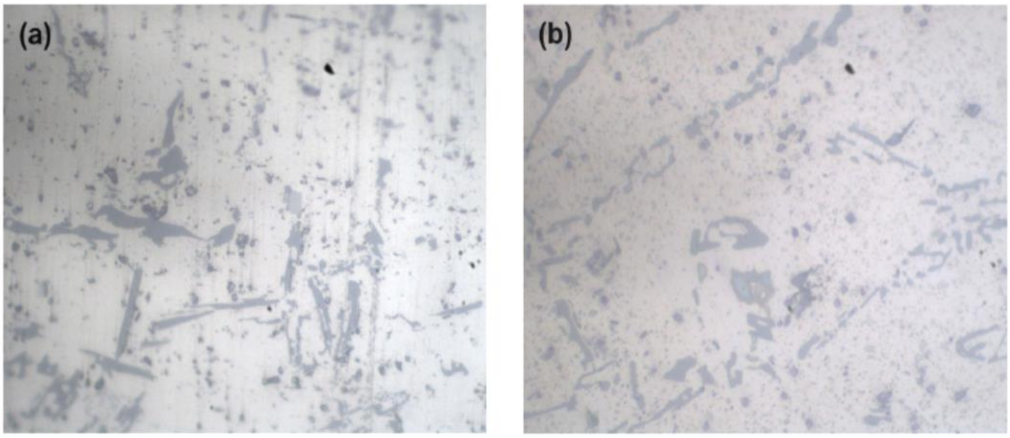


Figure 2.5: Optical microphotograph of 332 aluminum silicon alloy: (a) as-cast, (b) Single-step solution treatment

Source: (M.A. Azmah Hanim, et al 2010)

2.5.2 Effect on mechanical properties

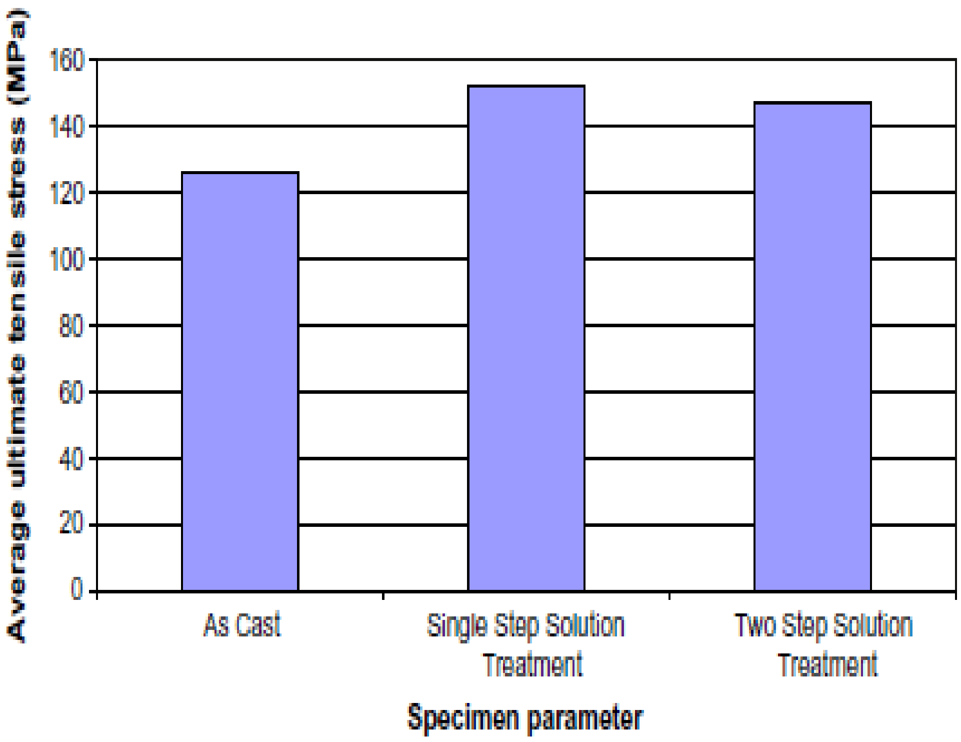
The mechanical properties of the aluminum alloys is depend on the microstructure and alloying element of the alloy as previously review. To alter the mechanical properties, microstructure must also be altered. Thus, if precipitate hardening heat treatment can change the microstructure, it also changes the mechanical properties.

Based on the study conduct by M.A. Azmah Hanim, it was found that the mechanical properties in term of hardness, tensile strength is increasing after undergo heat treatment. Figure 2.6 show the result of various mechanical properties change obtain on this study review. In this study, it was state in the discussion that hardness value of the as-cast and heat-treated specimens’ increases as the silicon-rich phase is spheroidised and refined. For the tensile test result, the value of ultimate tensile stress increases with heat treatment. From the stress–strain graph obtained for the specimens with and without heat treatment. Clearly show at early stage the specimens went through elastic elongation until the tensile stress was around 25–30 MPa. After that, samples went through plastic deformation and fractured in a brittle mode at the ultimate tensile stress value (M.A. Azmah Hanim, et al 2010)

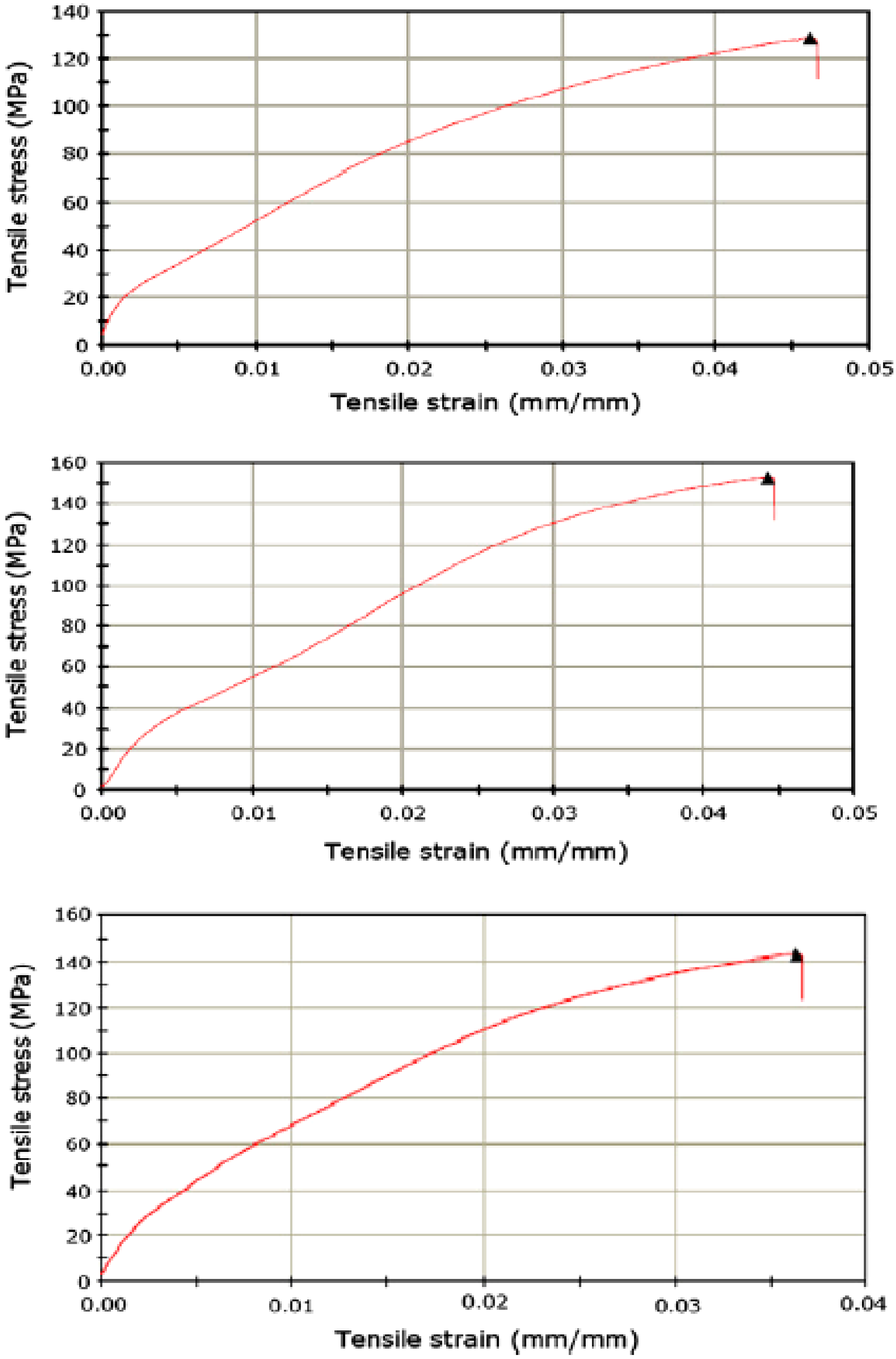
Average hardness values for the as-cast and heat-treated specimens.

No.	Specimen parameter	Average hardness value (15Y)	Percent difference compared to as-cast
1	As-cast	79.32	0
2	Single-step solution treatment	84.05	5.96
3	Two-step solution treatment	84.59	6.64

(a)



(b)



(c)

Figure 2.6: (a) Hardness value, (b) Ultimate tensile stress, (c) Stress-strain curve

Source: (M.A. Azmah Hanim, et al 2010)

2.6 INSPECTION METHOD

Inspection is a process to determine the result is acceptable or not. These processes need a specific machine for each inspection. Each result then compared to the hypothesis result to know it is acceptable or rejected. There are three results to be inspect which is microstructure, tensile test, and hardness test for mechanical properties.

2.6.1 Microstructure inspection

The metallurgical of a material is study by observing its microstructure. By study the microstructure using metallurgy microscope, the grain size, phase present, and heat treatment inclusions can be determined. The technique of analyzing metal microstructure is referred as metallographic. The importance of microstructure study is it help material engineer to solve problem and give more understanding in material response to treatments. By having this information, it can help them in material selection for design and prevent material failure in service (Kenneth G. Budinski and Michael K. Budinski, 2010). Figure 2.7 shows an example of metallurgical microscope for microstructure inspection.

Figure 2.7: Metallurgical microscope

Source: Central Scientific Instrument Corporation Company

2.6.2 Tensile test inspection

Generally, mechanical properties of a metal are divided into five categories which are strength, formality, stiffness, toughness, and durability. Tensile properties are properties under strength category that determine the strength of a material. Tensile test inspection are laboratory technique in determine several important material properties such as tensile strength, yield strength, modulus of elasticity, percentage reduction in area, and percentage elongation. The equipment for tensile test inspection called universal test machine (Kenneth G. Budinski and Michael K. Budinski, 2010). Figure 2.8 shows example of universal test machine. During the test, the machine crosshead is moved by power screw or hydraulic to create the tension force.

Figure 2.8: Universal test machine

Source: Instron Company

The specimen for tensile test is usually cylindrical rods with reduced diameter in the centre or flat plate with a narrow section in the centre. The testing process start with measuring the reduce section and making gage mark at the measuring section of the sample. The sample then mounted in the machine jaws. One of the jaw machines is fixed to the base and the other one is affixed to a movable crosshead driven to pull the sample apart. Force applied is measured by force transducer that connected to one of the jaws. The length of the reduce area measured using an equipment called extensometer that clamps on the sample body and convert length change to an electrical measurement. (Kenneth G. Budinski and Michael K. Budinski, 2010).figure 2.9 shows example of cylindrical rods tensile test sample.

Figure 2.9: Cylindrical rods shape of tensile test sample

Source: Beijing united test co. Ltd Company

The tensile stress then calculated by dividing the force measured by the force transducer by the original cross sectional area. The strain is calculated by dividing the change in length by the original length of the sample. The stress-strain curve is obtained by the computer. The modulus of elasticity can be calculated by dividing the respective increment of stress by the respective increment of strain on the linear portion of the stress-strain curve (Kenneth G. Budinski and Michael K. Budinski, 2010). The stress, strain and modulus of elasticity are given by the following expression:

$$\text{Engineering stress, } \sigma = \frac{F}{A} \qquad \text{(e.q 2.1)}$$

$$\text{Engineering strain, } \varepsilon = \frac{\Delta L}{L_0} \qquad \text{(e.q 2.2)}$$

$$\text{Modulus of elasticity, } E = \frac{\Delta stress}{\Delta strain} \qquad \text{(e.q 2.3)}$$

Refer to the stress-strain curve result example in figure 2.6, the early curve is linear where it represents the elastic of the sample. At this stage, the sample will return to its original length if the crosshead is stopped. The slope of this linear curve shows the elastic modulus. If material stress-strain curve is linear, it is said to be Hookean after the name of Robert Hook (Kenneth G. Budinski and Michael K. Budinski, 2010).

As the forces applied continue putting stress to the sample, it will reach a point where some permanent plastic deformation occurs and if the crosshead stopped, the sample will no longer return to its original length. The points where elastic deformation change to plastic deformation is called yield point. As the crossheads continue to pull the sample, the cross sectional area will rapidly decrease and reduce the load carrying capacity of the sample. When the load is reducing, the force needed will reach the peak value and then decrease with the reduction in load-carrying capacity. The stress calculated using the force peak value is called ultimate tensile strength of the sample (Kenneth G. Budinski and Michael K. Budinski, 2010).

As the testers continue, the sample will finally fracture and break. The sample will remove from the machine jaws and two measurements are taken which is the final length of the mark area length, and final diameter of the necked-down portion. This measurement data will be used to determine ductility of the material by calculated the percentage of elongation and percentage of reduction area. The higher the percent elongation, the more ductile the material will be (Kenneth G. Budinski and Michael K. Budinski, 2010). The percent elongation and percent in reduction area are given by the following expression:

$$\text{Percent elongation} = \frac{final\ length - initial\ length}{initial\ length} \qquad \text{(e.q 2.4)}$$

$$\text{Percent reduction in area} = \frac{initial\ area - final\ area}{initial\ area} \qquad \text{(e.q 2.5)}$$

From this data, we can also calculate the Poisson's ratio by dividing the transverse strain by longitudinal strain. The expressions to calculate the Poisson's ratio are given below:

$$\text{Longitudinal strain, } \varepsilon_{longitudinal} = \frac{final\ length - initial\ length}{initial\ length} \qquad \text{(e.q 2.6)}$$

$$\text{Transverse strain, } \varepsilon_{transverse} = \frac{final\ diameter - initial\ diameter}{initial\ diameter} \qquad \text{(e.q2.7)}$$

2.6.3 Hardness test inspection

Hardness is mechanical properties under the category of durability. There are probably 100 ways of measuring hardness. In the early days, hardness of heat treated steel was tested by filing an edge of the sample and if the sample cannot file, it is considered as hard. Today, most of hardness test is done by pushing a penetrator into material surface and measuring the effects. The common use of hardness test is brinell, Rockwell, and Vickers hardness tester (Kenneth G. Budinski and Michael K. Budinski, 2010). The figure 2.10 shows an example of universal hardness tester that able to test Brinell, Rockwell, and Vickers hardness.

Figure 2.10: Universal hardness tester

Source: Instron Company

The sample for hardness tests is simply a flat surface material. Rockwell hardness test is done by using diamond shape of indenter to penetrate the sample surface. The depth of the indentation then measured by the machine and converted on a dial to a hardness number (Kenneth G. Budinski and Michael K. Budinski, 2010).

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Chapter 3 discusses methodology of the project in general, with a specific focus on effect of precipitate hardening treatment holding time upon microstructure and mechanical properties of aluminum silicon cast alloy. In succession of this project, a flow of method was used. The analysis starts off with project planning by using a Gantt chart and a flow chart. The flow chart acts as a guide to successfully carry out this case study step by step while the Gantt chart helps to make sure that the project is within its timeframe. Using sand casting to make aluminum silicon alloys product and applied precipitate hardening heat treatment for the sand casting product is the backbone of this project, therefore using appropriate and precise steps is imperative in order to achieve the expected result. Once this has been done, the alloys further inspected and tested for their microstructure and mechanical properties. Finally the analysis of the whole project may be tabulated and concluded in the following chapter. The overall flowchart for this project is presented in figure 3.1.

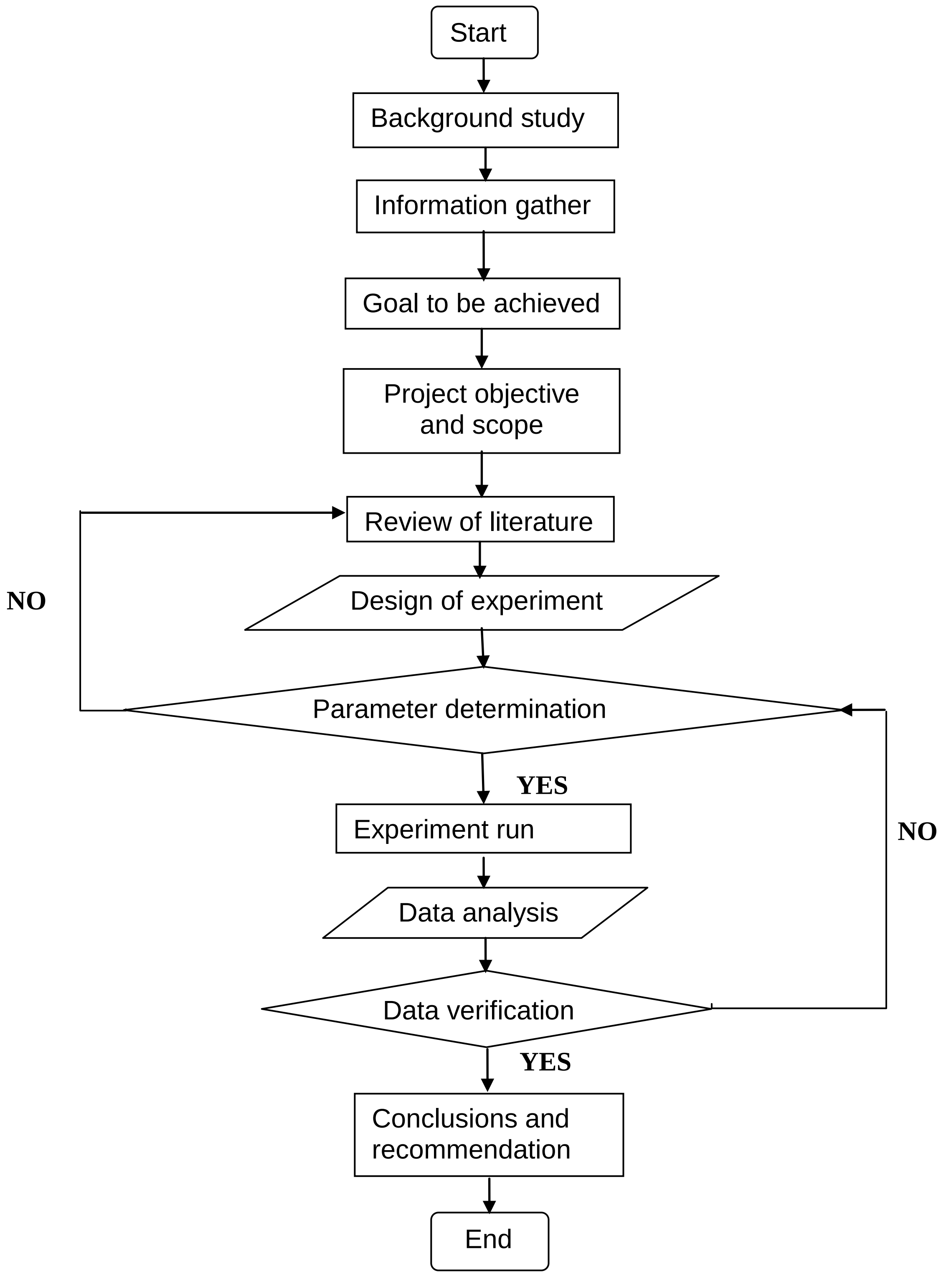


Figure 3.1: Project flow chart

3.3 DESIGN OF EXPERIMENT

The test rig for this experiment was design to investigate the microstructure and mechanical properties of aluminium silicon sand cast product before and after undergoes precipitate hardening heat treatment. It was designed specifically to provide information about the microstructure and mechanical properties changed during heat treatment to enhance the use of aluminium alloys applications in the industry. The aluminium silicon cast alloys were prepared by sand casting process, four samples are prepared. Three of the sample is then being treated with precipitate hardening heat treatment with different parameters. The other one remaining sample is left without undergoes heat treatment. Then the sample is inspected and tested using metallurgical microscope, universal test machine, and hardness tester. The microstructure, tensile strength and hardness of all the sample of aluminium silicon alloys is determine and result is verify by comparison among the result and refers to review of the literature.

3.4 SAND CASTING PROCESS

Sand casting was done to produce the samples of aluminium silicon cast alloys. The important step in this process is mould making, melting process, pouring process and felting process. After this process, the specimen preparation for further test was done. The important parameter in sand casting needed to be taken into care were melting temperature and pouring rate.

3.4.1 Sand mould making

In this process, the method used was hand ramming method which is suitable because only few casting were to be made. The mould material was olivine sand. The sand was transferred to the drag and continually hand rammed to make sure the sand structure were dense and compact so that the mould has a solid structure and will not ruptured during hot melting metal flow into the mould. In addition, the parting powder was applied to the pattern to make it easier to remove from the sand mould. Figure 3.2 shows mould making process with parting powder applied to the sand.

Figure 3.2: Sand mould making

3.4.2 Melting process

The melting process was done using a crucible furnace. About 10kg of aluminum raw material was melted inside the furnace. Aluminum alloy working temperature for casting was in the range of 690˚C to 790˚C (A.K Chakrabarti, 2005). In this process, the temperature is set to 740˚C for optimum melting temperature of aluminum casting. The melting temperature was important to give them enough fluidity to the molten aluminum. The temperature was measured using thermocouple. Meanwhile, molten metal was continually stir in the furnace will causing slag to occur, this slag is filtered using slag catcher to ensure the level of purity of the molten metal. Figure 3.3 shows the raw aluminum melting process in the furnace.

Figure 3.3: Melting of raw material

3.4.3 Pouring process

Pouring process was done by using a ladle. The molten aluminum was poured into the ladle and by using the ladle the molten metal is poured into the mould cavity. To make sure the molten aluminum temperature was in its optimum temperature when pouring into cavity process is done, the temperature first raise to 750˚C in the furnace before transfer into ladle to compensate the temperature lost when transfer process is done. The temperature is measured using thermocouple. In the pouring process, the pouring rate is important to be taken care to make sure the solidification rate is in the optimum rate. The optimum pouring rate should be in the range of 0.25 to 0.30kg/s (Rao, 1998). Figure 3.4 shows how the pouring process was done.

Figure 3.4: Pouring process

3.4.4 Felting (removing and cleaning)

This process was done after the molten aluminum was completely solidified inside the mould cavity. Its involve removing the casting from the mould cavity and cleaning the casting. The process starts with breaking the sand mould using hammer to get the casting. After that, the casting was cleaned by using sand blow process which was the casting will be blasted by a jet of compressed air to removed the sand that stick with the casting surface. The process followed by removing the gates from the casting by cutting using disc cutting machine. Figure 3.5 shows the specimens after felting was done.

Figure 3.5: Specimen after felting process

3.3.5 Specimens preparation

The dog bone shaped casting then machined by CNC milling machine into a suitable dimension that fit with the tensile test machine. Small cross section pieces were cut from casting product for microstructure and hardness test specimens of as-cast condition. Then, small cross section was cut from the casting each time it complete a heat treatment for microstructure and hardness test of cast alloy undergoes heat treatment with different holding time condition . Figure 3.6 was the result of machined specimens.

Figure 3.6: Specimen after machining process

3.5 PRECIPITATE HARDENING TREATMENT

In this experiment, precipitate hardening heat treatment was applied to three aluminum casting alloys out of four produced. The heat treated specimens was subjected to different holding time to determine the effect of holding time upon microstructure result and the mechanical properties result. The other one specimen remain was left without undergoes heat treatment to get the result of microstructure and mechanical properties of the casting product without heat treatment applied. The process in precipitate hardening was solution treatment or homogenizing, quenching, and aging. In this experiment precipitate hardening was done using T6 designation treatment which includes quenching after heating and completes artificial aging and divide into long time treatment and short time treatment.

3.5.1 Solution treatment (homogenizing)

Solution treatment or homogenizing primary objective was to eliminate the consequences of microsegragation and also increase the mechanical properties level of casting (Vadim S. Zolotorevsky, Nikolai A. Belov, Michael V. Glazoff, 2007). In this experiment solution treatment was done by heating the aluminum casting alloys to a temperature above the solvus. However, the temperature must not exceed the eutectic temperature or it might cause melting of the casting. In this process, the long treatment heating temperature and time was done in 540˚C and 6 hours respectively while short time treatment heating temperature and time was done in 540˚C and 2 hours respectively. The process involve was heating the samples and specimen by putting it into the furnace that have been heated to a specific temperature and wait until the required time is meet.

3.5.2 Quenching

Quenching was a process of cooling the heated samples and specimens rapidly to room temperature. In this process, delay which result in temperature drop should be minimized. The medium used for quenching is water at room temperature. The steps were simply taking out the heated samples from the furnace and put it into the water medium. In these experiments, both long and short treatment undergoes the same process, quenching medium, and parameters for quenching.

3.5.3 Aging

In this experiment, aging was done by artificial aging process. These process steps involved heating the samples to elevated temperature but lower than the heating temperature in solution treatment. The heating temperature and time for long treatment was 170˚C and 6 hours respectively while short treatment temperature and time was 170˚C and 2 hours respectively. The heating process was done after quenching and the steps is simply by putting the samples into the furnace that have been heated to specific desired temperature and wait for the desired time needed. After the desired time achieved, the samples and specimen was taken out from the furnace and left cooled by air to room temperature. Table 3.1 shows the summary of each treatment holding time and the total time for heat treatment applied for each specimen.

Table 3.1: Heat treatment holding time

heat treatment	**solution treatment**	**artificial aging**	**total time**
As-cast	0	0	0
Solution treatment 540-2h Artificial aging 170-2h	540˚c for 2h	170˚c for 2h	4h
Solution treatment 540-2h Artificial aging 170-6h	540˚c for 2h	170˚c for 6h	8h
Solution treatment 540-6h Artificial aging 170-6h	540˚c for 6h	170˚c for 6h	12h

3.6 INSPECTION

Data acquisition was derived from the inspection process. In this experiment, the inspection was done to determine the microstructure, hardness and tensile strength of the samples. Each inspection process has its own procedure and steps to be followed before result was produce. This steps need to be follow to make sure the inspection process is running smoothly and provide the expected result.

3.6.1 Microstructure inspection

Microstructure inspection was done using metallurgical microscope. This process was done by putting the specimen under the microscope and gets the clear picture of the specimen’s microstructure. Before the inspection was done, the specimens undergo steps of process to make sure the result can be obtained clearly from the picture. These steps were grinding and polishing the surface of the specimens needs to be observed. The steps started with grinding the specimen surface using rotating grinder. Then, it will continually grind using vertical grinding machine that have four specification of grinder which is 240x, 320x, 400x, and 600x. In this stage, the method was by grind the specimen in only one direction in each specification for about 3 minutes each. Then, the specimens was polished using the disc grinding and polish machine. It acts to remove blemish and make the scratch not visible for inspection. After polishing, the specimen undergoes etching process which the specimen was soaked into and acid solution for specific purpose before washed and dried to be inspected. The etching reagents used for aluminium alloy are hydrofluoric acid solution in water 0.5%, sodium hydroxide solution in water 1.0%. During etching, sulphuric acid dissolved the thin bright layer (Jain, 1995). The samples are shown in figure 3.7.

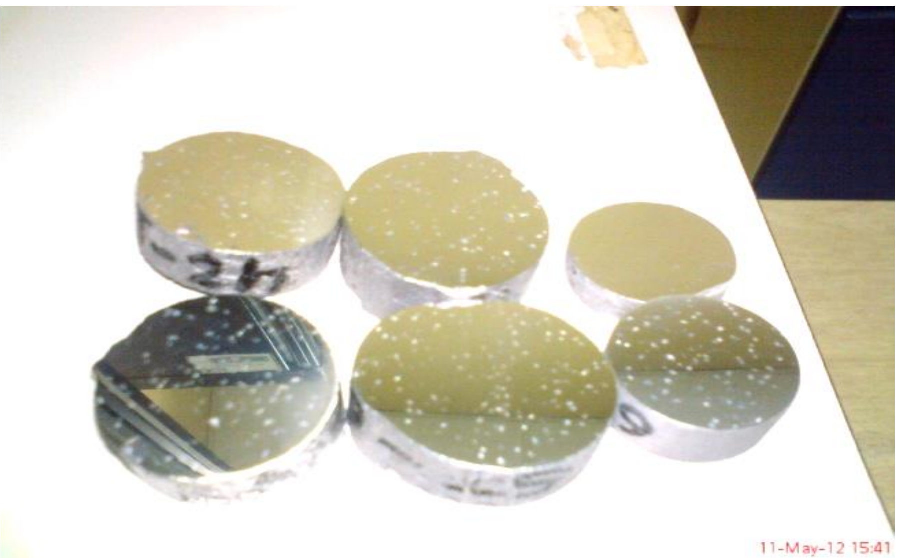


Figure 3.7: specimen for microstructure observation

3.6.2 Hardness test

Hardness test inspection was done using digital Rockwell hardness tester machine. The Rockwell test was done by putting the specimen on the machine and pushing it until the diamond shaped indenter indent the specimen’s flat surface. The value was then measured by the digital machine. Six values were taken from one specimen and the hardness average value is then calculated. To make sure the result obtain was more accurate, the surface was make sure to be flat by grinding process. Figure 3.8 shows the prepared hardness specimen.

Figure 3.8: Specimen for hardness test

3.6.3 Tensile test

Tensile test was done using the tensile test machine. The process started with measuring and marking the gage section of the dog bone shape aluminium silicon alloys casting product. Then it was claimed to the machine jaw and load was applied. In this process, the result data was provided by the machine therefore no calculation is made. The processes are shown in figure 3.9.

Figure 3.9: Specimen undergoes tensile test

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

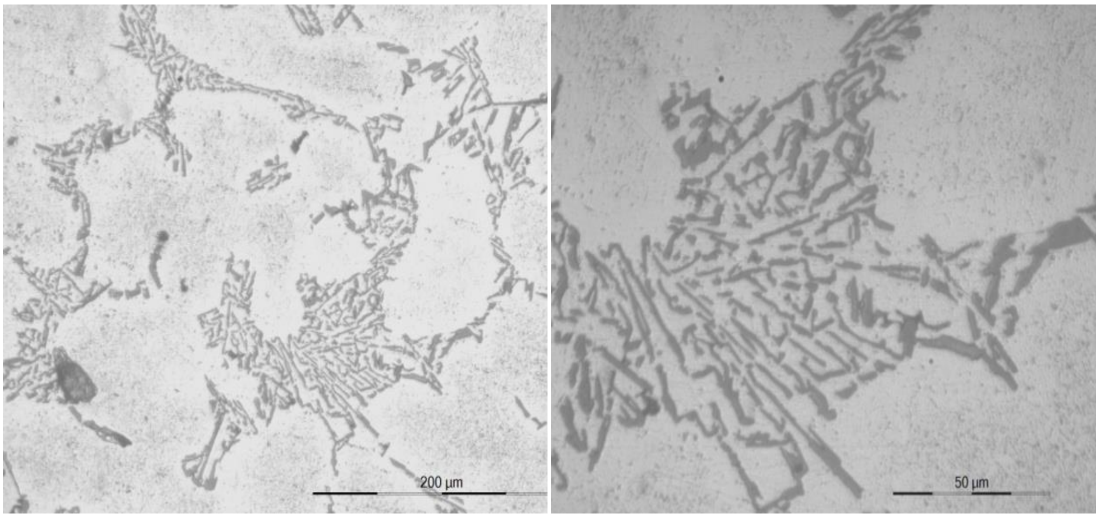
Chapter 4 demonstrates the result of microstructure in the form of figure and tensile and hardness test in the form of table obtained from the experiment. In this chapter also discussion and evaluation of the result for validation by comparing to the previous research and references from literature review.

4.2 RESULT

4.2.1 Microstructure result

Microstructure observation is done before treatment which is in as-cast condition, after undergoes solution treatment for 2 hours and 6 hours and after undergoes artificial aging for 2 hours and 6 hours. The summary of heat treatment holding time is presented in table 3.1 of previous chapter.

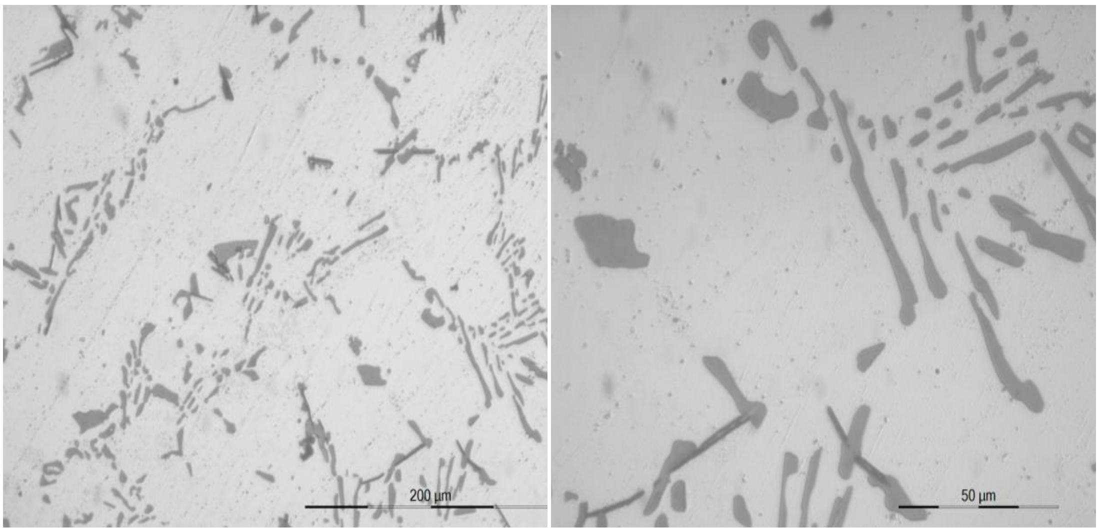
From figure 4.1, it shows as-castA356 alloy microstructure in different magnification (a) 20 micrometer (b) 50 micrometer. From the figure, it is clearly shows that the primary Į(Al) is in dendrite cell structure, also the silicon particle was in eutectic structure and segregated which means in big bulk form in the alloy phase. The segregation makes the alloy phase non-homogenize and eutectic structure makes the precipitate less dispersed in the alloy phase (Vadim S. Zolotorevsky, 2007).



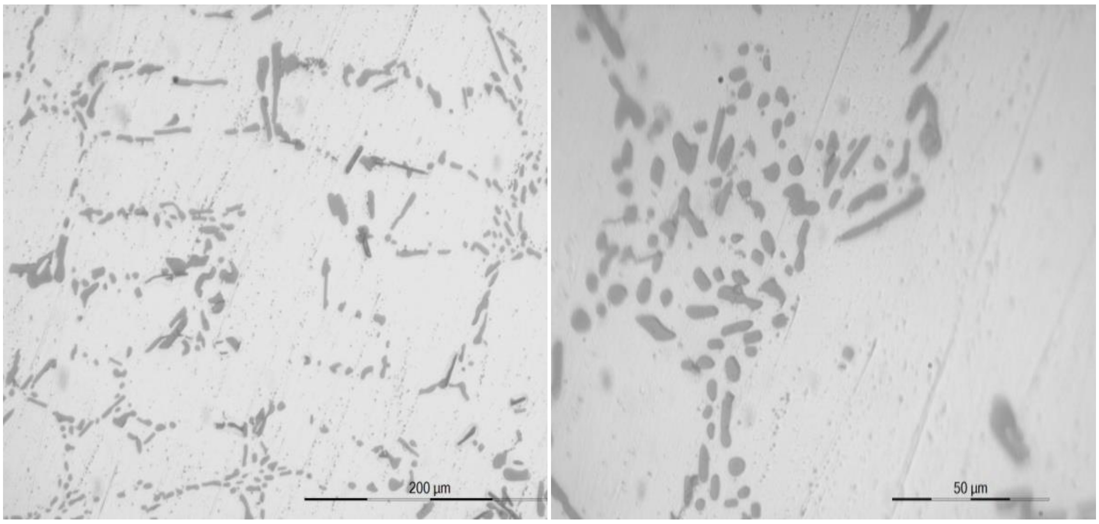
a) 20ɥm magnification **b) 50ɥm magnification**

Figure 4.1: Microstructure in as-cast condition (a) 20ɥm magnification (b)50ɥm magnification

The microstructures of A356 alloys treated with solution at 540 °C for holding time of 2 hours and 6 hours are presented in Figure 4.2. From figure 4.2 (a) and (b), It is shown that during solution treatment at 2 hours the eutectic structure changing to a globular type structure. The eutectic silicon also spheroidized. At 6 hours, the effect is the same with more spherodisation occur and globular structure also increased. This is shown in figure 4.2 (c) and (d).



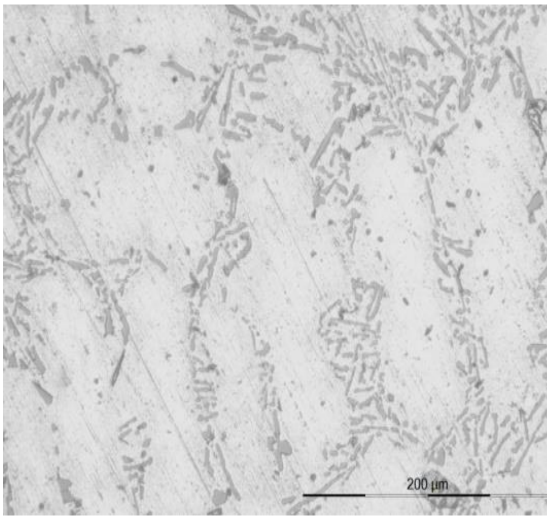
a) 20ɥm magnification **b) 50ɥm magnification**

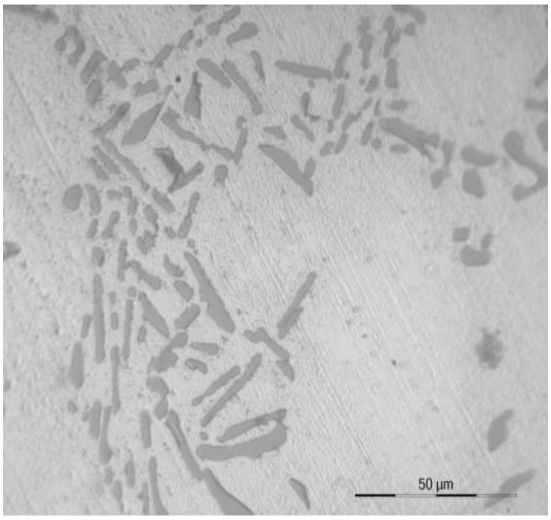


c) 20ɥm magnification **d) 50ɥm magnification**

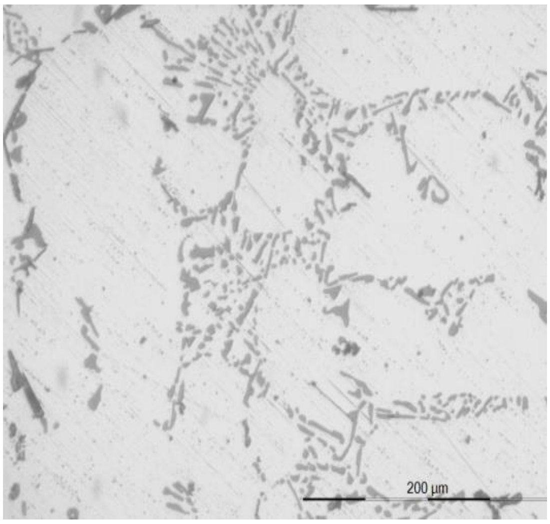
Figure 4.2: Microstructure after solution treatment (a) solution at 2hours in 20ɥm magnification (b) solution at 2 hours in 50ɥm magnification (c) solution at 6hours in 20ɥm magnification (d) solution at 6hours in 50ɥm magnification

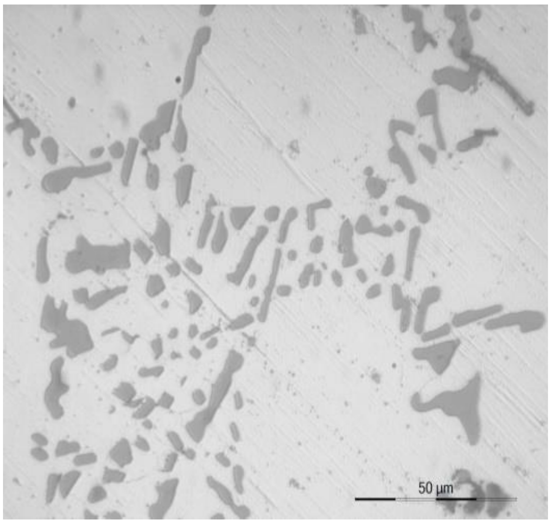
Figure 4.3 show the microstructure obtained after specimen undergoes artificial aging process after solution treatment with different magnification which was 20 micrometer and 50 micrometer. From figure 4.3 (a) and (b), it is shown that after aging, the eutectic si particle is coarser and this refined precipitate is more evenly dispersed in the alloy phase. From figure 4.3 (c) and (d) also shown that after undergoes six hour holding time of an artificial aging, the coarser the eutectic si particle become and more evenly dispersed precipitate occurred in the alloy phase. Lastly, figure 4.3 (e) and (f) shows that eutectic si particle is the coarser and most evenly dispersed precipitate occurred when the holding time of solution treatment and artificial aging holding time is the longest which is 6 hours.



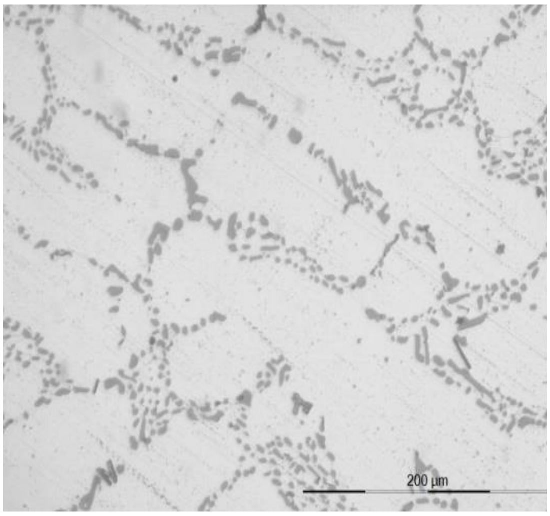


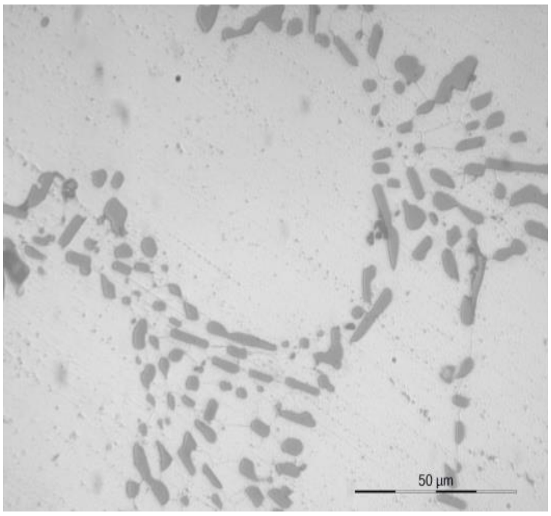
(a) 20ɥm magnification **(b) 50ɥm magnification**





(c) 20ɥm magnification **(d) 50ɥm magnification**



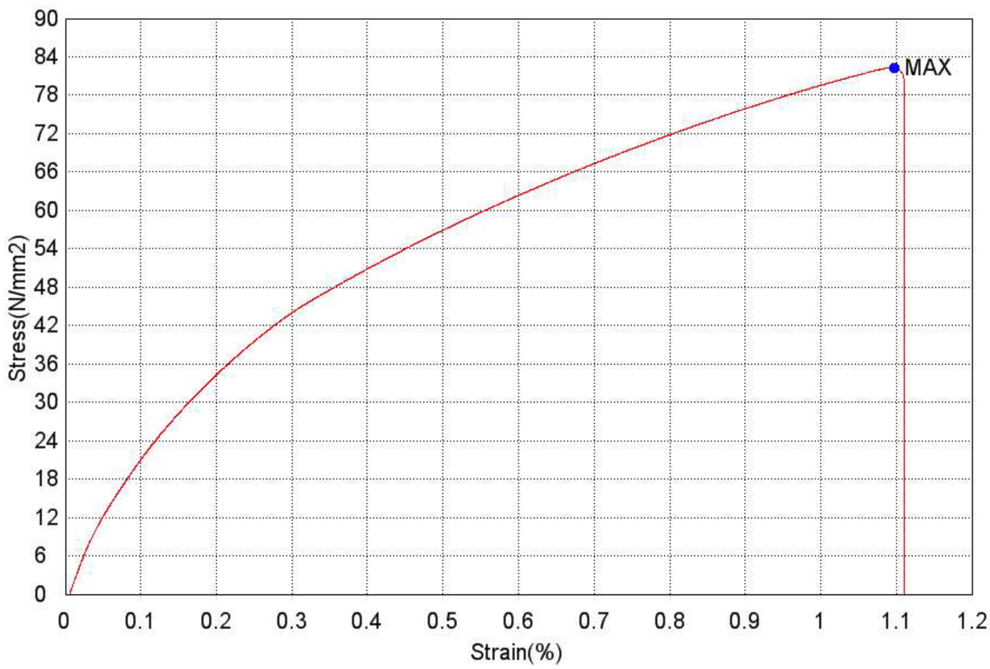


(e) 20ɥm magnification **(f) 50ɥm magnification**

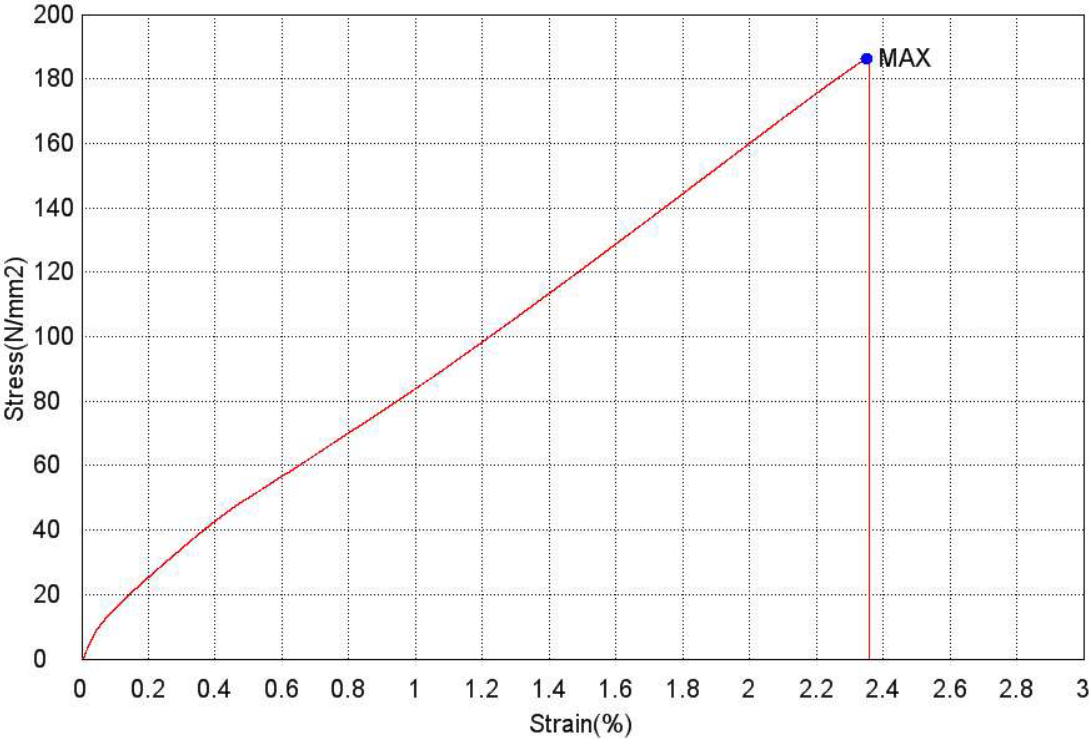
Figure 4.3: Microstructure after complete treatment (a) solution 2h + aging 2h 20ɥm magnification (b) solution 2h + aging 2h 50ɥm magnification (c) solution in 2h + aging 6h in 20ɥm magnification (d) solution in 2h + aging 6h in 50ɥm magnification (e) solution in 6h + aging 6h in 20ɥm magnification (f) solution in 6h + aging 6h in 50ɥm magnification

4.2.2 Tensile properties result

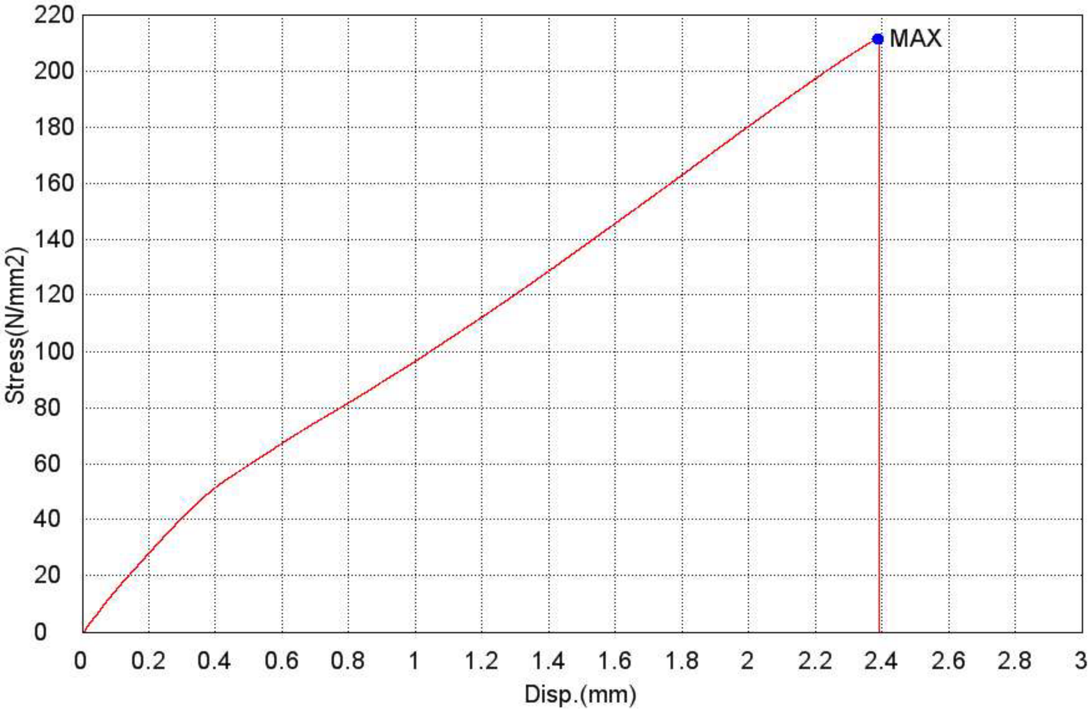
Figure 4.4 shows the stress versus strain curve obtained for each specimen. From the figure 4.4 (a), (b), (c), and (d), it is shown the maximum stress of the as cast condition sample was 82.3 N/mm, maximum stress of the 2 hour solution treatment with 2 hour artificial aging condition sample was 186.2 N/mm, maximum stress of the 2 hour solution treatment with 6 hour of artificial aging sample was 211.3 N/mm, and maximum stress of the 6 hour solution treatment with 6 hour artificial aging sample was 234.7 N/mm. The summary of tensile properties is presented by the Table 4.1 and compared to each other by a graph as shown in figure 4.5. From the table, it shows the value of maximum stress and elongation of each specimen with different condition of heat treatment holding time applied. It shows that maximum stress and elongation is improved with longer holding time applied to the specimens.



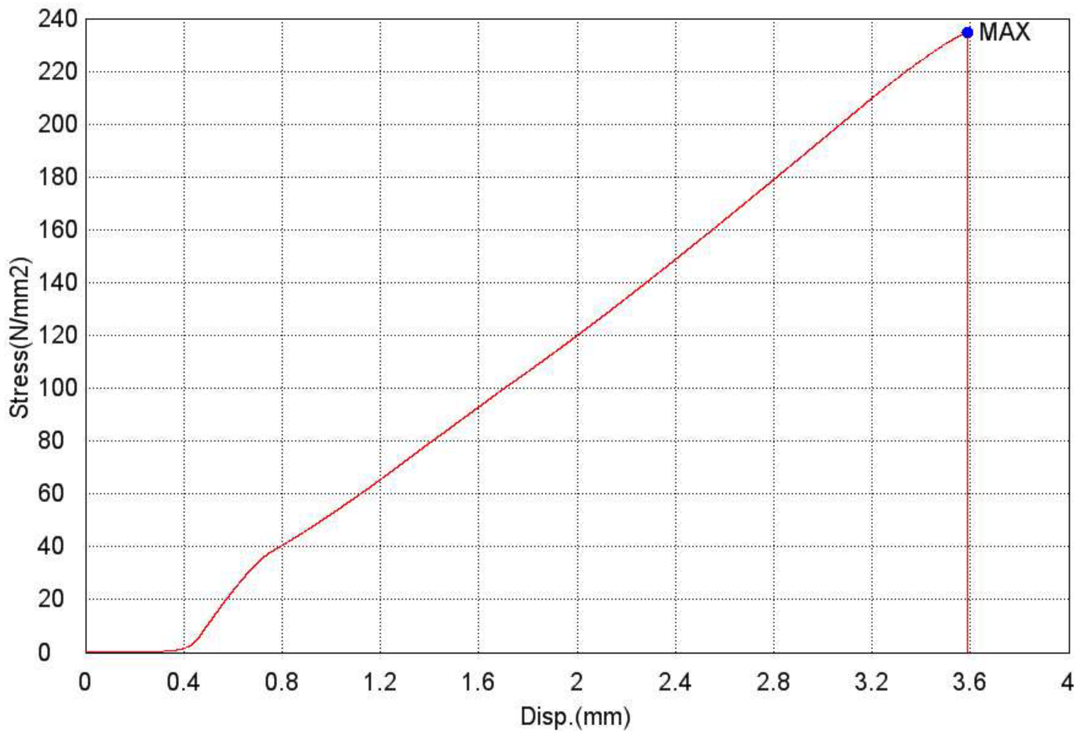
(a) As-cast



(b) Solution treatment 2hours and aging 2hours



(c) Solution treatment 2hours and aging 6hours



(d) Solution treatment 6hours and aging 6hours

Figure 4.4: Stress versus strain curve of specimen with (a) as-cast (b) ST 2hours+ aging 2hours (c) ST 2hours+ aging 6hours (d) ST 6hours+ aging 6hours

Table 4.1 Tensile properties of A356 alloy with different heat treatment holding time

specimen condition	UTS/Max stress (N/mm2)	Elongation/Max strain (%)
As-cast	82.3	1.1
ST 540-2h, AA 170-2h	186.2	2.35
ST 540-2h, AA 170-6h	211.3	2.39
ST 540-6h, AA 170-6h	234.7	3.59

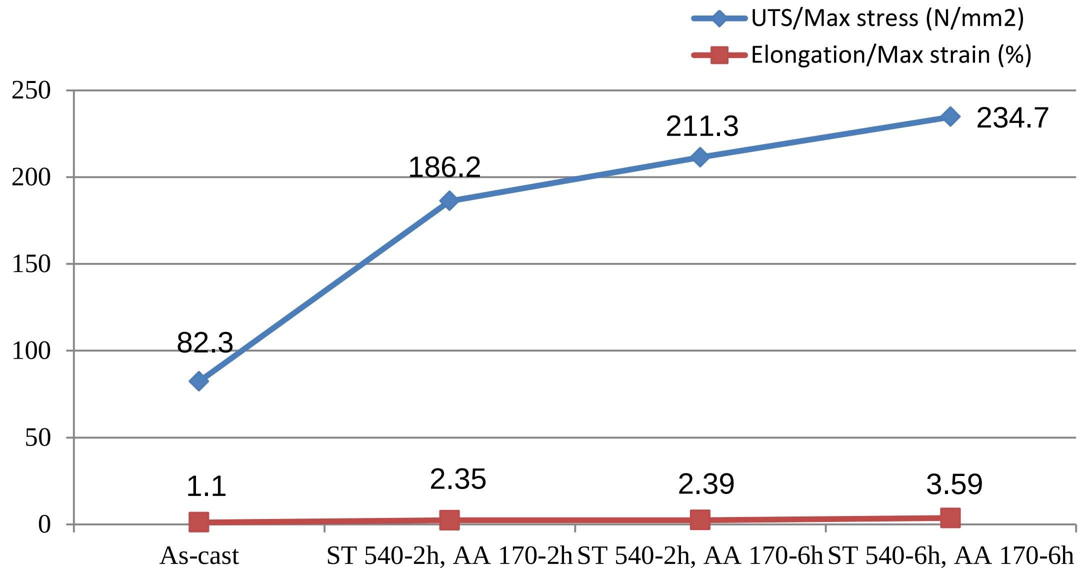


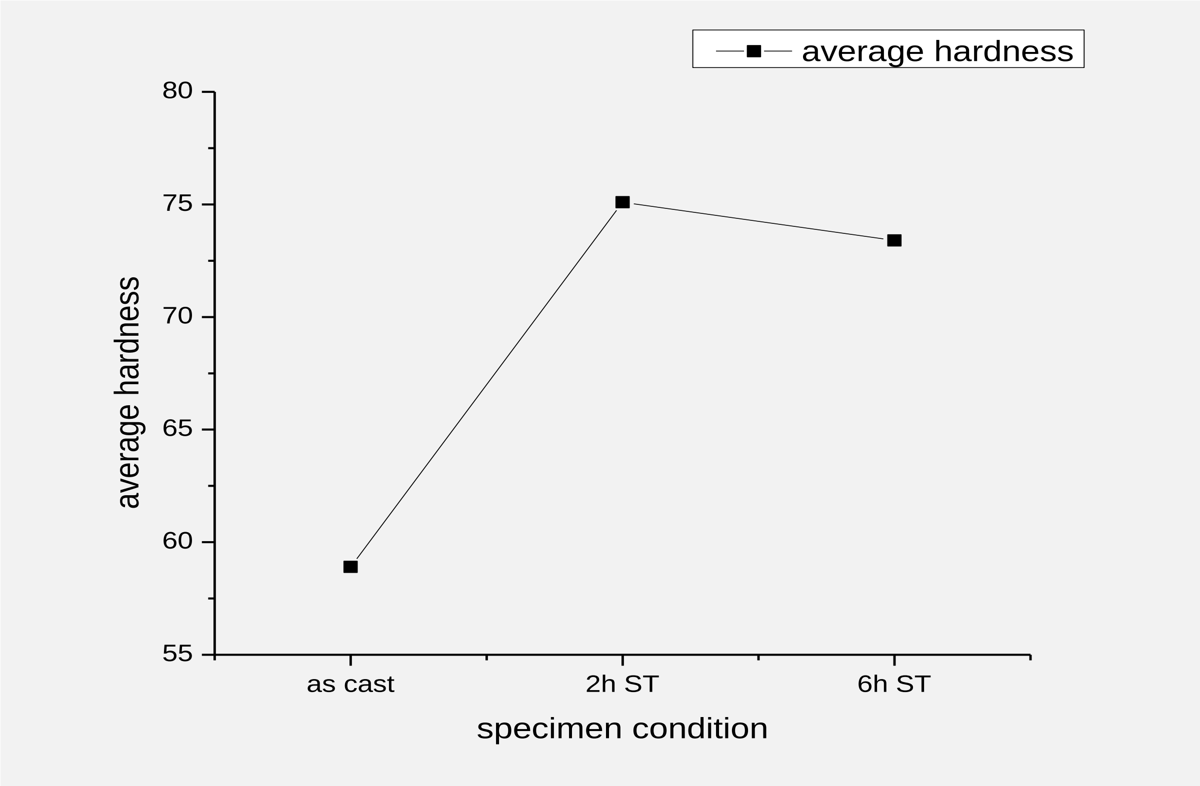
Figure 4.5: Max stress and max strain value with different heat treatment holding time

4.2.3 Rockwell hardness result

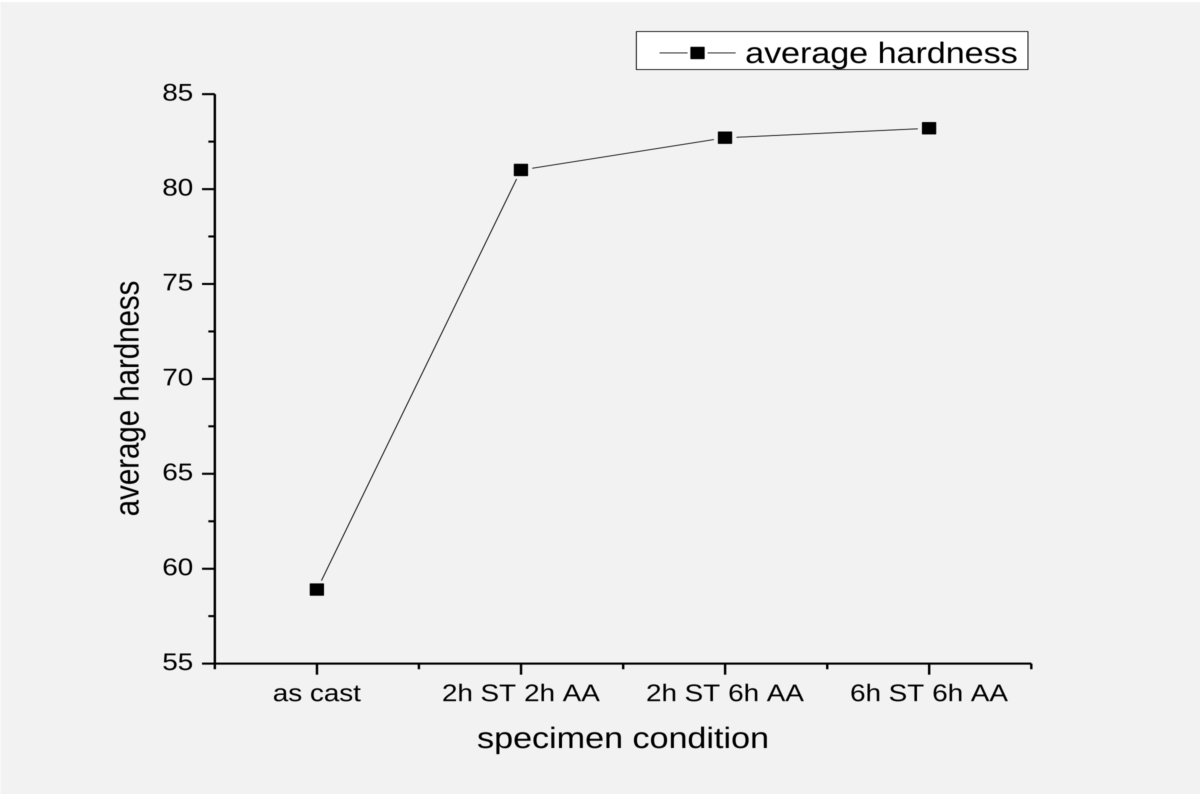
Table 4.2 is the result of Rockwell hardness value on each specimen with different holding time. There are six values taken and the average is calculated and present in the last column of table 4.2. The average value was compared to each other specimen with different holding time by a graph as show in figure 4.6.

Table 4.2 Hardness properties of A356 alloy with different heat treatment holding time

specimen condition	Rockwell hardness result						
	1	2	3	4	5	6	Average value
as cast	60.4	57.6	58	58	59.8	59.6	58.9
2h ST	74.8	75.4	74.4	75.6	74.8	75.4	75.1
6h ST	74.2	74	73.2	72.2	73.4	73.4	73.4
2h ST 2h AA	81.4	80.2	81	81.2	80.8	81.4	81
2h ST 6h AA	82.6	82.8	82.2	82.6	82.6	83.2	82.7
6h ST 6h AA	83.8	83.4	83.6	82.6	82.4	83.6	83.2



(a)



(b)

Figure 4.6: Average Rockwell hardness value with different holding time at different solution treatment (a) without aging and (b) with aging.

4.3 DISCUSSION

4.3.1 Precipitate hardening effect upon microstructure

From the figure 4.2, the eutectic silicon was spheroidized. The spheroidization of eutectic silicon has reduced the segregation effect. The alloy phase also has been homogenized with the distribution of the coarsened silicon particle (Sjölander, 2010). It is also clear from Figures 4.2 (c) and (d) that the silicon particles of the eutectic were much coarser after solution treatment at 540 °C for holding time of 6 hours than 2 hours, and the interparticle spacing was increased by longer solution treatment.

From figure 4.3, it is clear that the longer aging holding time, the more refined precipitate silicon particle dispersed in the alloy microstructure. This achieved the objective of aging which is to obtain a uniform distribution of small precipitates in the alloy microstructure (Sjölander, 2010).

In summary, precipitate hardening treatment spheroidized the eutectic structure into globular type structure. Precipitate silicon particle is refined and homogenized throughout alloy microstructure. The more refined precipitate silicon particle dispersed in the alloy microstructure during artificial aging heating period.

4.3.2 Precipitate hardening effect upon tensile properties

From figure 4.4, it is clearly shown that tensile strength and fracture elongation or strain of as-cast can reach about 82.3 N/mm^2 and 1.1% respectively. Using precipitate hardening treatment in this study, strength and elongation can be improved significantly. For those samples treated with 6 hours solution and 6 hours aging, the tensile strength and strain achieved the maximum values which is 234.7 N/mm^2 and 3.59%. Meanwhile, the sample treated with 2 hours solution and 2 hours aging is already can greatly improve the tensile properties of A356 alloy. However, the maximum tensile properties value spends about 12 hours on heat treatment.

4.3.3 Precipitate hardening effect upon hardness

From figure 4.5 (a), it is shown that hardness will increase after solution treatment at 540 °C. However, hardness will decrease when the holding time is 6 hours compare to 2 hours of holding time. This result is same with the previous research which states that the longer solution treatment time of 6 hours produced a relatively coarse microstructure which probably resulted in the lower maximum hardness values being obtained (H. Möller). From figure 4.5 (b), the result show that, hardness will increase significantly after aging complete. It also shows that the longer holding time, the higher hardness value is obtained. Meanwhile, the lower hardness value of the solution treated sample with holding time of 6 hours will increase and achieve maximum value. This is because the relatively fine microstructure produced by long solution treatment is more easily to be dispersed in the alloy compare to the less fine microstructure produced by short solution treatment.

4.4 SUMMARY

In summary, precipitate hardening treatment spheroidized the eutectic structure into globular type structure. Precipitate silicon particle is refined and homogenized throughout alloy microstructure. The more refined precipitate silicon particle dispersed in the alloy microstructure during artificial aging heating period. This finely dispersed precipitate si particle will impedes dislocation movement of the alloy microstructure during deformation under force. Thus dislocation only can occur by cut through the dispersed precipitate or go around them. The restricting dislocation movement during deformation is the reason why mechanical properties are increased (William F. Smith, 2006).

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The study on effect of precipitate hardening treatment on microstructure and mechanical properties of aluminum silicon casting alloy (A356) was performed. From the microscopy results obtained, it can be concluded that Aluminum silicon cast alloys A356 microstructure was in eutectic structure, non-homogenize and in segregation form that cause tensile and hardness properties relatively low in as-cast state. After that, The eutectic structure change to globular type and the si particle is homogenized, refined and dispersed uniformly in the alloy microstructure and cause tensile and hardness properties increase after undergoes precipitate hardening treatment due to the finely dispersed precipitate si particle will impedes dislocation movement of the alloy microstructure during deformation under force. Thus dislocation only can occur by cut through the dispersed precipitate or go around them. The restricting dislocation movement during deformation is the reason why mechanical properties are increased. Meanwhile, the parameter which is the holding time of solution treatment and artificial aging will further increased the properties if the holding time increased.

5.2 RECOMMENDATION

From this study, the sand casting process design can be improve better to reduce porosity in the casting which will affect casting properties. The porosity is a very small empty section in the casting. This is a general defect for casting and can be seen when the casting cross section is cut. The more porosity occurs, the lower mechanical properties of the casting.

Two heating furnace also should be used to proceed artificial aging after solution treatment and quenching to avoid natural aging occur. Natural aging is a process of aging by room temperature. Subjected to natural aging, it can alter the microstructure and mechanical properties.

Besides that, longer solution treatment or artificial aging heating holding time can be done when equipment and time is sufficient to get the result using optimum parameter.

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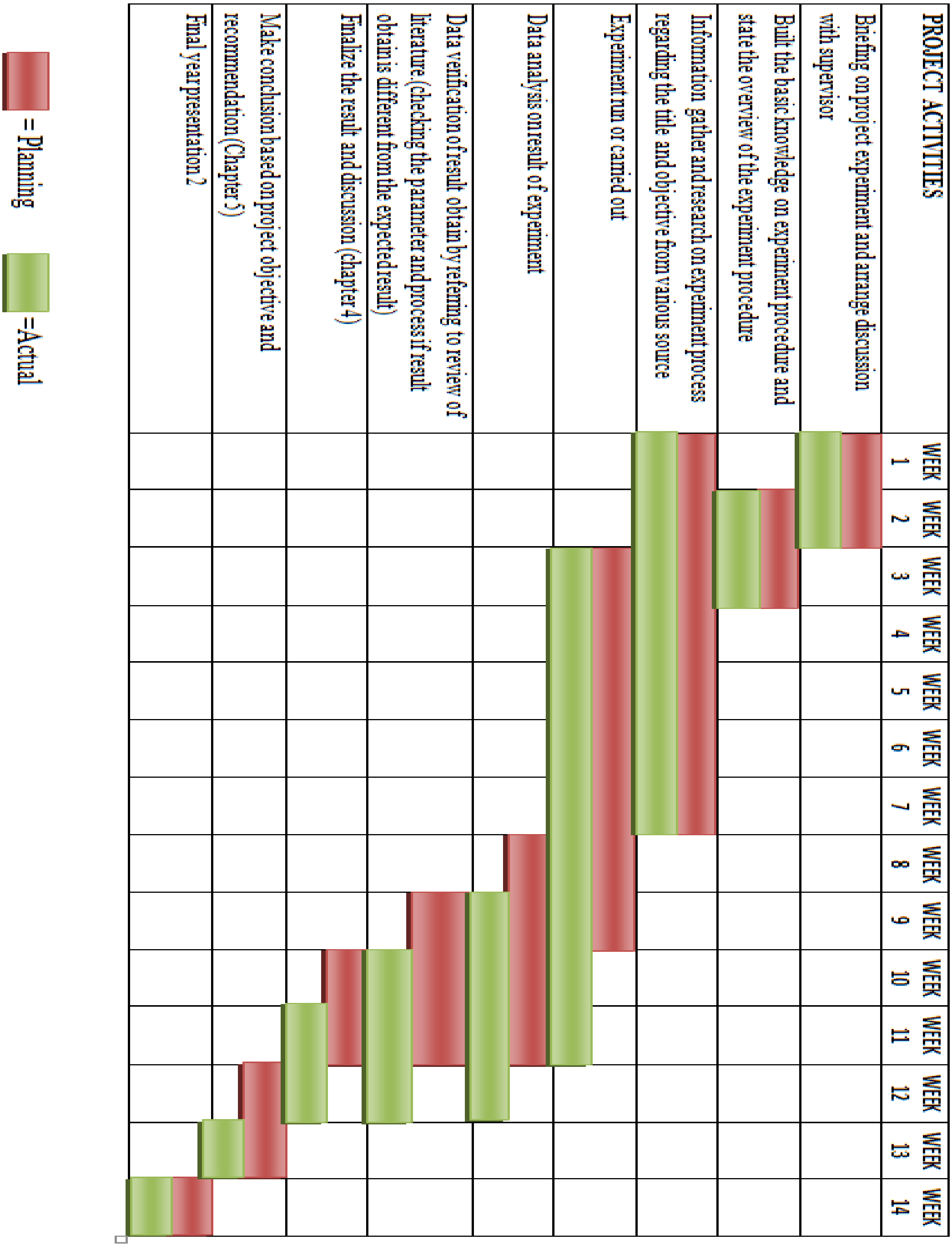
APPENDIX A

GANTT CHART / PROJECT SCHEDULE FOR FINAL YEAR PROJECT

GANTT CHART / PROJECT SCHEDULE PLANNING FOR FINAL YEAR PROJECT 2



GANTT CHART / PROJECT SCHEDULE FOR FINAL YEAR PROJECT 1